

The Comprehension of Main and Embedded Clauses

by

Kara L. Ko

Submitted to the Department of Brain and Cognitive Sciences
in partial fulfillment of the requirements for the degree of
Master of Science in Brain and Cognitive Sciences at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

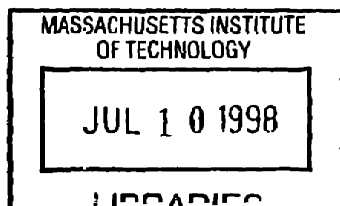
June 1998

© 1998 Massachusetts Institute of Technology
All rights reserved.

Author
Department of Brain and Cognitive Sciences
April 3, 1998

Certified by
Edward Albert Fletcher Gibson
Associate Professor
Thesis Supervisor

Accepted by
Gerald Schneider
Chairman, Department Committee on Graduate Students



ARCHIVES

Acknowledgments

I would like to thank the following people for all their support during my graduate career and beyond:

Ted Gibson, Edson Miyamoto, Molly Potter, Neal Pearlmuter, Ken Wexler, Dan Grodner, Tessa Warren, San Tunstall, and Bryan Gick for invaluable comments and hours of discussion on my thesis work and work during my graduate career.

For general, all-around support, friendship, and other resources such as food, laughs, and even references:

Pat Claffey, Ellie Bonsaint, Fei, Edson, Hilary, Kelly, Claudia, Stephen, Josh, Jenny, Javid, Kim, my roomies Deepa, Hannes, Olivera, Maria-Cristina, Anand, and the gang at 24 Mag.

Very special thanks to Jana, Mom, Dad, Grandma, and Tai Gong for a lifetime of love and encouragement which has opened a world of opportunity for me. And very special thanks to Bryan who has been there for me through it all.

The Comprehension of Main and Embedded Clauses

by

Kara L. Ko

Submitted to the Department of Brain and Cognitive Sciences
on April 3, 1998, in partial fulfillment of the
requirements for the degree of
Master of Science in Brain and Cognitive Sciences

ABSTRACT

This paper presents the results from an experiment which tested the zero memory cost matrix predicate proposal of Gibson's (1997) Syntactic Prediction Locality Theory (SPLT) in English. Subject modifying relative clause (RC) and object modifying RC constructions were crossed with embedded and non-embedded conditions. According to the SPLT, subject modifying RC constructions should be no more complex than object modifying RC constructions in main clauses (the non-embedded conditions). Subject modifying RC constructions should be more complex than object modifying RC constructions in all clauses other than main clauses (the embedded conditions). The results of the experiment do not support the zero memory cost component of the SPLT and support Gibson's alternative integration-based SPLT.

Thesis Supervisor: Edward Albert Fletcher Gibson
Title: Associate Professor

1 Introduction

This paper presents an experiment designed to address the question of whether Gibson's (1997) Syntactic Prediction Locality Theory (SPLT) correctly predicts how the human sentence processor deals with main and embedded clauses in English. This question follows from the more general questions of what makes a sentence difficult to understand, and how the sentence processor operates. Much of the recent sentence processing literature has focused on processing difficulties caused by ambiguous structures (Frazier, 1987; MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994; Mitchell, 1994). However, this approach alone is not sufficient—understanding how sentences are comprehended also involves examining what causes processing complexity in unambiguous structures (Just & Carpenter 1992, Gibson 1997).

One well-established complexity phenomenon in unambiguous structures is the difference in processing complexity between object-extracted relative clause (RC) and the subject-extracted RC (henceforth referred to as object gap RC and subject gap RC, respectively).

(1)

a. Object gap

The cheerleader [who [the quarterback dated t]] denounced the track star.
RC

b. Subject gap

The cheerleader [who [t dated the quarterback]] denounced the track star.
RC

In sentence (1a), the relative pronoun "who" is extracted from the object position of the RC, whereas "who" is extracted from the subject position of the RC in sentence (1b). A number of studies using various measures such as phoneme-monitoring, on-line lexical decision, reading times, and response-accuracy to probe questions have shown that object gaps are more difficult to process than subject gaps (Holmes, 1973; Hakes, Evans, & Brannon, 1976; Wanner & Maratsos 1978; Ford, 1983; King & Just, 1991). This complexity in processing is not due to reanalysis caused by local ambiguity. For such sentences, it is possible for the reader to resolve the ambiguity and find the correct interpretation and process the sentence without difficulty. What, then, causes the processing difficulty in object gap constructions as compared with subject gap constructions? Presumably, there is a difference in the computational resources required by each of the two structures. In this type of sentence, where the reader understands the correct interpretation of a sentence, there is a processing overload effect, and the reader is not able to arrive at the correct interpretation because of the limitations of the normal sentence processing mechanism.

Gibson's (1997) Syntactic Prediction Locality Theory (SPLT) offers an account of the above results as well as the ones discussed in the next section. The SPLT has two components—a memory cost component and an integration cost component. Both components are influenced by locality. In terms of memory, locality is how long a predicted category must be held in memory. In terms of integration, locality is how many new discourse referents occur between an incoming word and the closest head to which it attaches. The SPLT memory cost component has two parts: the first part states that the cost for maintaining predictions is increasing in all clauses other than top level clauses. The second part has to do with top-level—or main—clauses and states that the cost for maintaining the prediction of the matrix predicate (main verb) is zero. It is this second component of the SPLT memory cost component that is addressed in the experiment discussed in this paper. This component will be investigated by comparing subject modifying RC constructions and object modifying RC constructions in main and embedded clauses.

Section 2 documents various accounts of complexity in processing unambiguous constructions known as nested structures—complexities of subject and object modifying RCs in main clauses as compared to those RCs in embedded clauses. Section 3 reports the experiment in which the SPLT proposals for main clauses and embedded clauses are tested. A general discussion is provided in Section 4.

2 Accounts of complexity

2.1 Nested structures

Nested structures have long been known to be sources of processing complexity independent of ambiguity.

A syntactic category A is said to be nested or center-embedded within another category B with lexical material on either side of A within B (Chomsky and Miller, 1963; Miller and Chomsky, 1963).

This can be seen in the following way:

(2) [B X A Y]

When category A is the same as category B, the nested structure is called a self-embedded structure. The structures dealt with in this paper are all self-embedded, and the type of nested categories referred to in this paper are sentence (S) nodes.

In the following examples, sentence (3b) is constructed by embedding the RC "who the artist teased" within sentence (3a), modifying "the model", the subject of the main (or matrix) clause of the sentence. Sentence (3c) contains yet another embedding within the embedded portion of sentence (3b).

(3)

a) Zero levels of nesting

The model winked at the journalist.
main clause

b) One level of nesting

The model [who the artist teased] winked at the journalist.
main clause single embedded clause main clause
B A B

c) Two levels of nesting

The model [who the artist [who the student listened to] teased] winked at the journalist.
main clause embedded clause embedded clause embedded clause main clause
C B A B C

It is not just the mere number of clauses present that makes the sentence difficult to understand. Rather, it is the nesting of the structures. The nested structure in (3c) is more difficult to understand than the right-branching structure in (3d) even though they contain the same number of clauses and the same lexical material and the same thematic relations among the NPs.

d) Right-branching

[The student listened to the artist [who teased the model [who winked at the journalist]]].

2.2 The interruption hypothesis

Miller and his collaborators proposed the interruption hypothesis to explain why nested sentences are more difficult to understand than right-branching sentences (Miller & Chomsky, 1963; Miller & Isard, 1964). The interruption hypothesis claims that intervening linguistic material makes processing harder because it interrupts the clause in which it is embedded in a nested sentence. Processing the first relative clause interrupts the processing of the main clause between the subject and predicate. In contrast, each relative clause in a right-branching sentence occurs after the predicate and thus does not interrupt the clause it modifies. This makes it easier to process.

2.3 No complexity difference due to RC Modifier Position found in main clause

The interruption hypothesis predicts a difference in processing complexity depending on the location of the RC for nested sentences and right-branching sentences. A subject modifying RC creates a nested structure in English. In this case, the RC lies between the subject and the predicate of the clause. An object modifying RC creates a right-branching structure and follows the predicate of the main clause. Hence, for the remainder of this paper, the RCs

in nested sentences will be referred to as subject modifying RCs and the RCs in right-branching sentences will be known as object modifying RCs.

Hakes et al. originally questioned the validity of the interruption hypothesis' attempt to account for the fact that nested sentences are difficult to understand. They pointed out that Miller's experiments confounded the question of whether the gaps in the RCs were object or subject gaps with whether a sentence was right-branching or nested. Miller and his colleagues happened to use object gap RCs in their subject modifying RC sentences and subject gap RCs in their object modifying RC sentences. In their own experiments, Hakes et al. eliminated this confound by comparing object gap constructions with only object gap constructions and subject gap constructions with only subject gap constructions.

The following are sentences that were used in Hakes et al.'s experiments. (4a) contains the subject modifying RC and (4b) contains the object modifying RC. The RCs are contained in the square brackets.

(4)

a) Subject modifying RC

The director [that the repertory company had hired] praised the star performer.

RC

b) Object modifying RC

The star performer praised the director [that the repertory company had hired].

RC

Using a phoneme monitoring task, Hakes et al. found that subject modifying RCs are not more difficult than object modifying RCs. Even though their tests were sensitive enough to replicate the result that object extracted RCs are harder to understand than subject extracted RCs, their experiments failed to support the interruption hypothesis and there was no difference in complexity found between zero and one level of nesting.

2.4 Evidence for difference in how main clauses and embedded clauses are processed

Eady and Fodor (1981) further tested differences in complexity between various levels of embedding and found that there was a higher level of complexity associated with subject modifying RCs (self-embedding) for embedded clauses. They tested sentences which had a main clause and two RCs embedded one within the other where the upper RC was either object modifying or subject modifying. The lower RC was also either object modifying or subject modifying.

Eady and Fodor used a reading time test in which subjects saw sentences presented one at a time. Subjects read each sentence as quickly as possible and pressed a key once they felt they comprehended the meaning of the sentence. The total reading time for the sentence was recorded.

The following are some of Eady and Fodor's examples.

(5)

a) object modifying, object modifying

[Jack met the patient [the nurse sent t to the doctor [the clinic had hired t]]].

b) subject modifying, object modifying

[The patient [the nurse sent t to the doctor [the clinic had hired t]] met Jack]].

c) object modifying, subject modifying

[Jack met the patient [the nurse [the clinic had hired t] sent t to the doctor]].

d) subject modifying, subject modifying

[The patient [the nurse [the clinic had hired t] sent t to the doctor] met Jack].

They found that (5b) was not significantly more complex than (5a), but (5d) was significantly more complex than (5c), $p < .01$. Also, the difference in reading times between (5c) and (5b) was significant, $p < .005$. Examples (5c) and (5d) were significantly slower than (5a) and (5b).

The greatest difference they found was between the two conditions with a single subject modifying clause—one in which the subject modifying clause was the upper clause and the one in which the subject modifying clause was in the lower clause. They concluded that it was not the mere presence of the subject modifying clause, but also its position in the sentence that caused complexity. Namely, when the subject modifying clause was the main clause of the sentence (the upper), it was not (much) more complex, whereas when it was in the embedded (the lower) clause, it was much more complex. Eady and Fodor tested structures with two RCs—one RC embedded within the other, whereas Hakes et al. tested only one level of RC modifying either the subject or object of the main clause. The experiment discussed in this paper tests conditions similar to those of Hakes et al. as well as testing the same levels of nesting as Eady and Fodor, though using only one RC per condition.

