

Featural Analysis and Short-term Memory Retrieval in On-Line Parsing: Evidence for Syntactic, but Not Phonological, Similarity-Based Interference*

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1. Introduction

This paper investigates mechanisms of short-term memory involved in human sentence processing, focusing on how short-term memory functions are realized and constrained in establishing certain linguistic dependencies. We specifically examine a cue-based retrieval approach to short-term memory (Lewis et al. 2005, 2006) which assumes that a proceduralized grammar together with incoming words trigger the generation of retrieval cues necessary to make contact with the relevant preceding structure. By hypothesis the key factor affecting such retrievals is the effectiveness of the retrieval cues in discriminating the target representation from a background of distractors which may share syntactic or semantic features with the target—i.e., there exists *similarity-based retrieval interference* (cf. Van Dyke and Lewis 2003, Gordon et al. 2002, Vasishth and Lewis 2006, 2008) One of the active theoretical and empirical questions regarding similarity-based interference is how, precisely, “similarity” is to be defined: what cues and linguistic features induce similarity-based interference?

We present new empirical results from an on-line reading task that provide clear evidence for intra-sentential, proactive interference that is sensitive to the overlap of syntactic features, but is not sensitive to overlap of phonological features. Some of the empirical and theoretical consequences obtained from the current study are then discussed.

This paper is organized as follows: Section 2 briefly reviews a cue-based retrieval approach to short-term memory, on which our study is based, and clarifies the specific research questions we pursue. Section 3 discusses the design of the experiment we conducted while Section 4 specifies the experimental method. Section 5 shows the results of our study and Section 6 clarifies and discusses some theoretical and empirical

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consequences of our results.

2. Theoretical Background

2.1 Cue-Based Parsing

A subject-verb agreement relation and a filler-gap relation are just two examples of a dependency. There is substantial evidence that the linguistic parser has a very limited cognitive focus of about two items (Lewis et al. 2006; McElree et al. 2003; McElree, 2006); given this constraint, how are non-local dependencies—especially so-called ‘long-distance’ dependencies—processed? One of the possible answers to this question is that all computation of linguistic dependencies is (or perhaps, must in fact be) mediated by short-term memory retrieval.

One cue-based retrieval approach to short-term memory, presented in Lewis et al. (2005, 2006), proposes that linguistic dependencies are established by retrieving information encoded in the already constructed and stored representation of preceding input that is no longer in the focus of processing. For example, consider the subject-verb dependency in the following sentence:

- (1) Melissa knew that the toy from her uncle in Bogotá arrived today.
-

(Lewis et al. 2006: 448)

In (1), as “the toy” is read it is encoded via representations that include (at least) phonological/phonetic representations, syntactic features such as category (DP) and abstract nominative Case (Vergnaud, 1977)—having no overt realization in English morpho-phonetics of nonpronominal NPs—semantic and discourse features, and features representing expectations of upcoming input (here, a required predicate; for details see Lewis and Vasishth, 2005). This representation of the DP is maintained outside the focus of attention as the parser processes the remainder of the sentence. When the embedded verb “arrived” is analyzed as such by the parser, this verb triggers (via the proceduralized grammar) the generation of a cue to access retrieve the antecedent “the toy”. The subject-verb dependency is ultimately established through this procedure. This is the basic scenario a cue-based retrieval approach deploys. Remember that the other material, presented prior to “arrived”—namely “Melissa”, “knew”, “that”, “from”, “her”, “uncle”, “in” and “Bogotá”—as well as the phrasal representations of their constituent (sub)structures are also stored as representations along with the embedded subject “the toy” when “arrived” retrieves “the toy”. Do those previously constructed representations, generated by the parser and held in short-term memory, have some effect on the retrieval? The answer is yes. Prior representations act as distractors causing interference. The distractors preceding the retrieval target “the toy” provide proactive interference for the retrieval: “Melissa”, “knew” and “that”. On the other hand, the distractors following the target give retroactive interference to the retrieval: “from”, “her”, “uncle”, “in” and “Bogotá”. We now briefly review some of the evidence for this assumption.

