References and Notes

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8. Visual "searching" stimuli consisted of light and dark moving rectangular bars and stationary flashed lights. Visual receptive fields were mapped on the transparent hemisphere by the edge of a bar, 3° wide, moved inward from all directions in visual space until a closed area was delimited. Somatic "searching" stimuli consisted of stroking and tapping of the body. Somatic receptive fields were mapped with camel's hair brushes or calibrated von Frey hairs that vertically displaced the skin or moved across it. Acoustic stimuli consisted of clicks and handclaps, but acoustic neurons were not studied in detail.
9. Tactile stimuli were never observed to activate upper layer visual cells, and the possible influence of somatic stimuli upon responses to visual stimuli in upper layer visual cells was examined in ten examples. Simultaneous or alternating visual (moving bar or flashed light) and somatic (tapping or electrical stimulation) stimuli were delivered, but no obvious interactions were noted.
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* Present address: Department of Physiology, Medical College of Virginia, Box 144, Richmond 23298. Send reprint requests to this address.

† Present address: Laboratório de Neurobiologia, Departmento Biologia Animal, Universidade de Brasília, Brasília, D.F., Brasil.

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Sentence Perception as an Interactive Parallel Process

Abstract. *The restoration of disrupted words to their original form in a sentence shadowing task is dependent upon semantic and syntactic context variables, thus demonstrating an on-line interaction between the structural and the lexical and phonetic levels of sentence processing.*

A normal spoken sentence can be characterized by at least four levels of description—phonetic, lexical, syntactic, and semantic. How do the listener's analyses at these different levels interact during his processing of the sentence?

This report presents evidence that sentence perception is most plausibly modeled as a fully interactive parallel process: that each word, as it is heard in the context of normal discourse, is immediately entered into the processing system at *all* levels of description, and is simultaneously analyzed at all these levels in the light of whatever information is available at each level at that point in the processing of the sentence. This is in direct contrast to the view that the direction of information flow in sentence perception is primarily serial, so that, whatever the later interactions between levels, the initial input to any higher level consists of at least a preliminary analysis conducted just at a lower level (*1*).

The present experiment directly tests the parallel model by combining two levels of anomaly in a sentence shadowing task. The shadowing paradigm, in which the subject repeats back speech as he hears it, provides an on-line response measure of the information available to the listener during processing. The first level of anomaly—the disruption of semantic and syntactic constraints—tests for the availability of higher-order information. The second level of anomaly, by disrupting the lexical integrity of individual words in the sentence, tests for the interaction of this higher-order information with the lower-level, lexical and phonetic analysis of the sentence.

The stimulus materials were constructed from a pool of 120 pairs of normal sentences. The second sentence in each pair contained a trisyllabic target-word. These 120 sentences were randomly assigned to three Context groups of 40 pairs each. The target-words in the Normal group were left unchanged. In the Semantic group the target-words were replaced by new words that were semantically anomalous—for example: "The new peace terms have been announced. They call for the unconditional *universe* of all the enemy forces." In the Syntactic group, the new words were syntactically anomalous as well—for example: "He thinks she won't get the letter. He's afraid he forgot to put a stamp on the *already* before he went to post it." These Context Disruptions constituted the first level of anomaly.

The 40 sentences in each Context group were then randomly assigned to four subgroups of ten sentences each. In one subgroup (labeled 0) in each Context group the target-word was left unchanged; in the other three (labeled 1, 2, and 3, respectively) the first, second, or third syllable of the target-word was changed so as to make it into a nonsense word. These Word Disruptions constituted the second level of anomaly, thus producing 12 combinations of Word and Context Disruptions, which ranged from Normal_0 (no contextual or lexical disruption of the target-word) to Syntactic_3 (the third syllable disrupted in a semantically and syntactically anomalous target-word).

The purpose of this interweaving of Word and Context disruption was to examine the effects of context on "word restoration" (that is, the restoration of disrupted words to their original form). If the interaction between higher and lower levels of analysis takes place (serially) only after the initial phonetic and lexical identification of the word, then restoration of disrupted words should be equally frequent in all Context conditions. The shadower would have no basis, in his initial repetition, for rejecting contextually anomalous restorations. However, if immediate identification does interact on-line with the semantic and syntactic context, then it becomes possible for context variables to determine word restoration frequency.

