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Abstract

Prepositional phrase attachment was investigated in temporarily ambiguous sentences. Both attachment site (noun phrase or verb phrase) and argument status (argument or adjunct) were manipulated to test the hypothesis that arguments are processed differently than adjuncts. Contrary to this hypothesis, some previous research suggested that arguments and adjuncts are initially processed in the same manner, following a general bias to attach prepositional phrases to the verb phrase whenever possible (Clifton et al., 1991). The current study supports the hypothesis for differential processing, even during the initial stages of syntactic analysis. In an eye movement experiment, readers spent less first-pass time on argument prepositional phrases (PPs) than adjunct PPs. The results support a view in which a noun's or verb's argument structure can facilitate the analysis of its arguments.

Key words: parsing, sentence comprehension, syntactic ambiguity, prepositional phrase attachment

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Argument Status and PP-Attachment

The interface between lexical and syntactic processing is a central issue in current theories of sentence processing, and the distinction between arguments and adjuncts lies at the heart of the debate. In brief, arguments and adjuncts are dependent phrases that are embedded within a larger constitutent, such as a noun phrase (NP) or verb phrase (VP). While arguments serve as fundamental participants within those larger phrases, adjuncts do not. Some approaches maintain that both argument and adjunct attachment sites (as well as most other syntactic knowledge) are stored lexically (e.g., MacDonald et al., 1994; Trueswell et al., 1994). Other approaches maintain a strict division between global and lexical syntactic knowledge (e.g., Frazier, 1987; Mitchell, 1989; Ferreira & Henderson, 1990). The first approach makes predictions about processing difficulty based on lexical preferences (e.g., How frequently does *sent* occur with an indirect object?). The second approach posits a privileged role for globally represented syntactic knowledge and therefore predicts broad structural preferences, such as that embodied by Minimal Attachment (Frazier, 1978). Intermediate positions are also possible; for example, arguments might be represented lexically, but not adjuncts (e.g., Boland & Boehm-Jernigan, 1998).

The argument/adjunct distinction is important in many linguistic theories, although there is disagreement as to whether the argument/adjunct distinction is binary or even categorical (e.g., Grimshaw, 1990; Kegl & Fellbaum, 1988). Within theories that maintain a distinction between arguments and adjuncts, only arguments are lexically specified by their heads. At a minimum, the lexical representation of the head includes a subcategorization frame that marks the syntactic category of each argument. For example, *sent* can subcategorize for a direct object NP and an indirect object prepositional phrase (PP). The semantic content of an argument is limited by selectional restrictions and by thematic role assignments made by the head. Thus, the semantic contribution of an argument depends in part on the particular head with which it is associated. For example, in *The bully sent a threatening letter to Harry*, the interpretation of *Harry* as a

recipient depends upon the dative verb. When the verb does not subcategorize for a *to*-PP, *Harry* is interpreted as merely a location (e.g., *The bully stapled a threatening letter to Harry*).

In contrast, adjuncts are traditionally not subcategorized for by lexical heads. An adjunct can appear after a wide range of heads while maintaining a consistent semantic contribution across those heads. For example, *during the night* will have the same meaning following either *sent* or *stapled*. Furthermore, a similar contribution could be made by dependent phrases of several other syntactic types (e.g., NP: *this evening*; Adverb: *recently*). In (1), the PP *to his son* is an argument because a giving event must specify a recipient. The head (*gave*) specifies both the syntactic category of this phrase and the thematic role assigned by the preposition *to* (recipient). *During the afternoon*, however, is an adjunct because time is not central to the event denoted by the verb. If *the afternoon* receives a thematic role in (1), it is assigned by the preposition *during*.

(1) *John gave a letter to his son during the afternoon.*

Syntactic categories other than verbs may also take arguments and adjuncts. For example, in (1), *the afternoon* is an argument of the preposition *during*. In (2), *for lobsters* is an argument of the noun *fondness*, while *from Maine* is an adjunct of the noun *lobsters*.

(2) *Her fondness for lobsters from Maine was obvious.*

The argument/adjunct distinction may have a structural component. For theories that use an X-bar framework, there are different attachment sites for the two types of phrases (Jackendoff, 1977; Chomsky, 1986, 1995). As shown in Figure 1, arguments are attached as sisters to the heads that subcategorize for them, whereas adjuncts are attached as sisters to the intermediate phrasal category that the head projects. However, such a structural distinction is not universally accepted. Argument and adjunct attachments are not differentiated in the strictly binary branching structures of Pesetsky's Layered Syntax (1995), in Head-driven Phrase Structure Grammar (HPSG; Pollard & Sag, 1994), and in Combinatorial Categorial Grammar (CCG; Steedman, 1996). In the latter two approaches, arguments are characterized as phrases that are selected by heads, while adjuncts are characterized as phrases that select heads.

INSERT FIGURE 1 ABOUT HERE

Despite the linguistic debate, hypotheses about the representation and processing of arguments and adjuncts feature prominently in many psycholinguistic proposals (Abney, 1989; Boland & Boehm-Jernigan, 1998; Boland & Lewis, 1998; Frazier & Clifton, 1996; Schutze & Gibson, 1999; Stevenson, 1998). For example, MacDonald et al. (1994) argued that all phrases, not just those typically considered to be arguments, are lexically specified by their heads. Under this account, phrases that are classified as arguments in other models simply occur more frequently with their heads than phrases that are traditionally classified as adjuncts. As a result, "arguments" are more strongly represented in the lexical entries of the relevant heads, but have the same syntactic and semantic status as "adjuncts." We'll call this the Pure Frequency Hypothesis, or PFH. MacDonald et al. advocated a highly lexicalized mode of parsing, in which structural fragments are accessed during word recognition and joined together to form sentence structure. For example, upon hearing *John gave*, all the argument/adjunct structures associated with *gave* would be accessed, with the more frequent argument/adjunct structures more strongly available. The PFH predicts that direct and indirect object arguments will be attached more easily than locative and temporal adjuncts, simply because the arguments co-occur with *gave* more frequently and are, therefore, more strongly weighted among the possible argument/adjunct structures.