2.2 Similarity-Based Interference

Gordon et al. (2002) and Van Dyke and Lewis (2003) provide evidence for both proactive and retroactive interference as a function of syntactic and semantic similarity (see also Vasishth and Lewis 2006, 2008, Nakayama et al. 2005, Lewis and Nakayama 2002 for relevant discussion.) Consider the following paradigm testing semantic similarities presented in Gordon et al. (2002):

- (2) Matched
 - a. *Memory-load set:* poet, cartoonist, voter
 - b. It was the dancer that liked the fireman before the argument began
 - (3) Unmatched
 - a. *Memory-load set:* poet, cartoonist, voter
 - b. It was Tony that liked Joey before the argument began
- (Gordon et al. 2002: 427)

In this study, participants first read the memory-load items and then the sentences were presented word by word in a moving-window paradigm. In the matched condition (2), the memory-load set and the sentence both include NPs referring to ‘human roles’. In the unmatched condition (3), the memory-load items and the nouns in the sentence are of different types. Although the memory-load set consists of NPs referring to human roles as in the matched condition, proper names appear in (3b). In terms of degree of similarity, the matched condition (by Gordon’s argument) contains items of greater similarity than in the unmatched condition. Under similarity-based interference, it is predicted that the memory items in the matched condition interfere with sentence parsing more than the ones in the unmatched condition. The study conducted by Gordon et al. (2002) confirms the prediction: the critical region “liked Joey” takes longer to read in the matched condition (2) than in the unmatched condition (3). The study reported in Gordon et al. (2002) substantiates proactive interference with syntactic processing triggered by semantic similarities. In addition, Van Dyke and Lewis (2003) demonstrate that syntactic similarities also cause retroactive interference. Lewis et al (2006) review a range of other evidence to support the assumption of similarity-based retrieval interference.

Although similarity-based interference has significant empirical support, one of the active theoretical and empirical questions is how, precisely, “similarity” is to be defined: what cues and linguistic features induce similarity-based interference, and which do not? For example, what about phonological similarities? That is, does phonological similarity or identity between two potential ‘fillers’ interfere with retrieval under similarity-based interference? This is one of the problems we address in the current study. In the next section we discuss some theoretical considerations that lead to the prediction that phonological similarity should *not* lead to increased retrieval interference. We then present the empirical studies and results that test this claim.

3. Exploring Phonological Similarities

3.1 Interference by Phonological Similarities

What kind of feature triggers similarity-based interference? The type of linguistic feature this paper specifically concentrates on is phonological features. With respect to this issue, Baddeley's (1966) study indicated that phonological similarities increase difficulty of recall of lists of words and the effect is more significant than semantic similarities. Baddeley compared phonologically similar words such as "mad", "man", "mat", "cad", "can", "cat" and "cap" with phonologically different words such as "cow", "day", "bar", "few", "hot", "pen", "sup" and "pit" to test whether recall of the former word list involves more difficulty than the latter. He found that phonological similarities do in fact interfere with the effective retrieval of representations from short-term memory. However, this study examined the recall of lists of words; the question remains to what extent phonological similarity affects the retrievals in on-line sentence processing. One possible theoretical approach is to assume that any similarity matters and therefore phonological feature overlap should matter. We pursue here the possibility of a more constrained theory that takes into consideration the functions of the parser and the nature of the retrievals that it must effect.

Lewis (1996) and Lewis et al. (2006) discuss phonological similarities in the context of syntactic processing and advance the hypothesis that phonological feature overlap should not matter to the retrieval process, because the parser (by hypothesis) is not operating over phonological representations. In terms of retrieval cues, the targets of retrieval are not selected based on their phonological content—e.g. in retrieving a subject-dependent of a verb, the parser does not "care" what the target sounds like. Caplan and Waters (1998) and Lewis (1996) review early behavioral and neuropsychological studies consistent with this separation of phonological short-term memory. For example, Martin (1993) reports patients whose phonological short-term memory is impaired but who are nevertheless still able to parse even complex constructions. And Larkin and Burns (1977) report cases of short-center embedded structures that subjects can repeat back verbatim but nevertheless fail to parse.