The use of the shadowing task makes possible the accurate temporal location of any interaction effects. The shadower's repetition latency, measured from the onset of a word in the input to the onset of that word in his output, specifies precisely how much of the material he could have heard before initiating his response. In this experiment 13 shadowers were used, with mean normal shadowing latencies ranging from 250 to 750 msec (*2*). The performance of the closer shadowers is central to the interactive parallel hypothesis. At a shadowing latency of 250 msec, their repetition of the target-words is initiated when only the first syllable could have been heard. Thus any context effects would be restricted to the initial processing of the incoming word.

The 120 stimulus sentences were recorded in random order at a rate of 160 words per minute, with a 3-second break between sentences. The subjects heard the sentences in a single session, and were instructed to shadow them as naturally as possible, while maintaining their normal shadowing distances.

Two types of restoration were distinguished in the error analysis. The critical errors are the Word Restoration (WR) errors, which are the restoration of disrupted words to their original lexical form—for

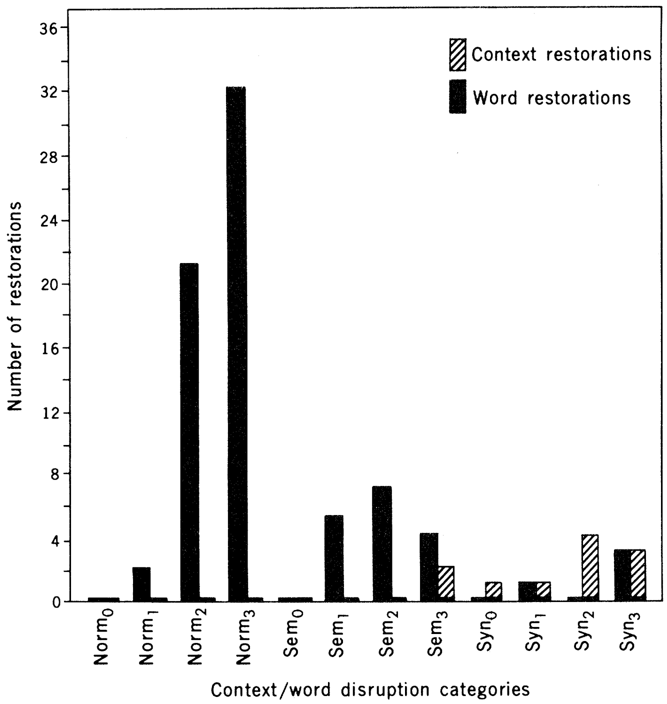

Fig. 1. The distribution of Word and Context Restorations into the 12 disruption categories. The subscripts refer to the target-word syllable disrupted. Abbreviations: *Norm*, Normal; *Sem*, Semantic; *Syn*, Syntactic.

example, repeating "tomorrane" as "tomorrow." Seventy-five of the total 85 restoration errors were WR errors. These WR errors (Fig. 1) were heavily concentrated in the disruption categories Normal_2 and Normal_3 ($P < .001$). That is, word restorations were most likely to occur when the disrupted word was (i) normal with respect to the preceding semantic and syntactic context, and (ii) when its first one or two syllables were not disrupted.

The remaining 11 restorations were Context Restoration (CR) errors. These errors, which can occur only in the Semantic and Syntactic context groups, are reinstatements of the original word that had been replaced by a contextually anomalous word.

The shadowing latencies (*3*) for each restoration error are given for each subject in Table 1. Although the majority of errors were made by subjects shadowing at shorter latencies, the correlation with latency ($r_s = .241$) was not significant. However, latencies for CR errors were shorter than those for WR errors ($t = 3.025$, d.f. = 5, $P < .05$). The latencies for WR errors falling into categories Normal_2 and Normal_3 were significantly shorter than those for WR errors falling into other disruption categories ($t = 6.806$, d.f. = 9, $P < .001$).

