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Charting the time-course of VP-ellipsis sentence comprehension: Evidence for an initial and independent structural analysis

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Abstract

We exploited the properties of VP-ellipsis constructions containing inherently reflexive and inalienable possession verbs that severely constrained final interpretation (e.g., “The policeman perjured himself, and the fireman did too...”). Using the cross-modal lexical priming task, we found that listeners reactivated the subject NP from the first clause at the elided position in the second clause (i.e., the “strict” reading), even though verb properties disallowed such an interpretation. We also found that listeners reactivated the subject NP from the second clause, demonstrating the “sloppy” interpretation. In a final experiment we examined VP-ellipsis constructions that did not contain anaphors (e.g., “The mailman bought a tie for Easter, and his brother did too...”). We found that only the object NP of the first clause was reconstructed in the second clause. We interpret these findings as support for a parser that computes multiple interpretations on-line, yet is initially insensitive to lexical and probabilistic information.

Keywords

Language comprehension; VP-ellipsis; Syntax; Lexical

There is no shortage of fundamental issues that remain unresolved in the study of language processing. Even the most basic assumptions continue to be questioned (as they should be). For example, though on some accounts it is common to assume ‘separate’ lexical, syntactic, and semantic operations when processing sentences, it remains unclear where to draw the boundaries. Indeed, given some theoretical viewpoints it is not entirely clear whether such boundaries are necessary (e.g., Bates & Goodman, 1997; MacDonald, Pearlmutter, & Seidenberg, 1994; but see Frazier, 1995). In the following study, we consider some of these fundamental issues by examining how on-line operations give way to final sentence interpretation. Specifically, we describe three experiments investigating how normal listeners understand constructions containing covert material that is inherent in verb phrase (VP) ellipsis. In two experiments we examine if lexical properties that constrain final interpretation also affect momentary, on-line comprehension. In a third experiment we examine which noun phrase arguments are ‘reconstructed’ at the elided VP site.

We begin with a linguistic characterization of VP-ellipsis constructions. Our focus on the linguistic underpinnings of such constructions is justified, we feel, by the descriptive details linguistic theory offers, and also by the fruit it has borne for accounts of language processing. We then discuss previous efforts investigating the comprehension of ellipsis constructions and attempt to ground this work in accounts of sentence processing. We then move on to the description of our current experiments and the discussion of our results. We are ultimately interested in the time-course of activation and use of different kinds of information, which, in turn, should shed light on the architecture of the sentence processing system and its mechanisms.

Theoretical linguistics background

We begin, then, with the linguistic details of the constructions under investigation. Consider the following utterance:

(1) “John likes apples, and Bill does too.”

Even though nothing more than “Bill does too” is produced in the second clause, it is interpreted as “Bill likes apples too.” Linguistic theory accounts for this fact by analyzing the phonetic string “does too” as corresponding to an abstract mental representation that is a copy of the verb phrase (VP; e.g., “likes apples”) in the first clause via a process of *reconstruction*. There are a number of proposals in the linguistic literature regarding ellipsis reconstruction (see Sag, 1976; Williams, 1977; and more recently Fiengo & May, 1994). For expository purposes we present here a simplified version of reconstruction that preserves the basic insights of these theories.

Reconstruction makes a copy of the predicate in the first clause (by a process of *predicate abstraction*) and pastes it into the “empty” predicate slot in the second clause. Thus, the phonetic string in (2a) results in the representation in (2b):

(2)

- a. John likes apples, and Bill does [e] too.
- b. John $\lambda x[x \text{ likes apples}]$, and Bill does $\lambda x[x \text{ like apples}]$ too.

Given the meaning of the lambda operator, the second clause is equivalent to, and interpreted as, Bill likes apples.¹

One of the most notable aspects of ellipsis is the so-called “strict” and “sloppy” ambiguities that arise in these constructions. Consider the following example:

(3) John likes his car, and Bill does too.

The second clause in this sentence has two meanings: It can mean that ‘Bill likes John’s car’ (labelled the “strict” reading), or it can mean that ‘Bill likes his own car’ (labelled the “sloppy” reading). In the linguistic literature this difference turns on whether the possessive pronoun in the first clause is interpreted as a bound variable pronoun or as a deictic, directly referring pronoun. To represent the sloppy reading, the possessive pronoun is assumed to be initially *coindexed* with the subject of the first clause. When lambda abstraction applies, this coindexing relation will cause both the possessive pronoun and the subject to be replaced by

¹Predicate abstraction is the conversion of a functional expression of the form $F(a)$ into another equivalent expression $\lambda x.F[x](a)$, where the argument of the first function is replaced by a variable bound by a lambda operator. The inverse process, lambda conversion, is the application of the functor $\lambda x.F[x]$ to the argument a , which replaces the variable x with the argument a , i.e. $\lambda x.F[x](a)$. In semantic terms, λ abstraction is an operation that extracts the predicate from a proposition.

the same variable. When the predicate subsequently is copied, so is the binding relation between the subject and the pronoun variables. Given the meaning of lambda conversion in the second clause, the subject “Bill” takes the place of the subject “John” when the expression is evaluated semantically, resulting in the sloppy reading. The series of derivational steps is illustrated in (4):

(4)

- a. John_i likes his_i car, and Bill does too.
- b. John $\lambda x[x \text{ likes } x\text{'s car}]$, and Bill does too.
- c. John $\lambda x[x \text{ likes } x\text{'s car}]$, and Bill $\lambda x[x \text{ likes } x\text{'s car}]$ too.
- d. =“John likes John’s car and Bill likes Bill’s car”

For the strict reading, the pronoun is not coindexed with the subject, but rather refers deictically to the same referent as the subject does. We indicate this with the subscript *John* in the following derivation. The consequence is that only the subject is replaced by a variable during predicate abstraction, and the possessive pronoun preserves its fixed reference throughout the process of ellipsis reconstruction:

(5)

- a. John likes his_{John} car, and Bill_j does too.
- b. John $\lambda x[x \text{ likes his}_{\text{John}} \text{ car}]$, and Bill does too.
- c. John $\lambda x[x \text{ likes his}_{\text{John}} \text{ car}]$, and Bill ? $\lambda x[x \text{ likes his}_{\text{John}} \text{ car}]$ too.
- d. =“John likes John’s car and Bill likes John’s car”

(5d) is a paraphrase of the interpretation of the logical-semantic representation in (5c), representing the strict reading.

Consider, now, a VP-ellipsis construction where the elided VP is anaphoric to another VP that contains a reflexive pronoun:

(6) John defended himself, and Bill did too.

Since reflexive pronouns have the property that they must be obligatorily bound by the subject of its containing clause, the basic prediction is that only the sloppy reading is derivable in VP-ellipsis. The two derivations are illustrated in (7):

(7)

- a. John_i defended himself_i, and Bill did too.
- b. John $\lambda x[x \text{ defended } x]$, and Bill did too.
- c. John $\lambda x[x \text{ defended } x]$, and Bill $\lambda x[x \text{ defended } x]$ too.
- d. =“John defended John and Bill defended Bill.”

The strict reading would be barred by the principle that requires that reflexives be bound in their containing clause (Principle A of the Binding Theory, Chomsky, 1985); this requirement is violated in the second clause in (8c). Suppose the reflexive is marked as deictically referring and the following derivation ensues:

(8)

- a. John defended himself_{John}, and Bill did too.

- b. John $\lambda x[x \text{ defended himself}_{\text{John}}]$, and Bill did too.
- c. John $\lambda x[x \text{ defended himself}_{\text{John}}]$, and Bill $\lambda x[x \text{ defended himself}_{\text{John}}]$ too.
- d. =“John defended John and Bill defended John.”

It is the second occurrence of the reflexive (with the subscript *John*) that violates Principle A. One would then expect this interpretation to be nonexistent. However, the empirical status of “strict reflexives” has varied in the literature. Whereas Williams (1977) took it to be a correct prediction that strict reflexives were ungrammatical, others have argued that under some circumstances strict reflexives are grammatical. Fiengo and May (1994) suggested that reflexives may be copied as *pronouns* (via what they have termed “vehicle change”) under specific conditions, and thereby the strict reading becomes available. Others have argued that the meaning of VP-ellipsis constructions is determined by interaction between linguistic and nonlinguistic information sources (Dalrymple, Shieber, & Pereira, 1991; Hardt, 1993; Hestvik, 1995). What seems clear, however, is that strict reflexives are generally dispreferred by most speakers.

Implications for sentence processing

VP-ellipsis offers a test case for various features of a sentence processor. In previous work exploiting these constructions, Shapiro and Hestvik (1995) addressed the following questions: What is the nature of the mental process that takes the acoustic-phonetic string in (1) and derives the representation in (2)? In particular, what is the time course of the assembly of various types of information, such as preference for interpretation, syntactic structure building, and the calculation of grammatical relations? This question gets at the heart of the purported functional architecture of the sentence processing system. In a constraint-based architecture various types of information interact—with some constraints having preference over others—and converge on a final interpretation. In a multiple-stage, ‘parser-independent’ account, only syntactically relevant information is employed initially; other information (e.g., probabilistic, discourse context) is used subsequently to resolve interpretation.