2.5 Further evidence for a lack of difference in complexity between subject modifying RC (pre-verbal) and object modifying RC (post-verbal) sentences in main clause

In support of Hakes et al.'s (1976) findings, Gibson & Thomas (1997) provide evidence that there is no difference in complexity between subject modifying and object modifying RC structures in main clauses.

Gibson & Thomas reported an off-line questionnaire study in which subjects were asked to rate the difficulty of sentences containing doubly embedded structures according to how easy or difficult they were to understand based on their first reading.

Some of the items tested were RC/RC sentences in which an RC was nested within another RC.

Here are some of their examples:

(6)

a) RC/RC-object gap, pre-verbal:

The school board which the students who the teachers were neglecting had angered troubled the superintendent.

b) RC/RC-object gap, post-verbal:

The superintendent was troubled by the school board which the students who the teachers were neglecting had angered.

c) RC/RC-subject gap, pre-verbal:

The school board which the teachers who were neglecting the students had angered troubled the superintendent.

d) RC/RC-subject gap, post-verbal:

The superintendent was troubled by the school board which the teachers who were neglecting the students had angered.

Gibson & Thomas found no difference in complexity between pre-verbal and post-verbal complexity effects in the matrix clause.

2.6 Syntactic Prediction Locality Theory (SPLT)

Gibson's (1997) SPLT proposes an explanation of sentence processing complexity as being associated with memory cost and integration cost in terms of locality. The SPLT states that memory cost is associated with predicting required syntactic categories during processing. Locality refers to the direct relationship between distance and memory cost—the longer a prediction is kept in memory, the more expensive it becomes. Distance is computed in terms of new discourse referents (Gibson & Warren, in preparation).

2.6.1 Memory Cost

The underlying assumption of the SPLT is that there is a memory cost associated with predicting each syntactic category needed to complete an input string as a grammatical sentence. At a particular point in a sentence, there is a higher cost if a category has been predicted at an earlier point than if a category is predicted more recently.

The following are the two components for the syntactic prediction memory cost:

Proposal 1) There is an increasing memory cost for maintaining predictions in all non-top level clauses. More formally stated, for each required syntactic head C_i besides the matrix verb V_0 , there is a memory cost of $M(n)$ memory units where M is a monotone increasing function of n , the number of new

discourse referents that have been processed from the point C_i was initially predicted up to the current position of the parser.

For the purposes of this paper, it suffices to assume that $M(n) = k*n$, where k is a constant.

Proposal 2) There is zero memory cost for maintaining the syntactic predictions in the top-level clause.

2.6.2 Integration Cost

The computational resources needed for integration of an input work into the structure at hand can be expressed by an increasing function $I(n)=k*n$ (where k is constant). n is the number of new discourse referents between the current word and the place where integration is to take place.

Demonstration of Integration Cost

(7)

a) Object gap

The reporter who the senator attacked admitted the error.

$I(1) \quad I(1) I(0) I(1) \quad 2I(2) \quad I(4) \quad I(1) \quad I(1)$

b) Subject gap

The reporter who attacked the senator admitted the error

$I(1) \quad I(1) \quad I(0)+I(1) \quad I(1) \quad I(1) \quad I(4) \quad I(1) \quad I(1)$

The SPLT integration theory predicts that both RC constructions should not be very complex. The only exceptions are the matrix verb in each which should be complex because that is where a long distance integration takes place and the embedded verb in the object gap construction where two significant integrations occur.

While the SPLT is similar to other dependency-cost theories, the difference is that processing difficulty is not caused merely by the number of predicted categories, but rather, the number of predicted categories multiplied by the number of discourse referents processed since the prediction was made. The experiment described in this paper focuses on the memory cost components of the SPLT rather than on integration cost.

Eady and Fodor's (1981) findings provide empirical support for the SPLT memory cost Proposal 1).

Hakes et al's (1976) findings provide empirical support for memory cost component 2)—namely, the findings that a relative clause modifying the subject of a matrix verb is not more difficult to process than a relative clause modifying the object of the matrix verb. Additional support is provided by Gibson & Thomas' (1997) off-line observation that there was no complexity difference between subject and object modifiers in the matrix clause.

We did an experiment to test to see whether or not there is a zero cost for the highest level clause.

The following three factors were tested:

1) RC modifier position and 2) Embedded vs. non-embedded test the SPLT prediction that the cost for predicting the verb in the matrix clause is zero and the cost for predicting the verb in embedded clauses is increasing.

3) RC gap position was tested to replicate a well-established effect and confirm the effectiveness of our measure.

2.6.2 SPLT Predictions

Predictions for object gap vs. subject gap RCs

The SPLT predicts that the object gap RC (8a) is more difficult than the subject gap RC (8b). Testing this factor is a replication of Hakes et al and other experiments (Holmes, 1973; Wanner & Maratsos 1978; Ford, 1983; King & Just, 1991) which can verify the validity of our chosen measure (reading times).

(8)

a. Object gap

The reporter [who [the senator attacked t]] admitted the error.

RC

b. Subject gap

The reporter [who [t attacked the senator]] admitted the error.

RC

Table I shows the complexity profile for an object gap sentence in terms of memory cost in MUs (memory units).

Table I: Complexity profile for an object gap sentence (Gibson, 1997, p. 33)

SYNTACTIC PREDICTION	INPUT WORD								
	The	reporter	who	the	senator	attacked	admitted	the	error
matrix verb	0	0	0	0	0	0	0	0	0
matrix subject	M(0)	*	-	-	-	-	-	-	-
matrix obj NP	-	-	-	-	-	-	M(0)	M(0)	*
embed subj NP	-	-	-	M(0)	*	-	-	-	-
embed verb	-	-	M(0)	M(0)	M(1)	*	-	-	-
wh-pronoun	-	-	M(0)	M(0)	M(1)	*	-	-	-
gap									
MEMORY COST (MUs)	M(0)	0	2M(0)	3M(0)	2M(1)	0	M(0)	M(0)	0

* indicates a position at which a syntactic prediction is satisfied

Table I shows that the memory cost when processing the first word of the sentence is $M(0)$ MUs incurred by the prediction of the head noun of the matrix subject ($M(0)$ MUs) and the prediction of the matrix verb (0 MUs). The memory cost at the next word "reporter" is 0 MUs which corresponds to the prediction of the matrix verb (see Assumption 2 of the SPLT above). Under the word "reporter," the asterisk in the matrix subject row indicates that the memory cost for the prediction of the head noun has been satisfied. The memory cost at the next word "who" is $2M(0)$ MUs corresponding to the 0 MUs for the prediction of the matrix verb, plus the $M(0)$ MUs for the prediction of the embedded verb, plus the $M(0)$ MUs for the prediction of the NP gap coindexed with "who". The memory cost at the next word "the" is $3M(0)$ MUs, which carries the predictions from the previous state plus the prediction of the embedded subject noun. At the next word "senator", the embedded subject noun prediction is satisfied. However, the memory cost increases to $M(1)$ MUs because of the appearance of the new discourse referent—the NP "the senator". This new discourse referent intervenes between the point at which the predictions were first made and the point at which they are satisfied. Thus, the memory cost at "senator" is $2M(1)$ MUs. After the next word "attacked" is processed, the predictions for embedded verb and NP gap are satisfied, and the memory cost is 0 MUs. The next word, "admitted" satisfies the matrix verb prediction, and an object NP is predicted at this point incurring a cost of $M(0)$ MUs. The memory cost for the last two words "the" and "error" can be seen on Table I. In processing the object gap RC sentence, the maximal memory complexity is $2M(1)$ MUs which occurs at the embedded NP subject "senator". In contrast, the maximal memory complexity for processing a subject gap RC sentence is $2M(0)$ MUs which occurs at the relative pronoun "who". Table II presents the memory cost profile for subject gap sentences. Thus, the SPLT predicts that processing subject gap RCs requires less memory resources than processing object gap RCs.

Table II: Complexity profile for a subject gap sentence
(Gibson, 1997, p. 34)

SYNTACTIC PREDICTION	INPUT WORD								
	The	reporter	who	attacked	the	senator	admitted	the	error
matrix verb	0	0	0	0	0	0	0	0	0
matrix subject	$M(0)$	*	-	-	-	-	-	-	-
matrix obj NP	-	-	-	-	-	-	$M(0)$	$M(0)$	*
embed verb	-	-	$M(0)$	*	-	-	-	-	-
embed obj NP	-	-	$M(0)$	*	-	-	-	-	-
wh-pronoun	-	-	-	$M(0)$	$M(0)$	*	-	-	-
gap									
MEMORY COST (MUs)	$M(0)$	0	$2M(0)$	$M(0)$	$M(0)$	0	$M(0)$	$M(0)$	0

* again indicates a position at which a syntactic prediction is satisfied

Predictions for embedded and non-embedded structures

The SPLT predicts that embedded sentences should be more complex than non-embedded sentences because there are more syntactic predictions in embedded structures than in non-embedded structures.

Predictions for subject vs. object modifying RCs: an interaction between modifier position and embedding

According to the SPLT memory cost Proposal 2, there is zero cost for maintaining the prediction of the matrix predicate. Thus, the SPLT predicts that there should be no difference in processing the subject modifying RC in (9a) and the object modifying RC in (9b) because these are the non-embedded conditions. The SPLT memory cost Proposal 1 states there is an increasing memory cost for predicting the predicate of every clause other than the matrix clause. This component of the SPLT predicts that there should be greater difficulty in processing the subject modifying RC in (9c) than in processing the object modifying RC in (9d). The reason for this difference in processing complexity is that there is an extra syntactic prediction in the subject modifying RC in (9c), namely, the prediction of the embedded verb which incurs an additional cost. In the object modifying RC in (9d), there exists no such memory cost because the embedded verb has already been processed by the time the parser reaches the RC in the sentence. Therefore, there should be an interaction between modifier position and embedding.

The RCs are in square brackets in the following example:

(9)

NON-EMBEDDED (matrix clause)

a. Subject modifier, non-embedded

The reporter [who the senator attacked] ignored the president.

b. Object modifier, non-embedded

The president ignored the reporter [who the senator attacked].

EMBEDDED

c. Subject modifier, embedded

The chance that the reporter [who the senator attacked] ignored the president bothered the editor.

d. Object modifier, embedded

The chance that the president ignored the reporter [who the senator attacked] bothered the editor.

The prediction that there should be no difference between (9a) and (9b), the non-embedded conditions, is consistent with the findings of Hakes et al (1976), Gibson & Thomas (1997), and component 2) of the SPLT. For the embedded conditions, the prediction that the subject modifying RC in (9c) is more difficult than the object modifying RC is consistent with the findings of Eady & Fodor. The experiment discussed in this paper examines RC modifier

position (subject, object) crossed with clause type (non-embedded (matrix), embedded) to directly test the SPLT proposals for main and embedded clauses.

3 Experiment

3.1 Method

3.1.1 Participants

A total of 74 native English speakers drawn from the Cambridge, Massachusetts area (primarily MIT undergraduate and graduate students) participated in the experiment for \$8/hour.

3.1.2 Materials and Design

The stimuli consisted of 32 items in which a core sentence was either embedded or non-embedded. Each core sentence contained one RC that 1) had either a subject gap or an object gap and 2) modifying either the subject or the object of that sentence. Sentences (10a) and (10b) below are examples of core sentences.