This paper further investigates the issue of whether phonological similarities interfere with retrievals in parsing, and we present new empirical results from an on-line reading task that provide evidence for intra-sentential (proactive) interference that is sensitive to the overlap of syntactic features, but not to the overlap of phonological features, which lends additional support for the hypothesis advanced in Lewis (1996) and Lewis et al. (2006).

3.2 Phonologically Null Elements

In this section, the stimuli to be used in our experiment are considered. As mentioned in Section 2.2, we focus on how phonologically null elements might interfere with short-term memory retrieval in parsing. The type of retrieval considered here mediates a filler-gap dependency created by overt movement/Internal Merge of wh-phrases to Spec-CP.

(4) The man whom John introduced likes Mary.

(5) *Syntactic Representation of (4):*

[The man whom John introduced <whom>] likes Mary.



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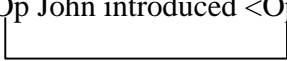
The angle brackets stand for the gap—the “deep structure” position of "whom". English relative clauses involve wh-dependencies. That is, the filler "whom" needs to be related to the object gap after the verb "introduced". One (of many) motivations for this transformational view is that the wh-phrase "whom" is marked with accusative Case, which is assigned to objects. This implies that "whom" has to have some syntactic relation to the canonical object position. The simplest and most explanatory assumption is that it acts like an object because it is an object in a post-verbal position. Since "whom" is an accusative form of "who", it cannot be in a subject wh-question sentence as shown in (6). Also, transitive verbs such as "introduce" need to give/assign accusative Case to some NP/DP, otherwise the sentence becomes ungrammatical as in the contrast in (7).

- (6) a. Who introduced Mary?
- b. *Whom introduced Mary?
- (7) a. John laughed. (intransitive)
- b. *John introduced.

These data indicate that "whom" in (4)/(5) enters into a syntactic relation/dependency with the object position of "introduce". Based on this view, consider what happens if "whom" in (4)/(5) is omitted as follows:

- (8) The man John introduced likes Mary.

(8), unlike (7b), is grammatical. How can this be, if “introduce” requires an object, which is apparently absent in (8)? Chomsky (1982, 1986, 1995) proposes the null operator analysis as a solution to this paradox (while presenting independent evidence for the presence of such a null operator (an operator like “whom” but lacking phonological features), as well as evidence for its overt syntactic movement)

- (9) *Syntactic Representation of (8):*
[The man Op John introduced <Op>] likes Mary.
- 

The proposal is that an operator “Op” which does not have any phonological form behaves in the same manner as a lexical wh-phrase. That is, the null operator receives accusative Case from "introduce" and also constructs the dependency with the object position as illustrated in (9). There is assumed to be no difference between null operators and lexical wh-phrases except existence of the phonological features. Given this analysis, and the processing theory sketched above in which phonological features do not affect retrieval processes, it follows that the short-term memory retrievals at “introduced” in the following two sentences should be equal in difficulty:

- (10) a. The man whom John introduced likes Mary.
- b. The man John introduced likes Mary.

By using this paradigm, the next section illustrates stimulus sentences used in our study and clarifies what the study tells us about similarity-based interference with syntactic

retrievals.

3.3 Stimulus Materials and Predictions

We directly test for effects of proactive interference from Case feature overlap (Lewis and Nakayama 2002, Nakayama et al. 2005), using wh-questions to construct minimal pairs that differ only in the type of wh-extraction and presence or absence of Case overlap. We examine here whether the Case/syntactic-similarity effects are observed in online processing of English, and even for phonologically null elements. If a phonologically null element displays the same interference effects as its overt counterpart, then this indicates that phonological similarity does not contribute to similarity-based interference (while concomitantly, syntactic similarity does). The following six conditions are examined in this study:

- (11) [The kids whom the brave woman easily *saved* _ from the worst crime] hugged the adults at the beach.
- (12) [The kids _____ the brave woman easily *saved* _ from the worst crime] hugged the adults at the beach.
- (13) Where₁ did [the kids whom₂ the brave woman easily *saved* _₂ from the worst crime] hug the adults _₁?
- (14) Where₁ did [the kids _₂ the brave woman easily *saved* _₂ from the worst crime] hug the adults _₁?
- (15) Whom₁ did [the kids whom₂ the brave woman easily *saved* _₂ from the worst crime] hug _₁ at the beach?
- (16) Whom₁ did [the kids _₂ the brave woman easily *saved* _₂ from the worst crime] hug _₁ at the beach?