To investigate the architecture of the processing system, Shapiro and Hestvik chose a task that has been found to be sensitive to evanescent effects that occur prior to final interpretation—the cross-modal lexical priming task. This task is an extension of the lexical priming task, whereby visually or aurally presented words are momentarily presented to normal readers/listeners for lexical decision. Subsequent presentation of associatively related words are found to be primed relative to unrelated control words. In the cross-modal version of this task, sentences are presented aurally and the probes for lexical decision are presented visually, usually in the immediate temporal vicinity of a word of interest in the sentence. This task has been found to be quite sensitive to the temporal manifestations of sentence processing, showing, for example, that ambiguous words in sentences activate multiple senses (Swinney, 1979), and more to the point of this paper, word positions that appear later in the sentence (re)activate earlier-appearing words to which these later positions refer (Love & Swinney, 1996; Nagel, Shapiro, & Naway, 1994).

For example, Shapiro and Hestvik (1995) aurally presented sentences like (9) to normal listeners, who were required to perform two tasks: The first was to attempt to comprehend the sentences as they were presented; the second was to make a lexical decision (i.e., word/nonword decision) to a briefly presented visual stimulus; that is, to a letter array that did or did not form an English word. Reaction times to the lexical decision were recorded. When the letter array formed an English word, the word was either related (e.g., ROBBER) or unrelated (e.g., ROLLER) to the subject NP from the first clause (e.g., to *the policeman*):

(9) The policeman defended himself, and the fire [1] man did [2] too, according to someone who was there.

Note that the verbs (e.g., *defended*) used in these constructions were simple transitives that in principle allowed a direct object NP, and consequently allowed an anaphor (e.g., *himself/him*). Subjects responded significantly faster to related probes relative to unrelated control probes, but only when the probes were presented at the elided position, that is, at probe position [2] in example (9), and not at a pre-ellipsis position [1]. This pattern suggested that listeners *reactivated* the subject NP via the copied anaphor from the first clause at the elided VP position in the second clause. In essence, listeners computed the strict reading of the structure on-line even though the sloppy reading was highly preferred.

Consider, now, how various accounts of sentence processing can deal with these ellipsis results. Most constraint-based accounts suggest that different analyses of sentences are pursued roughly in parallel; these analyses are weighted in terms of their compatibility with different constraints (e.g., MacDonald et al., 1994; Trueswell, Tanenhaus, & Garnsey, 1994). For example, an analysis which is highly preferred, most frequently occurring, compatible with context and other constraints will take the lead in a race for final interpretation. As more input is received and processed, different analyses may be activated. It is difficult to reconcile the ellipsis results in such constraint-based terms, since the sloppy reading was highly preferred (in terms of off-line judgments, and in the literature as well; see for example, Frazier & Clifton, 2000) and preference and frequency are a guiding factor during sentence analysis on this account.

Constraint-based accounts can be considered ‘unrestricted’ in the sense that all sources of information can be used to help determine an initial analysis (see Pickering, Clifton, & Crocker, 2000). ‘Restricted’ accounts, on the other hand, suggest that there is a stage where such constraints, though in principle available, are ignored (Ferreira & Clifton, 1986; Frazier & Fodor, 1978). Most restricted accounts suggest that the initial analysis of a sentence is based solely on syntactic information (lexical categories, phrasal categories, and perhaps argument structure), and that extra-syntactic information is subsequently used to help converge onto a final interpretation. Indeed, it is just this type of account in which we cast our previous ellipsis work. That is, the off-line preference for the sloppy reading was initially ignored, given that we found evidence that the strict reading was activated on-line.

There were three limitations to the original Shapiro and Hestvik (1995) experiment that we intend to address in the present study. First, though it was demonstrated that probabilistic information (in terms of preference for a particular structure) was ignored during the initial syntactic reconstruction underlying VP-ellipsis, Shapiro and Hestvik did not address the question of whether *lexically specific* information has an initial influence on early syntactic processing. There are several versions of constraint-based accounts that suggest a privileged role for lexical properties (e.g., MacDonald et al., 1994; McRae, Ferretti, & Amyote, 1997; Trueswell et al., 1994). MacDonald et al. (1994) claim that the information inherent to lexical items (including probabilistic information, argument structure, lexical-semantic constraints, and even phrase structure fragments) is used predictively to suggest the analysis of sentence input. Indeed, it has been argued that syntactic processing is simply the result of concatenated lexical processing. A related, though not as detailed account is offered by Bates and colleagues (Bates & Goodman, 1997; Dick et al., 2001) who suggest that there is no separation between the “grammar” and the lexicon. Thus, in the present study we manipulate lexical properties that have a direct influence on final interpretation and investigate how such information is reflected in the time-course of sentence processing. Second, it was demonstrated that listeners computed the strict reading even though the sloppy reading was highly preferred. Yet, there was no evidence that the sloppy reading was

also activated on-line. If it turns out that both strict and sloppy readings are momentarily available as the sentence unfolds, we will have evidence to support an account that establishes multiple parses relatively simultaneously. This possible parallelism effect would have important implications for the architecture of the processing system. Finally, we consider an alternative explanation to the ellipsis results, one that suggests that the reason why there is activation for a subject NP at the VP-ellipsis site is because of the predication relation between the two positions, and not because there is syntactic reconstruction. We test each of these, in turn, in the following experiments.

Experiment 1: VP-ellipsis with inherently reflexive verbs and verbs of inalienable possession; strict reading

In this experiment we use verbs that restrict the type of objects they entail, and thus constrain final interpretation of VP-ellipsis constructions. Consider the sentences in (10). Certainly, only (10b) is a grammatical reconstruction, since ‘the fireman’ cannot perjure ‘the policeman’ (that is, an individual can only perjure him/herself, and not another individual):

(10)

- a. The policeman perjured himself, and the fireman did too.
- b. The policeman perjured himself_i, and the fireman_j did [**perjure himself_j**] too.
- c. *The policeman perjured himself_i, and the fireman_j did [**perjure him_i**] too.

Thus, unlike a typical transitive verb (such as “defend”) that places few limitations on its direct object, the verb “perjure” restricts its direct object to only a reflexive pronoun. This lexical constraint thus yields only a sloppy interpretation (10b) of an ellipsis construction that contains such verbs in the initial clause; the strict interpretation (10c) is not allowed, or at the very least, is highly dispreferred.

A similar constraint exists for verbs that impose an inalienable possession interpretation on the possessive pronoun of an object (see, for example, Levin, 1993), as in:

(11)

- a. The policeman_i winked his eye_i, and the fireman_j did [winked his eye_j] too.
- b. *The policeman_i winked his eye_i, and the fireman_j did [winked his eye_i] too.

That is, “the fireman” can only wink his own eye, not the policeman’s. The verb’s inherent semantic properties thus severely constrain the interpretation of VP-ellipsis; only the sloppy reading is allowed in examples (10) and (11) above—only the local subject should be available at the elided position.

This interaction between lexical properties and ellipsis allows us to conduct a strong test of the separability or inseparability of the lexicon from structural processing routines. Consider:

(12) The optometrist who had signed the release form [1] asserted himself [2], and the pilot who needed to pass [3] the training exam did [4] too.

(13) The gambler who won 10 hands in a row [1] winked his [2] eyes, and the pit boss who was in on [3] the elaborate scheme did [4] too.

In both (12) and (13), probe position [1] serves as a baseline (the pre-anaphor position); position [2] is in the immediate vicinity of the overt anaphor; position [3] serves as the pre-ellipsis position; and position [4], the ellipsis position. Given previous work we predict no

activation of the subject NP (e.g., *the optometrist, the gambler*) from the first clause at the baseline [1] position (that is, we predict no significant differences between the related relative to the control probes), but we do predict activation for this NP at the anaphor position [2]. Such a pattern will suggest that overt material such as anaphors re-activate their antecedents on-line (see also Nicol & Swinney, 1989).

More to the point of the issues we hope to resolve here, even though the inherent verb properties disallow the strict reading of the ellipsis construction, we predict that nevertheless the strict reading should be available on-line, stemming from our hypothesis that lexical–semantic information does not constrain the initial analysis since that analysis should only consider structural information. This prediction should translate into the following pattern: The subject NP from the first clause should not be available at the pre-ellipsis position [3], but will be reactivated at the elided position [4]. RTs to related probes (that is, related to the subject NP from the first clause) should therefore be faster than to control probes only at positions [2] and [4], suggesting that the time-course of activation is initially impervious to influences from lexical properties.

An alternative prediction more in line with constraint satisfaction models is that because the lexical–semantic information inherent to the verb disallows the strict reading, we should fail to observe activation for that reading during on-line comprehension.

Method

Participants—Eighty college students, all native English speakers with normal or correct-to-normal auditory and visual acuity, participated in Experiment 1 for course credit. Twenty subjects each were randomly assigned to one of the four probe positions.

