

Linguistic Intuitions are the Result of Interactions Between Perceptual Processes and Linguistic Universals

LOUANN GERKEN

Columbia University

THOMAS G. BEVER

University of Rochester

We found a direct relationship between variation in informants' grammaticality intuitions about pronoun coreference and variation in the same informants' use of a clause segmentation strategy during sentence perception. It has been proposed that 'c-command', a structural principle defined in terms of constituent dominance relations, constrains within-sentence coreference between pronouns and noun antecedents. The relative height of the pronoun and the noun in the phrase structure hierarchy determines whether the c-command constraint blocks coreference: Coreference is allowed only when the complement structure containing the noun is attached higher than the pronoun. We collected informants' judgments on pronoun-noun coreference in which the noun antecedent was contained in a complement structure dominated by either the Sentence-node (S-node) (higher than the pronoun) or the Verb-phrase-node (VP-node) (not higher than the pronoun). We also assessed each informant's perceptual clause-closure tendency using an auditory word-monitor paradigm. Informants who strongly segmented clauses in the perceptual task did not differentiate between an S- and VP-attachment of sentence complements, as revealed in their coreference judgments, but rather appeared to attach all sentence complements to the S-node. Informants with relatively weak perceptual segmentation differentiated their coreference judgments according to the node attachment of the complement structure. These results indicate that the linguistic universal controlling within-sentence coreference applies to the *perceptually* available structure for a sequence, not to its pure linguistic structure. Hence, linguistic intuitions result from the interaction of three independent faculties: language-specific knowledge, perceptual processes, and linguistic universals.

INTRODUCTION

Intuitions about the grammaticality of sequences, abstracted away from natural contexts, are taken to reflect the speaker's knowledge of his language. Grammaticality intuitions have a privileged status as empirical linguistic data for several reasons: They are readily available without requiring

Correspondence and requests for reprints should be sent to LouAnn Gerken, Columbia University, Psychology Department, 406 Schermerhorn Hall, New York, NY 10027.

experimental or statistical manipulation and they represent the direct attempt of informants to introspect about their linguistic knowledge. Despite such advantages, it is clear that even the most carefully elicited grammaticality intuitions are subject to variability, in part because of the informant's sophistication (e.g., Gleitman & Gleitman, 1970), the linguistic context (e.g., Bever, 1970; Spencer, 1973), the multidimensional nature of sentence acceptability (e.g., Bever, 1975; Fillmore, 1979; Ross, 1979), and the behavioral situation in which they occur (Carroll, Bever, & Pollack, 1981).

The importance of this variability depends on the way grammaticality intuitions are assumed to reflect linguistic universals. We distinguish three models of how linguistic universals express themselves in intuitions. The first model is associated with generative grammar research between 1960 and 1975. On this model, linguistic universals are primarily embedded within the form of the language-specific rules (e.g., grammatical rules specific to English; Chomsky, 1957, 1965): a rule has a given form, or applies in a certain way because of the universal. Acceptability intuitions, on this view, reflect a universal only indirectly; a hypothetical universal, x , is confirmed via the following inferential chain:

- (1) "A" is an acceptable sentence
"B" is not an acceptable sentence
- (2) α is the required rule (because it generates A)
 β is the rejected rule (because it generates B)
- (3) α conforms to principle x
 β does not conform to principle x
- (4) Hence, x is confirmed as a universal principle

On this model, language-specific rules and universal principles appear in a "homogeneous" form, expressed only in the language-specific rule. The implication of this model for the behavioral nature of acceptability intuitions is depicted in Figure 1a. An informant has no way of isolating the linguistic universals from the rules or structures which they constrain; he or she can only report that the sentence either is or is not grammatical. For this reason, we will refer to this as the 'homogeneous grammatical model of intuitions'.

Current generative theory is modular, compared with the previous theory; universals are segregated primarily within formally separate subtheories (Chomsky, 1981). Language-specific rules generate structures to which universal principles separately apply. In this sense, the modular model conforms more directly to the goal of isolating linguistic universals.

The current linguistic model also has implications for the status of acceptability intuitions. A corresponding framework for how intuitions are formed is that informants assign each string a language-specific structure (e.g., a constituent structure generated by language-specific rules), and simultaneously apply linguistic universals to this structure (see Figure 1b); hence, in this model, both language-specific knowledge and knowledge of

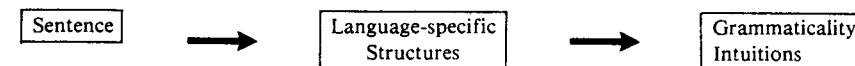


Figure 1a. The homogeneous model of linguistic intuitions

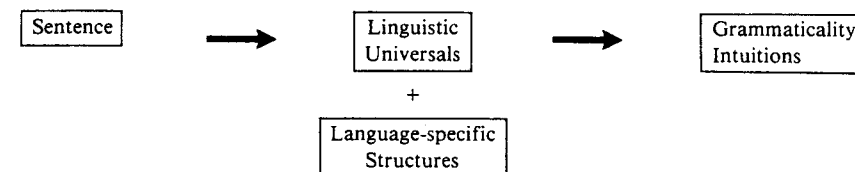


Figure 1b. The modular model of linguistic intuitions

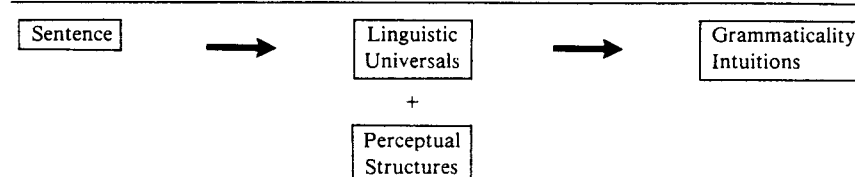


Figure 1c. The interactionist model of linguistic intuitions

linguistic universals are reflected in every grammaticality intuition. In order to isolate the universal from the language-specific structure, it is usually assumed that all speakers of a language apply the relevant universal constraint to the *same*, fully formed, grammatical structure. Because this model of intuitions distinguishes between linguistic universals and the language-specific structures to which they apply, we shall refer to it as the 'modular grammatical model of intuitions'.

Both of the preceding models assume that judging the grammaticality of a sentence requires the assignment of its fully formed grammatical structure. We shall contrast these two 'grammatical models' of intuitions with an 'interactionist model'. On the interactionist model of linguistic intuitions, linguistic universals are not applied to the sequence's grammatical structure, as in the grammatical models, but rather are applied to the informant's *perceived* structure for the sequence (see Figure 1c).