(10)

a. Subject modifier, non-embedded

The reporter [who the senator attacked] ignored the president. (object gap)
[who attacked the senator] (subject gap)

b. Object modifier, non-embedded

The president ignored the reporter [who the senator attacked], (object gap)
[who attacked the senator] (subject gap)

Each core with a subject modifying RC contained a subject NP NP_{C1} followed by an RC (either subject gap or object gap), a verb V_C , and the object NP_{C2} . Each core with an object modifying RC contained a subject NP NP_{C1} followed by a verb V_C , the object NP_{C2} , and an RC (either subject gap or object gap). The subject gap RCs had the format: who V_{RC} NP_{RC2} . The object gap RCs had the format: who NP_{RC1} V_{RC} .

The three factors were tested:

(See Appendix for a list of the experimental items.)

1) RC modifier position:

RC modifying subject vs. RC modifying object of the core sentence.

2) Embedded vs. non-embedded:

The core sentence was either embedded or else it was the main clause of the sentence.

3) RC gap position:

Subject vs. object gap within the relative clause in the core sentence.

(11) Each part of the sentence is labeled above the sentence.

Subject modifying, non-embedded, object gap

a) NPC₁ who NRC₁ VRC t PP₁ V_C NP_Q Adv
 The model who the artist teased after the debut winked at the journalist at the exhibit.

Subject modifying, non-embedded, subject gap

b) NPC₁ who t VRC NRC₂ PP₁ V_C NP_Q Adv
 The model who teased the artist after the debut winked at the journalist at the exhibit.

Object modifying, non-embedded, object gap

c) NPC₁ V_C NP_Q who NRC₁ VRC t PP₁ Adv
 The journalist winked at the model who the artist teased after the debut at the exhibit.

Object modifying, non-embedded, subject gap

d) NPC₁ V_C NP_Q who t VRC NRC₂ PP₁ Adv
 The journalist winked at the model who teased the artist after the debut at the exhibit.

Subject modifying, embedded, object gap

e) NP_{E1} that NPC₁ who NRC₁ VRC t PP₁ V_C NP_Q
 The observation that the model who the artist teased after the debut winked at the journalist
 V_E NP_{E2}
 excited the onlookers.

Subject modifying, embedded, subject gap

f) NP_{E1} that NPC₁ who t VRC NRC₂ PP₁ V_C NP_Q
 The observation that the model who teased the artist after the debut winked at the journalist
 V_E NP_{E2}
 excited the onlookers.

Object modifying, embedded, object gap

g) NP_{E1} that NPC₁ V_C NP_Q who NRC₁ VRC t PP₁
 The observation that the journalist winked at the model who the artist teased after the debut
 V_E NP_{E2}
 excited the onlookers.

Object modifying, embedded, subject gap

h) NP_{E1} that NPC₁ V_C NP_Q who t VRC NRC₂ PP₁
 The observation that the journalist winked at the model who teased the artist after the debut
 V_E NP_{E2}
 excited the onlookers.

The lexical items were chosen so as to be symmetrical around both the core verb (V_C) and around the verb in the RC (V_{RC})—that is, equally plausible in both directions. For example, it is approximately as likely that an artist should tease a model as it would be for a model to tease an artist, whereas it is less likely that a model should "sketch" an artist than vice versa. For the embedded sentences, an NP_E and the word "that" were placed before the core and a V_E and an NP_{E2} were placed after the core.

Each sentence was divided into the following regions for analysis.

1	2	3	4	5	6	7	8	9	10	11	12
The	the	winked	the	who	the	teased	the	after	winked	the	Rest
obser-	jour-	at	model		artist		artist	the	at	jour-	of
vation	nalist							de-		nalist	sen-
that								but			tence
NPE1+	NP _{C1}	V _C	NP _{C1}	who	NP _{RC1}	V _{RC}	NP _{RC2}	PP ₁	V _C	NP _{C2}	
that			or								
			NP _{C2}								

Region 1: NP_E + "that"

Lexical material was placed before the core sentence in the embedded conditions.

Region 2: NP_{C1}
core sentence subject for object mod cases

Region 3: V_C core sentence verb (predicate) for object modifying conditions

Region 4: NP_{C1} core sentence subject for subject modifying conditions and NP_{C2} core sentence object for object modifying conditions.

Region 5: "who"

Region 6: NP_{RC1} Subject for object gap RC case in core sentence

Region 7: V_{RC}
The verb in the relative clause.

Region 8: NP_{RC2} object for subject gap RC case in core sentence

Region 9: PP₁ to capture possible spillover reading time (see explanation in section below)

Region 10: V_C core sentence verb for subject modifying conditions.

Region 11: NP_{C2} Core sentence object for subject modifying RC conditions.

Region 12: The rest of the sentence.

On-line complexity was measured by recording reading times (RT) of the RCs to see the effects of being before or after the verb (whether there was

the load of the prediction (subject mod) or not (object mod)) of the main verb).

Often, with reading time tests, there is “spillover” whereby the increased RT effects of a complex region of the sentence will affect the immediately following region. A prepositional phrase (PP) was inserted after the RC of each sentence to capture potential spillover RTs associated with the RC. Capturing potential spillover RTs is to prevent any effects on the RTs of the ensuing lexical material of the sentence which was relevant to the hypothesis being tested. Lexical material was also added to the end of the sentence to capture spillover RT.

3.1.3 Procedure

Sentences were presented to participants in an on-line word-at-a-time self-paced reading test on Apple Macintosh Power PCs (Just, Carpenter, & Woolley, 1980). Participants' reading times were measured at each word. Participants were shown two screens of instructions and given practice examples followed by the experimental and filler items. The items were presented in a different pseudo-random order for each participant.

After every item, there was a yes/no comprehension question to see if participants were paying attention.

At the beginning of each trial, the item appeared on the screen with all characters except spaces replaced with dashes. When participants pressed the space bar, the first word was displayed replacing the dashes. The participant pressed the space bar again and the letters of the first word became dashes again and the letters of the second word replaced the corresponding dashes. Every time the participant pressed the space bar, the letters of the next word were revealed and the letters of the previous word reverted to dashes. After pressing the space bar on the last word of the item, a yes-no question appeared, and the participant was asked to press 'F' for YES and 'J' for NO. The computer measured the time elapsed between each button press as well as the response to the comprehension question and informed the participant when a question was answered incorrectly.

3.2 Results & Analysis

A total of seventy-four participants were run. Eight participants were excluded from analysis because they either had less than 65% questions answered correctly (response accuracy) or a baseline reading rate that was very fast (183 ms/word)). Sixty-six participants were included in the final analysis. Before data analysis, all outlier words (RT>2,500ms) were removed. These accounted for less than 1% of the data. The RT and response accuracy data were analyzed in separate ANOVAs conducted on participants and items.

The response accuracies for the gap, modifier position, and embedding conditions are presented in Figures 1, 2, and 3. Participants were correct in answering questions to the non-embedded condition significantly more often

than in answering questions to the embedded condition, $F(1,65) = 13.9, p < .001$; $F(1,31) = 12.7, p = .001$. The differences for the gap and modifier position conditions were not significant by participant or by item. For the gap conditions, $F(1,65) = 1.53, p > .2$ and $F(1,31) < 1, p > .3$. For the modifier position conditions, $F(1,65) = 1.72, p > .1$.

Figure 1: Gap Response Accuracy

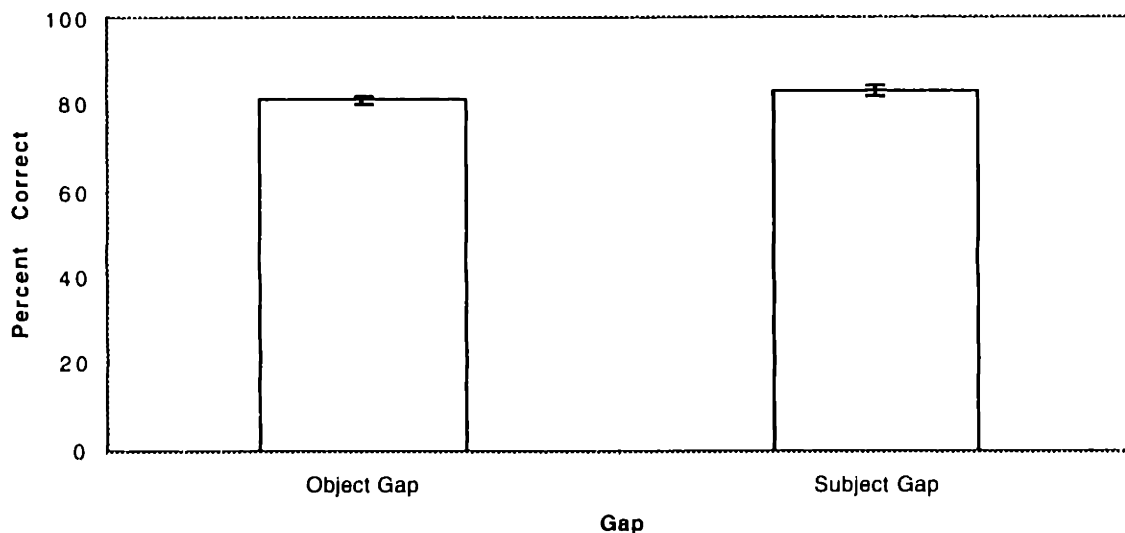


Figure 1 shows the percentage of comprehension questions answered correctly by participant for object gap conditions versus subject gap conditions.

Figure 2: Modifier Position Response Accuracy

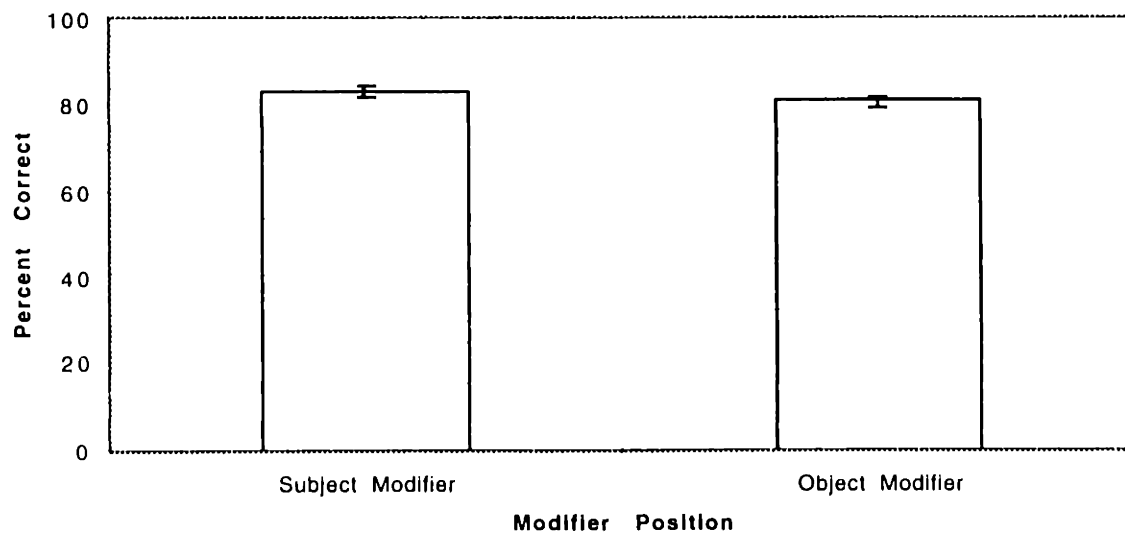


Figure 2 shows the percentage of comprehension questions answered correctly by participant for subject modifying RC conditions versus object modifying RC conditions.