Materials and Design—A list of inherently reflexive and inalienable possession verbs were created (see, for example, Levin, 1993). These verbs, along with a set of typical transitive verbs that did not place restrictions on their direct objects, were placed in ellipsis constructions (similar to (12) and (13) above) and presented to an independent group of normal readers ($N = 30$). Subjects were asked to circle the NP to which the missing VP referred (and were asked whether or not the sentences had any other interpretation). The data show that for the typical transitive verbs, approximately 80% of the respondents initially chose the local NP (that is, the sloppy reading), while the remaining subjects chose the long-distance NP (the strict reading). Additionally, most subjects (approximately 70%) suggested that the sentences allowed both interpretations. These pre-test results are in-line with what we found in our earlier work (see Shapiro & Hestvik, 1995; see also Frazier & Clifton, 2000). Importantly, for the inherently reflexive and inalienable possession verbs, subjects interpreted these as *only allowing the sloppy reading*, corroborating that our sentence materials were appropriately selected.

From these latter verbs we created 36 test sentences (see Appendix A), each containing a coordinated two-clause structure as shown in (12) and (13) above. The test sentences were embedded into two identical lists, each of which included 64 fillers, yielding a total of 100 sentences per list. Each test sentence was matched to a related lexical decision probe (in this case, related to the subject NP from the first clause) and to an unrelated control probe.

We selected our lexical decision probes in the following manner (and we did this for the remaining experiments as well): We began by polling college-age adults ($N = 40$) for their first associates to the words that were later incorporated in the sentences (that is, to the NPs to which the probes were related). In the present case we eliminated any probes that were first or second associates to any NP other than the subject NP from the first clause for more than 10% of the subjects. Once this initial probe list was established, we asked an

independent group of college-age adults to rate the relatedness of the probes to various NPs. Again, we eliminated any probes that were related to any NPs in the sentences other than the one of interest. The control probes were selected in a similar manner, but were those that bore no relation to any word in the sentence, and were matched to the related probes in terms frequency of occurrence, number of letters/syllables, part of speech, and animacy. We then gathered base RTs to these probes from a simple visual lexical decision experiment, presenting the probes for 300 ms to an independent group of subjects ($N = 30$). Importantly, there were no significant base RT differences found between the related and control probes (mean related = 578 ms; mean control = 576 ms). The similarity of the base RTs to these lexical decision probes insures that any differences found between related and control probes would not be due to inherent probe differences.

Half of the test sentences in one list were paired with a control probe, the other half with the related probe; this order was reversed in the second list. The lists were presented at least two weeks apart. In addition to the 36 test sentences, real-word probes were assigned to 14 filler sentences; for the remaining 50 fillers, nonword probes (conforming to English orthographic rules) were assigned. Each subject therefore heard 100 sentences during each of the two sessions, half of these paired with visually presented real word probes and half with nonwords. Thus, a total of 36 related probes and 36 unrelated control probes, tied to the test sentences, were viewed by the subjects across the two sessions.

The four test probe positions were determined structurally. Using (12) and (13) as examples, probe position [1] was placed within the relative clause and before the verb; probe position [2] was placed immediately after the anaphor; probe position [3] was placed within the relative clause of the second clause, approximately eight syllables after probe position [2] and approximately five syllables before probe position [4]; and finally, probe position [4] was placed at the elided VP position, directly after the bare auxiliary. These probe positions were selected so that any observed activation patterns would likely not be because of proximity effects, that is, because the probe positions were too close to one another. Probe positions in the fillers were assigned to various temporal locations to lessen any expectations on the part of the subjects.

Procedure—We used the Cross-Modal Lexical Priming (CMLP) task. Participants sat in a small testing room in front of a computer monitor and a button box. The sentences were presented over headphones via a digital tape recorder. During the temporal unfolding of each sentence, a visually presented lexical decision probe appeared centrally (for 300 ms) on the monitor. Subjects were required to attend to the aurally presented sentences and to make a visual lexical decision quickly and accurately by pressing one of two response keys (labelled WORD, NONWORD); RTs to this decision were recorded by the computer. In approximately 20% of the trials, the tape was stopped and subjects were asked to paraphrase the sentence that they had just heard, with the purpose of ensuring that the subjects were paying attention to the sentences. RTLab software was used to deliver stimuli and record RTs.

Results

Error rates on test probes (answering “Nonword” to real word probes) were distributed as follows: Pre-anaphor position probes yielded 4.1% errors, anaphor position probes yielded 3.9% errors, pre-ellipsis position probes yielded 5.6% errors, and ellipsis position probes yielded 3.6% errors; these were approximately evenly distributed across the control and related probes.

Because the pre-anaphor and anaphor probe positions were theoretically independent from the pre-ellipsis and ellipsis positions, we examined these paired probe positions separately.

Mixed design analyses of variance (ANOVA) were first run on the correct RT data using subjects as the random factor (i.e., collapsing across items).

In our first subject-based ANOVA, probe position (pre-anaphor and anaphor) was a between-subjects factor and probe type (control and related) was a within-subjects factor. The mean RT data used in this analysis are shown in Table 1 (in the following tables we present only the subject-based data; the item-based data were in all cases quite similar to these).

There was a main effect of probe type; related probes (712 ms) yielded significantly faster RTs than unrelated control probes (731 ms), $F(1, 38) = 13.22, p < .001$. We also observed a significant interaction between probe type and probe position, $F(1, 38) = 8.77, p < .01$.

Paired *t*-tests (all *t*-tests in this and subsequent experiments were Bonferroni-corrected) found that only at the anaphor position did related probes (711 ms) yield significantly faster RTs than unrelated control probes (745 ms), $t(19) = 4.81, p < .001$ (2-tailed). In terms of possible individual differences, 85% of the subjects conformed to this pattern; that is, they performed faster on the related as compared to the control probes at the anaphor position (only 45% of the subjects performed faster on the related relative to the controls at the pre-anaphor position).

We next used items as the random factor (i.e., collapsing across subjects) and conducted a similar set of analyses. In a repeated measures ANOVA with probe position (pre-anaphor and anaphor) and probe type (control, related) as the within-subjects factors, we observed a main effect of probe type, $F(1, 35) = 3.905, p = .056$. We also observed a significant interaction between probe type and probe position, $F(1, 35) = 6.78, p = .01$. We then conducted paired *t*-tests to examine the source of this effect. Supporting our *a priori* predictions, we found that only at the anaphor position did related probes (712 ms) yield significantly faster RTs than unrelated control probes (745 ms), $t(35) = 2.99, p < .01$. 72% of the items yielded faster RTs on the related relative to the unrelated control probes, when those probes were presented at the anaphor position (53% of the items showed a similar pattern at the pre-anaphor position).

Next, we compared the pre-ellipsis and ellipsis probe positions as the between-subjects factor, and probe type (related, control) as the within-subjects factor in an ANOVA with subjects treated as the random factor. The mean RT data used in these analyses are shown in Table 2.

There was a main effect of probe type; related probes (725 ms) yielded significantly faster RTs than unrelated control probes (744 ms), $F(1, 38) = 10.02, p < .01$. We also observed a significant interaction between probe type and probe position, $F(1, 38) = 7.54, p < .01$.

Paired *t*-tests found that only at the ellipsis position did related probes (744 ms) yield significantly faster RTs than unrelated control probes (778 ms), $t(19) = 3.95, p = .001$ (2-tailed). Eighty-five percent of the subjects evinced faster RTs on the related relative to the unrelated control probes at the ellipsis position (60% showed this pattern at the pre-ellipsis position).

Next, we examined the pre-ellipsis and ellipsis positions treating items as the random factor. In a repeated measures ANOVA with probe position (pre-ellipsis and ellipsis) and probe type (control and related) as the within-subjects factors, we observed a main effect of probe position, $F(1, 35) = 34.95, p < .001$. We also observed a marginally significant (using $p < .05$ as our significance level) effect of probe type, $F(1, 35) = 3.68, p = .06$. And we observed a marginally significant interaction between probe position and probe type, $F(1, 35) =$

3.179, $p = .08$. We then conducted paired comparisons between probe type within each position given our apriori predictions that only at the ellipsis position would there be differences found between the probe types. And, indeed, these predictions were borne out; only at the ellipsis position were RTs to related probes (734 ms) significantly faster than to unrelated control probes (762 ms), $t(35) = 2.40$, $p = .02$. Sixty-seven percent of the items yielded faster RTs on the related relative to the unrelated control probes, when those probes were presented at the ellipsis position (58% of the probes yielded a similar pattern at the pre-ellipsis position).

Discussion

Our first set of analyses examined activation patterns at the pre-anaphor and anaphor positions. At the pre-anaphor position, no significant RT differences were observed between probes related to the NP to which the anaphor referred and to unrelated control probes. Yet, at the anaphor position, subjects responded significantly faster to related than to unrelated control probes. This pattern—observed on both subject and item analyses—strongly suggests that listeners automatically reactivate the NP to which the anaphor refers, in the immediate temporal vicinity of the anaphor.

More to the point of the issues we address in this paper, our second set of analyses examined activation patterns at the pre-ellipsis and ellipsis positions. We examined if listeners reactivate the subject NP from the first clause at the elided position in the second clause. And indeed, the patterns support this possibility. Treating subjects as the random factor, we found that only at the elided position did listeners respond significantly faster to related probes (that is, related to the first clause subject) compared to unrelated control probes. The item-based analysis did not uncover such unambiguous effects, finding only a marginally significant interaction between probe position and probe type. Yet, paired comparisons found that only at the elided position did listeners respond faster to probes related to the long-distance subject NP than to unrelated control probes, exhibiting the priming effect that suggests activation from a covert category. This overall pattern, then, suggests that though the strict reading of a VP-ellipsis construction is unavailable off-line when verb properties disallow such an interpretation, listeners nevertheless momentarily compute this interpretation on-line.² We detail our interpretations of these findings, ground them in the sentence processing literature, and consider alternatives in the General Discussion to follow the next two experiments.