Listeners normally perceive a sentence to extract its meaning, not to assign it structure or assess its grammaticality. It is not clear that a complete grammatical structure is required to discover the meaning of a sentence: Accordingly, the structure rendered by the perceptual system is related to the complete grammatical structure for the sequence but may not be the same. In fact, there is no direct empirical evidence that, during ongoing comprehension, listeners assign sentences a complete linguistic structure of the kind assumed by the two grammatical models of intuitions. There is, however, experimental evidence that listeners impose a perceptually based constituent organization on a word string that locates and interrelates the major phrasal constituents and propositions (Aaronson, 1976; Abrams & Bever, 1969; Bever, 1970; Bever, Garrett, & Hurtig, 1973; Bever & Hurtig,

1975; Bever, Lackner, & Kirk, 1969; Caplan, 1972; Carroll & Bever, 1976; Fodor, Bever, & Katz, 1974; Forster & Olbrei, 1973; Garrett, Bever, & Fodor, 1966; Tanenhaus & Carroll, 1975; Townsend & Bever, 1978, 1982).

The different models of intuitions can make distinct empirical predictions. Individual listeners may use different strategies in perceiving a sequence (see Langendoen, Kalish-Landon, & Dore, 1973); It follows that they may arrive at individually unique perceptual structures for each sentence. The interactionist model of intuitions claims that linguistic universals are applied to *perceived* constituent structures; on this view, there could be a direct relationship between a listener's use of a particular perceptual strategy and the kinds of acceptability judgments he or she gives.

On both grammatical models of intuitions, conversely, there is no relationship between variation in perceptual strategies and grammaticality intuitions. On these models, informant variation in the use of perceptual strategies is a random performance factor, which does not systematically affect grammaticality intuitions. Neither grammatical model of intuitions predicts a correlation between an individual's perceptual style and his or her grammaticality intuitions. To compare the predictions of the grammatical and perceptual models, we performed an experiment in two parts. In the first part, we collected informants' coreference intuitions for pronouns with potential antecedents in sentence-final complements. In the second part, we tested the degree to which each informant employed the strategy of perceptually segregating clausal units from each other.

We chose to study coreference intuitions between pronouns and noun-phrases, because many recent developments in linguistic theory have depended on such intuitions (e.g., Bach & Partee, 1980; Bresnan, 1970; Chomsky, 1981; Culicover, 1976; Evans, 1980; Fiengo, 1979; Fiengo & Higginbotham, 1981; Higginbotham, 1980; Kayne, 1979; Kuno, 1972; Langacker, 1966; Lasnik, 1976; Postal, 1972; Reinhart, 1981; Rizzi, 1978; Ross, 1967; Wasow, 1972). According to many theories, pronoun coreference involves the application of a universal structural constraint to the phrase-structure configuration of sentences; this makes coreference intuitions a test of whether informants base their judgments on a linguistically defined phrase structure or a perceived structure. Our results show a systematic relationship between the strength of an informant's perceptual closure and his coreference intuitions: This fact suggests that, consistent with the interactionist model, informants use their perceived constituent structure as the basis for assessing coreference relations.

C-COMMAND AND COREFERENCE FROM SENTENTIAL COMPLEMENTS

The sentences we studied all had a pronoun and a noun in an initial clause, followed by a complement structure containing one noun. There were eight sentence types, defined by three orthogonal dimensions: the complement

TABLE 1
Sample Sentences from the Coreference Judgment Task

Linguistic Status				Sample Sentences
VP	cl	subj	(1)	*He told the dog that the horse would fall.
VP	cl	obj	(2)	*The dog told him that the horse would fall.
VP	phr	subj	(3)	*He hit the dog with the horse's stick.
VP	phr	obj	(4)	*The dog hit him with the horse's stick.
S	cl	subj	(5)	*He hit the dog while the horse ate lunch.
S	cl	obj	(6)	The dog hit him while the horse ate lunch.
S	phr	subj	(7)	*He hit the dog during the horse's lunch.
S	phr	obj	(8)	The dog hit him during the horse's lunch.

^a The three orthogonal dimensions defining linguistic status are complement attachment (VP or S), complement type (clause or phrase), and pronoun position (subject or object).

structure was either attached to the VP- or to the S-node; the complement itself was either a subordinate clause or a prepositional phrase; and the pronoun was either the subject or object of the main clause. (See Table 1. The content of the sentences involves animals, because the sentences were also used in a separate experiment with children; see Gerken, 1982.)

The general principle governing coreference is that any noun and pronoun can corefer (*pace* sex and number morphology) unless the constituent structure relationship between them blocks coreference. A recent formulation of this restriction is that a pronoun cannot c-command its antecedent ("A c-commands B, if the first branching node most immediately dominating A also dominates B"; Reinhart, 1981, p. 612). The pronoun position and complement attachment dimensions that define our sentences reflect structural properties which can block possible coreference relations. For example, a pronoun in subject position c-commands all other subsequent nouns, which rules out coreference with them (see Figure 2a). A noun in a complement structure attached to the VP-node is c-commanded by any main-clause pronoun, which again rules out coreference (see Figure 2b). Applying these restrictions to the materials in Table 1, the only possible coreference relation between a pronoun and a following noun is between a pronoun in object position and a following noun in an S-attached complement structure (examples [6] and [8] in Table 1; also see Figure 2c).¹

The claim that the object noun phrase is part of the verb phrase, whereas the subject noun phrase is dominated by S, is a standard part of most syntactic theories. The structural distinction between S- and VP-node attachment is less obvious, although it is motivated by a variety of facts. For example,

¹ The design of the materials is based on Solan (1978). The pronoun position and complement-attachment dimensions of our materials are well accepted in the literature as affecting coreference judgments vis-à-vis their interaction with c-command; we included the phrasal/clausal complement dimension because Solan suggests that coreference is more likely from complement clauses, which are subject to c-command, than from complement phrases, which are allegedly subject to the simpler principle of command (Ross, 1967).

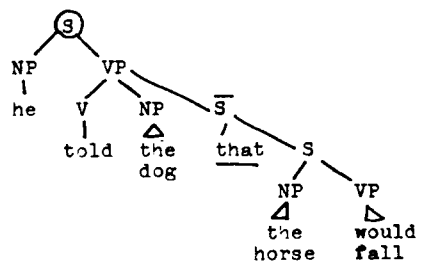


Figure 2a. (same as example 1 in Table 1) The pronoun 'he' c-commands all other nodes, because it is immediately dominated by the circled S-node which dominates all lower nodes, including the nodes in the underlined complement structure.

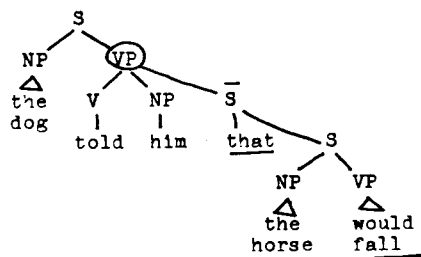


Figure 2b. (same as example 2 in Table 1) The pronoun 'him' c-commands all nodes in the underlined complement structure, because both are immediately dominated by the circled VP-node.