This pattern of results is fully consistent with the interactive parallel processing model. Word restorations occur primarily in the Disruption categories where the first one or two syllables of the critical word are consistent with the prior context. But in category Normal_1, where the first syllable (of an otherwise appropriate word) is not consistent with the prior context, there are very few restoration errors. Conversely, there are also few such errors in $\text{Semantic}_{2\&3}$ and $\text{Syntactic}_{2\&3}$, where the first one or two syllables of the critical words are evidence for a particular word but where that word is not itself consistent with the preceding context.

The latency measurements define the temporal parameters of these interactions between the different levels of analysis. Serial models of sentence processing would require that contextual information be less effective at short than at long shadowing latencies. But it is clear from Table 1 that shadowing latency does not determine the availability of semantic and syntactic information, nor the degree to which it is integrated with lower-order analyses. Subjects do not differ as a function of latency in the number of WR errors they make, and, most strikingly, word restorations determined by contextual constraints (WR errors in Normal_2 and Normal_3) are just as likely to occur at latencies of 250 msec as at latencies of 600 or 1000 msec.

In addition, the CR errors, which are a pure reflection of higher-level constraints, have a shorter mean latency than WR errors. Similarly, the WR errors that most reflect prior constraints (those in Normal_2 and Normal_3) have shorter latencies than WR errors which are not dependent upon prior context. None of these effects are in the direction predicted by a serial model.

The high incidence of WR errors in Normal_2 (*4*) illustrates the speed and the precision with which structural information can be utilized. If the first syllable indicates a word that matches the context, then the close shadower can immediately start to restore that word in his repetition. This implies, first, that the constraints derived from the preceding items of the string are available to guide the analysis of even the first syllable of the target-word. Second, these constraints can specify the permissible form-class and meaning of the word with sufficient precision to enable the shadower to assess the appropriateness of just its first syllable.

This experiment, in summary, supports a model of sentence processing in which the listener analyzes the incoming material at all available levels of analysis, such that information at each level can constrain and guide simultaneous processing at other levels. This can also be regarded as direct psychological evidence for the interactive parallel models of sentence processing proposed, on quite different grounds, in the field of artificial intelligence (*5*).

WILLIAM D. MARSLEN-WILSON
Committee on Cognition and Communication, Department of Behavioral Sciences, University of Chicago, Chicago, Illinois 60637

Table 1. Number and mean latency (in milliseconds) of restoration errors. The numbers in parentheses represent the number and the mean latency of the combined Word Restoration errors falling into categories Normal_2 and Normal_3.

Subjects	Word Restoration errors		Context Restoration errors	
	Number of errors	Mean latency	Number of errors	Mean latency
S1	10 (9)	275 (233)	2	162
S2	5 (4)	249 (258)	1	130
S3	5 (3)	287 (285)	2	190
S4	9 (7)	348 (341)	0	
S5	7 (6)	368 (365)	4	362
S6	11 (6)	409 (358)	1	415
S7	0		0	
S8	1	365	0	
S9	5 (3)	654 (623)	0	
S10	1 (1)	465 (465)	0	
S11	9 (6)	534 (485)	1	380
S12	4 (3)	630 (640)	0	
S13	8 (5)	1074 (944)	0	

References and Notes

1. Recent psycholinguistic theories of sentence processing strongly imply a serial processing model, where higher-level analyses develop toward the end of the clause [see J. A. Fodor, T. G. Bever, M. F. Garrett, *The Psychology of Language* (McGraw-Hill, New York, 1974)]. The most explicit serial model is found in G. A. Miller, *IRE Trans. Inform. Theory* **IT-8**, 81 (1962).
2. Practised shadowers have a stable shadowing latency at which they reliably shadow normal prose materials. The shadowers in this experiment had extensive training in earlier experiments [see W. D. Marslen-Wilson, thesis, Massachusetts Institute of Technology (1973); *Nature* **244**, 522 (1973)].
3. For details of the latency-measurement techniques see references in (*2*). The latency measurements are accurate to ± 10 msec.
4. Normal, WR errors are as frequent at short as at long latencies. Although the majority of these errors were made by subjects shadowing at shorter latencies, this trend was not significant ($t = 1.153$, d.f. = 11, $P < .20$).
5. See, for example, D. R. Reddy, L. D. Erman, R. B. Neely, *IEEE-AFCRL Conference on Speech Communication and Processing* (1972), pp. 334–337; R. Kaplan, in *Natural Language Processing*, R. Rustin, Ed. (Algorithmics, New York, 1973).
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Primate Evolution: Analysis of Trends