Figure 3: Embedding Response Accuracy

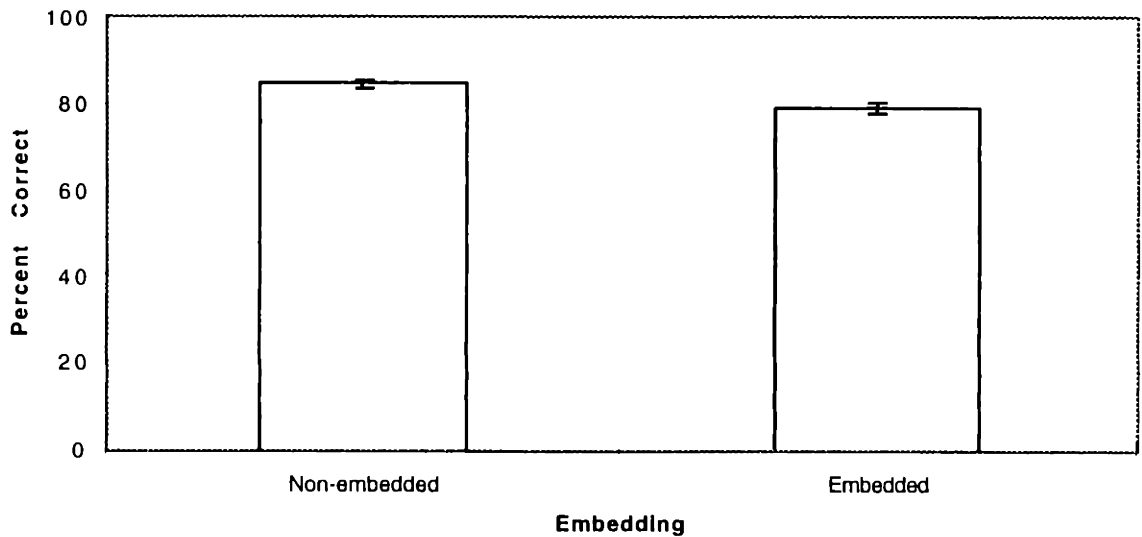


Figure 3 shows the percentage of comprehension questions answered correctly by participant for non-embedded conditions versus embedded conditions. A significantly higher percentage of questions for non-embedded conditions were answered correctly than for embedded conditions.

Residual Reading Times

Each participant had a corresponding regression equation which predicted reading time from word length. At each word, the reading time predicted by the participant's regression equation was subtracted from the actual measured reading time to derive the residual reading time (RRT) (Ferreira & Clifton, 1986). Residual reading times and standard errors are shown in Figures 4 through 9. Object gap and subject gap conditions were analyzed separately to isolate the interaction between the modifier position and embedding conditions.

The following are the results from the object gap conditions for region 4, the word before the RC in every condition. The reading times for the subject modifier condition were significantly faster than those for the object modifier condition both by participant and by item— $F(1,65)=7.53, p<.01$; $F(1,31)=9.37, p=.005$. The difference in reading times between embedded and non-embedded conditions was not significant by participant or by item, $F_s<1$.

The interaction between modifier position and embedding was significant both by participant and by item— $F(1,65)=4.17, p=.05$; $F(1,31)=7.40, p=.01$. The following are the results from the subject gap conditions for region 4. The reading times for the subject modifier condition were significantly faster than those for the object modifier condition both by participant and by item— $F(1,65)=5.29, p<.05$; $F(1,31)=7.61, p=.01$. The difference in reading times between embedded and non-embedded conditions was not significant by participant or by item, $F_s<1$. The interaction between modifier position and embedding was significant both by participant and by item— $F(1,65)=5.38, p<.05$; $F(1,31)=5.84, p<.05$.

Region 5 is the word "who" which begins the RC. Again, the object gap results will be presented first. The only significant difference in reading times was that the subject modifying conditions were significantly faster than the object modifying conditions— $F(1,65)=4.16, p<.05$; $F(1,31)=6.44, p<.05$. This was the case for the subject gap results as well—subject modifying conditions were significantly faster than the object modifying conditions— $F(1,65)=8.19, p<.01$; $F(1,31)=16.5, p<.001$.

Region 6 is the subject NP of the object gap RCs. There was a main effect of position and of embedding both by participant and by item. Again, subject modifiers were significantly faster than object modifiers— $F(1,65)=8.42, p=.005$; $F(1,31)=11.4, p<.005$. The non-embedded cases were significantly faster than the embedded cases— $F(1,65)=5.87, p<.05$; $F(1,31)=7.41, p=.01$.

In region 7, the RC verb, there were no significant reading time differences by participant or by item for object gap conditions. For subject gap, the RTs for modifier position were significantly different (subject modifier faster) both by participant and by item— $F(1,65)=4.0, p=.05$; $F(1,31)=5.43, p<.05$. The RTs for embedding were marginally faster for non-embedding than for embedding by participant— $F(1,65)=3.80, p=.055$. They were significantly faster for non-embedding than for embedding by item— $F(1,31)=7.37, p=.01$.

Region 8 is the object NP of the subject gap RCs. There was a main effect of embedding both by participant and by item. The non-embedded cases were significantly faster than the embedded cases— $F(1,65)=8.43, p=.005$; $F(1,31)=7.67, p<.01$.

In region 9, the spillover PP, for object gap conditions, the RTs for modifier position were significantly different (subject modifier faster) both by participant— $F(1,65)=4.16, p=.045$; but only marginally by item $F(1,31)=3.99, p=.055$. For subject gap, there were no significant reading time differences by participant or by item.

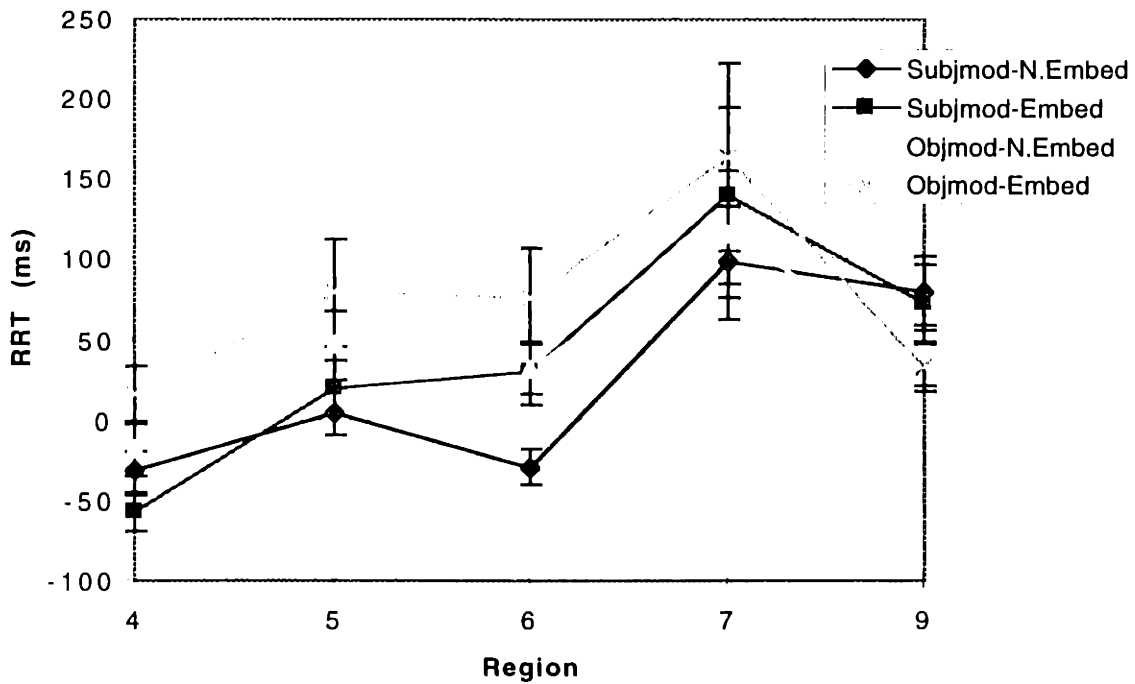
The RC is the region combining regions 6 and 7 in object gap conditions and regions 7 and 8 in subject gap conditions. The RC should show the most memory load because it comes right before the verb (at this point, the reader has had to wait the longest time before finally getting the verb). In the object gap RC items, the subject modifiers were faster than the object modifiers. The ANOVAs showed that for modifier position, $F(1,$

65)=11.2, $p=.001$; embedding $F2(1, 65)=4.23$, $p<.05$. For the subject gap RC items, the ANOVAs showed that for modifier position, $F1(1, 65)=7.91$, $p<.01$, and embedding $F2(1, 65)=8.88$, $p<.005$.

In Figures 4 through 7, the residual reading times for regions 4 through 9 are plotted. These regions include the word directly preceding the RC, the RC, and the PP following the RC.

The interaction between modifier position and embedding for the object gap conditions is shown in Figure 4. The SPLT prediction that subject modifying RC conditions should be significantly slower than object modifying RC conditions for embedded conditions was not observed. Subject modifying conditions were significantly faster than object modifying conditions in all regions except for regions 7 and 8.

Figure 4: Modifier position-Embedding Interaction for Object Gap Conditions



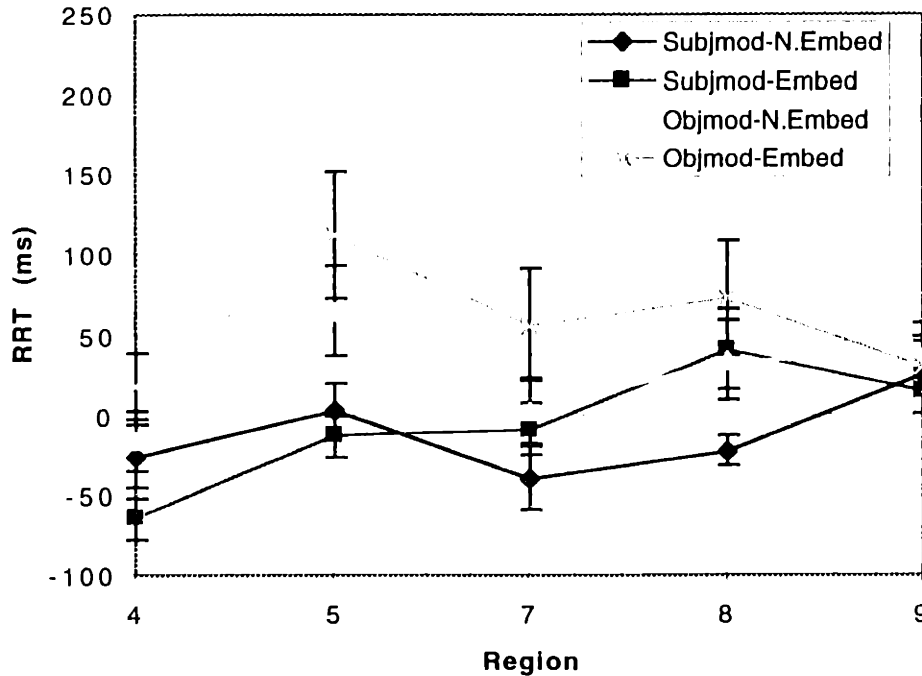
the model who the artist teased after the debut

Figure 4: A plot of the interaction between modifier position and embedding conditions for object gap conditions.

The interaction between modifier position and embedding for the subject gap conditions is shown in Figure 5. The SPLT prediction that subject modifying RC conditions should be significantly slower than object modifying RC conditions for embedded conditions was not observed. Subject modifying RC conditions were significantly faster than object modifying RC conditions in all regions except for regions 7 and 8.

modifying conditions were significantly faster than object modifying conditions in all regions except for region 8 and 9.