In contrast, Boland and Boehm-Jernigan (1998) proposed that argument and adjunct PPs are attached via different mechanisms. In their proposal, argument attachment sites are processed just as in the PFH: They are generated during lexical access, and ease of argument attachment is mediated by the relative frequencies of ranked, competing verb forms (the competitors of *moved* include [V_{past}], [V_{past} <NP>], [V_{past} <NP PP>], and [$V_{past\ participle}$]). But contrary to the PFH, adjunct attachment sites are not lexically represented, and adjunct attachments must therefore be accomplished via non-lexicalized syntactic rules. We call this the *Argument Structure Hypothesis*, or ASH.

ASH predicts argument/adjunct differences at the earliest stage of processing. Consider the examples in (3). Let us assume that *offered* lexically specifies a PP-*to* recipient as an argument and *exemptions* lexically specifies a PP-*from* source argument. Upon hearing *The agency offered*…, a prepositional dative structure <NP-theme PP-*to*-recipient> would be made available, along with a double object structure <NP-recipient NP-theme> and any other structures associated with *offered*. The availability of each structure is initially a function of its frequency for that lexical item. Thus, if the prepositional dative is a frequent form, it would be strongly available. The next NP, *some exemptions*, would be easily incorporated with this prepositional dative structure, as would the preposition *to* in (3a). At the same time, grammatical rules would postulate options in which *to* heads a NP-attached PP adjunct and a VP-attached PP adjunct, but these options would not be activated as strongly as the prepositional dative. Upon recognition of *exemptions*, a < PP-*from* > frame would have been activated, and it would be supported by the preposition *from* in (3b) and (3c), but it would not have been supported by the prepositions in (3a) or (3d).

(3) *The agency offered some exemptions …*

a. *…to the business.* VP Argument

b. *…from the start.* VP Adjunct

c. *…from the rules.* NP Argument

d. *…over ten dollars.* NP Adjunct

Frazier and Clifton (1996) made almost the opposite proposal from ASH. They suggested that "primary" phrases (essentially arguments and their heads) are analyzed using global structural principles, such as Minimal Attachment, while adjuncts are "associated" using detailed lexical information and real world knowledge. Because phrases that might or might not be primary are first analyzed as primary phrases, argument/adjunct differences would not be predicted in the initial analysis of the PPs investigated here; Frazier and Clifton explicitly claimed that PPs in V-NP-PP constructions are initially minimally attached to the VP.

Some experimental research seems to support the Minimal Attachment view. Clifton,

Speer, and Abney (1991; See also Speer & Clifton, 1998) manipulated attachment site and argument status as shown in (4), with the attachment site boldfaced. VP-attached PPs were read faster than NP-attached PPs, but argument status had no effect until the region after the PP, where argument conditions were faster than adjunct conditions. Clifton et al. suggested that a PP is initially attached to the VP (as an argument) using a Minimal Attachment strategy. When detailed lexical information was consulted to check the attachments, adjuncts and NP arguments had to be reanalyzed, causing the late effect of argument status.

(4) a. *The saleswoman tried to* ***interest*** *the man* *in a wallet*... (VP argument)

b. *The man expressed his* ***interest*** *in a wallet*... (NP argument)

c. *The man* ***expressed*** *his interest in a hurry*... (VP adjunct)

d. *The saleswoman tried to interest the* ***man*** *in his fifties*... (NP adjunct)

There are several reasons to be cautious in adopting this conclusion. First, only 12 of their 16 items passed tests for argument status (Schutze & Gibson, 1999), and some of those 12 seem like borderline arguments to us. Examples include *arranged the ceremony with a minister, disgusted the woman with his dirty diapers, tapped his cane on the door,* and *vaccinated the young Americans for the flu* in the VP argument stimuli, and *arrangements with a minister, disgust with a dirty baby,* and *tap on the door* in the NP argument stimuli. Second, the argument-assigning verbs (*interest* in [4a]) used in their experiment occur most frequently as past participles (76%), rather than as simple past tense verbs (24%; See Table 1 below). This is relevant because the two verb forms select different arguments and assign different thematic roles.[1] If an argument attachment is affected by the frequency of the lexical structure that provides that attachment site, one is unlikely to find an advantage for arguments over adjuncts

[1] For example, in the simple past form (*The woman interested Chris*), *interest* assigns the role of theme (object of interest) to its subject and the role of patient (affected participant) to its direct object. In the past participle form (*The woman interested in Chris left*), *woman* and *Chris* have swapped roles, and the syntactic properties of *interest*'s arguments have changed also. The subject of *interested* is an empty category co-indexed with *woman*, and the post-verb entity is in a PP rather than a NP.

unless one uses verbs and nouns that frequently select the arguments being investigated. Clifton et al.'s failure to find early effects of argument status may have been because lexical competitors (i.e., past participle forms) were more strongly available than the needed form [V_{past} <NP PP>]. Third, Clifton et al. (1991) embedded their VP argument and NP adjunct PPs in infinitive clauses, constructions that are syntactically more complex than those containing the VP adjunct and NP argument PPs. Lastly, other researchers have found effects of argument status (e.g., Britt, 1994; Schutze and Gibson, 1999)

Normative Studies

We compared the processing of VP- and NP-attached arguments and adjuncts in a two-by-two factorial design, using sentences like those in (5). Our materials differed from Clifton et al.'s (1991) in several respects. First, a corpus search conducted on our verbs demonstrated that the past participle forms were not more frequent than the simple past forms. This change was implemented to insure that the [V_{past} <NP PP>] form of the verbs was at least as accessible as the past participle form. Both the verbs and direct object nouns in our materials frequently selected their PP arguments, and normative data demonstrated that even though our argument and adjunct PPs were equally plausible, the argument PPs were preferred. Second, most of our verbs were chosen from Levin's (1993) dative classes, and our noun and verb arguments passed a battery of linguistic tests for argument status, as in Schutze and Gibson (1999). Our VP adjuncts functioned as adverbs, most commonly expressing temporal information, and our NP adjuncts frequently expressed location or other descriptive information.