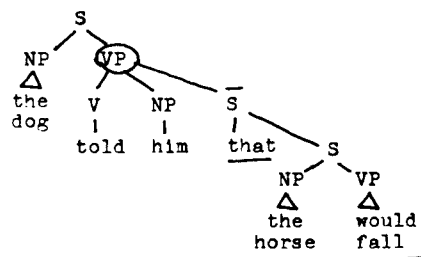


Figure 2c. (same as example 6 in Table 1) The pronoun 'him' does not c-command any of the nodes in the underlined complement structure, because the pronoun is dominated by the circled VP-node and the complement structure is not.

the ambiguity of sentences such as (9a) and (9b) requires that the complements ('exactly...hiding') and ('after...parade') be attached to either the S- or the VP-node of the main clause, each meaning corresponding to the (ii) and (iii) versions of (9a) and (9b).

- (9a)(i) Max pointed to Bill *exactly where Harry was hiding*.
 (9a)(ii) Max lost to bill *exactly where Harry was hiding*.
 (9a)(iii) Max intimidated to Bill *exactly where Harry was hiding*.

- (9b)(i) Max jogged *after the parade*.
 (9b)(ii) Max slept *after the parade*.
 (9b)(iii) Max chased *after the parade*.

The attachment distinction is also needed to explain the difference in acceptability of sentences whose complements are in topic position: This is possible only when the complement is S-attached. This explains the unacceptability of sentences (10a)(iii) and (10b)(iii) in which the fronted complement is related to a VP-attached element.

- (10a)(i) *Exactly where Harry was hiding*, Max pointed to Bill.
 (10a)(ii) *Exactly where Harry was hiding*, Max lost to Bill.
 (10a)(iii) **Exactly where Harry was hiding*, Max intimidated to Bill.

- (10b)(i) *After the parade*, Max jogged.
 (10b)(ii) *After the parade*, Max slept.
 (10b)(iii) **After the parade*, Max chased.

COREFERENCE JUDGMENTS BY NAIVE INFORMANTS

Our informants were 24 college-age native speakers of English without any training in linguistics. Subjects were given a booklet containing two tokens of the sentence types in Table 1 presented in random order, along with eight sentences having the pronoun in the complement sequence. (The latter were included to give subjects some examples of clearly acceptable cases of coreference in which the pronoun follows the noun.) For each sentence, the informants rated, on a 4-point scale, the potential acceptability of coreference between the pronoun and each of the two nouns separately. The informants were encouraged to distribute their responses over the entire 4-point range; they were also told that the pronoun 'he' was used to refer to all the animals, because the sentences were taken from a study with children (Gerken, 1982).

The informants rated the likelihood of coreference between the pronoun and the main-clause noun in each sentence to be uniformly low. In English, the relationship between a pronoun and noun that occupy subject and object positions in the same clause is reflexive; because the pronoun was not marked as reflexive, informants rated coreference to be unlikely. We do not consider these ratings further because of their lack of variability by subject and by sentence. (Also, 1 subject was dropped from further analysis, because he showed no variability in his ratings.)

When judging the possibility of coreference between the pronoun and the noun in the complement, the informants gave higher coreference ratings for those sentences with pronouns in object position (the even-numbered examples in Table 1) than in subject position ($p < .001$ on a Wilcoxon matched-pairs, signed-ranks test by informant; $p < .005$ on a Fisher exact test by sentence with 8 tokens in each group). This was numerically true both for

constructions in which the object-pronoun version is taken to be grammatical in the linguistic literature (examples 6 and 8 in Table 1) and the ostensibly ungrammatical constructions (examples 2 and 4. The mean ratings for each of the eight sentence types are in Table 2.).²

The by-informant analysis showed that subjects gave consistently higher coreference ratings to sentences with phrasal complements than with clausal complements ($p < .001$ on a Wilcoxon matched-pairs, signed-ranks test). However, the by-materials analysis showed no significant difference on this dimension. Further analysis of the data indicated why the phrase/clause difference was so significant by informant but not by materials: Only when the complement structure was VP-attached did subjects give sentences with clausal complements (examples 1 and 2 in Table 1) lower coreference ratings than sentences with phrasal complements (examples 3 and 4 in Table 1): ($p < .001$ on Wilcoxon matched-pairs, signed-ranks test by informant; $p < .025$ on Fisher exact by item with four tokens in each group). The effect of the phrase/clause distinction on coreference has been found in children by other researchers (Gerken, 1982; Solan, 1978). This distinction is not motivated by any particular current linguistic theory; we will explain it below.

Surprisingly, the informants did not produce lower average coreference ratings for VP-attached structures than for S-attached structures. That is, the intuitions of our subjects fail to confirm certain coreference distinctions that have been taken for granted in the linguistics literature (e.g., Langacker, 1966; Lasnik, 1976; Reinhart, 1981; Ross, 1967).

The sensitivity of our informants to several structural dimensions of our materials shows that their coreference judgments had a systematic basis. However, several aspects of these results are not consistent with either grammatical model of intuitions. There is no basis in grammatical structure for the strong difference between phrasal and clausal VP-attached complements. Most important, there is no grammatical explanation for the failure of the S-/VP- node distinction to affect average coreference judgments.

On the modular theory of linguistic intuitions, there are at least two explanations why our informants' intuitions did not support the c-command constraint: Either the universal itself is incorrectly formulated, or the language-specific structure to which the constraint applies is not the one assumed by linguistic theory. Consider first the possibility that the S-/VP-attachment distinction is incorrect for English complements. We have already given a few of the kind of examples that motivate the distinction (9 and 10). It ap-

² Note that even sentence-types (6) and (8) did not receive a within-sentence rating of 4, despite the fact that we (and all discussants) claim that within-sentence coreference is fully acceptable in them. This result is not a problem for the present research, because we are concerned only with relative within-sentence coreference across subjects. Every nonreflexive pronoun *can* have sentence-external reference: Apparently, our subjects always kept this possibility in mind.

TABLE 2
Mean Coreference Ratings (out of a possible 4) for Each Sentence Type

Type	Mean Rating
(1)	1.39
(2)	1.76
(3)	2.00
(4)	2.48
(5)	1.48
(6)	2.20
(7)	1.70
(8)	2.57

pears we would lose more than we would gain if we gave up the distinction to explain our informants' insensitivity to it.