First, consider (13) and (15). In both, when the parser encounters the verb “saved”, a correct parse must retrieve the relative pronoun object “whom₂” occupying Spec-CP. The preceding structure contains the phon-lexically identical interrogative “whom₁” in (15) but in (13) the other wh-phrase is the interrogative “where₁”. While the two wh-phrases in (15) are phonologically identical and both are marked with accusative Case, the two wh-phrases in (13) do not exhibit phonological identity nor do they bear identical syntactic Case-features because the adjunct “where” is never Case-marked. That is, the degree of *syntactic similarity*, as based on Case feature identity in (15) is higher than in (13) predicting that “whom₁” in (15) provides higher proactive interference for the retrieval of “whom₂” than “where₁” does in (13).

Next, consider (14) and (16). According to Chomsky (1982, 1986, 1995) and subsequent work, even in (14) and (16), as discussed in Section 3.2, a relative pronoun ‘just like’ “whom₂” ‘exists’ but bears no phonological features (the null operator analysis). Therefore, the degree of syntactic similarity between (14) and (16) is the same as the one between (13) and (15) while the degree of phonological similarity between (13) and (15) (the latter containing two relative pronouns that are phonologically identical) is higher than the one between (14) and (16). The (14)/(16) paradigm is for testing whether syntactic similarity effects are observed with phonologically null elements in the same manner as their overt counterparts. If phonologically null elements

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and their overt counterparts are processed in the same manner, it implies that syntactic retrievals take place independently of phonological representations, supporting Lewis (1996) and Lewis et al. (2006).

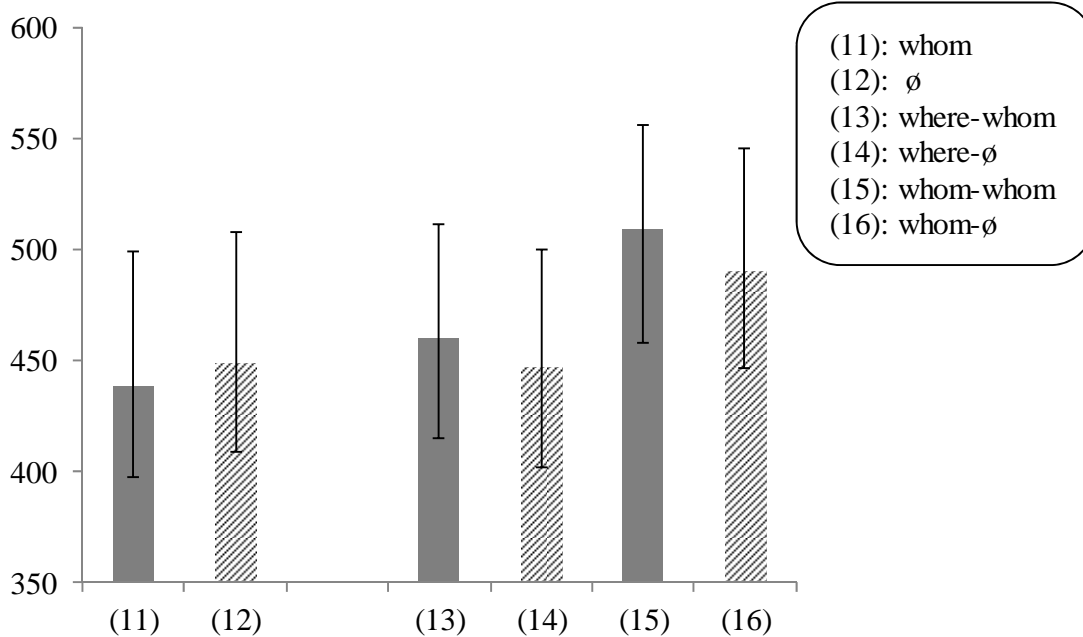
To summarize the predictions: If reading times on “saved” in (15) are longer than in (13), this would suggest that the accusative Case of “whom₁” stored in memory interferes with the object retrieval at “saved”. If the same contrast between (13) and (15) is also observed between (14) and (16), this would suggest that phonological features do not present any additional or independent interference of their own with the retrieval procedure and implies that the interference effect in (13) and (15) is not due to phonological overlap/phonological identity, in (15).