Figure 5: Modifier position-Embedding Interaction for Subject Gap Conditions

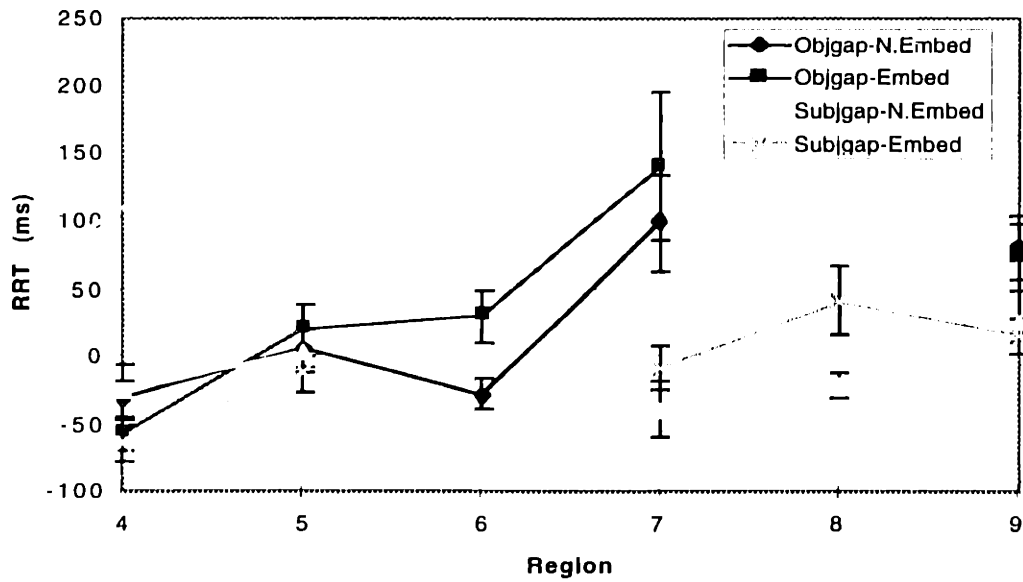


the model who teased the artist after the debut

Figure 5: A plot of the interaction between modifier position and embedding conditions for subject gap conditions.

The interaction between gap and embedding for the subject gap conditions is shown in Figure 6. The SPLT prediction that subject modifying RC conditions should be significantly slower than object modifying RC conditions for embedded conditions was not observed. Subject modifying conditions were significantly faster than object modifying conditions in all regions except for region 8 and 9.

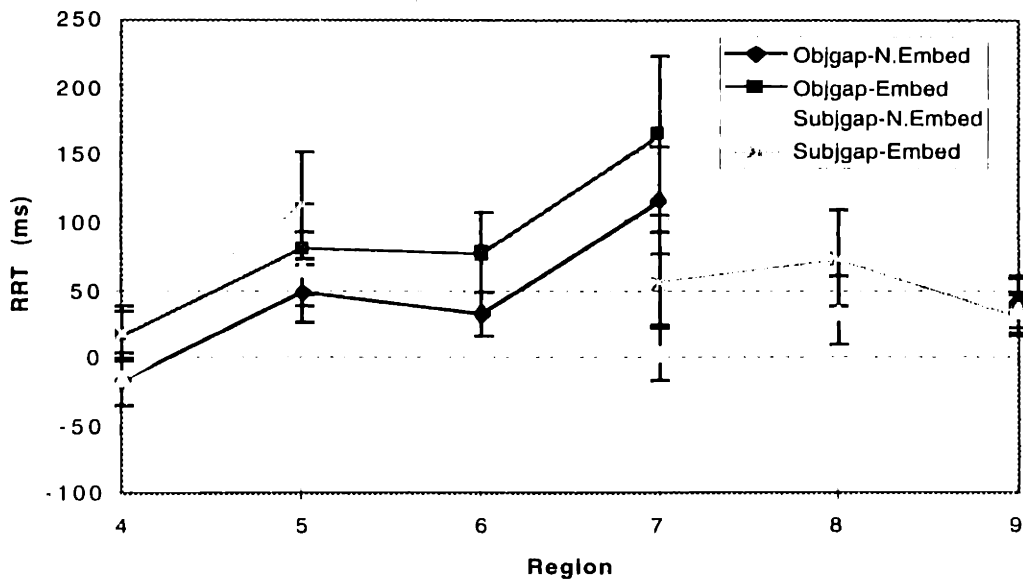
Figure 6: Gap-Embedding Interaction in Subject Modified Conditions



the model who the artist teased the artist after the debut

Figure 6: A plot of the interaction between gap and embedding conditions for subject modifying conditions.

Figure 7: Gap-Embedding Interaction in Object Modified Conditions

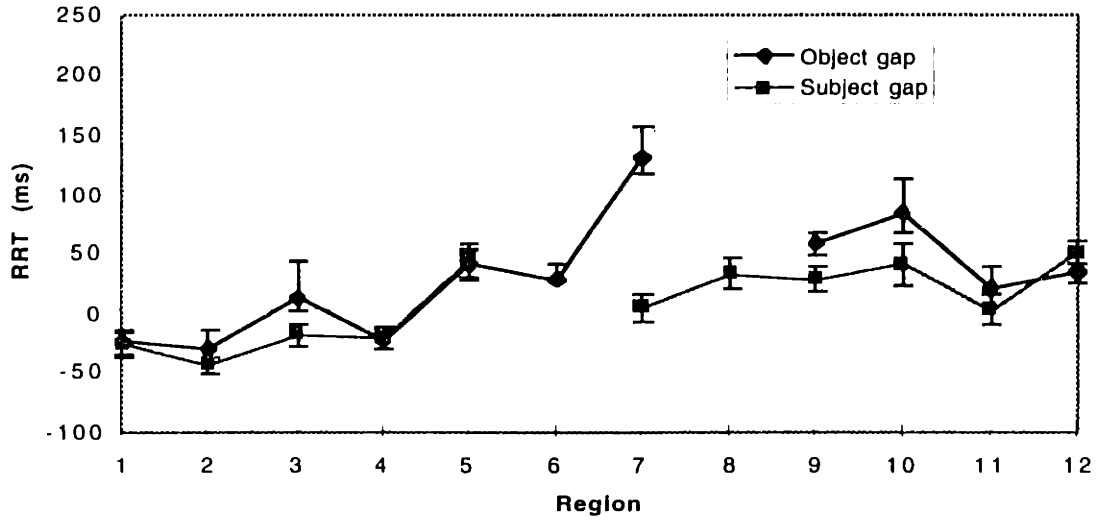


the model who the artist teased the artist after the debut

Figure 7: A plot of the interaction between gap and embedding conditions for object modifying conditions.

Figures 8 and 9 plot the residual reading times for all regions.

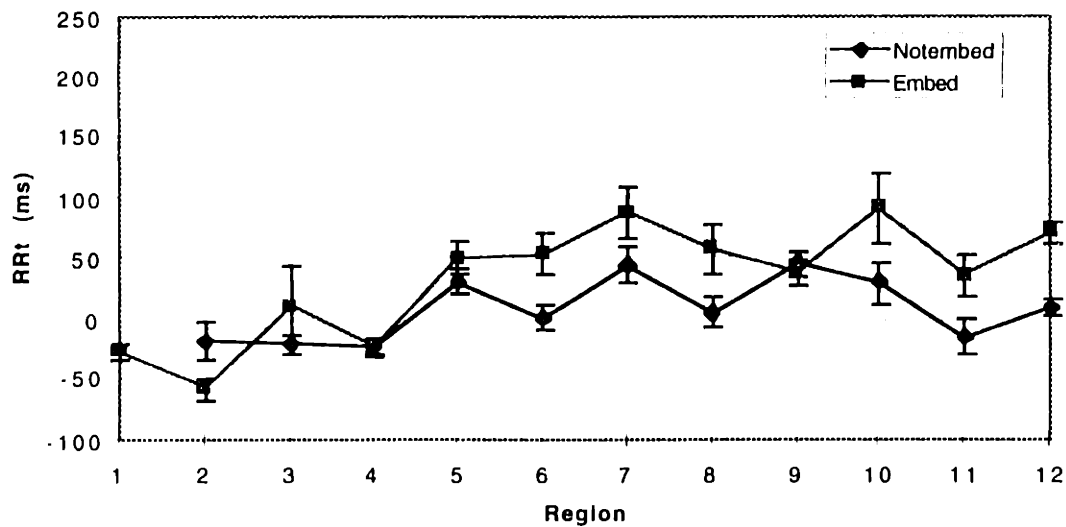
Figure 8: Object gap vs. Subject gap



1	2	3	4	5	6	7	8	9	10	11	12
The	the	winked	the	who	the	teased	the	after	winked	the	Rest
observ-	journalist	at	model	artist	artist	artist	artist	the	at	journalist	of
ation								de-		but	sen-
that								but			tence

Figure 8: A plot of the object gap conditions vs. the subject gap conditions.

Figure 9: Nonembedded vs. Embedded



1	2	3	4	5	6	7	8	9	10	11	12
The	the	winked	the	who	the	teased	the	after	winked	the	Rest
obser-	jour-	at	model		artist		artist	the	at	journalist	of
vation	nalist							de-			sen-
that								but			tence

Figure 9: A plot of the non-embedded conditions vs. the embedded conditions.

The subject modifier was not found to be more difficult to process than the object modifier in the embedded clause. The experiment showed that object gaps turned out to be more difficult to process than subject gaps.

3.3 Discussion

Predictions for object gap vs. subject gap RCs

The SPLT predicted that the object gap RC is more difficult than the subject gap RC, and this turns out to be the case. This successfully replicates this well-established complexity phenomenon and demonstrates the validity of the measure used in this experiment.

Predictions for embedded and non-embedded clauses

The SPLT predicted that non-embedded conditions should be faster than embedded conditions, and this was the case.

Predictions for subject vs. object modifying RCs and the interaction between modifier position and embedding

The SPLT predicted that subject modifying RCs should be no more difficult to process than object modifying RCs in main clauses, and that in embedded clauses, the subject modifier should be more complex than the object modifier. The above experimental results show that subject modifying RC constructions were significantly faster overall than object modifying RC constructions. The subject modifying conditions were also significantly faster than the object modifying conditions in both non-embedded conditions and embedded conditions. Thus, there was no interaction between modifier position and embedding and the predictions of the zero-memory cost of the SPLT were not supported by this experiment.

4 General Discussion

The results of this experiment do not support the zero-memory cost hypothesis of the SPLT. These results do support an alternative to the SPLT also proposed by Gibson.

4.1 The Integration-based SPLT

4.1.1 The theory

In Gibson's (1997) alternative version of the SPLT, there are two components—a memory cost and an integration cost, and only the integration cost is locality-based. Under locality, longer integration distance leads to higher complexity. There is a fixed memory cost associated with each predicted syntactic head needed to form a grammatical sentence from the input for both the matrix verb and other heads. In the original version of the SPLT, the memory cost was zero for maintaining the prediction of the matrix verb and increasing for predictions of all other heads in non-matrix clauses, whereas the prediction for the matrix verb has the same fixed cost as the predictions for other heads in the Integration-based SPLT.

Complexity is expressed as a function of integration divided by the available space. Available space refers to the total memory available to the reader or comprehender minus the amount of memory that has been used already in reading the sentence up to the current position. The two components of memory cost are 1) the larger the number of predicted categories, the greater the memory cost and 2) the more structures held in memory up the current reading position in the sentence, the greater the memory cost. The new theory proposes that syntactic predictions are costly as is maintaining the structure built thus far. Reading times are a function of the maximal ratio of integration cost to the memory space available.