The alternative move for modular theory is to give up c-command as the correct sort of universal principle involved in coreference. This would be a major change, given the variety of phenomena in which c-command (or something like it) plays a role. It would also leave us to find some other principle to account for the cases that c-command accounts for. Before giving up c-command, we consider an explanation of our coreference data based on the interactionist theory of intuitions.³

PERCEPTUAL PROCESS INVOLVED IN COREFERENCE INTUITIONS

We assume that c-command is the linguistic universal that constrains coreference in the kinds of cases we are studying; on the interactionist model of intuitions, c-command applies to the *perceived* constituent structure of a sentence. The interactionist theory of coreference intuitions must then explain why a S-/VP- attachment distinction was not perceived by at least some of our informants. The interactionist theory must also explain why the

³ Reinhart (1983) contends that many of the cases of coreference previously thought to be constrained by c-command (Reinhart, 1981) are actually constrained by discourse principles; the sentences we used for coreference judgments are among these cases. Our finding that individual differences in perceptual segmentation covary with coreference intuitions still demonstrates that informants apply some coreference constraining rule to the perceived constituent structure for that sentence. Furthermore, all informants' coreference intuitions indicated sensitivity to the pronoun-position dimension of our sentences; some informants' (the low segmenters; see below) intuitions were sensitive to complement attachment. That is, two constituent structure dimensions that appear to have determined at least some of our subjects coreference judgments were predicted from the c-command constraint. Hence, if a discourse rule is what actually constrains coreference in our sentences, these two dimensions and something like c-command appear to be represented in the discourse rule as well.

subject/object distinction is perceived, and why a phrase/clause distinction emerges for VP-attached complements.

Consider first the efficacy of the subject/object distinction in perception. The goal of the listener is normally to assign a meaning to a linguistic sequence. Certain structural features are crucially important to the organization of meaning, and consequently are relatively salient during sentence perception. These include the isolation of major phrases that correspond to the predicates and arguments of a proposition (Bever et al., 1973). The organization of phrases into propositional predicates and arguments typically isolates the sentential subject from the verb phrase: The sentential object is then perceived as a subcomponent of the verb phrase.⁴ In this way, the perceptual system creates a hierarchical distinction between subject and object. Accordingly, our informants were able to apply the c-command constraint to this perceived hierarchy so that it blocks coreference to a pronoun in subject position but allows coreference to pronouns in object position.

There is no evidence that the perceptual system creates a structural distinction between S-node and VP-node complement attachment. In English, there are no order or morphological cues for the level of attachment: Except for those cases in which verb subcategorization requires that a sentential complement be an argument of the verb, the only cues for the node of complement attachment are indirect (see examples 9 and 10). Furthermore, the attachment distinction plays no direct role when the main verb and its arguments are perceptually organized into a proposition. The use of such a perceptual organization that makes no commitment to a particular attachment would explain our informants' apparent insensitivity to this distinction. The ultimate meaning of the complement is independently determined by its interaction with the meaning of the verb.

The emergence of a phrase/clause distinction among VP complements is also explained by the listener's perceptual organization of the sentence into a verb and its arguments. The subcategorization of the verbs we used with VP-attached clausal complements (examples 1 and 2 in Table 1) requires that the clausal complement be the direct object of the verb: Hence it must be dominated by VP, allowing c-command to block coreference in these cases. In none of the other sentence types is there a direct cue as to the sentential complement's relation to the main clause. Thus the apparent phrase/clause distinction can actually be interpreted as due to a S-/VP- attachment distinction that subjects perceive on the basis of verb structure: Only when verb subcategorization information indicated the sentential complement's

⁴ Levelt (1970) demonstrated that subjects' relatedness intuitions between lexical items motivate the inclusion of the object noun phrase in the predicate. Martin (1970) demonstrated that this was true primarily when the object phrase was short, which was characteristic of all our materials.

role in the main propositional structure were informants apparently sensitive to complement attachment.⁵

INDIVIDUAL DIFFERENCES IN PROPOSITIONAL CLOSURE

The preceding discussion outlines the interactionist explanation of the coreference data. This explanation assumes that informants need only have available those parts of a complete constituent structure representation of a sequence that are vital to comprehension. This leaves open the possibility that there is informant variability in the way in which the perceived constituent structure is developed, especially aspects of the structure that are not uniquely required for comprehension of a particular sentence. We tested our informants for the extent to which each used a basic propositional segmentation strategy, establishing perceptual closure around a noun-verb-noun (NVN) sequence that corresponds to the propositional grouping 'agent-action-object'. We found that informants who strongly use such a grouping strategy do not show a S-/VP- node distinction in their coreference judgments and treat all complements as though they were S-attached; the other informants, who do not segment propositions as strongly, respect the S/VP distinction.

To test each informant's dependence on the propositional-segmentation strategy, we had him participate in a word-monitor experiment which assessed his relative degree of perceptual closure after a proposition. Informants were given a target word (e.g., 'steak') to listen for which was either the last word of the initial clause (as in [11a] and [b]), or the first word of a second clause (as in [12a] and [b]) of a sentence. The sentences had either an initial noun subject (e.g., 'Sue') or an initial pronoun subject (e.g., 'she'). (The materials were derived from Garrett et al., 1966; this particular method follows that of Marslen-Wilson, Tyler, & Seidenberg, 1978.)

- (11a) When Sue cooks *steak*, she also cooks French fries.
- (11b) When she cooks *steak*, Sue also cooks French fries.
- (12a) When Sue cooks, *steak* is what she makes.
- (12b) When she cooks, *steak* is what Sue makes.

The sentences were spoken with a subdued, but acceptable intonation so that an informant could distinguish the two structural roles for the critical

⁵ The data did not show that the S/VP distinction is significant for clausal complements, but did show a trend in that direction. If this difference were true, but obscured by random factors in our study, it would offer a separate explanation for the low coreference judgments out of VP-attached clauses: The node of clausal-complement attachment is easier to distinguish than that of phrasal-complement attachment. This seems to us to be true. However, even if true, it would be consistent with our explanation of individual differences and with our overall argument that intuitions emerge as an interaction of universals and the perceptual representation of linguistic objects.

word. Previous research (Marslen-Wilson et al., 1978) has reported that listeners respond faster when the target word is perceived as ending the initial clause than when it is perceived as beginning the second. Because all of the verbs used in the first clause could either take an object or not, we interpret an informant's relatively faster responses to first-clause targets as an expectation of the final noun in the initial propositional structure.