(5) *The environmental agency …*

a. …*offered some exemptions to the business, this year.* (VP argument)

b. …*offered some exemptions from the law, this year.* (NP argument)

c. …*offered some exemptions from the start, this year*. (VP adjunct)

d. …*offered some exemptions over ten dollars, this year.* (NP adjunct)

Corpus Analyses. We used both the Brown and the parsed Wall Street Journal (WSJ) databases in the Penn Treebank corpora to conduct several normative analyses. First, we

estimated the frequency of the past participle forms, relative to simple past tense forms, for verbs in our own materials and in the materials from three other studies, We searched on the orthographic string for each verb and calculated the proportion of past participles out of the total number of simple past and past participle forms. The results are summarized in Table 1. In our study, we use the same verb across conditions within each item, while Clifton et al. (1991) used different verbs within items for the VP argument and VP adjunct conditions.[2] There was a higher proportion of past participles in Clifton et al.'s argument assigning verbs compared to our verbs [$t(29) = 3.43$, $p < .01$][3], which were comparable to Clifton et al.s' non-argument assigning verbs. In fact, for the verbs in the Clifton et al. VP argument condition, the past participle forms were about three times more frequent than the simple past tense forms. Thus, it is not surprising that the effects of argument status were seen late in the Clifton et al. study. With less interference from the participle forms in the current experiment, however, we expect argument effects to dominate attachment site in the early measures. In our materials, the proportions of past participle forms are comparable to those for the critical verbs from Schutze and Gibson (1999) and Britt (1994) [t's $< .8$, $p > .10$], who each found a privileged role for the processing of arguments.

INSERT TABLE 1 ABOUT HERE

Second, we estimated the frequency with which our verbs and direct object nouns are used with argument and adjunct PPs of the type used in our study. We searched each corpus on the orthographic string for each verb and counted tokens that were exact matches to our materials. Then we searched for each direct object noun and again counted only exact matches. For both verbs and nouns, if there were more than 200 matches, we used the first 200 tokens. We omitted one noun (*tattoos*) and five verbs (*withheld, concealed, hid, mailed*, and *communicated*) from

[2] For the Clifton et al. materials, there were no matches for *vaccinated* in either Brown or WSJ; there were no matches for *exempted* in Brown and none for *preached* in WSJ.

[3] All proportions underwent an arcsine transform prior to any parametric test, throughout the paper.

further analysis because each resulted in fewer than six matches. For each set of verb and noun tokens, we examined tokens that were modified by a PP and calculated the probability of an argument or adjunct PP of the same type used in our critical stimuli. We classified PP types in two ways. First, for each verb and noun, we calculated the proportion of tokens that were modified by a PP having the same participatory role (e.g., marking the recipient, location, or time) as the argument or adjunct PP in our critical materials. Next, we calculated the proportion of tokens with PPs of the same preposition as our argument or adjunct PP. To obtain the most stable estimate of argument/adjunct frequency, we combined the data from the Brown and WSJ corpora by summing the raw counts for a given item before calculating the proportion of singular nouns and simple past tense verbs that occurred with argument and adjunct PPs having the same role and/or the same preposition as our target PPs. These data are summarized in Appendix A.

We submitted each of three variables in Appendix A to a two(verb or noun) by two (argument or adjunct) ANOVA. The frequency of the head was not affected by either head type or argument status, although after undergoing a log transform, the frequencies were reliably higher for verbs than nouns [$F2(1,29) = 4.89$, $p < .05$]. The proportion of PPs with the same role was higher for nouns compared to verbs [$F2(1,29) = 8.57$, $p < .01$] and higher for arguments compared to adjuncts [$F2(1,29) = 21.24$, $p < .01$]. The two variables also interacted [$F2(1,29) = 5.02$, $p < .05$]; the highest proportion of PPs with the same role were in the noun argument condition. When considering the proportion of PPs by preposition, the results were the same. There were main effects of head type [$F2(1,29) = 6.52$, $p < .05$] and argument status [$F2(1,29) = 23.64$, $p < .01$], and an interaction between the two [$F2(1,29) = 6.69$, $p < .05$].

Forced-choice judgments. We collected forced-choice judgments to determine how strongly readers prefer to have an explicit PP argument for each verb and noun in our study. For each critical item, the VP + PP argument and NP + PP argument fragments were paired with PP argumentless fragments using the same noun or verb. The examples in (6) and (7) list the argument fragments first. The adjunct PP was not necessarily the same as the target adjunct, so this measure does not provide an indicator of adjunct bias. In the norming study, the pairs were

randomly ordered on a list (together with 32 pairs of fillers that varied in syntactic complexity and form), and within half of the critical pairs, the argument alternative was presented first. We created a second list by reversing the order within each pair. Forty-two students from The Ohio State University were instructed to read each pair of fragments and choose the one that sounded more natural. All participants received credit in undergraduate, introductory psychology or linguistics classes in exchange for their participation, and all were native speakers of English.

(6) Verb example pair

a. The police detective proposed a search to the captain.

b. The police detective proposed a search for a day.

(7) Noun example pair

a. There was a search for a weapon.

b. There was a search through the city.

As we expected, there was an overall preference for the fragments containing PP arguments in both the verb (73%) and noun (68%) conditions. The difference between the noun and verb scores was not significant [$t(30) = 0.53$, $p > .10$]. Thus, the results suggested that, in our materials (in contrast to the Clifton et al., 1991, materials), the PP argument forms of the verbs and nouns were more accessible than competing forms without PP arguments, and that the verbs and nouns were comparably biased toward taking PP arguments.

