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 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 \( \lambda x[x \text{ likes } x’s \text{ car}], \) and Bill does too.

b. John \( \lambda x[x \text{ likes } x’s \text{ car}], \) and Bill \( \lambda x[x \text{ likes } x’s \text{ car}] \) too.

c. John \( \lambda x[x \text{ likes } x’s \text{ car}], \) and Bill \( \lambda x[x \text{ likes } x’s \text{ car}] \) too.

(5a) John \( \lambda x[x \text{ likes his } x’s \text{ car}], \) and Bill \( \lambda x[x \text{ likes his } x’s \text{ car}] \) too.

(5d) = “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:

(5b) a. John \( \lambda x[x \text{ likes } x’s \text{ car}], \) and Bill \( \lambda x[x \text{ likes } x’s \text{ car}] \) too.

b. John \( \lambda x[x \text{ likes } x’s \text{ car}], \) and Bill \( \lambda x[x \text{ likes } x’s \text{ car}] \) too.

c. John \( \lambda x[x \text{ likes hisJohn } x’s \text{ car}], \) and Bill \( \lambda x[x \text{ likes hisJohn } x’s \text{ car}] \) too.

d. = “John likes John’s car and Bill likes Bill’s car”

(5c) is a paraphrase of the interpretation of the logical-semantic representation in (5e), 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):

(7a) a. John \( \lambda x[x \text{ defended }] \), and Bill \( \lambda x[x \text{ defended }] \) too.

b. John \( \lambda x[x \text{ defended }] \), and Bill \( \lambda x[x \text{ defended }] \) 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

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1 Predicate 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 \( \lambda x F[x](a) \) to the argument \( a \), which replaces the variable \( x \) with the argument \( a \), i.e., \( \lambda x F[x](a) = F(a) \). In semantic terms, lambda abstraction is an operation that extracts the predicate from a proposition.
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, & Nawy, 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[l] 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; McMae, 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, and the fireman did [perjure himself] 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 possesive pronoun of an object (see, for example, Levin, 1993), as in:

(11) a. The policeman winked his eye, and the fireman did [winked his eye] too.
   b. *The policeman winked his eye, and the fireman did [winked his eye] 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:
The optometrist who had signed the release form 
[1] asserted himself [2], and the pilot who needed to 

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–se-
monic information does not constrain the initial anal-
ysis 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 in-
fluences 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 possess-
sion 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 in-
terpretation). The data show that for the typical tran-
sitive 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 (ap-
proximately 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). Im-
portantly, for the inherently reflexive and inalienable 
possession verbs, subjects interpreted these as only al-
lowing the sloppy reading, corroborating that our sen-
tence 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 fol-
lowing manner (and we did this for the remaining ex-
periments 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 indepen-
dent 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 re-
lated 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
probes yielded 3.6% errors; these were approximately
tion probes yielded 5.6% errors, and ellipsis position
position probes yielded 3.9% errors, pre-ellipsis posi-
position probes yielded 4.1% errors, anaphor

results
sentences. RTLab software was used to deliver stimuli
to real word probes) were distributed as follows: Pre-

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 re-
corder. During the temporal unfolding of each sentence,
a visually presented lexical decision probe appeared
centrally (for 300 ms) on the monitor. Subjects were re-
quired 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-

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

<table>
<thead>
<tr>
<th>Probe type</th>
<th>Pre-reflexive</th>
<th>Reflexive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>716 (108)</td>
<td>745 (71)</td>
</tr>
<tr>
<td>Related</td>
<td>713 (109)</td>
<td>711 (74)</td>
</tr>
</tbody>
</table>
interaction between probe position and probe type, 

control probes (762 ms), probes (734 ms) significantly faster than to unrelated 

out; only at the ellipsis position were RTs to related 

position would there be differences found between the 

given our apriori predictions that only at the ellipsis 

position. We observed a marginally significant (using 

marginally significant effect of probe type, 

probes, exhibiting the priming effect that suggests acti-

long-distance subject NP than to unrelated control 

probes, exhibiting the priming effect that suggests acti-

To insure that our results were not due to subjects 

attending 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 

continuations” rating. We presented visual fragments (e.g., “The optometrist who had signed the release form”; “The optomet-

the probe into the temporal unfolding of the sentence,

and

discussed

of

Table 2

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

<table>
<thead>
<tr>
<th>Probe type</th>
<th>Probe position</th>
<th>Pre-ellipsis</th>
<th>Ellipse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>709 (116)</td>
<td>778 (156)</td>
<td></td>
</tr>
<tr>
<td>Related</td>
<td>707 (124)</td>
<td>744 (153)</td>
<td></td>
</tr>
</tbody>
</table>