This method of assessing perceptual closure around a proposition-bearing clause is neutral between several current theories of speech perception which emphasize the importance and perceptual coherence of the proposition during listening. On the *propositional-processing* view, the listener deploys language-specific canonical schemata that isolate and interrelate the predicate and arguments of a proposition (for reviews, see Bever, 1970; Bever, 1975; Carrithers & Bever, 1984; Slobin & Bever, 1982; Townsend & Bever, 1982): In English, a powerful schema is 'NVN corresponds to actor-action-object'. On this theory, a listener's relative speed in monitoring intonationally cued clause-final nouns (as in [11a] and [b]) indicates application of this schema. This schema facilitates on-line recognition that the critical noun is about to occur as the schema's completion.

On the *on-line interactive* model, listeners actively integrate each word at all levels of representation, as it is heard (Marslen-Wilson & Tyler, 1975; Marslen-Wilson et al., 1978; Tyler & Marslen-Wilson, 1984). This view lends a similar interpretation to the relative speed in monitoring clause-final words: The listener can predict on-line that the noun monitor will fit as the intonationally cued object of the current proposition.

Finally, on the *lexicalist* model, listeners use verb frames to predict and assign argument functions to noun phrases and complements (Fodor et al., 1974; Ford, Bresnan, & Kaplan, 1983; Carlson & Tanenhaus, in press). On this model, the lexical representation of the verb signals that a final argument of a proposition could potentially follow. Hence, a listener's relative speed on clause-final nouns reflects closure around the proposition.

THE RELATIONSHIP BETWEEN SEGMENTATION AND COREFERENCE

Sentences with both nouns and pronouns elicited slower responses to second-clause (nouns: 460 ms, pronouns: 455 ms) than to first-clause (nouns: 369 ms, pronouns: 398 ms) targets.⁶ To assess the degree to which each sub-

⁶ The perceptual segmentation effect was strongly significant in the noun-subject cases ($p < .001$ on a sign test by informant; $p < .02$ on a sign test by sentence with 12 tokens in each group), but only a trend in the pronoun-subject cases ($p < .10$ on a sign test by informant; $p < .19$ on a sign test by sentence with 12 tokens in each group). The difference in segmentation strength between sentences with noun and pronoun subjects replicates previous research (Carroll, 1978; Marslen-Wilson et al., 1978); segmentation is relatively weak with subject pronouns, perhaps because they are less complete propositions.

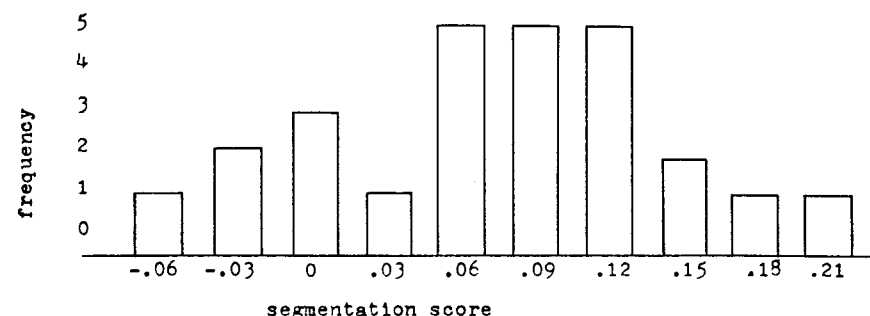


Figure 3. Distribution of normalized segmentation scores

ject segmented propositional units from each other, we computed a normalized 'segmentation score' for each informant. We divided each informant's mean difference in the noun- and pronoun-subject examples by the mean of his (subjects were all male) reaction times to all target words.⁷

The distribution of the normalized segmentation scores was bimodal (see Figure 3). For purposes of comparison we divided the informants into two groups, 'high segmenters' ($N = 17$) and 'low segmenters' ($N = 6$) around the two modes. We then used correlations and group comparisons to assess the relation of segmentation score to the three dimensions that defined the sentences in the coreference intuitions part of our experiment.⁸

According to the interactionist model of intuitions, high and low segmenters may have different coreference intuitions about sentences on the complement attachment dimension, because the two groups of informants have available different perceived constituent structures for these sentences. When c-command is applied to the different perceptual structures, correspondingly different intuitions about the coreference relations in the sequence result. In particular, we can expect that informants who show strong clausal segmentation may not differentiate S- and VP-attached complements in their coreference judgments: They should tend to treat all complements as S-attached, because their strong perceptual closure around the main NVN unit makes the VP-node unavailable for complement attachment.

The results confirm the interactionist model's prediction that individual variation in perceptual segmentation strength is related to variation in co-

⁷ The formula for each subject's normalized segmentation score was:

$$\frac{(\Sigma r.t., \text{ 2nd-clause targets}) - (\Sigma r.t., \text{ 1st-clause targets})}{(\Sigma \text{ all targets})}$$

⁸ We also correlated informants' segmentation scores against their scores on the verbal measure of the Scholastic Aptitude Test to test whether general verbal ability could explain our results. The correlation was not meaningful ($r = -.05$; $p > .25$), nor was there a large numerical difference between the SAT scores of the high and low segmenters; the means were 648 and 618, respectively.

TABLE 3
High and Low Segmenters' Mean Coreference Ratings on the Complement-Attachment Dimension

	High Segmenters	Low Segmenters	High-Low
VP-attached complements	1.99	1.67	0.32
S-attached complements	1.97	2.02	-.05
Difference	0.02	0.35	0.37

reference judgments. The correlation between informants' degree of sensitivity to the S/VP distinction and their segmentation scores was significant ($r = -.37$ $p < .05$, $df = 21$). There was also a significant difference when comparing the groups of high and low segmenters on this dimension ($p < .05$ on a Fisher exact, two-tailed, by informant; $p < .005$ on a Fisher exact, two-tailed, by sentence). As further predicted, the difference between high and low segmenters is almost exclusively due to the lower ratings that low segmenters gave to VP-attached structures (See Table 3; $p < .035$ on a sign test comparing high and low segmenters on their ratings for VP-attached complement sentences with eight tokens; the same measure was not significant for S-attached complement sentences). That is, high segmenters do not use the S/VP distinction in coreference intuitions, whereas low segmenters do.

How do the perceptual structures of high and low segmenters differ? As we discussed above, high segmenters are listeners who strongly segregate NVN propositional units. Because they perceive the NVN proposition as a closed unit, they do not allow other units to be attached within it. The VP-node is within the NVN unit, thus it is not perceptually available to dominate the complement. Consequently, high segmenters perceive all complement structures as though they were attached to the S-node.

Low segmenters, conversely, do not segregate the NVN unit so strongly, and thus do not perceive complements as always attached to the S-node. Because we were testing only for informants' use of the segmentation strategy, we do not know what strategy the low segmenters use to assign a perceptual structure to a sentence, but clearly their perceptual structures distinguish between sentences with S- and VP-attached complements. This distinction is reflected in the lower coreference ratings they give to sentences with VP-attached complements.