Experiment 2: VP-ellipsis with inherently reflexive verbs and verbs of inalienable possession; sloppy reading

In Experiment 1 we found that listeners re-activate the subject NP from the first clause when encountering an elided VP position in the second clause, suggesting that the ‘strict’ reading is computed even though the lexical properties constrain final interpretation to only a ‘sloppy’ reading. In this experiment we examined if listeners also compute this ‘sloppy’ reading on-line. Consider, again:

²To insure that our results were not due to subjects attempting to integrate the probe into the temporal unfolding of the sentence, and that some probes were simply better continuations than others, we randomly selected half of our sentence materials and conducted a post-hoc “goodness of continuation” rating. We presented visual fragments (e.g., “The optometrist who had signed the release form”; “The optometrist who signed the release form asserted herself”; etc.) to an independent group of subjects ($N = 20$) and asked them to rate on a 7 point scale whether each probe word constituted a good or plausible continuation of the sentence at that point. We found no ‘goodness of continuation’ differences between our related and control probes at any of the probe positions, and, indeed, subjects rarely rated any of the probes as good continuations. Note that Love and Swinney (1996) have found that in the CMLP task, normal listeners do *not* attempt to integrate the lexical decision probe into the unfolding of the sentence.

(14) The optometrist who had signed the release form asserted himself, and the pilot who needed to pass [1] the training exam did [2] too, according to someone who was there.

If listeners also compute the sloppy reading, then we should observe reactivation of the subject NP from the *second* clause (e.g., the pilot). That is, we should observe significantly faster RTs to related probes than to unrelated control probes, but only at probe position [2]. Thus, the results from the present experiment, combined with the previous experiment, would suggest that listener's compute both the strict and sloppy analyses, in parallel.

Method

Participants—Forty college students, all native English speakers with normal or correct-to-normal auditory and visual acuity, participated in Experiment 2. Twenty subjects each were randomly assigned to one of the two probe positions.

Materials and design—The same set of materials used in Experiment 1 were used in the present experiment. Here, however, the visual lexical decision probes paired with the test sentences were either related to the subject NP from the *second* clause or were unrelated control probes. We selected our probes as we did for Experiment 1, but in the present case we eliminated any probes that were first or second associates to any NP other than the subject NP from the *second* clause. The control probes bore no relation to any word in the sentence, but were matched to the related probes in terms frequency of occurrence, number of letters/syllables, part of speech, animacy, and importantly, base RTs (mean related = 567 ms; mean control = 573 ms).

The two test probe positions were identical to the third and fourth probe positions from Experiment 1. That is, using (14) as an example, the pre-ellipsis probe position [1] was placed within the relative clause of the second clause, approximately five syllables before probe position [2], and the ellipsis probe position [2] was placed at the elided VP position, directly after the bare auxiliary.

Procedure—We again used the CMLP task. Participants sat in a small testing room in front of a computer monitor and a button box. The sentences were presented over headphones via a digital tape recorder. During the temporal unfolding of each sentence, a visually presented lexical decision probe appeared centrally (for 300 ms) on the monitor. Subjects were required to attend to the aurally presented sentences and to make a visual lexical decision quickly and accurately by pressing one of two response keys (labelled WORD, NONWORD); RTs to this decision were recorded by the computer. In approximately 20% of the trials, the tape was stopped and subjects were asked to paraphrase the sentence that they had just heard, with the purpose of ensuring that the subjects were paying attention to the sentences. RTLab software was used to deliver stimuli and record RTs.

Results

Error rates on test probes (answering “Nonword” to real word probes) were distributed as follows: Pre-ellipsis position probes yielded 5.9% and ellipsis position probes yielded 8.5%.

A mixed design analysis of variance (ANOVA) was run on the subject-averaged correct RT data (collapsing across items). Probe position (pre-ellipsis and ellipsis) was a between-subjects factor and probe type (control and related) was a within-subjects factor. The mean RT data used in this analysis are show in Table 3.

There was a main effect of probe type; related probes (814 ms) yielded significantly faster RTs than unrelated control probes (830 ms), $F(1, 38) = 5.63$, $p < .05$. We also observed a significant interaction between probe type and probe position, $F(1, 38) = 4.83$, $p < .05$. Paired comparisons found that only at the ellipsis position did related probes (807 ms) yield significantly faster RTs than unrelated control probes (839 ms), $t(19) = 3.59$, $p = .002$ (2-tailed). Eighty percent of the subjects evinced faster RTs on the related relative to the control probes at the ellipsis position (50% showed this pattern at the pre-ellipsis position).

Next, an item-based repeated measures ANOVA (collapsing across subjects) was conducted, treating probe position and probe type as within-subjects factors. A significant interaction between probe position and probe type was observed, $F(1, 35) = 5.985$, $p = .02$. We subsequently conducted paired comparisons between probe type within each position. We found that only at the ellipsis position did related probes (805 ms) yield significantly faster RTs than unrelated control probes (839 ms), $t(35) = 3.13$, $p < .01$. 67% of the items yielded faster RTs on the related relative to the control probes when those probes were presented at the ellipsis position (53% of the probes yielded a similar pattern when presented at the pre-ellipsis position).

Discussion

In this experiment, we found that for both the subject- and item-based analyses, probes related to the subject of the second clause were responded to significantly faster than unrelated control probes, but only at the elided position. This pattern suggests that listeners re-activate the subject NP from the second clause, demonstrating the sloppy interpretation of the ellipsis construction, on-line. Taken together with Experiment 1, both the subject NP from the first clause and the subject NP from the second clause appear to be re-activated at the elided position, suggesting that listeners compute both the strict and sloppy readings momentarily and relatively simultaneously.

Experiment 3: VP-ellipsis containing nonanaphoric NPs

There is another set of explanations for the subject activations that were observed both in the Shapiro and Hestvik (1995) study and in the present Experiment 1. Note that when the parser copies the (abstracted) VP from the first clause so that it can insert it into the elided position in the second clause, it comes into contact with an expression that stands in a predication relation with the subject of the first clause. An alternative explanation for the strict antecedent reactivation is that by identifying this predication relation, the parser causes the activation of the *subject* from the first clause. If so, the activation effects we have observed are but a side effect of the search for an antecedent VP. Another alternative suggests that a VP entails the activation of the verb's arguments (see, for example, Shapiro, Brookins, Gordon, & Nagel, 1991; Trueswell, Tanenhaus, & Kello, 1993), thus, at the elided position all possible arguments are reconstructed, including the subject arguments from *both* clauses. Finally, a broader alternative is that anything in the first clause would be reactivated as a result of the search through a memory representation of the first clause (see Koenenman, Baauw, & Wijnen, 1998; see also a mental models approach suggested by, for example, the work of Johnson-Laird, 1983). In our next, final, experiment we investigate these alternatives.

Consider the following:

- (15) *The mailman* bought *a tie* for Easter, and his brother, who was [1] playing volleyball, did [2] too, according to the sales clerk.

To review, reconstruction copies the contents of the VP in the first clause into the ‘empty’ VP-position in the second clause. Thus, the phonetic string in (15) yields the interpretation in (16):

(16) The mailman bought a tie for Easter, and his brother, who was playing volleyball did [*buy a tie for Easter*] too, according to the sales clerk.

If reactivation of the subject NP from the first clause is just a consequence of the predication relation between the VP and its subject, then we should observe such subject activation effects even in ellipsis constructions that do not contain anaphors. That is, in (15), we should observe reactivation of the subject NP (e.g., *the mailman*) from the first clause at the elided position [2] in the second clause. Furthermore, if all arguments of the verb are reconstructed at the elided VP, then we should observe activation of *both* the subject and object NP at the elision site (e.g., both *the mailman* and a tie). However, if—as we have been suggesting—what is copied or reconstructed at the VP-ellipsis site is only the VP, then we should observe activation only for the argument that is reconstructed with the VP, that is, only the object NP. Thus, the discriminating factor here that differentiates our account from the others is whether or not the subject NP (other accounts) or object NP (our current account) is activated in the second clause.

Method

Participants—Forty college students, all native English speakers with normal or correct-to-normal auditory and visual acuity, participated in Experiment 3. Twenty subjects each were randomly assigned to one of two probe positions, either the pre-ellipsis or ellipsis positions.

Materials and design—Forty test sentences were developed (see (15) above as an example, see Appendix B for the full set). The test sentences were embedded into two identical lists, each of which included 60 fillers, yielding a total of 100 sentences per list which were randomly ordered. Half the sentences in each list were paired with a related probe, and the other half to an unrelated, control probe. Of the 20 related probes, 10 were related to the subject NP, and 10 to the object NP. The two lists differed in terms of which sentences were paired with which probes. In list 1, the first 20 test sentences were paired with probes designed to assess subject activation; the last 20 designed to assess object activation. In list 2, this order was reversed. Again, we selected our probes by polling college-age adults for their first associates to the words that were later incorporated in the sentences (that is, to the NPs to which the probes were related). In the case where we were assessing the subject NP, we eliminated any probes that were first or second associates to the object NP; and in the case of assessing activation from the object NP, we eliminated any probes related to the subject NP. The control probes bore no relation to any word in the sentence, but were matched to the related probes in terms frequency of occurrence, number of letters/syllables, part of speech, animacy, and importantly, base RTs (subject-related mean = 577 ms, control = 571 ms; object-related mean = 550 ms, control = 556 ms).