The Integration-based SPLT proposes that the lack of complexity difference between the subject modifying RCs and object modifying RCs is because the memory costs for retaining structures in the object modifying

cases approximately cancel the memory costs for the prediction of categories in the subject modifying cases.

The Integration-based SPLT predicts that when the number of predicted categories is kept constant, RTs should become slower later in sentences. The greater the number of predicted categories, the more complex the sentence.

4.2 Two new proposed experiments:

To test the predictions of the Integration-based SPLT, two pilot studies are proposed.

4.2.1 Proposal 1

The results should yield longer RTs on (12b) during "the reporter attacked the senator" because there are more discourse referents in (12b) than in (12a), but they both have the same number of syntactic predictions.

(12)

a. [The reporter attacked the senator].

A

b. The president believed that [the reporter attacked the senator].

Additional lexical material

B

Shared lexical material

A

4.2.2 Proposal 2

In this proposed experiment, the prediction that greater numbers of predicted categories increases the complexity of a sentence is tested. The plan is to keep the amount of structure up to the point that the sentences share lexical material the same, and vary the number of syntactic predictions. The results should yield longer RTs in (12c) during "the reporter attacked the senator" because there is an additional prediction to be satisfied, the matrix verb, which must be held in memory while processing the bracketed sentence.

(12)

b. The president believed that [the reporter attacked the senator].

Additional lexical material

B

Shared lexical material

A

c. The president's belief that [the reporter attacked the senator] bugged me.

Additional lexical material

C

Shared lexical material

A

Length of B = Length of C, but number of syntactic predictions is greater in c.

References

- Daneman, M. & Carpenter, P.A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, 19, 450-466.
- Eady, S. J. and Fodor, J. D. (1981) Is center-embedding a source of processing difficulty? *Paper presented at the annual meeting of the Linguistic Society of America*. New York City, December 29, 1981.
- Ford, M. (1983). A method for obtaining measures of local parsing complexity throughout sentences. *Journal for Verbal Learning and Verbal Behavior*, 22, 203-218.
- Frazier, L. (1987). Sentence processing: A tutorial review. In M. Coltheart (Ed.), *Attention and performance XII*, Lawrence Erlbaum, Hillsdale, NJ.
- Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. To appear in *Cognition*.
- Gibson, E. & Thomas, J. (1997). The complexity of nested structures in English: Evidence for the syntactic prediction locality theory of linguistic complexity.
- Gibson, E. & Warren, T. (in preparation). Discourse reference and syntactic complexity. Department of Brain and Cognitive Sciences, MIT.
- Hakes, D. T., Evans, J. S., and Brannon, L.L. (1976) Understanding sentences with relative clauses. *Memory & Cognition*, 4, (3), 283-290.
- Holmes, V. (1973). Order of main and subordinate clauses in sentence perception. *Journal of verbal Learning and Verbal Behavior*, 12, 285-293.
- Holmes, V. M. & O'Regan, J. K. (1981). Eye fixation patterns during the reading of relative clause sentences. *Journal of Verbal Learning and Verbal Behavior*, 20, 417-430.
- Just, M. & Carpenter, P.A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, 99, 122-149

- Just, M. A., Carpenter, P. A., & Woolley, J. D. (1982). Paradigms and processes in reading comprehension. *Journal of Experimental Psychology: General*, 111, 228-238.
- King, J. & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language*, 30, 580-602.
- MacDonald, M., Pearlmutter, N., & Seidenberg, M. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review*, 101, 676-703.
- Miller, G. A., & Chomsky, N. (1963). Finitary models of language users. In R. D. Luce, R. R. Bush, & E. Galanter (Eds.) *Handbook of mathematical psychology*, Vol. II. New York: Wiley, 419-492.
- Miller, G. A., & Isard, S. (1964). Free recall of self-embedded English sentences. *Information and Control*, 7, 292-303.
- Mitchell, D. C. (1994). Sentence parsing. In M. A. Gernsbacher (Ed.), *Handbook of Psycholinguistics*, Academic Press.
- Miyamoto, E. (personal consultation).
- Thomas, J. D. (1995) Center embedding and self embedding in human language processing. Unpublished Masters thesis.
- Trueswell, J. C., & Tanenhaus, M. K. (1994). Towards a lexicalist framework of constraint-based syntactic ambiguity resolution. In C. Clifton, L. Frazier, & K. Rayner (Eds.), *Perspectives on sentence processing* (pp. 155-179). Hillsdale, NJ: Lawrence Erlbaum.
- Wanner, E. & Maratsos, M. (1978). An ATN approach in comprehension. In M. Halle, J. Bresnan, & G. Miller (Eds.) *Linguistic theory and psychological reality*, MIT Press, Cambridge, MA, 119-161.

Appendix

Stimuli

1. on Tuesday

1a. The reporter who the senator attacked on Tuesday ignored the president when the limousine arrived.

1b. The reporter who attacked the senator on Tuesday ignored the president when the limousine arrived.

1c. The president ignored the reporter who the senator attacked on Tuesday when the limousine arrived.

1d. The president ignored the reporter who attacked the senator on Tuesday when the limousine arrived.

1e. The chance that the reporter who the senator attacked on Tuesday ignored the president bothered the editor.

1f. The chance that the reporter who attacked the senator on Tuesday ignored the president bothered the editor.

1g. The chance that the president ignored the reporter who the senator attacked on Tuesday bothered the editor.

1h. The chance that the president ignored the reporter who attacked the senator on Tuesday bothered the editor.

2. very much

2a. The babysitter who the parents liked very much played with the child for most of the summer.

2b. The babysitter who liked the parents very much played with the child for most of the summer.

2c. The child played with the babysitter who the parents liked very much for most of the summer.

2d. The child played with the babysitter who liked the parents very much for most of the summer.

2e. The knowledge that the babysitter who the parents liked very much played with the child pleased the grandparents.

2f. The knowledge that the babysitter who liked the parents very much played with the child pleased the grandparents.

2g. The knowledge that the child played with the babysitter who the parents liked very much pleased the grandparents.

2h. The knowledge that the child played with the babysitter who liked the parents very much pleased the grandparents.

3. during lunch

3a. The banker who the chairman praised during lunch distrusted the broker after the merger.

3b. The banker who praised the chairman during lunch distrusted the broker

after the merger.

3c. The broker distrusted the banker who the chairman praised during lunch after the merger.

3d. The broker distrusted the banker who praised the chairman during lunch after the merger.

3e. The perception that the banker who the chairman praised during lunch distrusted the broker annoyed the clients.

3f. The perception that the banker who praised the chairman during lunch distrusted the broker annoyed the clients.

3g. The perception that the broker distrusted the banker who the chairman praised during lunch annoyed the clients.

3h. The perception that the broker distrusted the banker who praised the chairman during lunch annoyed the clients.

4. at the rehearsal

4a. The violinist who the sponsors flattered at the rehearsal insulted the singer before the performance.

4b. The violinist who flattered the sponsors at the rehearsal insulted the singer before the performance.

4c. The singer insulted the violinist who the sponsors flattered at the rehearsal before the performance.

4d. The singer insulted the violinist who flattered the sponsors at the rehearsal before the performance.

4e. The information that the violinist who the sponsors flattered at the rehearsal insulted the singer disappointed the conductor.

4f. The information that the violinist who flattered the sponsors at the rehearsal insulted the singer disappointed the conductor.

4g. The information that the singer insulted the violinist who the sponsors flattered at the rehearsal disappointed the conductor.

4h. The information that the singer insulted the violinist who flattered the sponsors at the rehearsal disappointed the conductor.

5. on Monday

5a. The burglar who the police negotiated with on Monday had frightened the dog before the arrest.

5b. The burglar who negotiated with the police on Monday had frightened the dog before the arrest.

5c. The dog had frightened the burglar who the police negotiated with on Monday before the arrest.

5d. The dog had frightened the burglar who negotiated with the police on Monday before the arrest.

5e. The realization that the burglar who the police negotiated with on Monday had frightened the dog distressed the neighbors.

5f. The realization that the burglar who negotiated with the police on Monday had frightened the dog distressed the neighbors.

5g. The realization that the dog had frightened the burglar who the police

negotiated with on Monday distressed the neighbors.

5h. The realization that the dog had frightened the burglar who negotiated with the police on Monday distressed the neighbors.

6. in the nose

6a. The carpenter who the plumber punched in the nose yelled at the painter during the fight at the bar.

6b. The carpenter who punched the plumber in the nose yelled at the painter during the fight at the bar.

6c. The painter yelled at the carpenter who the plumber punched in the nose during the fight at the bar.

6d. The painter yelled at the carpenter who punched the plumber in the nose during the fight at the bar.

6e. The speculation that the carpenter who the plumber punched in the nose yelled at the painter worried the contractor.

6f. The speculation that the carpenter who punched the plumber in the nose yelled at the painter worried the contractor.

6g. The speculation that the painter yelled at the carpenter who the plumber punched in the nose worried the contractor.

6h. The speculation that the painter yelled at the carpenter who punched the plumber in the nose worried the contractor.

7. during the meeting

7a. The accountant who the engineer advised during the meeting spoke to the secretary after the paperwork was completed.

7b. The accountant who advised the engineer during the meeting spoke to the secretary after the paperwork was completed.

7c. The secretary spoke to the accountant who the engineer advised during the meeting after the paperwork was completed.

7d. The secretary spoke to the accountant who advised the engineer during the meeting after the paperwork was completed.

7e. The implication that the accountant who the engineer advised during the meeting spoke to the secretary irritated the boss.

7f. The implication that the accountant who advised the engineer during the meeting spoke to the secretary irritated the boss.

7g. The implication that the secretary spoke to the accountant who the engineer advised during the meeting irritated the boss.

7h. The implication that the secretary spoke to the accountant who advised the engineer during the meeting irritated the boss.

8. after the debut

8a. The model who the artist teased after the debut winked at the journalist at the exhibit.

8b. The model who teased the artist after the debut winked at the journalist at the exhibit.

8c. The journalist winked at the model who the artist teased after the debut

at the exhibit.

8d. The journalist winked at the model who teased the artist after the debut at the exhibit.

8e. The observation that the model who the artist teased after the debut winked at the journalist excited the onlookers.

8f. The observation that the model who teased the artist after the debut winked at the journalist excited the onlookers.

8g. The observation that the journalist winked at the model who the artist teased after the debut excited the onlookers.

8h. The observation that the journalist winked at the model who teased the artist after the debut excited the onlookers.

9. for a long time

9a. The student who the professor trusted for a long time met with the provost in the office.

9b. The student who trusted the professor for a long time met with the provost in the office.

9c. The provost met with the student who the professor trusted for a long time in the office.

9d. The provost met with the student who trusted the professor for a long time in the office.

9e. The reminder that the student who the professor trusted for a long time met with the provost tormented the teaching assistant.

9f. The reminder that the student who trusted the professor for a long time met with the provost tormented the teaching assistant.

9g. The reminder that the provost met with the student who the professor trusted for a long time tormented the teaching assistant.

9h. The reminder that the provost met with the student who trusted the professor for a long time tormented the teaching assistant.

10. on Monday

10a. The mobster who the media criticized on Monday kidnapped the spy before the trial.

10b. The mobster who criticized the media on Monday kidnapped the spy before the trial.

10c. The spy kidnapped the mobster who the media criticized on Monday before the trial.

10d. The spy kidnapped the mobster who criticized the media on Monday before the trial.