Finally, there was no relationship between segmentation score and the phrasal/clausal complement dimension of the coreference intuitions part of the experiment. Above, we interpreted the apparent phrase/clause difference actually to be a difference between those sentences in which verb subcategorization determined complement attachment to the VP as a direct object and those sentences where it did not. The fact that there was no relationship be-

tween the phrase/clause dimension and segmentation score indicates that all subjects used verb subcategorization information (when relevant) to assign the object of the main-clause verb.⁹

THE STATUS OF GRAMMATICAL STRUCTURE IN PERCEPTION

The interactionist model of linguistic intuitions does not necessarily deny the psychological role of complete grammatical structures in comprehension. The fact that we found a direct relationship between an informant's use of a particular perceptual strategy and his intuitions about pronoun coreference could support one of two positions on the topic. On a strong behavioral interpretation, listeners may assign only a perceptual structure to a sequence, so the complete constituent structure proposed by the two grammatical models of intuitions is irrelevant to comprehension.¹⁰

This interpretation requires an explanation of how a complete and correct linguistic structure is ever assigned to a sentence. It is intuitively clear that listeners can determine the meaning of a sentence from an incomplete syntactic analysis. This is clearest when listening to comprehensible but ungrammatical sentences: for example, 'Me Tarzan, you Jane'. Hence, a mechanism is always available to assign a linguistic structure to a sentence *once it has been understood*. Accordingly, at least some of the time, listening may occur in two stages: In the first stage, a partial linguistic analysis is the basis for semantic interpretation. In the second stage, a full linguistic analysis is synthesized back from the semantic to the syntactic form (Abrams & Bever, 1969; Bever et al., 1973). That is, listeners may reconstruct a complete constituent structure only after isolating the major phrases and comprehending their semantic relations.¹¹

⁹ Although there was a significant correlation between segmentation score and the rating difference given to sentences with pronouns in subject versus object positions ($r = -.39$, $p < .05$, $df = 21$), there was not a significant difference on this dimension when comparing the two separate groups of high and low segmenters. Because there was such a strong overall difference on the pronoun-position dimension, the failure to find a significant difference between groups may reflect a ceiling effect on the ratings. The positive correlation suggests that whatever strategy the low segmenters were using, it decreased the strength of the subject/object distinction for them in comparison to the high segmenters.

¹⁰ The view that assigning an incomplete constituent structure to a sentence is consistent with understanding the sentence's meaning is supported by recent work on a parser that assigns a meaning from an incomplete surface phrase structure (Church, 1980; Hindle, 1983; Marcus, Hindle, & Fleck, 1983). It contradicts any perceptual theory that presupposes the necessary formation of a specific and complete surface-phrase structure as an early stage in comprehension (e.g., Clifton & Frazier, in press; Frazier & Fodor, 1978).

¹¹ Support for the two-stage model comes from Bever (1970) in which certain minor aspects of surface-constituent structure affected subjects' click-location reports, only if the subjects waited 10 s before reporting: further support that the assignment of incomplete constituent structures is consistent with comprehending the sentence.

Alternatively, the listener may in fact assign a full constituent structure to the incoming sequence but be unable to access it for certain tasks. On this view, the complete grammatical structure remains an unconscious by-product of sentence perception. The only structures available for further processing are those reported out by the perceptual system. This view of the grammatical structure opens up the interesting possibility that sophisticated informants (including linguists) have developed still other strategies to extract as much information as possible from the normally unconscious grammatical structure (see Gleitman & Gleitman, 1970). It also may help us to understand how low segmenters differentiate between S- and VP-attached complement structures. The differentiation might already be made in the complete grammatical structure that they unconsciously assign. Because their perceptual strategy for meaning-extraction does not obscure this distinction, it allows c-command to block coreference in the VP-attached cases.

CONCLUSION—THE INTERACTIONIST BASIS OF COREFERENCE INTUITIONS

This research is an example of how the distinction between intuitions about individual sentences and the application of universal linguistic principles can become an empirical problem, possibly a solvable one. We have demonstrated that if one assumes that rendering acceptability intuitions involves the interaction of different linguistic and cognitive systems, one can account for a variety of facts with a consistent theory. In particular, we propose that the c-command constraint on coreference (or something like it) is correct: it applies, however, to the output of the perceptual system, not to the grammatical structure itself. That is, our results confirm the c-command constraint, independently of the structure to which it applies.

The distinction between a universal principle like c-command and the structure it applies to is common in explanations of language-acquisition patterns (e.g., Goodluck, 1978; Hsu, 1981; Matthei, 1981; Phinney, 1981; Solan & Roeper, 1978; Tavakolian, 1978). For example, Tavakolian (1977) proposed that all children go through a stage of treating final complements as S-attached. Our study shows that such variability in perceived structure exists among adults as well.

IMPLICATIONS FOR MODULAR LINGUISTIC THEORY

Each approach to linguistic theory of the last few decades has made specific assumptions about the role of sentence acceptability intuitions. The taxonomic linguists attempted to restrict their dependence on intuitions to judgments about meaning-free minimal contrasts, a technique which seemed at least defensible for the study of phonology. Harris (1954) elaborated this

notion into "eliciting situations," in order to rationalize with the taxonomic program his use of structural intuitions about sentences: He utilized acceptability intuitions quite freely, but was careful to argue that such intuitions could, in principle, ultimately be reproduced via operationally impeccable methods (see Katz & Bever, 1975, for a discussion). Chomsky (1957) argued that intuitions are a reflection of linguistic knowledge which provide data directly relevant to linguistic theory, itself about linguistic knowledge; hence, no operationalist rationalization is needed to justify the use of acceptability intuitions about sentences. A grammar is justified by its success in accounting for all and only the sentences deemed acceptable by native speakers of a language. The distinction between competence and performance explained cases in which systematic variation in acceptability intuitions did not correspond to variations in presumed grammatical structure. Linguistic universals were to emerge inferentially on the homogeneous model as a result of demonstrating that they are required for the description of distinct languages. Psycholinguistic research, corresponding to the homogeneous linguistic theory, had a corresponding role: Insofar as a particular grammar was shown to be behaviorally relevant, the psychological validity of the linguistic universals underlying that grammar was confirmed.

The goal of current, modular, linguistic theory has shifted: The emphasis now is on the discovery of linguistic universals. It is not the goal to describe a 'language' (e.g., 'English'); rather it is to provide an analysis of linguistic data such as acceptability intuitions, which elucidates the universals of the grammars of languages (Chomsky, 1981). A particularly relevant shift is the new emphasis on distinguishing levels of representation from well-formedness constraints that apply to each structural level, such as those sensitive to c-command.