The two lists were presented at least two weeks apart. In addition to the 40 test sentences, real-word probes were assigned to 10 filler sentences; for the remaining 50 fillers, nonword probes (conforming to English orthographic rules) were assigned. Thus, each subject heard 100 sentences during the experiment, half of these paired with visually presented real word probes and half with nonwords.

The two test probe positions were determined by structure. Using (15) as an example, the pre-ellipsis probe position [1] was placed at least 6 syllables past the occurrence of the object NP from the first clause, and immediately after the auxiliary within the relative clause

and approximately six syllables before the ellipsis position [2]. Probe positions in the fillers were assigned to various temporal locations to lessen any expectations on the part of the subjects.

Procedure—We again used the CMLP task. Participants sat in a small testing room in front of a computer monitor and a button box. The sentences were presented over headphones via a digital tape recorder. During the temporal unfolding of each sentence, a visually presented lexical decision probe appeared centrally (for 300 ms) on the monitor. Subjects were required to attend to the aurally presented sentences and to make a visual lexical decision quickly and accurately by pressing one of two response keys (labelled WORD, NONWORD); RTs to this decision were recorded by the computer. In approximately 20% of the trials, the tape was stopped and subjects were asked to paraphrase the sentence that they had just heard, with the purpose of ensuring that the subjects were paying attention to the sentences. RTLab software was used to deliver stimuli and record RTs.

Results

Error rates on test probes (answering “Nonword” to real word probes) were distributed as follows: Pre-ellipsis position probes for subject grammatical function yielded 4.6% errors, and for grammatical object, 5.3% errors; ellipsis position probes for subject yielded 5% errors, and for grammatical object, 6% errors.

A subject-based mixed design analysis of variance (ANOVA) was run on the correct RT data (collapsing across items). Probe position (pre-ellipsis and ellipsis) was a between-subjects factor with probe type (control and related) and grammatical function of prime (subject and object) as within-subjects factors. The mean RT data used in this analysis are shown in Table 4.

A main effect of probe type was observed; related probes (703 ms) yielded significantly faster RTs than unrelated control probes (722 ms), $F(1, 38) = 14.63$, $p < .001$. A marginally significant interaction between probe type and grammatical function was also observed, $F(1, 38) = 3.11$, $p = .086$.

We then performed separate mixed-design ANOVA's for subject and object grammatical function (based on our apriori predictions of differential effects, as well as on the observed interaction involving grammatical function). For grammatical subject, no significant effects or interactions were observed. For grammatical object, a main effect of probe type was observed; object-related probes (692 ms) yielded significantly faster RTs than unrelated control probes (721 ms), $F(1, 38) = 21.28$, $p < .001$. A near-significant interaction between probe type and probe position was observed, $F(1, 38) = 3.45$, $p = .07$. A set of paired comparisons was subsequently performed. Only the difference between object-related (687 ms) and unrelated control probes (727 ms) at the elided position was found to be significant, $t(19) = 3.83$, $p < .001$, though the difference between related (696 ms) and control probes (713 ms) approached significance, $t(19) = 2.57$, $p = .02$ ($p = .01$ was required to reach a .05 level, given the Bonferroni correction). Seventy-five percent of the subjects conformed to this pattern; that is, they evinced faster RTs on object-related relative to control probes when presented at the ellipsis site (50% yielded a similar pattern at the pre-ellipsis site).

A series of item-based analyses (collapsing across subjects) was also performed. A mixed design analysis of variance (ANOVA) was run, with grammatical function of prime (subject and object) as a between-subjects factor (since different probes were used for subject and object grammatical function), and probe position (pre-ellipsis and ellipsis) and probe type (control and related) as within-subjects factors. A marginally significant main effect of

probe type was observed; related probes (700 ms) yielded faster RTs than unrelated control probes (720 ms), $F(1, 38) = 3.169$, $p = .08$. A marginally significant interaction between probe type and grammatical function was observed, $F(1, 38) = 3.072$, $p = .09$.

Based on our predictions of effects for grammatical object but not for subject, separate item-based repeated measures ANOVA's for subject and object grammatical function were performed. And indeed, for grammatical subject no significant effects were observed. A main effect of probe type was observed for grammatical object; related probes (681 ms) yielded significantly faster RTs than unrelated control probes (720 ms), $F(1, 19) = 4.63$, $p = .04$. Eighty-three percent of the items yielded faster RTs on the object-related relative to the control probes (57% of the items yielded faster RTs on the subject-related relative to control probes).

Discussion

In this experiment we found no activation for the subject NP, eliminating the hypothesis that the predication relation between the VP and its subject might explain our previous effects indicating on-line activation of the strict reading. However, on the subject-based analyses we did observe faster RTs for object-related compared to control probes collapsing across the probe positions, and also at the elision site (and indications of priming at the pre-ellipsis position). Item-based analyses also found significant effects for related versus control probes, but only for the object grammatical function. Thus, since only the object NP was found to be activated, the hypothesis that all arguments are reconstructed at the VP ellipsis site is also not supported by the evidence. Nor is the possibility that listeners search through a memory representation.³ In essence, then, our findings suggest that when listeners encounter a VP-ellipsis site in a second clause, they activate the VP from the first clause, including the direct object NP and any referential dependency that this object enters into, represented formally by the index carried on this NP.

General discussion

To summarize, we exploited the syntactic and interpretive aspects of VP-ellipsis constructions in order to examine the temporal unfolding of language processing. As a precursor to the issues pertinent to VP-ellipsis comprehension, in Experiment 1 we found that listeners reactivate an antecedent in the immediate temporal vicinity of a reflexive pronoun, showing that co-reference relations are established on-line. This result also suggests that the lexical decision probes we selected were well-controlled, since at the pre-anaphor position there were no significant differences between related and unrelated controls, but at the anaphor position RTs were significantly faster to related compared to controls. Note that these lexical decision probes were also used in subsequent experiments, ruling out explanations involving any spurious interactions between probes and the material in the sentences that did not have to do with possible co-reference relations.

More to the point of the present paper, Experiment 1 also examined how lexical properties influence on-line comprehension of covert material inherent to VP-ellipsis constructions. We used reflexive and inalienable possession verbs with properties that primarily disallowed the strict reading (e.g., “the fireman *perjured* himself, and the policeman did too...”), and we

³There is a slight caveat to our interpretation. Note that we reported that the related probes for the subject prime yielded baseline RTs that were 6 ms slower than for their control probes, and the related probes for the object prime yielded baseline RTs that were 6 ms faster than for their control probes. Thus, there appears to be a 12 ms advantage to finding an effect for object activation over subject activation. However, such small differences are unavoidable when attempting to control for base RTs, and often the best we can do is to ensure that these differences are nonsignificant (and indeed, they were) and that the differences, when subtracted out of the cross-modal results, do not affect the overall pattern (and they did not).

examined if listeners still show on-line activation for that interpretation. Indeed, we found strong evidence suggesting that listeners activate the strict reading in the immediate temporal vicinity of the elided position, initially ignoring lexical constraints. In Experiment 2, we found that listeners are also sensitive to the sloppy interpretation on-line (again, at the elided position), suggesting that listeners activate *both* the strict and sloppy readings momentarily and relatively simultaneously. In Experiment 3, we examined the processing of VP-ellipsis that did not contain anaphors (e.g., “the mailman bought a tie for Easter, and his brother did too...”). We found that in the second clause, listeners activate the object NP and not the subject NP from the first clause. This pattern disallows several alternative explanations for our results, one that suggests that the predication relation between the first VP and its subject yields reactivation of the elided NP, one that suggests that the distant subject is reactivated as a result of a search through the memory representation of the first clause (Koenen et al., 1998), and one that suggests that all arguments of the copied verb are activated at the elided position.

In terms of the results we have observed here and in terms of our previous effort (Shapiro & Hestvik, 1995), then, any account of sentence processing must be sensitive to the fact that listeners momentarily activate antecedents to overt anaphors and to covert material at the point where such material is encountered; and it must acknowledge that lexical properties and probabilistic information influence structure-building, but that there are moments in time where these properties are ignored. We therefore suggest that our findings generally support a ‘restricted’ account of sentence processing whereby some information is ignored during the initial analysis. Thus far, this information includes overall preference for a particular interpretation, the overall probabilistic effect that the sloppy interpretation occurs more frequently than the strict interpretation, and finally, the lexical-semantic properties of the verb that restricts final interpretation.