Naturalness ratings. The 16 critical items were randomized with 59 fillers and presented to students as one of four balanced lists. Forty students from The Ohio State University (ten per list) rated the naturalness of each sentence as a description of an event or situation on a scale ranging from 1 (Very Unnatural) to 7 (Very Natural). The mean scores (and standard deviations) were 4.04 (0.48) and 3.67 (0.50) for the VP argument and adjunct conditions, respectively, and 3.99 (0.57) and 3.76 (0.66) for the NP argument and adjunct conditions. Argument conditions were rated as slightly better descriptions than adjunct conditions [$F(1,12) = 8.502$, $p < .05$] in a 4(list) by 2(argument status) by 2(attachment site) ANOVA by items, but there were no effects of attachment site ($Fs < .1$). The argument preference is predicted by the corpus analysis and

forced choice judgments, which both demonstrated that the argument-selecting form of the verbs and nouns were more accessible than alternative forms without PP arguments.

Plausibility Ratings. Both the naturalness ratings and the forced-choice judgments suggested that our head nouns and verbs are most naturally used with an argument. Thus, it is not possible to match the argument and adjunct conditions for naturalness. We can, however, match argument and adjunct conditions on real world plausibility. To estimate plausibility, 40 students from Rutgers University (ten per list) were asked to rate the likelihood of the event in the sentence occurring in the real world, on a scale of 1 (likely) to 7 (unlikely). The 16 critical items were randomized with 44 filler sentences, and four lists were created. Each item appeared only once per list, and conditions were balanced within and across lists. Following Schutze and Gibson (1999), all critical and filler sentences were presented in the passive voice (e.g., *Many cuts in the staff were announced by the administrator*) in order to eliminate any potential structural ambiguity. NP-attached PPs always followed the subject. VP-attached PPs occurred either after the verb or at the end of the sentence, whichever sounded more natural (e.g., *Many cuts were announced in the meeting by the administrator*, but *Some exemptions were offered by the environmental agency from the start*).

The mean scores (and standard deviations) for the VP argument and adjunct conditions were 2.91 (0.83) and 2.94 (0.84), respectively. The corresponding scores for the NP argument and adjunct conditions were 2.78 (1.00) and 3.11 (0.78). In 4(list) by 2(argument status) by 2(attachment site) repeated measures Analyses of Variance (ANOVAs) conducted over participant (F1) and item (F2) means, there was no effect of attachment site [Fs < 1.0] or argument status [$F1(1,36) = 2.23$, $p = 0.14$; $F2(1,12) = 1.50$, $p = 0.24$], and no interaction between the two [Fs < 1.1]. Therefore, any effects of argument status obtained in the reading time data are unlikely to be due to differences in plausibility.

Eye Movement Study

This experiment was designed to test the prediction that argument PPs would be processed more easily than adjunct PPs. This argument status effect is predicted both by the PFH and by

ASH. The PFH predicts an argument advantage because arguments co-occur more frequently with their heads, and thus a lexical structure with the appropriate attachment site will be more strongly available. ASH predicts an argument advantage because only argument PPs are lexically specified, and, if they occur frequently, they are likely to be selected over rule-generated adjunct options. No effects of attachment site are predicted by ASH, although such an effect was predicted by Clifton et al. (1991). Secondarily, we had hoped to test the prediction that ease of argument attachment, but not adjunct attachment, would be correlated with the argument/adjunct frequency for a given head noun or verb. The PFH would predict that ease of PP processing is always a function of the co-occurrence frequency between the PP type and the head noun/verb. Unfortunately, differential frequency patterns between arguments and adjuncts were found, as described in the Corpus Analysis section above. We will return to this issue in the Discussion and explain why we could not adequately test hypotheses about the correlation between processing load and argument/adjunct frequency.

Methods

Participants. Thirty-two students from Rutgers University participated either for credit in an undergraduate, introductory psychology class, or for a nominal sum. All were native speakers of English, who had normal vision or vision corrected to normal with soft contacts.

Materials. We developed 16 sets of sentences like the example in (5), repeated here as (6). The full set of critical stimuli is in Appendix B. For every item, the verb remained constant across all four conditions, and for 11 items, the same was true of the direct object NP. The mean frequency (Francis & Kucera, 1982) of the direct object NP was 58 in the first three conditions and 54 in the NP adjunct condition. The length averaged 8.5 characters in the first three conditions and 8.1 characters in the NP adjunct condition. The preposition varied across the four conditions, though the same preposition was used in the NP argument and VP adjunct conditions

in 15 out of the 16 items.[4] The noun in the PP also differed across the four conditions. Length and frequencies (Francis & Kucera) for the noun are provided in Table 2. The nouns in the critical PP of the two argument conditions were less frequent, averaging 159.5, than the nouns in the two adjunct conditions, which averaged 191.5 Mean length was almost identical: 6.45 for argument conditions, 6.40 for adjunct conditions.

(8) *The environmental agency* | …

a. …*offered* | *some exemptions* | *to the business,* | *this year*. (VP argument)

b. …*offered* | *some exemptions* | *from the law,* | *this year*. (NP argument)

c. …*offered* | *some exemptions* | *from the start,* | *this year*. (VP adjunct)

d. …*offered* | *some exemptions* | *over ten dollars,* | *this year*. (NP adjunct)

INSERT TABLE 2 ABOUT HERE

The 16 critical items and 120 filler sentences were randomized, and four lists were created. Fifty-three of the filler sentences contained semantic and/or syntactic anomalies from unrelated experiments. Yes/no comprehension questions were created for one-third of the items. Each item appeared only once per list, and conditions were balanced within and across lists. For data analysis, each critical item was divided into five regions, separated by vertical bars in (8). The first region contained the subject NP, the second region contained the verb, the third region contained the direct object NP, the fourth region contained the PP, and the fifth region contained the final two words, usually a temporal NP or adverbial phrase.