One by-product of our research bears on the psychological validity of the current modular form of grammar (Chomsky, 1981), as compared with the earlier, homogeneous grammatical model. Homogeneous grammatical theory, taken as a psychological model of an adult's linguistic knowledge, does not afford an isolation of universals; current modular grammatical theory hypothesizes such a segregation as a specific property of the structure of what an adult knows. The entire interactionist explanation of our data presupposes that informants have separate access to language-specific structures, on the one hand, and linguistic universals, on the other. Our research shows that an informant can separately access the distinct components of his or her knowledge. Accordingly, our results lend support to a modular representation of grammatical knowledge with psychologically distinct components.

Our major aim has been to clarify the role of adult acceptability intuitions as an empirical foundation for linguistic research. The traditional position in generative grammar has been that by confirming a particular

grammar, acceptability intuitions indirectly confirm universal grammatical principles. We have shown that such principles can also be directly confirmed as part of the explanation of variations in acceptability judgments between informants. Our research serves as a case study in how psycholinguistic research can interact with current linguistic theory: to explore the direct role of linguistic universals in language behavior.

REFERENCES

- Aaronson, D. (1976). Performance theories for sentence coding: Some qualitative observations. *Journal of Experimental Psychology: Human Perception and Performance*, 2, 42-55.
- Abrams, K., & Bever, T.G. (1969). Syntactic structure modifies attention during speech perception and recognition. *Quarterly Journal of Experimental Psychology*, 21, 280-290.
- Bach, E., & Partee, B. (1980). Anaphora and semantic structure. In K.J. Kreiman & A.E. Oteda (Eds.), *Papers from the parasession on pronouns and anaphora*. Chicago, IL: Chicago Linguistic Society.
- Bever, T.G. (1970). A cognitive basis for linguistic universals. In R. Hayes (Ed.), *Cognition and the development of language*. New York: Wiley.
- Bever, T.G. (1975). *Functional explanations presuppose independently motivated theories of behavior*. Chicago: Chicago Linguistic Society.
- Bever, T.G., Garrett, M., & Hurtig, R. (1973). The interaction of perceptual processes and ambiguous sentences. *Memory and Cognition*, 1, 277-286.
- Bever, T.G., & Hurtig, R. (1975). Detection of a nonlinguistic stimulus is poorest at the end of a clause. *Journal of Psycholinguistic Research*, 4, 1-7.
- Bever, T.G., Lackner, J., & Kirk, R. (1969). The underlying structure of sentences are the primary units of immediate speech processing. *Perception and Psychophysics*, 5, 225-234.
- Bresnan, J. (1970). An argument against pronominalization. *Linguistic Inquiry*, 1, 122-124.
- Caplan, D. (1972). Clause boundaries and recognition latencies for words in sentences. *Perception and Psychophysics*, 12, 73-76.
- Carlson, G., & Tanenhaus, M.K. (in press). Thematic roles in parsing. In W. Wilkins (Ed.), *Syntax and semantics 14*. New York: Academic.
- Carrithers, C., & Bever, T.G. (1984). Eye-movements confirm theories of language comprehension. *Cognitive Science*, 8, 157-172.
- Carroll, J.M. (1978). Sentence perception units and levels of syntactic structure. *Perception and Psychophysics*, 23, 506-514.
- Carroll, J.M., & Bever, T.G. (1976). Sentence comprehension: A case study in the relation of knowledge and perception. In E. Carterette and J. Friedman (Eds.), *The handbook of perception: Vol. 7. Language and speech*. New York: Academic.
- Carroll, J.M., Bever, T.G., & Pollack, C.R. (1981). The non-uniqueness of linguistic intuitions. *Language*, 57, 368-383.
- Chomsky, N. (1957). *Syntactic structures*. The Hague: Mouton.
- Chomsky, N. (1965). *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.
- Chomsky, N. (1981). *Lectures on Government and Binding*. Cambridge, MA: MIT Press.
- Church, D. (1980). *On memory limitations in natural language processing*. (LSC-TR245). Cambridge: Massachusetts Institute of Technology.
- Clifton, C., & Frazier, L. (in press). Processing long distance dependencies. In G. Carlson and M.T. Tanenhaus (Eds.), *Linguistic structure in language processing*. New York: Rydel.
- Culicover, P.W. (1976). A constraint on coreferentiality. *Foundations of Language*, 14, 109-118.
- Evans, G. (1980). Pronouns, quantifiers, and relative clauses. *Canadian Journal of Philosophy*, 7, 467-536.
- Fiengo, R. (1979). *Surface structure: The interface of autonomous components*. Mimeographed, Queens College-CUNY.
- Fiengo, R., Higginbotham, J. (1981). Opacity in NP. *Linguistic Analysis*, 7, 395-421.
- Fillmore, C.J. (1979). In C.J. Fillmore, D. Kempler, & W.S.Y. Wang (Eds.), *Individual differences in language ability and language behavior*. New York: Academic.
- Fodor, J.A., Bever, T.G., & Katz, J.J. (1974). *The psychology of language*. New York: McGraw-Hill.
- Frazier, L., & Fodor, J.D. (1978). The sausage machine. *Cognition*, 6, 291-325.
- Ford, M., Bresnan, J., & Kaplan, R. (1983). A competence-based theory of syntactic closure. In J. Bresnan (Ed.), *The mental representation of grammatical relations*. Cambridge, MA: MIT Press.
- Forster, K., & Olbrei, I. (1973). Semantic heuristics and syntactic analysis. *Cognition*, 2, 319-347.
- Garrett, M., Bever, T.G., & Fodor, J.A. (1966). The active use of grammar in speech perception. *Perception and Psychophysics*, 1, 30-32.
- Gerken, L.A. (1982). *The effect of clause segmentation on coreference interpretations in children*. Unpublished master's thesis, Columbia University, New York.
- Gleitman, L., & Gleitman, H. (1970). *Phrase and paraphrase: Some innovative uses of language*. New York: Norton.
- Goodluck, H. (1978). *Linguistic principles in children's grammar of complement interpretation*. Unpublished doctoral dissertation, University of Massachusetts, Amherst.
- Harris, Z. (1954). Distributional structure. *Word*, 10, 146-162.
- Higginbotham, J. (1980). Pronouns and bound variables. *Linguistic Inquiry*, 11, 679-708.
- Hindle, D. (1983). Deterministic parsing of syntactic fluencies. *Proceedings of the 21st Meeting of the Association for Computational Linguistics* pp. 123-128.
- Hsu, J. (1981). The development of structural principles related to complement subject interpretation. Unpublished doctoral dissertation, City University of New York.
- Katz, J.J., & Bever, T.G., (1975). The fall and rise of empiricism. In T.G. Bever, J.J. Katz, & T.D. Langendoen (Eds.), *An integrated theory of linguistic ability*. New York: Crowell.
- Kayne, R. (1979). *Binding, quantifiers, clitics, and control*. Mimeographed. Université de Paris VIII.
- Kuno, S. (1972). Pronominalization, reflexivation, and direct discourse. *Linguistic Inquiry*, 3, 161-195.
- Langacker, R. (1966). On pronominalization and the chain of command. In W. Reibel and S. Schane (Eds.), *Modern Studies in English*. Englewood Cliffs, NJ: Prentice Hall.
- Langendoen, D.T., Kalish-Landon, N., & Dore, J. (1973). Dative questions: A study in the relation of acceptability to grammaticality of an English sentence type. *Cognition*, 2, 451-478.
- Lasnik, H. (1976). Remarks on coreference. *Linguistic Analysis*, 2, 1-22.
- Levelt, W.J. (1970). A scaling approach to the study of syntactic relations. In G.B. Flores d'Arcais & W.J. Levelt (Eds.), *Advances in psycholinguistics*. Amsterdam: North-Holland.
- Marcus, M., Hindle, D., & Fleck, M. (1983). D-theory: Talking about talking about talking trees. *Proceedings of the 21st Meeting of the Association for Computational Linguistics*, 129-136.
- Marslen-Wilson, W., & Tyler, L.K. (1975). The processing structure of sentence perception. *Nature*, 257, 784-786.
- Marslen, Wilson, W., Tyler, L.K., & Seidenberg, M. (1975). Sentence processing and the clause boundary. In W.J.M. Levelt & Flores d'Arcais (Eds.), *Studies in the perception of language*. New York: Wiley.
- Martin, E. (1970). Toward an analysis of subjective phrase structure. *Psychological Bulletin*, 74, 153-166.
- Matthei, E. (1981). Children's interpretations of sentences containing reciprocals. In S. Tavakolian (Ed.), *Language acquisition and linguistic theory*. Cambridge, MA: MIT Press.