Following Frazier and Fodor (1978), Friederici (1995), and Friederici and Mecklinger (1996), we propose that the initial stage parses the input based on lexical categories and the skeleton of a verb’s argument structure (Shapiro et al., 1987), essentially deriving a shallow representation of phrase structure, syntactic categories, and—we suggest—syntactic indices on NPs in the tree, the latter allowing immediate co-reference relations among nonadjacent categories to be established. Furthermore, because we have found on-line activation for both the strict and sloppy interpretation of VP-ellipsis, we suggest that parallel syntactic analyses are momentarily available at the initial stage (see also Gibson, Hickok, & Schuetze, 1994; Hickok, 1993). This latter result is also compatible with an account where multiple senses of lexical ambiguities are immediately available in the vicinity of the lexically ambiguous item (Swinney, 1979), but those that are not contextually compatible are quickly discarded. In the present case we have yet to examine when during the moment-by-moment processing of sentences the less-preferred structure (i.e., strict reading) becomes unavailable, but we know of course based on our off-line data that this does eventually occur.

Lagging behind the first stage temporally is an additional stage (or multiple stages), which has as its input, the output of the first stage. Here, lexical-semantic information is used as well as thematic role assignment (so, for example, a DET and N merges into an NP in Stage 1; this NP is assigned a particular thematic role in Stage 2). It is at the output of this stage that we observe, for example, preference for a particular structure and the influence of lexical constraints. Indeed, supporting this account, there is evidence from lesion studies that brain damage selectively affects some lexical and syntactic routines (Grodzinsky, 2000; Shapiro, Gordon, Hack, & Killackey, 1993; Zurif et al., 1993). One interesting question is just how far apart the initial stage is from subsequent stages, and how such ‘distances’ should even be measured (temporally? In terms of constituent structure?). Based on

neurophysiological evidence, Friederici (1995; Friederici & Mecklinger, 1996) suggests a lag of approximately 200–400 ms between the initial parse and subsequent analyses.

So, how do we accommodate our findings with claims in the literature from constraint-based approaches that there is little or no distinction between lexical and syntactic operations, and that, for example, probabilistic information is used immediately (e.g., Garnsey, Pearlmutter, Myers, & Lotocky, 1997; MacDonald et al., 1994; McRae et al., 1997; McRae, Spivey-Knowlton, & Tanenhaus, 1998)? The most conservative possibility is that our results can be viewed as an aberration, perhaps because of task-specific effects generated by our use of cross-modal priming. Since we often observe sentence context, lexical information, probabilistic information, and generally, extra-syntactic information having their effects temporally downstream from the point at which such information is licensed, it could be argued that cross-modal priming delays the observation (i.e., recording) of these effects, even though this information could, in principle, be available earlier. We do not think this is an accurate interpretation, however, since syntactic effects are observed at the immediate temporal point where they are licensed and only lexical and extra-syntactic effects are observed later. Of course, it is always possible that the CMLP task is particularly sensitive to initial syntactic effects and insensitive to initial extra-syntactic effects, independent of where during the time-course such effects actually operate. However, we are not aware of any data that support this possibility.

Another possibility is that for some of these studies that have found initial extra-syntactic effects, on-line analyses are more apparent than real; that the tasks used to assess on-line behavior *cannot*, in principle, probe the output of a relatively independent process. For example, word-by-word, moving-window reading tasks are often used to assess so-called on-line effects. Yet, it can be argued that such tasks are particularly *insensitive* to fast-acting, relatively automatic operations just because of their self-paced nature. Furthermore, such tasks allow subjects to ‘consciously reflect’ at every decision point, essentially forcing predictions of upcoming material based on previous input. For example, McRae et al. (1998), using data generated from self-paced reading, claim that thematic role information and role-filler information (whether an NP is a ‘good’ Agent of Patient) influences immediate on-line interpretation. Yet, in a recent study using a cross-modal task, we found such roll-filler effects temporally downstream from where the information was initially licensed in the sentence (Lesan, 2002).

Similar arguments can be made against the sensitivity of ‘on-line’ grammaticality and plausibility judgments (Boland, 1997), ‘shadowing’ tasks (Liu, Bates, Powell, & Wulfeck, 1997), continuation priming (Ferretti, McRae, & Hatherell, 2001; McKoon & Radcliff, 1994), and tasks that alter typical speech and visual presentation rates (Dick et al., 2001; see also Swinney & Love, 1998). There is a relatively new technique—the “visual-world” eye-tracking paradigm (e.g., Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995)—that has shown some interesting predictive effects of argument structure (Boland, 2002), selectional restrictions (Altmann & Kamide, 1999), and syntactic information (Kamide, Scheepers, Altmann, & Crocker, 2002). What is needed here is a concerted effort to run multiple behavioral tasks on well-controlled and similar materials, so that the interaction of task-specific effects with purported lexical, syntactic, and extra-syntactic operations can be more clearly evaluated.

There are alternatives to our claims that do not involve possible task-specific effects. Perhaps what we observed here and in our previous effort was not a reflection of a multi-stage parser, but, instead, a reflection of the construction of a mental model (e.g., Garnham, 2001; Glenberg, Meyer, & Lindem, 1987; Johnson-Laird, 1983). On this account comprehension processes are not specific to language; instead they involve ‘structure-

building' of elements or events. So, for example, perhaps a listener constructs, incrementally, the event described in the first clause of an ellipsis construction, and then uses that to construct a model of the second clause. Though our experiments were not specifically designed to test such an account, the results from Experiment 3 would seem to contradict it. The mental model constructed incrementally from the first clause event would contain a reference to the subject NP, yet it turns out that the subject NP is not found to be active either in the pre-ellipsis or ellipsis position in the second clause. A mental model would have to explain why in some cases the subject NP is activated as part of an 'event', and in other cases it is not. There may be a way to reconcile these results with such an approach, but it would seem that in the present case a multiple-stage parser has more explanatory value.

Another alternative involves notions of memory cost. On this account comprehending long-distance dependencies involves computing the distance and integrating material between nonadjacent positions. The longer the distance (and, the more complex the material is between positions), the larger the computational load and the more 'difficult' it will be to process sentences (e.g., Gibson, 1998; McElree, 2000). In the present set of experiments both the long distance subject NP from the first clause as well as the local subject NP from the second clause are activated when the ellipsis construction contains an anaphor. This suggests that at least in these constructions, memory cost does not affect activation patterns observed during on-line processing. It may be the case, however, that memory cost is reflected in behavior observed in off-line, final interpretation. Indeed, we and others find that the strict reading (based on acknowledging the long-distance, first-clause subject) is significantly less preferred in off-line judgments than the sloppy reading (based on the local, second-clause subject). It is left unclear whether this is because of the statistical proclivities of the language, or because the strict reading involves a greater memory and integration cost given the long-distance nature of the co-reference relation between the subject NP position and the elided VP position. Frazier and colleagues consider another possibility (Frazier & Clifton, 2000; Frazier, Taft, Roeper, Clifton, & Ehrlich, 1984): The two clauses are 'parallel' on a sloppy interpretation (both predicates are reflexive) and are not on a strict interpretation, and perceiver's prefer conjoined clauses to be parallel. Frazier and Clifton (2000) report that, indeed, sloppy interpretations show a processing advantage over strict interpretations during self-paced reading (though their experiments were not intended to assess if and where the different interpretations were active during the unfolding of the sentence).

In conclusion, using ellipsis constructions and the cross-modal priming task as the means by which we examine the moment-by-moment processing routines underlying sentence comprehension, we find that the initial analysis of a sentence yields the construction of a shallow syntactic representation; lexical and probabilistic information are ignored.

Acknowledgments

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Appendix A: Experimental sentences and probes: Experiments 1 and 2

(NP1 = subject NP from first clause; NP2 subject NP from second clause; R = related probe; C = unrelated control = probe)

1. The ski *instructor* who was having marital [1] problems DISTANCED HERSELF [2] and her *friend* who was basically [3] antisocial did [4] too, according to their analyst.

NP1	NP2
R: TEACHER	R: BUDDY
C: TRAFFIC	C: BLADE

2. The *gambler* who won 10 hands in [1] a row WINKED HIS [2] eyes and the pit *boss* who was in on [3] the elaborate scheme did [4] too, according to the private eye.

NP1	NP2
R: MONEY	R: EMPLOYER
C: PAPER	C: REPUBLIC

3. The *bride* who needed to go [1] to the bathroom SHUFFLED HER [2] feet and the *bartender* who had a blister [3] on her big toe did [4] too, according to the guests waiting for their orders.

NP1	NP2
R: VEIL	R: WHISKEY
C: RASH	C: TRIBUTE

4. The *optometrist* who had signed the release [1] form ASSERTED HERSELF [2], and the *pilot* who needed to pass [3] the training exam did [4] too, according to the receptionist.

NP1	NP2
R: EYE	R: PLANE
C: LOT	C: SHARE

5. The *violinist* who was usually [1] temperamental BEHAVED HERSELF [2], and her *housekeeper*, who had just turned [3] 57, did [4] too, according to guests that attended the party.

NP1	NP2
R: MUSIC	R: APRON
C: LEVEL	C: TULIP

6. The *jeweler* who was suspicious [1] RAISED HIS [2] eyebrows and the *astronaut* who had actually [3] been cheating for years did [4] too, according to the others at the table.

NP1	NP2
R: GEM	R: SPACE
C: LOG	C: FLOOR

7. The *movie star* who was trying to quit [1] smoking COMPOSED HERSELF [2], and her *aunt*, who was going through [3] menopause, did [4] too, according to the leading tabloids.