10e. The rumor that the mobster who the media criticized on Monday kidnapped the spy intimidated the attorney.

10f. The rumor that the mobster who criticized the media on Monday kidnapped the spy intimidated the attorney.

10g. The rumor that the spy kidnapped the mobster who the media criticized on Monday intimidated the attorney.

10h. The rumor that the spy kidnapped the mobster who criticized the media

on Monday intimidated the attorney.

11. after the practice

11a. The player who the coach screamed at after practice wrestled with the trainer before the meet.

11b. The player who screamed at the coach after practice wrestled with the trainer before the meet.

11c. The trainer wrestled with the player who the coach screamed at after practice before the meet.

11d. The trainer wrestled with the player who screamed at the coach after practice before the meet.

11e. The news that the player who the coach screamed at after practice wrestled with the trainer surprised the team.

11f. The news that the player who screamed at the coach after practice wrestled with the trainer surprised the team.

11g. The news that the trainer wrestled with the player who the coach screamed at after practice surprised the team.

11h. The news that the trainer wrestled with the player who screamed at the coach after practice surprised the team.

12. a great deal

12a. The actor who the starlet annoyed a great deal forgot about the leading lady during the dress rehearsal.

12b. The actor who annoyed the starlet a great deal forgot about the leading lady during the dress rehearsal.

12c. The leading lady forgot about the actor who the starlet annoyed a great deal during the dress rehearsal.

12d. The leading lady forgot about the actor who annoyed the starlet a great deal during the dress rehearsal.

12e. The thought that the actor who the starlet annoyed a great deal forgot about the leading lady amused the comedian.

12f. The thought that the actor who annoyed the starlet a great deal forgot about the leading lady amused the comedian.

12g. The thought that the leading lady forgot about the actor who the starlet annoyed a great deal amused the comedian.

12h. The thought that the leading lady forgot about the actor who annoyed the starlet a great deal amused the comedian.

13. for millions of dollars

13a. The criminal who the lawyer sued for millions of dollars stared at the judge after the preliminary hearing.

13b. The criminal who sued the lawyer for millions of dollars stared at the judge after the preliminary hearing.

13c. The judge stared at the criminal who the lawyer sued for millions of dollars after the preliminary hearing.

13d. The judge stared at the criminal who sued the lawyer for millions of

dollars after the preliminary hearing.

13e. The fact that the criminal who the lawyer sued for millions of dollars stared at the judge unnerved the jury.

13f. The fact that the criminal who sued the lawyer for millions of dollars stared at the judge unnerved the jury.

13g. The fact that the judge stared at the criminal who the lawyer sued for millions of dollars unnerved the jury.

13h. The fact that the judge stared at the criminal who sued the lawyer for millions of dollars unnerved the jury.

14. during the evening

14a. The suitors who the king entertained during the evening wanted to see the princess at the ball.

14b. The suitors who entertained the king during the evening wanted to see the princess at the ball.

14c. The princess wanted to see the suitors who the king entertained during the evening at the ball.

14d. The princess wanted to see the suitors who entertained the king during the evening at the ball.

14e. The idea that the suitors who the king entertained during the evening wanted to see the princess overjoyed the queen.

14f. The idea that the suitors who entertained the king during the evening wanted to see the princess overjoyed the queen.

14g. The idea that the princess wanted to see the suitors who the king entertained during the evening overjoyed the queen.

14h. The idea that the princess wanted to see the suitors who entertained the king during the evening overjoyed the queen.

15. with passion

15a. The bachelor who the socialite pursued with passion resented the millionaire throughout the summer.

15b. The bachelor who pursued the socialite with passion resented the millionaire throughout the summer.

15c. The millionaire resented the bachelor who the socialite pursued with passion throughout the summer.

15d. The millionaire resented the bachelor who pursued the socialite with passion throughout the summer.

15e. The discovery that the bachelor who the socialite pursued with passion resented the millionaire fascinated the tabloids.

15f. The discovery that the bachelor who pursued the socialite with passion resented the millionaire fascinated the tabloids.

15g. The discovery that the millionaire resented the bachelor who the

socialite pursued with passion fascinated the tabloids.

15h. The discovery that the millionaire resented the bachelor who pursued the socialite with passion fascinated the tabloids.

16. last week

16a. The councilman who the radio host provoked last week married the secretary after three months in office.

16b. The councilman who provoked the radio host last week married the secretary after three months in office.

16c. The secretary married the councilman who the radio host provoked last week after three months in office.

16d. The secretary married the councilman who provoked the radio host last week after three months in office.

16e. The discovery that the councilman who the radio host provoked last week

married the secretary shocked the entire city.

16f. The discovery that the councilman who provoked the radio host last week

married the secretary shocked the entire city.

16g. The discovery that the secretary married the councilman who the radio host provoked last week shocked the entire city.

16h. The discovery that the secretary married the councilman who provoked the radio host last week shocked the entire city.

17. about the host

17a. The contestant who the judges joked with about the host turned toward the cameraman during the pageant.

17b. The contestant who joked with the judges about the host turned toward the cameraman during the pageant.

17c. The cameraman turned toward the contestant who the judges joked with about the host during the pageant.

17d. The cameraman turned toward the contestant who joked with the judges about the host during the pageant.

17e. The observation that the contestant who the judges joked with about the host turned toward the cameraman pleased the audience.

17f. The observation that the contestant who joked with the judges about the host turned toward the cameraman pleased the audience.

17g. The observation that the cameraman turned toward the contestant who the

judges joked with about the host pleased the audience.

17h. The observation that the cameraman turned toward the contestant who joked with the judges about the host pleased the audience.

18. during the therapy session

18a. The child who the psychologist talked to during the therapy session had hurt the woman in the office.

- 18b. The child who talked to the psychologist during the therapy session had hurt the woman in the office.
- 18c. The woman had hurt the child who the psychologist talked to during the therapy session in the office.
- 18d. The woman had hurt the child who talked to the psychologist during the therapy session in the office.
- 18e. The revelation that the child who the psychologist talked to during the therapy session had hurt the woman worried the young couple.
- 18f. The revelation that the child who talked to the psychologist during the therapy session had hurt the woman worried the young couple.
- 18g. The revelation that the woman had hurt the child who the psychologist talked to during the therapy session worried the young couple.
- 18h. The revelation that the woman had hurt the child who talked to the psychologist during the therapy session worried the young couple.

19. on Friday

- 19a. The diplomat who the prime minister insulted on Friday angered the dictator during the meeting.
- 19b. The diplomat who insulted the prime minister on Friday angered the dictator during the meeting.
- 19c. The dictator angered the diplomat who the prime minister insulted on Friday during the meeting.
- 19d. The dictator angered the diplomat who insulted the prime minister on Friday during the meeting.
- 19e. The news that the diplomat who the prime minister insulted on Friday angered the dictator discredited the government.
- 19f. The news that the diplomat who insulted the prime minister on Friday angered the dictator discredited the government.
- 19g. The news that the dictator angered the diplomat who the prime minister insulted on Friday discredited the government.
- 19h. The news that the dictator angered the diplomat who insulted the prime minister on Friday discredited the government.

20. during the visit

- 20a. The tourists who the guide walked with during the visit waved at the nuns in the courtyard.
- 20b. The tourists who walked with the guide during the visit waved at the nuns in the courtyard.
- 20c. The nuns waved at the tourists who the guide walked with during the visit in the courtyard.
- 20d. The nuns waved at the tourists who walked with the guide during the visit in the courtyard.
- 20e. The fact that the tourists who the guide walked with during the visit waved at the nuns embarrassed the priest.
- 20f. The fact that the tourists who walked with the guide during the visit waved at the nuns embarrassed the priest.

20g. The fact that the nuns waved at the tourists who the guide walked with during the visit embarrassed the priest.

20h. The fact that the nuns waved at the tourists who walked with the guide during the visit embarrassed the priest.

21. during the campaign

21a. The politician who the voters spoke to during the campaign smiled at the preacher before the election.

21b. The politician who spoke to the voters during the campaign smiled at the preacher before the election.

21c. The preacher smiled at the politician who the voters spoke to during the campaign before the election.

21d. The preacher smiled at the politician who spoke to the voters during the campaign before the election.

21e. The report that the politician who the voters spoke to during the campaign

smiled at the preacher softened the critics a bit.

21f. The report that the politician who spoke to the voters during the campaign

smiled at the preacher softened the critics a bit.

21g. The report that the preacher smiled at the politician who the voters spoke to during the campaign softened the critics a bit.

21h. The report that the preacher smiled at the politician who spoke to the voters during the campaign softened the critics a bit.

22. at dusk

22a. The farmer who the aliens had communicated with at dusk phoned the newspaper last Thursday.

22b. The farmer who had communicated with the aliens at dusk phoned the newspaper last Thursday.

22c. The newspaper phoned the farmer who the aliens had communicated with at dusk last Thursday.

22d. The newspaper phoned the farmer who had communicated with the aliens at dusk last Thursday.

22e. The suggestion that the farmer who the aliens had communicated with at

dusk phoned the newspaper had strengthened the credibility of the article.

22f. The suggestion that the farmer who had communicated with the aliens at dusk phoned the newspaper had strengthened the credibility of the article.

22g. The suggestion that the newspaper phoned the farmer who the aliens had communicated with at dusk had strengthened the credibility of the article.

22h. The suggestion that the newspaper phoned the farmer who had communicated with the aliens at dusk had strengthened the credibility of the

article.

23. very loudly

23a. The official who the governor argued with very loudly avoided the mayor

for a few hours.

23b. The official who argued with the governor very loudly avoided the mayor

for a few hours.

23c. The mayor avoided the official who the governor argued with very loudly

for a few hours.

23d. The mayor avoided the official who argued with the governor very loudly

for a few hours.

23e. The information that the official who the governor argued with very loudly avoided the mayor disillusioned the apprentice.

23f. The information that the official who argued with the governor very loudly avoided the mayor disillusioned the apprentice.

23g. The information that the mayor avoided the official who the governor argued with very loudly disillusioned the apprentice.

23h. The information that the mayor avoided the official who argued with the

governor very loudly disillusioned the apprentice.

24. very much

24a. The clerk who the manager disliked very much smiled at the customer for

no reason.

24b. The clerk who disliked the manager very much smiled at the customer for

no reason.

24c. The customer smiled at the clerk who the manager disliked very much for

no reason.

24d. The customer smiled at the clerk who disliked the manager very much for

no reason.

24e. The impression that the clerk who the manager disliked very much smiled

at the customer intrigued the security guard.

24f. The impression that the clerk who disliked the manager very much smiled

at the customer intrigued the security guard.

24g. The impression that the customer smiled at the clerk who the manager disliked very much intrigued the security guard.

24h. The impression that the customer smiled at the clerk who disliked the manager very much intrigued the security guard.

25. at concerts

25a. The guitarist who the band played with at concerts despised the agent when the new album was released.

25b. The guitarist who played with the band at concerts despised the agent when the new album was released.

25c. The agent despised the guitarist who the band played with at concerts when the new album was released.

25d. The agent despised the guitarist who played with the band at concerts when the new album was released.

25e. The suggestion that the guitarist who the band played with at concerts despised the agent upset the drummer.

25f. The suggestion that the guitarist who played with the band at concerts despised the agent upset the drummer.

25g. The suggestion that the agent despised the guitarist who the band played with at concerts upset the drummer.

25h. The suggestion that the agent despised the guitarist who played with the band at concerts upset the drummer.