4. Method and Procedure

61 undergraduates from the University of Michigan participated in a word-by-word self-paced non-cumulative moving-window reading task. They were all native English speakers and received \$10 for their participation. 24 versions of each of the experimental items were prepared; thus each subject saw 4 versions of each condition. Presentation was randomized with about 2/3 of the trials being unrelated filler sentences. Each sentence was followed by a comprehension question.

5. Results

Six subjects were eliminated because their accuracies were lower than 70 percent. One subject was eliminated because his/her reading times were extremely fast and low-variance, indicating a uniform tapping strategy to advance the moving window. Data from the remaining 54 subjects were analyzed. We report here analysis from trials on which subjects responded correctly to offline comprehension questions, although the conclusions do not differ if all trials are included. Reading times smaller/greater than 4 standard deviations from the mean were excluded; this affected 1.5% of the data. We focus here on reading times at the critical verb, which is the same lexical item (e.g., *saved*) across conditions. The following are the mean reading times (RT) at this verb:



The estimates of reading times between conditions were derived from linear mixed effects models with both subject and item entered simultaneously as random effects. The derived estimates, 95% highest posterior density intervals, and corresponding observed p-values were as follows:

<i>Contrast</i>	<i>Empirical RT Difference</i>	<i>model estimate</i>	<i>95% HPD interval</i>	<i>p-value</i>
(13) vs. (15)	49 ms	45 ms	[-6ms, 96ms]	0.08
(14) vs. (16)	43 ms	45 ms	[-6ms, 93ms]	0.07
(13)/(14) vs. (15)/(16)	46 ms	45 ms	[10ms, 80ms]	0.01

The [(13) vs. (15)] and [(14) vs. (16)] contrasts are marginally significant, and the overall interference effect is highly significant. There was not a significant effect of relative pronoun reduction (i.e. overt vs. null wh-phrases) ($p > 0.6$), either in pairwise contrasts ((11) vs. (12), (13) vs. (14), and (15) vs. (16)) or overall ((11)/(13)/(15) vs. (12)/(14)/(16)).

6. Discussion and Conclusion

The predicted online interference effects were obtained. “whom₁” creates proactive interference when the object (“whom₂”) is retrieved at the verb (*saved*) (the (13) vs. (15) contrast). Why is there such a contrast? Crucially, notice that interference effects were also observed for the reduced relative pronoun (null operator) counterparts (14) and (16), and there is no evidence for a difference in the size of this effect. That is, phonological features do not induce any additional interference here. (Although we do not present the

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details here, the accuracy data from offline comprehension questions show the same numerical pattern, though the differences do not reach significance.)

These results provide further evidence for the general theory of similarity-based retrieval interference outlined in the previous sections, but also lend support for two additional and more specific claims.

First, not all features are equal with respect to causing similarity-based interference in parsing. More specifically, these results lend support to the hypothesis that Case or structural position features—syntactic features—do play a clear functional role in short-term memory retrievals in parsing, while phonological features do not.

Second, this result, combined with the retrieval interference interpretation, provides online evidence for the hypothesis that (14) and (16) contain (phonologically-null) and overtly moved relative pronouns marked with accusative Case, exactly as hypothesized in Chomsky's (1982, 1986, 1995 and subsequent work) null operator analysis.