- Phinney, M. (1981). Children's interpretation of negation in complex sentences. In S. Tavakolian (Ed.), *Language acquisition and linguistic theory*. Cambridge, MA: MIT Press.
- Postal, P. (1972). A global constraint on pronominalization. *Linguistic Inquiry*, 3, 35-60.
- Reinhart, T. (1981). Definite NP anaphora and command domains. *Linguistic Inquiry*, 12, 605-635.
- Reinhart, T. (1983). *Anaphora and semantic interpretation*. Holland: Croon Helm.
- Rizzi, L. (1978). Violation of the wh-island constraint in the subjacency condition. In C. Dubisson, D. Lightfoot, & Y.C. Morin (Eds.), *Montreal working papers in linguistics*, 11. Montreal: McGill University.
- Ross, J. (1967). *Constraints on variables in syntax*. Unpublished doctoral dissertation, Massachusetts Institute of Technology, Cambridge.
- Ross, J. (1979). Where's English. In C.J. Fillmore, D. Kempler, & W.S.Y. Wang (Eds.), *Individual differences in language ability and language behavior*. New York: Academic.
- Slobin, D.I., & Bever, T.G. (1982). Children use canonical sentence schemas: A crosslinguistic study of word order. *Cognition*, 12, 229-265.
- Solan, L. (1978). *Anaphora in child language*. Unpublished doctoral dissertation, University of Massachusetts, Amherst.
- Solan, L., & Roeper, T. (1978). Children's use of syntactic structure in interpreting relative clauses. In H. Goodluck & L. Solan (Eds.), *Papers in the structure and development of child language*. Amherst: University of Massachusetts.
- Spencer, N.J. (1973). Differences between linguists and nonlinguists in intuitions of grammaticality-acceptability. *Journal of Psycholinguistic Research*, 2, 83-98.
- Tanenhaus, M.K., & Carroll, J.M. (1975). The clausal processing hierarchy and nouniness. In R. Grossman, J. San, & T. Vance (Eds.), *Papers from the parasession on functionalism*. Chicago: Chicago Linguistics Society.
- Tavakolian, S. (1977). Structural principles in the acquisition of complex sentences. Unpublished doctoral dissertation, Amherst: University of Massachusetts.
- Tavakolian, S. (1978). Children's comprehension of pronominal subjects and missing subjects in complicated sentences. In H. Goodluck & L. Solan (Eds.), *Papers in the structure and development of child language*. Amherst: University of Massachusetts.
- Townsend, D.J., & Bever, T.G. (1978). Interclause relations and clausal processing. *Journal of Verbal Learning and Verbal Behavior*, 17, 509-521.
- Townsend, D.J., & Bever, T.G. (1982). Natural units of representation interact during sentence comprehension. *Journal of Verbal Learning and Verbal Behavior*, 21, 688-703.
- Tyler, L., & Marslen-Wilson, W. (1984). Speech comprehension processes. In J. Mehler, E.C.T. Walker, & M.F. Garrett (Eds.), *Perspectives in mental representation*. Hillsdale, NJ: Erlbaum.
- Wasow, T. (1972). Anaphoric relations in English. Unpublished doctoral dissertation, Massachusetts Institute of Technology, Cambridge.

How Much Do People Remember? Some Estimates of the Quantity of Learned Information in Long-term Memory

THOMAS K. LANDAUER

Bell Communications Research

How much information from experience does a normal adult remember? The "functional information content" of human memory was estimated in several ways. The methods depend on measured rates of input and loss from very long-term memory and on analyses of the informational demands of human memory-based performance. Estimates ranged around 10^9 bits. It is speculated that the flexible and creative retrieval of facts by humans is a function of a large ratio of "hardware" capacity to functional storage requirements.

HOW MUCH INFORMATION DOES AN ADULT HUMAN REMEMBER?

The question is interesting in its own right, and its answer may bear on important questions about the requirements and mechanisms of information storage in the brain and in artificial devices that are designed to perform similar tasks.

Some previous speculations regarding the size of human memory have been based on anatomical or neurophysiological facts. For example, the most commonly quoted figure, 10^{13} bits, is simply an old estimate of the number of synapses in the cortex. Another widely quoted number, 10^{20} , due to John Von Neumann (1958), represents the estimated sum of all neural impulses conducted in the brain in a lifetime. From the perspective of this paper, the chief deficiency of these approaches is not their obviously questionable assumptions (e.g., that synapses or impulses represent only one flip-flop bit, rather than multiple thresholds or interpulse interval values). What is wrong with such estimates is their level. Even if we knew that the wetware of the brain was capable of representing 10^{20} bits, we would have

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Correspondence and requests for reprints should be addressed to Dr. Thomas K. Landauer, MRE 2L-363, Bell Communications Research, 435 South Street, Morristown, NJ 07960.