26. for stealing merchandise

26a. The salesman who the cashier resented for stealing merchandise ridiculed the shoppers after the clearance sale.

26b. The salesman who resented the cashier for stealing merchandise ridiculed the shoppers after the clearance sale.

26c. The shoppers ridiculed the salesman who the cashier resented for stealing merchandise after the clearance sale.

26d. The shoppers ridiculed the salesman who resented the cashier for stealing merchandise after the clearance sale.

26e. The speculation that the salesman who the cashier resented for stealing merchandise ridiculed the shoppers hurt business.

26f. The speculation that the salesman who resented the cashier for stealing merchandise ridiculed the shoppers hurt business.

26g. The speculation that the shoppers ridiculed the salesman who the cashier resented for stealing merchandise hurt business.

26h. The speculation that the shoppers ridiculed the salesman who resented the cashier for stealing merchandise hurt business.

27. for being lazy

27a. The waiter who the cook despised for being lazy ignored the busboy during the Sunday brunch.

27b. The waiter who despised the cook for being lazy ignored the busboy during the Sunday brunch.

27c. The busboy ignored the waiter who the cook despised for being lazy during the Sunday brunch.

- 27d. The busboy ignored the waiter who despised the cook for being lazy during the Sunday brunch.
- 27e. The fact that the waiter who the cook despised for being lazy ignored the busboy bothered the owner.
- 27f. The fact that the waiter who despised the cook for being lazy ignored the busboy bothered the owner.
- 27g. The fact that the busboy ignored the waiter who the cook despised for being lazy bothered the owner.
- 27h. The fact that the busboy ignored the waiter who despised the cook for being lazy bothered the owner.

28. on the weekends

- 28a. The medic who the doctor worked with on the weekends scolded the patient at the clinic.
- 28b. The medic who worked with the doctor on the weekends scolded the patient at the clinic.
- 28c. The patient scolded the medic who the doctor worked with on the weekends at the clinic.
- 28d. The patient scolded the medic who worked with the doctor on the weekends at the clinic.
- 28e. The disclosure that the medic who the doctor worked with on the weekends scolded the patient startled the board of directors.
- 28f. The disclosure that the medic who worked with the doctor on the weekends scolded the patient startled the board of directors.
- 28g. The disclosure that the patient scolded the medic who the doctor worked with on the weekends startled the board of directors.
- 28h. The disclosure that the patient scolded the medic who worked with the doctor on the weekends startled the board of directors.

29. at the party

- 29a. The passenger who the navigator had met at the party talked to the pilot in the airport.
- 29b. The passenger who had met the navigator at the party talked to the pilot in the airport.
- 29c. The pilot talked to the passenger who the navigator had met at the party in the airport.
- 29d. The pilot talked to the passenger who had met the navigator at the party in the airport.
- 29e. The evidence that the passenger who the navigator had met at the party talked to the pilot proved the identity of the criminal.
- 29f. The evidence that the passenger who had met the navigator at the party talked to the pilot proved the identity of the criminal.
- 29g. The evidence that the pilot talked to the passenger who the navigator had met at the party proved the identity of the criminal.
- 29h. The evidence that the pilot talked to the passenger who had met the navigator at the party proved the identity of the criminal.

30. up a tree

30a. The dog which the bear chased up a tree scratched the cubs in the woods.

30b. The dog which chased the bear up a tree scratched the cubs in the woods.

30c. The cubs scratched the dog which the bear chased up a tree in the woods.

30d. The cubs scratched the dog which chased the bear up a tree in the woods.

30e. The evidence that the dog which the bear chased up a tree scratched the cubs infuriated the owner.

30f. The evidence that the dog which chased the bear up a tree scratched the cubs infuriated the owner.

30g. The evidence that the cubs scratched the dog which the bear chased up a tree infuriated the owner.

30h. The evidence that the cubs scratched the dog which chased the bear up a tree infuriated the owner.

31. for a month

31a. The cheerleader who the quarterback dated for a month denounced the track star at the beginning of junior year.

31b. The cheerleader who dated the quarterback for a month denounced the track star at the beginning of junior year.

31c. The track star denounced the cheerleader who the quarterback dated for a month at the beginning of junior year.

31d. The track star denounced the cheerleader who dated the quarterback for a month at the beginning of junior year.

31e. The report that the cheerleader who the quarterback dated for a month denounced the track star amused the team.

31f. The report that the cheerleader who dated the quarterback for a month denounced the track star amused the team.

31g. The report that the track star denounced the cheerleader who the quarterback dated for a month amused the team.

31h. The report that the track star denounced the cheerleader who dated the quarterback for a month amused the team.

32. on the leg

32a. The raccoon which the fox bit on the leg ran from the deer during the rain storm.

32b. The raccoon which bit the fox on the leg ran from the deer during the rain storm.

32c. The deer ran from the raccoon which the fox bit on the leg during the rain storm.

32d. The deer ran from the raccoon which bit the fox on the leg during the rain storm.

- 32e. The claim that the raccoon which the fox bit on the leg ran from the deer interested the nature show host.
- 32f. The claim that the raccoon which bit the fox on the leg ran from the deer interested the nature show host.
- 32g. The claim that the deer ran from the raccoon which the fox bit on the leg interested the nature show host.
- 32h. The claim that the deer ran from the raccoon which bit the fox on the leg interested the nature show host.

Questions

kara.qs

11 April 1997

1. Did the senator attack the reporter?
 - 1a. yes
 - 1b. no
 - 1c. yes
 - 1d. no
 - 1e. yes
 - 1f. no
 - 1g. yes
 - 1h. no
2. Did the parents play with the child?
 - 2a. no
 - 2b. no
 - 2c. no
 - 2d. no
 - 2e. no
 - 2f. no
 - 2g. no
 - 2h. no
3. Did the chairman praise the banker?
 - 3a. yes
 - 3b. no
 - 3c. yes
 - 3d. no
 - 3e. yes
 - 3f. no
 - 3g. yes
 - 3h. no
4. Did the sponsors flatter the violinist?
 - 4a. yes
 - 4b. no
 - 4c. yes
 - 4d. no

- 4e. yes
- 4f. no
- 4g. yes
- 4h. no
- 5. Did the police negotiate with the burglar?
- 5a. yes
- 5b. yes
- 5c. yes
- 5d. yes
- 5e. yes
- 5f. yes
- 5g. yes
- 5h. yes
- 6. Did the plumber punch the carpenter?
- 6a. yes
- 6b. no
- 6c. yes
- 6d. no
- 6e. yes
- 6f. no
- 6g. yes
- 6h. no
- 7. Did the engineer advise the accountant?
- 7a. yes
- 7b. no
- 7c. yes
- 7d. no
- 7e. yes
- 7f. no
- 7g. yes
- 7h. no
- 8. Did the artist tease the model?
- 8a. yes
- 8b. no
- 8c. yes
- 8d. no
- 8e. yes
- 8f. no
- 8g. yes
- 8h. no
- 9. Did the student trust the professor?
- 9a. no
- 9b. yes
- 9c. no
- 9d. yes
- 9e. no

- 9f. yes
- 9g. no
- 9h. yes
- 10. Did the mobster criticize the media?
- 10a. no
- 10b. yes
- 10c. no
- 10d. yes
- 10e. no
- 10f. yes
- 10g. no
- 10h. yes
- 11. Did the player scream at the coach?
- 11a. no
- 11b. yes
- 11c. no
- 11d. yes
- 11e. no
- 11f. yes
- 11g. no
- 11h. yes
- 12. Did the actor annoy the starlet?
- 12a. no
- 12b. yes
- 12c. no
- 12d. yes
- 12e. no
- 12f. yes
- 12g. no
- 12h. yes
- 13. Did the criminal sue the lawyer?
- 13a. no
- 13b. yes
- 13c. no
- 13d. yes
- 13e. no
- 13f. yes
- 13g. no
- 13h. yes
- 14. Did the suitors entertain the king?
- 14a. no
- 14b. yes
- 14c. no
- 14d. yes
- 14e. no
- 14f. yes

- 14g. no
- 14h. yes
- 15. Did the millionaire resent the bachelor?
 - 15a. no
 - 15b. no
 - 15c. yes
 - 15d. yes
 - 15e. no
 - 15f. no
 - 15g. yes
 - 15h. yes
- 16. Did the councilman provoke the radio host?
 - 16a. no
 - 16b. yes
 - 16c. no
 - 16d. yes
 - 16e. no
 - 16f. yes
 - 16g. no
 - 16h. yes
- 17. Did the contestant turn toward the cameraman?
 - 17a. yes
 - 17b. yes
 - 17c. no
 - 17d. no
 - 17e. yes
 - 17f. yes
 - 17g. no
 - 17h. no
- 18. Did the child hurt the woman?
 - 18a. yes
 - 18b. yes
 - 18c. no
 - 18d. no
 - 18e. yes
 - 18f. yes
 - 18g. no
 - 18h. no
- 19. Did the diplomat anger the dictator?
 - 19a. yes
 - 19b. yes
 - 19c. no
 - 19d. no
 - 19e. yes
 - 19f. yes
 - 19g. no

- 19h. no
20. Did the tourists wave at the nuns?
- 20a. yes
- 20b. yes
- 20c. no
- 20d. no
- 20e. yes
- 20f. yes
- 20g. no
- 20h. no
21. Did the politician smile at the preacher?
- 21a. yes
- 21b. yes
- 21c. no
- 21d. no
- 21e. yes
- 21f. yes
- 21g. no
- 21h. no
22. Did the farmer phone the newspaper?
- 22a. yes
- 22b. yes
- 22c. no
- 22d. no
- 22e. yes
- 22f. yes
- 22g. no
- 22h. no
23. Did the official avoid the mayor?
- 23a. yes
- 23b. yes
- 23c. no
- 23d. no
- 23e. yes
- 23f. yes
- 23g. no
- 23h. no
24. Did the clerk smile at the customer??
- 24a. yes
- 24b. yes
- 24c. no
- 24d. no
- 24e. yes
- 24f. yes
- 24g. no
- 24h. no

25. Did the agent despise the guitarist?
25a. no
25b. no
25c. yes
25d. yes
25e. no
25f. no
25g. yes
25h. yes
26. Did the shoppers ridicule the salesman?
26a. no
26b. no
26c. yes
26d. yes
26e. no
26f. no
26g. yes
26h. yes
27. Did the busboy ignore the waiter??
27a. no
27b. no
27c. yes
27d. yes
27e. no
27f. no
27g. yes
27h. yes
28. Did the patient scold the medic?
28a. no
28b. no
28c. yes
28d. yes
28e. no
28f. no
28g. yes
28h. yes
29.
29a. no, Did the navigator talk to the pilot?
29b. yes, Did the navigator meet the passenger?
29c. no, Did the navigator talk to the pilot?
29d. yes, Did the navigator meet the passenger?
29e. no, Did the navigator talk to the pilot?
29f. yes, Did the navigator meet the passenger?
29g. no, Did the navigator talk to the pilot?
29h. yes, Did the navigator meet the passenger?
30. Did the cubs scratch the dog?

- 30a. no
- 30b. no
- 30c. yes
- 30d. yes
- 30e. no
- 30f. no
- 30g. yes
- 30h. yes
- 31. Did the track star denounce the cheerleader?
- 31a. no
- 31b. no
- 31c. yes
- 31d. yes
- 31e. no
- 31f. no
- 31g. yes
- 31h. yes
- 32. Did the deer run from the raccoon?
- 32a. no
- 32b. no
- 32c. yes
- 32d. yes
- 32e. no
- 32f. no
- 32g. yes
- 32h. yes