Finally, and more speculatively, the present results may bear on the following important question: to what extent does the on-line parser make optimal use of available information sources—in particular, to what extent does it *ignore* encoded information that is (by hypothesis) irrelevant to the on-line computation of intra-sentential linguistic dependencies? This is one form of the modularity question—one that places emphasis on the functional motivations for modularity (efficient computation; Fodor, 1983; Frazier & Fodor, 1978). The results of the current study suggest both positive and negative answers to this question. The negative result here for “optimal” processing is that the parser seems unable to ignore representations that are *not* the targets of the dependency being computed—consistent with the results of Vasishth and Lewis (2008), Van Dyke (2007) and elsewhere indicating that even distractors in positions that violate structural constraints on the dependency may cause interference (see Ming et al. 2009 for an alternative view). But the positive result for “optimal” processing is that the parser *does* seem to ignore irrelevant information in the formation of the retrieval cues themselves, in a way consistent with theories of the grammar: in the syntax proper, the assignment of antecedents is not phonologically determined (we do not find, in grammars, gap assignment algorithms whereby the antecedent for a particular gap is determined by phonological properties, e.g., “assign an NP with a dental onset to a detected gap”). To this extent, the parser may be functioning in a *boundedly optimal* manner (Howes, Lewis and Vera, 2009)—that is, doing the best it can *given* that it must operate with the bounds of a memory system subject to similarity-based interference, a general principle of human memory that works across memory systems—a “third factor” in the sense of Chomsky (2005).

Appendix

Experimental Stimuli:

- 1 a. The kids [whom/ Ø] the brave woman easily saved from the worst crime hugged the adults at the beach.
- b. Where did the kids [whom/ Ø] the brave woman easily saved from the worst crime hug the adults?
- c. Whom did the kids [whom/ Ø] the brave woman easily saved from the

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- worst crime hug at the beach?
- 2 a. The chief [whom/ Ø] the smart lawyer often served until the last year phoned the agent beside the river.
b. Where did the chief [whom/ Ø] the smart lawyer often served until the last year phone the agent?
c. Whom did the chief [whom/ Ø] the smart lawyer often served until the last year phone beside the river?
- 3 a. The editor [whom/ Ø] the ironic author once found after the local event noticed the fans in some cities.
b. Where did the editor [whom/ Ø] the ironic author once found after the local event notice the fans?
c. Whom did the editor [whom/ Ø] the ironic author once found after the local event notice in some cities?
- 4 a. The captain [whom/ Ø] the strong team never needed over the fall season abused the people on the avenue.
b. Where did the captain [whom/ Ø] the strong team never needed over the fall season abuse the people?
c. Whom did the captain [whom/ Ø] the strong team never needed over the fall season abuse on the avenue?
- 5 a. The expert [whom/ Ø] the young people mostly liked among the famous champs missed the pupils in the room.
b. Where did the expert [whom/ Ø] the young people mostly liked among the famous champs miss the pupils?
c. Whom did the expert [whom/ Ø] the young people mostly liked among the famous champs miss in the room?
- 6 a. The senior [whom/ Ø] the office staff simply added into the design class taught the novice in the studio.
b. Where did the senior [whom/ Ø] the office staff simply added into the design class teach the novice?
c. Whom did the senior [whom/ Ø] the office staff simply added into the design class teach in the studio?
- 7 a. The worker [whom/ Ø] the small agency again hired during the huge party obeyed the owner in the store.
b. Where did the worker [whom/ Ø] the small agency again hired during the huge party obey the owner?
c. Whom did the worker [whom/ Ø] the small agency again hired during the huge party obey in the store?
- 8 a. The singer [whom/ Ø] the kind family also helped before the spring show chose the band at the cinema.
b. Where did the singer [whom/ Ø] the kind family also helped before the spring show choose the band?
c. Whom did the singer [whom/ Ø] the kind family also helped before the spring show choose at the cinema?
- 9 a. The mother [whom/ Ø] the little boys first called with the older phone chased the thief along the road.
b. Where did the mother [whom/ Ø] the little boys first called with the older