Procedure. A dental impression was made for each research participant and attached to a "bite bar" in order to hold the participant's head in a fixed position. We also used a stationary

[4] The VP adjunct option may have been somewhat discriminated against if it had to compete against an argument option. Counter to this, however, the direct object was a definite NP in 11 of 16 items. Altmann and Steedman (1988), Crain (1980), and Crain and Steedman (1985) have argued that definite NPs bias reading time results toward VP-attachment.

headrest and an adjustable chin-rest to help secure the head in a comfortable fashion. Eye fixations were measured using a Dr. Bouis monoculor oculometer. The device provides two voltage outputs, corresponding to eye position along the X and Y axes. The sensor of the apparatus was first roughly aligned by mechanical means. It was then further adjusted to give zero-output voltages when the participant looked straight ahead, as well as balanced positive and negative voltages when the participant looked at equidistant points along the X and Y axes. The experimenter then ran a calibration routine during which the participant was asked to fixate on nine disparate points on the computer screen in order to establish the relationship between X/Y voltages and screen position. Unless this could be done with an error rate of less than ten pixels in each dimension, the experiment was aborted.

After successful calibration, participants began a series of ten practice trials. The participants were simply instructed to read each sentence as it appeared, and be prepared to answer comprehension questions after some of the trials. Half of the practice trials were followed by a yes/no comprehension question; participants pressed a button to indicate their answer. The set-up was re-calibrated between the practice trials and the main experiment, using the same criterion. During the experiment, analog eye position was digitized (1 kHz) and converted to screen coordinates. Each sentence was presented on the screen in its entirety, on a single line. One-third of trials in the actual experiment were followed by a yes/no comprehension question. None of the questions addressed the attachment of the PP. For each trial, the screen position and duration of each fixation were computed and stored. The set-up was recalibrated periodically during the experiment to ensure accurate tracking of the eye movements. The experiment took less than an hour.

Results

We computed four dependent measures in each of the regions that were outlined in (8). We calculated the duration of the first fixation, the duration of all first pass fixations (i.e., summing together multiple fixations in a region so long as there were no intervening saccades to another region), and total reading time (i.e., summing together all first and secondary pass fixations).

Because the PPs differed in length, we also calculated an adjusted first pass fixation measure (as in Ferreira & Clifton, 1986; Garnsey, Pearlmutter, Myers, & Lotocky, 1997; and many others). We computed the average reading time per character for each participant and used the slope and intercept to predict the amount of time that would be spent in a region if length were the only relevant factor.

The data from each critical region are summarized, for each of the dependent measures, in Tables 3 – 5. The three regions of interest were the direct object region, the PP region, and the final region. In general, we expected effects to emerge in the PP region. We submitted each dependent measure to a 4(list) by 2(argument status: argument or adjunct) by 2(attachment site: NP- or VP-attached) by 3(region) repeated measures ANOVA, once using the participant means as input and once using the item means.[5]

The first fixation data (summarized in Table 3) revealed a main effect of argument status, with longer fixations in the adjunct conditions [$F1(1,28) = 6.14$, $p < .05$; $F2(1,12) = 19.59$, $p < .01$]. This effect did not interact with region [$Fs < 1.0$], perhaps due to unexpectedly long fixations on the direct object in the VP adjunct condition. Individual ANOVAs conducted at each region found only one fully reliable effect: shorter fixations for argument conditions compared to adjunct conditions in the final region [$F1(1,28) = 6.96$, $p < .05$; $F2(1,12) = 6.30$, $p < .05$]. Surprisingly, there was no effect of argument for the first fixation on the PP itself [$F1(1,28) = 2.37$, $p > .10$; $F2(1,12) = 2.16$, $p > .10$], although our power to detect an effect of the observed size was .81 by subjects and .75 by items ($\alpha = .05$ for all analyses).

INSERT TABLES 3 AND 4 ABOUT HERE

In the unadjusted first pass reading times (see the upper half of Table 4), we again found an effect of argument status [$F1(1,28) = 6.77$, $p < .05$; $F2(1,12) = 13.79$, $p < .01$]. In addition, we

[5] We report the Huynh-Feldt (Huynh & Feldt, 1976) adjusted probability values for analyses involving three or more levels of word position or region as a factor. The degrees of freedom are unadjusted.

found the expected interaction with region, though the effect was marginal in the analysis by items [F1(2,56) = 3.21, $p < .05$; F2(2,24) = 3.24, $p = .06$]. In contrast to the first fixation data, the effect appeared largest in the PP region. This was confirmed in individual ANOVAs conducted at each region. At the direct object, argument status was reliable by items, but marginal by participants [F1(1,28) = 3.48, $p < .10$; F2(1,12) = 9.19, $p < .05$]. This unexpected result may help explain the null effect of argument at the PP in the first fixation data. If the PP was processed parafoveally at the direct object by some readers, then the first fixation on the PP itself might not reliably reflect initial parsing processes. Nonetheless, when all first pass fixations in the PP region were considered, the argument status effect was fully reliable [F1(1,28) = 14.69, $p < .01$; F2(1,12) = 16.67, $p < .01$]. No effects were found in the final region.

The potential effect of attachment site in the overall ANOVAs approached significance in first pass reading times [F1(1,28) = 3.91, $p < .10$; F2(1,12) = 3.54, $p < .10$], with NP-attached conditions slower than VP-attached conditions. Because our power to detect an effect of attachment was rather weak in these data ($\beta = .59$ by subjects and .36 by items, for an effect of the observed size), and because during the PP region, the effect was reliable by participants and marginal by items [F1(1,28) = 4.65, $p < .05$, $\beta = .93$; F2(1,12) = 3.51, $p < .10$, $\beta = .64$], the possible attachment effect warrants a closer look. To the extent that this effect is real, it is reminiscent of Clifton et al.'s (1991) finding of longer reading times for NP-attached PPs compared to VP-attached PPs. Such an effect was predicted by Frazier and Clifton (1996), because all PPs should initially be attached as VP arguments. However, when we analyzed the adjusted first pass times (see the lower half of Table 4),[6] only the main effect of argument status was preserved [F1(1,28) = 10.38, $p < .01$; F2(1,12) = 20.59, $p < .01$].

INSERT TABLE 5 ABOUT HERE

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[6] These times are skewed in the negative direction because all of our sentences are perfectly grammatical, while in contrast, many of the filler sentences contained anomalies. These anomalous sentences did not appear to slow RTs for the critical sentences; reading rates were comparable to other eye-tracking studies.