$t(35) = 2.99, p < .01$. 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 
evenced 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 posi-
tions treating items as the random factor. In a repeated 

measures ANOVA with probe position (pre-ellipsis and ellipsis) and probe type (related and control) 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. We detail our interpretations of these findings, ground them in the sentence processing literature, and

2 To 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.
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:

(14) The optometrist who had signed the release form asserted himself, and the pilot who needed to pass [l] 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

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Experiment 2: Mean RTs (and SDs) to probe type as a function of probe position; sloppy reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe type</td>
<td>Pre-ellipsis</td>
</tr>
<tr>
<td>Control</td>
<td>822 (83)</td>
</tr>
<tr>
<td>Related</td>
<td>820 (98)</td>
</tr>
</tbody>
</table>
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 through a memory representation of the first clause (see Koeneman, 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 show 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).

<table>
<thead>
<tr>
<th>Probe type</th>
<th>Probe position</th>
<th>Grammatical function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-ellipsis</td>
<td>Ellipsis</td>
</tr>
<tr>
<td></td>
<td>Subject</td>
<td>Object</td>
</tr>
<tr>
<td></td>
<td>Related</td>
<td>Subject</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Object</td>
</tr>
<tr>
<td>Control</td>
<td>728 (69)</td>
<td>713 (73)</td>
</tr>
<tr>
<td>Related</td>
<td>721 (84)</td>
<td>696 (61)</td>
</tr>
<tr>
<td></td>
<td>718 (107)</td>
<td>727 (109)</td>
</tr>
<tr>
<td></td>
<td>709 (115)</td>
<td>687 (111)</td>
</tr>
</tbody>
</table>
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 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. 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 reactivated 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 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 (Koeneman et al., 1998), and one that suggests that all arguments of the copied verb are activated at the elided position.

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3 There 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).
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 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., Garmsey, 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 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
would have to explain why in some cases the subject
lipsis position in the second clause. A mental model
not found to be active either in the pre-ellipsis or el-
the subject NP, yet it turns out that the subject NP is
from the first clause event would contain a reference to
dict it. The mental model constructed incrementally
the results from Experiment 3 would seem to contra-
tally, the event described in the first clause of an el-
ipsis 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 contra-
dict 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 el-
lipsis 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 explan-
atory value.

Another alternative involves notions of memory
cost. On this account comprehending long-distance
dependencies involves computing the distance and in-
tegrating material between nonadjacent positions. The
longer the distance (and, the more complex the ma-
erial is between positions), the larger the computational
load and the more ‘difficult’ it will be to process sen-
tences (e.g., Gibson, 1998; McElree, 2000). In the
present set of experiments both the long distance sub-
ject NP from the first clause as well as the local subject
NP from the second clause are activated when the ellip-
sis 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-dis-
tance, 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, & Ehrl-
ich, 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 dur-
ing self-paced reading (though their experiments were
not intended to assess if and where the different inter-
pretations 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 probabilis-
tic information are ignored.

Acknowledgments

This research was partially supported by NIH-
NIDCD grants DC00494 and by 5T32DC000039.

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 DIS-
TANCED HERSELF [2] and her friend who was basically [3] antisocial
did [4] too, according to their analyst.

<table>
<thead>
<tr>
<th>NP1</th>
<th>R</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP2</td>
<td>TEACHER</td>
<td>TRAFFIC</td>
</tr>
</tbody>
</table>

eyes and the pit boss who was in on [3] the elaborate scheme did [4] too,
according to the private eye.

<table>
<thead>
<tr>
<th>NP1</th>
<th>R</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP2</td>
<td>MONEY</td>
<td>PAPER</td>
</tr>
</tbody>
</table>


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


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

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

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.


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

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.

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.


15. The caddie who was impatient [1] drummed his fingers and the chauffeur who was a witness [3] to the prosecution did [4] too, according to the anchor person for Channel 4.

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

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

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.


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

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


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


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


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


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


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


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


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


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 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: ALCOHOLIC
C: MOUTH  C: UNION


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


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


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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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

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.

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.

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

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.

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

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

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.

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

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.
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  R: GEM  NP2  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  R: MONEY  NP2  R: HORSE
C: PAPER  C: DRESS


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

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  R: TRACTOR  NP2  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  R: ELEPHANTS  NP2  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  R: RELATIVE  NP2  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  R: BUDDY  NP2  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  R: PRO  NP2  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  R: CHILD  NP2  R: BACON
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  R: NURSE  NP2  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  R: GUN  NP2  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  R: TIGER  NP2  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  R: STUDENTS  NP2  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  R: DOUGH  NP2  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  R: GIRL  NP2  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  R: MILK  NP2  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  R: PIANO  NP2  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  R: TRIAL  NP2  R: EYE
C: TABLE  C: LOT

References


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