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- phone chase the thief?
- 10 c. Whom did the mother [whom/ Ø] the little boys first called with the older phone chase along the road?
- 10 a. The owner [whom/ Ø] the hair model almost passed before the fish dinner killed the driver behind the stage.
- 10 b. Where did the owner [whom/ Ø] the hair model almost passed before the fish dinner kill the driver?
- 10 c. Whom did the owner [whom/ Ø] the hair model almost passed before the fish dinner kill behind the stage?
- 11 a. The writer [whom/ Ø] the movie stars always asked about the next novel wanted the maid in the house.
- 11 b. Where did the writer [whom/ Ø] the movie stars always asked about the next novel want the maid?
- 11 c. Whom did the writer [whom/ Ø] the movie stars always asked about the next novel want in the house?
- 12 a. The scout [whom/ Ø] the Jewish player indeed knew since junior high school kicked the coach on the ground.
- 12 b. Where did the scout [whom/ Ø] the Jewish player indeed knew since junior high school kick the coach?
- 12 c. Whom did the scout [whom/ Ø] the Jewish player indeed knew since junior high school kick on the ground?
- 13 a. The child [whom/ Ø] the pretty girl once held during the golf game kissed the parent in the hall.
- 13 b. Where did the child [whom/ Ø] the pretty girl once held during the golf game kiss the parent?
- 13 c. Whom did the child [whom/ Ø] the pretty girl once held during the golf game kiss in the hall?
- 14 a. The chef [whom/ Ø] the former king often tested about the German food left the cook in the dorm.
- 14 b. Where did the chef [whom/ Ø] the former king often tested about the German food leave the cook?
- 14 c. Whom did the chef [whom/ Ø] the former king often tested about the German food leave in the dorm?
- 15 a. The critic [whom/ Ø] the debate teams easily beat during the game series walked the senior to the church.
- 15 b. Where did the critic [whom/ Ø] the debate teams easily beat during the game series walk the senior?
- 15 c. Whom did the critic [whom/ Ø] the debate teams easily beat during the game series walked to the church?
- 16 a. The doctor [whom/ Ø] the rich person fairly picked from the basic list cured the patient in the ICU.
- 16 b. Where did the doctor [whom/ Ø] the rich person fairly picked from the basic list cure the patient?
- 16 c. Whom did the doctor [whom/ Ø] the rich person fairly picked from the basic list cure in the ICU?
- 17 a. The guide [whom/ Ø] the poor guys always valued after the Europe tour

- faced the drunk in the park.
- 18 b. Where did the guide [whom/ Ø] the poor guys always valued after the Europe tour face the drunk?
c. Whom did the guide [whom/ Ø] the poor guys always valued after the Europe tour face in the park?
- 19 a. The actor [whom/ Ø] the funny wife really loved since the summer trip fired the tutor in the office.
b. Where did the actor [whom/ Ø] the funny wife really loved since the summer trip fire the tutor?
c. Whom did the actor [whom/ Ø] the funny wife really loved since the summer trip fire in the office?
- 20 a. The robber [whom/ Ø] the older leader first found before the public trial wrote the mayor in the prison.
b. Where did the robber [whom/ Ø] the older leader first found before the public trial write the mayor?
c. Whom did the robber [whom/ Ø] the older leader first found before the public trial write in the prison?
- 21 a. The victim [whom/ Ø] the secret agency nearly shot after the long fight caught the gang at the hotel.
b. Where did the victim [whom/ Ø] the secret agency nearly shot after the long fight catch the gang?
c. Whom did the victim [whom/ Ø] the secret agency nearly shot after the long fight catch at the hotel?
- 22 a. The baby [whom/ Ø] the older Father almost named after the famous player hated the child in the park.
b. Where did the baby [whom/ Ø] the older Father almost named after the famous player hate the child?
c. Whom did the baby [whom/ Ø] the older Father almost named after the famous player hate in the park?
- 23 a. The mayor [whom/ Ø] the fair voter later asked about the future plan used the decoy in the rally.
b. Where did the mayor [whom/ Ø] the fair voter later asked about the future plan use the decoy?
c. Whom did the mayor [whom/ Ø] the fair voter later asked about the future plan use in the rally?
- 24 a. The boys [whom/ Ø] the close couple almost saved from the murder trial took the runner to the clinic.
b. Where did the boys [whom/ Ø] the close couple almost saved from the murder trial take the runner?
c. Whom did the boys [whom/ Ø] the close couple almost saved from the murder trial take to the clinic?
- 25 a. The people [whom/ Ø] the mean king indeed ruled until the spring term defied the judge in the court.
b. Where did the people [whom/ Ø] the mean king indeed ruled until the spring term defy the judge?
c. Whom did the people [whom/ Ø] the mean king indeed ruled until the

spring term defy in the court?