The total reading times (see Table 5) exhibited the familiar effect of argument status [F1(1,28) = 6.06, $p < .05$; F2(1,12) = 10.76, $p < .01$], which interacted with region [F1(2,28) = 6.36, $p < .01$; F2(2,24) = 3.67, $p = .05$]. In individual ANOVAs by region, there were no effects in either the direct object region or the final region. But as expected, the argument conditions were read more quickly than the adjunct conditions during the PP region [F1(1,28) = 13.98, $p < .01$; F2(1.12) = 8.38, $p < .05$]. There was also a trend toward an effect of attachment site, with marginally faster times for VP-attached conditions in the overall ANOVAs [F1(1,28) = 3.76, $p < .10$; F2(1,12) = 3.80, $p < .10$]. At the PP region, this effect was marginally reliable by participants, but not by items [F1(1,28) = 4.10, $p = .05$; F2(1,12) = 2.59, $p > .10$].

Discussion

All four dependent measures indicate that argument attachments are easier than adjunct attachments, using stimuli in which the PP argument-taking form of the noun/verb is the dominant form. Furthermore, the effect of argument status was immediate. The timing of the argument effects in the first fixation and first pass data suggests that argument status influenced processing of the PP soon after recognition of the relevant words. The early influence of argument status seen in our data is incompatible with parsing heuristics such as Minimal Attachment that predict an advantage by attachment site (Frazier, 1978, 1987). Because the PPs in this experiment were all potential primary phrases, global structural principles would apply, even within Construal (Frazier & Clifton, 1996).

In sharp contrast to Clifton et al. (1991), any effects of attachment site in our data are quite minor compared to the robust effects of argument status. The influence of attachment site was limited to marginal effects in two dependent measures and may be attributable to length effects at the PP. Thus, our results provide evidence against parsing metrics or parsing preferences that routinely VP-attach PPs without regard to detailed lexical representations.

Early effects of argument status were predicted by accounts in which detailed lexical information guides parsing. However, we are not able to differentiate between several specific hypotheses about how lexical guidance occurs. In principle, the major hypotheses could be

distinguished by regressing argument/adjunct frequency against fixation times. For example, the Argument Structure Hypothesis, which we favor, maintains that argument attachments are generated from stored lexical alternatives, while adjunct attachments are generated by global syntactic rules. This predicts a negative correlation between the frequency with which a noun or verb assigns an argument and the ease of processing the argument attachment; while at the same time, there should be no such correlation in the processing of adjunct attachments. In contrast, the Pure Frequency Hypothesis maintains that argument and adjuncts are represented in the lexical entries of their heads (MacDonald et al., 1994), predicting that frequency effects should hold for all attachments. On the other hand, models that stipulate an argument preference (Abney, 1989; Schutze & Gibson, 1999) do not predict correlations for either arguments or adjuncts

In order to test these competing predictions with a regression analysis, the variance in argument frequency must approximate the variance in adjunct frequency. Unfortunately, this condition did not hold; the co-occurrence frequency between the adjunct categories and the head nouns/verbs was considerably less than the co-occurrence frequency between the argument categories and the head nouns/verbs. Our linear regressions, provided in Appendix C, are therefore merely suggestive and should not be considered an adequate test of these hypotheses.

Another way to distinguish among some of the hypotheses would be to find positive evidence for frequency effects on adjunct attachment. Such a pattern would clearly support the PFH over ASH. To the best of our knowledge, only Spivey-Knowlton and Sedivy (1995) come close to providing such evidence. They demonstrated in a corpus analysis that for action verbs, *with*-PPs are more likely to modify the verb than a direct object (e.g., *changed a tire with… a monkey wrench*). In the case of psych/perception verbs, *with*-PPs are more likely to modify a direct object than a verb (e.g., *glanced at a customer with… ripped jeans*). In turn, processing of an ambiguously attached *with*-PP was facilitated when the PP was consistent with attachment to the more frequent site. Because Spivey-Knowlton and Sedivy assumed that all the *with*-PPs were adjuncts, their findings appear to demonstrate that adjuncts are lexically specified and, for

that reason, produce frequency effects. However, it has long been noted that instrument PPs have some argument qualities (see Schutze & Gibson, 1999). Therefore, it might be the case that instrument PPs are lexically specified, but as arguments rather than adjuncts. In fact, Ferretti, McRae, and Hatherell (2001) also suggested that instruments are lexically specified after finding that verbs prime their prototypical instruments in a lexical decision task. In contrast, they found no evidence that verbs primed prototypical locations (e.g., *cooked* - *kitchen*), which are indisputably adjuncts.

While Ferretti et al.'s (2001) evidence that *stir* primes *spoon* might seem to provide positive evidence that a lexicalized structure for *stir* contains a slot for an instrument with spoon-like features, the finding is actually irrelevant to the question of argument status or the possibility that certain adjuncts are lexically specified. Although they used word association norms to demonstrate that their verbs were not associatively related to their instrument primes, priming is commonly found in lexical decision for nouns that are semantically, but not associatively, related (e.g., *glove-hat*; See Neely, 1991 and Lucas, 2000 for reviews). Thus, the finding that *stir* primes *spoon* is no more informative than if they had found that *sneeze* primes *nose*. The priming effect is merely evidence that the two words are semantically or situationally related. In contrast, Boland et al. (2001) do report some relevant evidence. They replicated the Spivey-Knowlton and Sedivy (1995) finding in locally ambiguous sentences. However, Boland et al. did not find comparable "frequency effects" in unambiguous constructions that used the same lexical items. This suggests that the Spivey-Knowlton and Sedivy effect was not due to differential activation of lexicalized structure. Rather, Boland et al. suggest that the so-called frequency effects that arise when there is a syntactic ambiguity are actually due to plausibility or semantic association. These constraints can guide syntactic ambiguity resolution, but they cannot influence the initial generation of syntactic structure in Boland's (1997) theory.