NP1	NP2
R: CELEBRITY	R: UNCLE
C: VEGETABLE	C: MINOR

8. The *skier* with the broken leg [1] TWIDDLED HIS [2] thumbs and the *boxer* with a couple of [3] rib fractures did [4] too, according to the world-famous surgeon.

NP1	NP2
R: SNOW	R: FIGHT
C: SAFE	C: CLAIM

9. The *kid* who wanted to lick [1] the bowl SMACKED HIS [2] lips and the *baker* who was 35 [3] pounds overweight did [4] too, according to the other customers watching the cooking demonstration.

NP1	NP2
R: CHILD	R: BREAD
C: CLEAR	C: MATCH

10. The *ranger* who was having a case [1] of the giggles SOBERED HIMSELF [2] and the *pharmacist* who did not want to be [3] rude did [4] too, according to the guests at the funeral.

NP1	NP2
R: FOREST	R: DRUGS
C: PRISON	C: DATES

11. The *fisherman* who was allergic [1] to hay TWITCHED HIS [2] nose and the *farmer* who had a very [3] bad head cold did [4] too, according to the daughter of one of them.

NP1	NP2
R: TROUT	R: TRACTOR
C: SCOUT	C: LEATHER

12. The *sniper* who was extremely [1] nervous PERJURED HIMSELF [2], and the *chauffeur* who was a witness [3] for the prosecution did [4] too, according to the anchor person for Channel 4.

NP1	NP2
R: GUN	R: DRIVER
C: CUT	C: WISDOM

13. The *florist* who was sitting on [1] the deck SUNNED HERSELF [2], and the *writer* who was visiting [3] for the day did [4] too, according to the couple that owns the house.

NP1	NP2
R: BLOOM	R: AUTHOR
C: THUMB	C: SECRET

14. The *soprano* who was broken-hearted [1] CRIED HERSELF [2] to hysterics and the *manicurist* who was in the same [3] situation did [4] too, according to their neighbors.

NP1	NP2
R: CHOIR	R: NAIL
C: RAZOR	C: SMOG

15. The *caddie* who was impatient [1] DRUMMED HIS [2] fingers and the *plumber* who hated waiting [3] for anything did [4] too, according to the other people in the foursome.

NP1	NP2
R: GOLF	R: DRAIN
C: RICE	C: BUNCH

16. The *conductor* who was a perfectionist [1] TOSSED HIS [2] hair and his star *pupil* who was vain about [3] his looks did [4] too, according to the person sitting in the third row.

NP1	NP2
R: SYMPHONY	R: STUDENT
C: STIMULUS	C: FREEDOM

17. The *dentist* who was attractive [1] but coy BATTED HER [2] eyelashes and the *painter* who was a little [3] tipsy did [4] too, according to the hostess at the party.

NP1	NP2
R: TEETH	R: CANVAS
C: DRINK	C: CEMENT

18. The *lawyer* who was rumored to be [1] lazy VINDICATED HIMSELF [2], and the *inventor* who was normally [3] very passive did [4] too, according to the local newspaper columnist.

NP1	NP2
R: JUROR	R: PATENT
C: ATTIC	C: PILLOW

19. The *acrobat* who was conceited [1] FLEXED HIS [2] muscles and the *golfer* who had an inflated [3] self-image did [4] too, according to someone else in the weight room.

NP1	NP2
R: SOMERSAULT	R: TEE
C: STEWARDESS	C: JUG

20. The chef who was frustrated by [1] the blackout CLENCHED HIS [2] fists and the caterer's *spouse* who was secretly [3] afraid of the dark did [4] too, according to the delivery truck driver.

NP1	NP2
R: COOK	R: HUSBAND
C: PACE	C: TROUBLE

21. The *doctor* who was waiting for [1] the subway BUSIED HERSELF [2], and the *terrorist* who was trying to blend [3] into the crowd did [4] too, according to the special agents for the FBI.

NP1	NP2
R: NURSE	R: BOMB
C: PRINT	C: DIRT

22. The *beaver* in the newly remodeled [1] exhibit slowly BLINKED HIS [2] eyes and the *parakeet* perched in the nearby [3] aviary did [4] too, according to the children on the field-trip.

NP1	NP2
R: DAM	R: PARROT
C: WEB	C: NICKEL

23. The *ballerina* who was ambitious [1] EXERTED HERSELF [2], and the *equestrian* who had just joined [3] the prestigious gym did [4] too, according to the top resident trainer.

NP1	NP2
R: DANCE	R: HORSE
C: TRAIN	C: DRESS

24. The *paramedic* who was first on the scene [1] WRINKLED HER [2] forehead and the *nanny* who was afraid it [3] might be too late did [4] too, according to the on-lookers.

NP1	NP2
R: AMBULANCE	R: NURSERY
C: AUTOGRAPH	C: HORIZON

25. The *priest* who saw the Halloween [1] candies CLICKED HIS [2] tongue and the *barber* who was a health food [3] enthusiast did [4] too, according to the person behind them in the checkout line.

NP1	NP2
R: BISHOP	R: COMB
C: LENSES	C: RAMP

26. The *sailor* who had a tattoo on [1] his neck COLLECTED HIMSELF [2] and the *teller* who had started to holler [3] first did [4] too, according to the transcripts of the trial.

NP1	NP2
R: SHIP	R: BANK
C: CAKE	C: WOOD

27. The *zoo-keeper* who had to work late [1] again POUTED HER [2] lips and the *spy* who could not make [3] the scheduled drop did [4] too, according to the first draft of the novel.

NP1	NP2
R: ELEPHANTS	R: CODE
C: INDUCTION	C: KNIT

28. The *king* who was always [1] impatient CLEARED HIS [2] throat and the *senator* who grew up in New [3] York City did [4] too, according to the new unauthorized biography.

NP1	NP2
R: QUEEN	R: CONGRESS
C: SPLIT	C: PROGRAMS

29. The *candidate* who had lost in the recent [1] elections SECLUDED HIMSELF [2] and the *postman* who had come to the retreat [3] for meditation did [4] too, according to the monks at the monastery.

NP1	NP2
R: POLITICS	R: MAIL
C: RELATIVE	C: CORE

30. The plaintiff who feared public [1] speaking FLUTTERED HIS [2] eyelashes and the *admiral* who had a piece of [3] fluff in his eyes did [4] too, according to the court reporter.

NP1	NP2
R: DEFENDANT	R: FLEET
C: ARTHRITIS	C: WHEAT

31. The *trucker*, knowing that the impact [1] was imminent, STEELED HIMSELF [2] and the *gardener*, who had been hitchhiking [3] into town did [4] too, according to the medical records.

NP1	NP2
R: DIESEL	R: LAWN
C: LOTION	C: DUKE

32. The *cardiologist* who loved to pull little [1] pranks LAUGHED HIMSELF [2] to tears and the *deejay* who was very fond [3] of practical jokes did [4] too, according to the other patrons at the bar.

NP1	NP2
R: HEART	R: RADIO
C: MOUTH	C: UNION

33. The *burglar* who was hiding in [1] the shadows HUNCHED HIS [2] shoulders and the *drunk* who wore only a thin [3] tattered coat did [4] too, according to the undercover detective.

NP1	NP2
R: THIEF	R: ALCOHOLIC
C: SCOOP	C: DECORATOR

34. The *Martian* who was undergoing [1] interrogation ROLLED HIS [2] eyes and the air force *officer* who had been the first [3] on the scene did [4] too, according to the cover story of the Enquirer.

NP1	NP2
R: GALAXY	R: CAPTAIN
C: HELIUM	C: PATIENT

35. The *athlete* who won the quarter [1] finals INTOXICATED HERSELF [2], and her *mother*, who was exceedingly [3] happy and proud, did [4] too, according to the magazine article.

NP1	NP2
R: SPORTS	R: FATHER
C: SCREEN	C: INSIDE

36. The *cowboy* who suggested making [1] the wager SHRUGGED HIS [2] shoulders and the *shortstop* who was not worried [3] about losing did [4] too, according to eye-witnesses.

NP1	NP2
R: CATTLE	R: BASEBALL
C: BOTTOM	C: CUPBOARD

Appendix B: Experimental sentences and probes: Experiment 3

1. The *mailman* bought a tie for Easter, and his brother, who was [1] playing volleyball, did [2] too, according to the sales clerk.

NP1	NP2
R: STAMP	R: NECK
C: STEER	C: ROSE

2. The old *professor* loved the *ocean*, and the teenager, who was [1] wearing a nose ring, did [2] too, according to students in the class.

NP1	NP2
R: TEACHER	R: PACIFIC
C: TRAFFIC	C: HARMONY

3. The criminal defense *attorney* voted for the *proposition*, and the real estate agent, who was [1] filing for bankruptcy, did [2] too, according to the county clerk.

NP1	NP2
R: JAIL	R: LAW
C: JOKE	C: JOB

4. The single *mother* talked about her child's retired *coach*, and the school principal, who was feeling [1] the need to give his opinion, did [2] too, according to neighbors in the group.

NP1	NP2
R: FATHER	R: SPORTS
C: FORCES	C: SCREEN

5. During the instructions the *samurai master* slipped on a *loafer*, and the student, who had [1] arrived disheveled and late, did [2] too, according to others in the class.