References

- Baddeley, A. D. (1966) Short-term memory for word sequences as a function of acoustic, semantic, and formal similarity. *Quarterly Journal of Experimental Psychology* 18:362–365.
- Caplan, D. and G. Waters (1998) Verbal working memory and sentence comprehension. *Behavioral and brain Sciences* 22: 77-126.
- Chomsky, N. (1982) *Some concepts and consequences of the theory of government and binding*. Cambridge: MIT Press.
- Chomsky, N. (1986) *Barriers*. Cambridge: MIT Press.
- Chomsky, N. (1995) *The minimalist program*. Cambridge: MIT Press.
- Chomsky, N. (2005) Three factors in language design. *Linguistic Inquiry* 35: 1–22.
- Fodor, J. A. (1983) *Modularity of Mind: An essay on faculty psychology*. Cambridge: MIT Press.
- Frazier, L. & Fodor, J. D. (1978) The Sausage Machine: a new two-stage parsing model. *Cognition* 6:291–325.
- Gordon, P.C., R. Hendrick and W. H. Levine (2002) Memory load interference in syntactic processing. *Psychological Science* 13: 425–430
- Larkin, W. & Burns, D. (1977) Sentence comprehension and memory for embedded structure. *Memory and Cognition* 5:17–22.
- Lewis, R. L. (1996) Interference in short-term memory: The magical number two (or three) in sentence processing. *Journal of Psycholinguistic Research* 25(1): 93-115
- Lewis, R. L. and M. Nakayama (2002) Syntactic and positional similarity effects in the processing of Japanese embeddings. In M. Nakayama, editor, *Sentence Processing in East Asian Languages*. Stanford: CSLI Publications.
- Lewis, R. L. and S. Vasishth (2005) An activation-based theory of sentence processing as skilled memory retrieval. *Cognitive Science* 29:375–419
- Lewis, R. L., S. Vasishth and J. Van Dyke (2006) Computational principles of working memory in sentence comprehension. *Trends in Cognitive Science* 10: 447-454.
- Howes, A., R. L. Lewis, and A. H. Vera (2009). Rational adaptation under task and processing constraints: Implications for testing theories of cognition and action. *Psychological Review* 116(4): 717-751.
- Martin, R. (1993) Short-term memory and sentence processing: Evidence from neuropsychology. *Memory and Cognition* 21: 176-183.
- McElree, B. (2006). Accessing recent events. In B. H. Ross (ed.), *The psychology of learning and motivation*, Vol. 46. San Diego: Academic Press.
- McElree, B., S. Foraker & L. Dyer (2003) Memory structures that subserve sentence comprehension. *Journal of Memory and Language* 48: 67-91.
- Ming X., B. Dillon, & C. Phillips. (2009) Illusory licensing effects across dependency types: ERP evidence. *Brain & Language* 108: 40-55.
- Nakayama, M., S.-H. Lee, and R. L. Lewis (2005) Difficulty of processing Japanese and Korean center-embedding constructions. In M. Minami, H. Kobayashi, M.

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- Nakayama, and H. Shirai, editors, *Studies in Language Sciences* 4: 99-118. Tokyo: Kurosio Publishers.
- Van Dyke, J. A. (2007) Interference effects from grammatically unavailable constituents during sentence processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 33(2): 407-430.
- Van Dyke, J. A., & Lewis, R. L. (2003) Distinguishing effects of structure and decay on attachment and repair: A cue-based parsing account of recovery from misanalyzed ambiguities. *Journal of Memory and Language* 49: 285–316.
- Vasishth, S. and Lewis, R. L. (2006) Argument-head distance and processing complexity: Explaining both locality and antilocality effects. *Language* 82(4): 767-794.
- Vergnaud, J.-R. (1977) Personal letter to Howard Lasnik and Noam Chomsky. [Published in *Foundational Issues in Linguistic Theory*, ed. by R. Freidin, C. P. Otero and M. Vergnaud, 3-15, Cambridge: MIT Press, 2008]