While our results are consistent with the Pure Frequency Hypothesis, there is some reason to prefer the Argument Structure Hypothesis. First, Foraker and McElree (2001) found that verb argument, but not verb adjunct, co-occurrence frequencies predicted processing success in an

SAT paradigm, providing further evidence that arguments and adjuncts are processed differently. Second, ASH is more appealing for logical reasons. It is simply not possible to specify all of the adjunct attachments that can modify a given head. Adjuncts can be adjoined one after another in theoretically limitless numbers, as in (9).

(9) *Susan pedaled on her Schwinn on the trail in the morning under the sun with a happy heart after breakfast with Edgar last Tuesday*.

In sum, the Argument Structure Hypothesis can account for parsing behavior when argument attachments represent the strongest lexical competitors, and it includes a mechanism that explains the parsing behavior of adjuncts. Additional work is needed in order to establish (1) how competition effects between lexically generated, but weak, argument attachments and globally generated, but frequent, adjunct attachments are resolved, and (2) how constraints combine to resolve adjunct attachments, in general. As these questions are investigated, the differing predictions of the Argument Structure Hypothesis and the Pure Frequency Hypothesis will be more thoroughly tested.

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Appendix A

For each head verb and head noun used in our critical stimuli, we note the total frequency (for exact matches) in the Brown corpus. Collapsing across both the parsed Brown corpus and the parsed Wall Street Journal corpus in the Penn Treebank Corpora, we also report the proportion of tokens that co-occurred with a PP of the same role or having the same preposition as the argument or adjunct PP in our critical stimuli.

Arguments				**Adjuncts**			
Head	**Head Freq.**	**Arguments, same role**	**PPs, same prep**	**Head**	**Head Freq.**	**Adjuncts, same role**	**PPs, same prep**
hid	61	0.0186	0.0186	hid	61	0.1191	0.0157
withheld	14	0	0	withheld	14	0	0
show	640	0.1667	0.1667	show	640	0.1667	0
expressed	135	0	0	expressed	135	0	0
concealed	18	0	0	concealed	18	0	0
gained	77	0.0345	0.0345	gained	77	0	0.0172
admitted	91	0.0556	0.0860	admitted	91	0	0
acknowledged	27	0.0236	0.0236	acknowledged	27	0.0556	0.0198
described	200	0.0516	0.0516	described	200	0	0
offered	217	0.085	0.0622	offered	217	0.0758	0.0034
communicated	22	0.1	0.1	communicated	22	0.02	0.02
proposed	110	0.1667	0	proposed	110	0	0
delivered	71	0.2051	0.2051	delivered	71	0	0.1154
announced	116	0.0192	0	announced	116	0	0.0541
explained	177	0.0732	0.0732	explained	177	0	0
mailed	25	0.5	0.17	mailed	25	0	0
mean	**125.1**	**.094**	**.062**		**125.1**	**.027**	**.015**
inclusion	3	0.1	0.1	child	213	0.02	0.02
support	124	0.36	0.18	comment	35	0.18	0
amusement	7	0	0	tattoos	0		
interest	323	0.24	0.23	complaint	14	0.09	0.05
surprise	44	0	0	book	175	0.08	0.02
confidence	56	0.36	0.35	confidence	56	0	0
participation	41	0.43	0.43	participation	41	0.02	0.17
authority	93	0.16	0.05	authority	93	0.03	0
alienation	22	0	0	alienation	22	0.05	0.05
exemptions	2	0.26	0.22	exemptions	2	0.06	0
excitement	32	0.2	0.02	excitement	32	0.06	0.03
search	58	0.6	0.53	search	58	0.03	0.02
demands	43	0.26	0.22	demands	43	0.01	0.02
cuts	16	0.16	0.09	cuts	16	0.04	0.01
absence	53	0.07	0.05	absence	53	0.01	0
revisions	9	0.36	0.21	revisions	9	0	0
mean	**57.9**	**.223**	**.168**		**53.9**	**.045**	**.026**

Appendix B

The critical items are listed below. The order of conditions from left to right within each item is VP argument, NP argument, VP adjunct, and NP adjunct.

1. The committee hid the secretary's {inclusion from the chairman / inclusion in the process / inclusion in their expressions / child with the handicap}, very easily.
2. The leader withheld his {support from the candidate / support for the candidate / support for the moment / comment about the candidate}, after all.
3. The two friends showed their {tattoos to the woman / amusement at the story / amusement at the party / tattoos on their arms}, without concern.
4. The busy shopper expressed his {interest to the clerk / interest in a wallet / interest in a hurry / complaint about a wallet}, before leaving.
5. The new guard concealed his {surprise from the visitor / surprise at the decision / surprise at the time / book about the war}, with difficulty.
6. The losing team gained some confidence {from the coach / in the coach / in the end / under the circumstances}, once again.
7. The suspect admitted his participation {to the police / in the robbery / in the morning / in a disguise}, under questioning.
8. The rowdy campers acknowledged John's authority {to the cops / over the group / over some coffee / about the region}, this morning.
9. The speaker described people's alienation {to the class / from the system / from his perspective / in the south}, in detail.
10. The environmental agency offered some exemptions {to the business / from the law / from the start / over ten dollars}, this year.
11. The teacher communicated much excitement {to the children / over the project / over the week / in her heart}, during class.
12. The police detective proposed a search {to the captain / for a weapon / for a day / through the city}, right away.

13. The lawyers delivered employee demands {to the president / for a raise / for a while / from last week}, despite criticism.
14. The administrator announced many cuts {to the reporter / in the staff / in the meeting / of some significance}, confirming rumors.
15. The female conductor explained Ed's absence {to the people / from the rehearsal / from her viewpoint / for an emergency}, very carefully.
16. The famous author mailed his revisions {to the editor / of the book / for a fee / from the margins}, last week.