NP1	NP2
R: WARRIOR	R: SHOE
C: WEAVING	C: YARN

6. The *policeman* defended the *abused child*, and the fireman, who had [1] seen the whole thing, did [2] too, according to people at the scene.

NP1	NP2
R: ROBBER	R: GIRL
C: ROLLER	C: LAND

7. The army *general* criticized the *food*, and the congressman, who was [1] his best friend, did [2] too, according to other high-ranking officers.

NP1	NP2
R: TANK	R: FLAVOR
C: TEAR	C: CLOSET

8. The *dentist* praised the *veterinarian*, and the real estate agent, who was [1] driving a rental car, did [2] too, according to others in the building.

NP1	NP2
R: TEETH	R: ANIMALS
C: DRINK	C: ARTIST

9. The *teller* blamed the black *van* for the accident, and the armed guard, who was [1] working all night long, did [2] too, according to witnesses at the scene.

NP1	NP2
R: BANK	R: CAR
C: WOOD	C: BOY

10. The DEA agent wrote a *memo* to the group's spokesperson, and the businessman, who had [1] been traveling nonstop for days, did [2] too, according to the reporters in the courtroom.

NP1	NP2
R: DRUG	R: PAGE
C: DATE	C: LAKE

11. The *pilot* failed to construct an origami *flower*, and the nanny, who was [1] from the south of Spain, did [2] too, according to the boy.

NP1	NP2
R: PLANE	R: LEAF
C: SHARE	C: BOOT

12. The *fisherman* went to see the *barber*, and the mayor, who was [1] winning at the polls, did [2] too, according to the receptionist.

NP1	NP2
R: TROUT	R: COMB
C: SCOUT	C: RAMP

13. The *shortstop* raved about the *deejay*, and the student, who was [1] failing speech class, did [2] too, according to classmates.

NP1	NP2
R: BASEBALL	R: RADIO
C: CUPBOARD	C: UNION

14. The *painter* dreamed of being a *writer*, and the manicurist, who was [1] attending City College, did [2] too, according to a mutual friend.

NP1	NP2
R: CANVAS	R: AUTHOR
C: CEMENT	C: SECRET

15. The *king* sent for a *spy*, and the husband, who suspected his wife was [1] having an affair, did [2] too, according to the businessman.

NP1	NP2
R: QUEEN	R: CODE

NP1	NP2
C: SPLIT	C: KNIT

16. The *bride* fell onto the *chauffeur*, and the candidate, who was not [1] photogenic, did [2] too, according to society column reporters.

NP1	NP2
R: VEIL	R: DRIVER
C: RASH	C: WISDOM

17. The *chef* banged his pans on the *cabinet*, and the tutor, who had [1] finished all of the math problems, did [2] too, according to the neighbors that heard them.

NP1	NP2
R: COOK	R: CUPBOARD
C: PACE	C: BACKDROP

18. The *skier* struggled with the *boots*, and the country singer, who was [1] touring California, did [2] too, according to the manufacturer.

NP1	NP2
R: SNOW	R: CATTLE
C: SAFE	C: BOTTOM

19. The *soprano* drank *herbal tea*, and the businesswoman, who was [1] wearing a fancy suit, did [2] too, according to the waitress.

NP1	NP2
R: CHOIR	R: CAKE
C: RAZOR	C: SHIP

20. The *acrobat* fell from a *chair*, and the student, who was [1] daydreaming during class, did [2] too, according to the citizens of the town.

NP1	NP2
R: SOMERSAULT	R: SEAT
C: STEWARDESS	C: WINE

21. The hungry *beaver* ate a *parakeet*, and the neighbor's ferocious feline, who was [1] sleeping in the sun, did [2] too, according to the animal control agents.

NP1	NP2
R: DAM	R: PARROT
C: WEB	C: NICKEL

22. The *trucker* laughed at the *drunk*, and the comedian, who had [1] worn his shirt open, did [2] too, according to patrons at the pub.

NP1	NP2
R: DIESEL	R: ALCOHOLIC
C: LOTION	C: DECORATOR

23. The *jeweler* cheated the *burglar*, and the corner hotdog vendor, who was [1] often out of onions, did [2] too, according to their customers.

NP1	NP2
R: GEM	R: THIEF
C: LOG	C: SCOOP

24. The *gambler* praised the *equestrian*, and the horse's owner, who was [1] driving a maroon sedan, did [2] too, according to people in the stables.

NP1	NP2
R: MONEY	R: HORSE
C: PAPER	C: DRESS

25. The *ballerina* yelled at the *housekeeper*, and the princess, who was [1] wearing Doc Martins, did [2] too, according to friends of the women.

NP1	NP2
R: DANCE	R: APRON
C: TRAIN	C: TULIP

26. The *farmer* had a *nightmare*, and the delivery truck driver, who was [1] 10 pounds overweight, did [2] too, according to his wife.

NP1	NP2
R: TRACTOR	R: DREAM
C: LEATHER	C: CROSS

27. The *zookeeper* pushed the *donkey* out of the truck, and a visitor, who was [1] sunburned all over his arms, did [2] too, according to others at the park.

NP1	NP2
R: ELEPHANTS	R: MULE
C: INDUCTION	C: MUSE

28. The *grandmother* cooed at the *baby* in the stroller, and the tour guide, who was [1] bored with her job, did [2] too, according to others in the group.

NP1	NP2
R: RELATIVE	R: BOTTLE
C: POLITICS	C: REGION

29. The *friend* chased the *child* wildly through the house, and the dog, who was [1] limping up the stairs, did [2] too, according to neighbors in the yard.

NP1	NP2
R: BUDDY	R: KID
C: BLADE	C: SIT

30. The *expert* placed a *snake* on a tree, and the gardener, who was [1] tending to the pond, did [2] too, according to the owners of the house.

NP1	NP2
R: PRO	R: COBRA
C: PAN	C: CANAL

31. The *boy* followed the pregnant *pig* closely, and the instructor, who was [1] not afraid to get his clothes dirty, did [2] too, according to others at the fair.

NP1	NP2
R: CHILD	R: BACON

NP1	NP2
C: CLEAR	C: BATON

32. The *doctor* examined the *yacht*, and the secretary, who was [1] on her break, did [2] too, according to patients in the office.

NP1	NP2
R: NURSE	R: BOAT
C: PRINT	C: RULE

33. The *guard* held the *postman* at gunpoint, and the TV star, who was [1] coloring her straight blond hair, did [2] too, according to producers of the show.

NP1	NP2
R: GUN	R: MAIL
C: SUN	C: CORE

34. The lion investigated the debris carefully, and the groundskeeper, who was [1] wearing a jumpsuit, did [2] too, according to visitors at the ranch.

NP1	NP2
R: TIGER	R: DIRT
C: TORSO	C: BOMB

35. The teacher drew a *monkey* on the blackboard, and the janitor, who was [1] bored with his cleaning, did [2] too, according to students at the school.

NP1	NP2
R: STUDENTS	R: BANANA
C: PROBLEMS	C: BOTANY

36. The *baker* bought some *candles*, and the mother, who was [1] the troop leader, did [2] too, according to girls at the party.

NP1	NP2
R: DOUGH	R: DINING
C: DRUMS	C: VICTIM

37. The *daughter* kicked the *ball* against the wall, and the garbage collector, who had [1] worked two shifts, did [2] too, according to neighbors in the yard.

NP1	NP2
R: GIRL	R: CATCH
C: MEAN	C: PORCH

38. The *cow* looked at the *moon*, and the coyote, who was [1] domesticated in the suburbs, did [2] too, according to the newspaper's amazing stories column.

NP1	NP2
R: MILK	R: SKY
C: MOLD	C: LEG

39. The *musician* chatted with the *florist*, and the mother, who was [1] fed up with all her chores, did [2] too, according to a friend.

NP1	NP2
R: PIANO	R: BLOOM
C: RATIO	C: THUMB

40. The *lawyer* bumped into the *optometrist*, and the child, who was [1] looking at the ground, did [2] too, according to others in the lobby.

NP1	NP2
R: TRIAL	R: EYE
C: TABLE	C: LOT

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Table 1

Experiment 1: Mean RTs (and SDs) to probe type as a function of probe position

Probe type	Probe position	
	Pre-reflexive	Reflexive
Control	716 (108)	745 (71)
Related	713 (109)	711 (74)

Table 2

Experiment 1: Mean RTs (and SDs) to probe type as a function of probe position; strict reading

Probe type	Probe position	
	Pre-ellipsis	Ellipsis
Control	709 (116)	778 (156)
Related	707 (124)	744 (153)

Table 3

Experiment 2: Mean RTs (and SDs) to probe type as a function of probe position; sloppy reading

Probe type	Probe position	
	Pre-ellipsis	Ellipsis
Control	822 (83)	839 (85)
Related	820 (98)	807 (110)

Table 4

Experiment 3: Mean RTs (and SDs) to probe type as a function of probe position and grammatical function

Probe type	Probe position			
	Grammatical function			
	Pre-ellipsis		Ellipsis	
	Subject	Object	Subject	Object
Control	728 (69)	713 (73)	718 (107)	727 (109)
Related	721 (84)	696 (61)	709 (115)	687 (111)