Appendix C

As described in the Discussion section, we would have liked to distinguish between the PFH and the ASH via regression analyses. The two hypotheses make differential predictions about whether negative correlations will be found between fixation times and frequency for adjunct PPs. Unfortunately, there was much less variance in the adjunct frequency data compared to the argument frequency data, making the lack of adjunct correlations uninformative. Thus, we report the regression analyses primarily as a demonstration of the argument correlations, which were predicted by both PFH and ASH. We regressed the first fixation data from the final region against frequency data obtained in the corpora analysis described in Normative Studies. We chose to regress proportions against the first fixation data from the final region for several reasons. This dependent measure provides the earliest measure of processing effects in a given region, while the region reflects the argument advantage seen in the ANOVAs.

We regressed the proportion of argument and adjunct PPs (having the same role and/or the same preposition as our target PP) from our corpora analysis against the corresponding mean first fixation data from the final region, once for the verbs and once for the nouns. For example, we regressed the total proportion of VP argument PPs bearing the same role as the target against that target's mean fixation time in the VP argument condition.[7] As shown in Table C.1, negative correlations were found for the argument conditions only.

We conducted regressions at the PP region to be sure that we did not overlook any reliable effects. There were none.

[7] We also considered an alternative, but related, hypothesis. Perhaps the overall frequency of the head noun/verb would predict initial fixation duration. On this account, it is not the relative frequency of the competing lexical forms that is important, but rather the overall strength of the lexical entry. To test this hypothesis, we computed the log frequency of all noun (or verb) forms for each head noun (or verb). We regressed the log total frequency against initial fixation duration in the PP region and the final region.No reliable or marginal correlations were found [VP-arg at PP, r = -.34, at Final, r = -.38; NP-arg at PP, r = .07, at Final, r = .12; VP-adj at PP, r = .09, at Final, r = -.07; NP-adj at PP, r = .34, at Final, r = -16].

Table C.1. The correlation for each critical comparison, with the degrees of freedom, F value, and *p* value. The *z* values indicate how different the regression coefficients are for the verb or noun argument/adjunct correlations in the same row.

By Proportion of PPs with Same Preposition as the Target PP			
	Argument	**Adjunct**	**Difference in *r*'s**
Verb	r = -.61, F(1,9) = 5.42, p < .05	r = .10, F(1,9) < 1.0, p > .10	z = - 1.62, p = .05
Noun	r = -.45, F(1,14) = 3.57, p = .08	r = .18, F(1,13) < 1.0, p > .10	z = - 1.67, p = .05
By Proportion of PPs with Same Participatory Role as the Target PP			
	Argument	**Adjunct**	**Difference in *r*'s**
Verb	r = -.62, F(1,9) = 5.59, p < .05	r = -.18, F(1,9) < 1.0, p >.10	z = - 1.10, p = .14
Noun	r = -.41, F(1,14) = 2.90, p = .11	r = .08, F(1,13) < 1.0, p >.10	z = - 1.29, p = .10

Not all of the predicted correlations were statistically reliable, and the argument correlations were not reliably different from the adjunct correlations in the analysis by participatory roles. Although the size of the correlation coefficients was uniformly large for the argument conditions, the small number of usable items led to low power: β ranged from .39 to .64 for the observed effect size. Thus, we are inclined to trust the statistically weak correlations in the argument conditions. Interpreting the null adjunct effects, in the face of even lower power values, is more difficult.

Table 1. The proportion (and standard deviations) of past participle verb forms out of the sum of simple past tense and past participle verb forms, by corpus and experiment. "WSJ" represents the Wall Street Journal corpus of the Penn Treebank.

	BROWN	**WSJ**	**COMBINED**
Current Experiment: All 16 Verbs	0.58 (0.25)	0.39 (0.32)	0.49 (0.25)
Clifton et al. (1991):			
Argument Assigning Verbs (14/16 in Brown, 15/16 in WSJ)	0.78 (0.22)	0.74 (0.31)	0.76 (0.24)
Non-argument Assigning Verbs (16/16 in Brown, 15/16 in WSJ)	0.51 (0.31)	0.46 (0.32)	0.47 (0.29)
Britt (1994): All 15 Verbs	0.51 (0.30)	0.43 (0.29)	0.47 (0.29)
Schutze & Gibson (1999): All 15 Verbs	0.62 (0.22)	0.52 (0.32)	0.55 (0.49)

Table 2. Length and Frequency of the noun in the critical PP

Condition	Length	Frequency
VP Argument	7.0	172
NP Argument	5.9	147
VP Adjunct	6.2	240
NP Adjunct	6.6	143

Table 3. Mean first fixation durations in milliseconds (ms) for the regions immediately before, during, and after the PP.

First Fixation Durations (ms) by Region and Condition			
	Direct Object	**PP**	**Final**
VP Argument	258	232	268
NP Argument	249	246	267
VP Adjunct	279	255	292
NP Adjunct	249	244	290

Table 4. Unadjusted (ms) and adjusted (deviations from predicted in ms) mean first pass fixation durations for the regions immediately before, during, and after the PP

First Pass Durations (ms) by Region and Condition			
	Direct Object	**PP**	**Final**
VP Argument	424	399	578
NP Argument	456	409	586
VP Adjunct	478	445	567
NP Adjunct	480	515	596
Adjusted First Pass Durations (dev from predicted in ms) by Region and Condition			
	Direct Object	**PP**	**Final**
VP Argument	-93.1	-149.8	-33.9
NP Argument	-75.9	-120.5	-43.5
VP Adjunct	-47.4	-83.6	-15.5
NP Adjunct	-32.9	-72.0	5.0

Table 5. Mean total fixation durations (ms) for the regions immediately before, during, and after the PP.

Total Fixation Durations (ms) by Region and Condition			
	Direct Object	**PP**	**Final**
VP Argument	603	541	648
NP Argument	644	580	719
VP Adjunct	652	653	685
NP Adjunct	641	722	682

Figure Captions

Figure 1. Traditional X-bar structure contrasting argument (PP-arg) and adjunct (PP-adj) attachment sites within a verb phrase.

Figure 1.