Cartmill (*1*) has advanced challenging arguments concerning the origin and persistence of primate specializations in the visual system and in grasping coordination. These specializations are hypothesized to have been strongly influenced by ancestral tendencies to subsist in a significant degree by predation on visually located and manually captured insects and other prey in the forest canopy and undergrowth. A subsequent exchange of views between Raczkowski and Cartmill (*2*) was useful in clarifying questions stimulated by the original article, but did not succeed in eliminating misinterpretations of the claims of certain other writers. I shall first examine a conclusion related to the logic of evolutionary arguments, and then discuss misconstruals of certain views of Le Gros Clark, indicating ways in which his discussion of arboreal influences on primates has much more significant implications than were credited to it.

In setting the stage for his evolutionary arguments, Cartmill discussed aspects of the logic of explanation. He noted that scientific explanations are frequently of a type involving deductions from certain givens, including lawlike generalizations—a statement which quite properly allows for other kinds of explanation. He continued, citing Simpson (*3*) and other writers, "yet some evolutionary biologists and philosophers of science . . . have argued that evolutionary explanations do not involve any such generalizations, and hence are not subject to refutation by counterexamples" (*1*, p. 436).

It is not necessary here to consider problems associated with "covering law" views of explanation (*4*), although these are important to a fuller analysis of the arguments advanced. It is true that writers referred to by Cartmill emphasize the frequency with which evolutionary explanations are of a different kind. However, the empirical use of counterexamples does not have to be tied to explanations of a covering law variety. "Counterexample" can stand for other things than its common designata in formal logic, and a useful meaning in the present context is, briefly, "observation inconsistent with hypothesis." In reconstructing trends in a certain lineage, a hypothetical explanation based on incomplete fossil remnants may well be subject to refutation by counterexample. Simpson's recent book (*3*) conveys to me no suggestion that he considers evolutionary explanations of necessity immune to such refutation, contrary to Cartmill's claims.

In the interest of brevity, I shall consider mainly the views of Le Gros Clark in the following arguments, but aspects of the conclusions concerning the vitality of these views apply also to certain overlapping claims made by earlier and subsequent writers. Cartmill has chosen to articulate much of his discussion around "the arboreal theory" (*1*, *5*)—a term that can be useful for identifying a close-knit set of arguments, but which is not helpful in the role of referring to partially contradictory groups of propositions by several writers who have dealt with a wide variety of arboreal influences. Nevertheless, Cartmill effectively showed that certain earlier arguments about expected consequences of arboreal life are erroneous. From such specific demonstrations, he jumped to the more general kind of statement that the comparative evidence "does not support the idea that the selection pressures of arboreal life favor the replacement of tree shrew-like morphology by primate-like morphology" (*1*, p. 438). Elsewhere he concludes, "evidently, the close-set eyes and grasping extremities typical of extant primates are adaptations to some activity other than simply running about in the trees; arboreal life per se cannot be expected to transform a primitive tree shrew-like primate into a lemur. Le Gros Clark's version of the arboreal theory is not adequate" (*1*, p. 439).

In the face of such a conclusion it is genuinely important to look at examples of what Le Gros Clark actually said, and to determine whether he based his inferences on the condition of "simply running about in the trees" or, as stated elsewhere, on "selection pressures imposed by arboreal locomotion per se" (*1*, p. 442). In the context of influences associated with arboreal life (*6*), he emphasized "the replacement of the grasping functions of the teeth by the use of the forelimb for prehension rather than simply for support and progression" (p. 126), and "the enhancement of the use of the hands as tactile organs" (p. 204). In the same context, he built on certain ideas of G. E. Smith (*7*) and Smith's predecessors, relating these ideas to more recent findings, to provide concepts that help systematize knowledge and suggest hypotheses about primate evolution. He noted the importance of the conjunction of visual and tactual developments in providing "opportunities for exploring objects of the immediate environment, and for comprehending their significance" (*6*, p. 266), and gave important place to the idea that the associated differentiation of the cerebral cortex eventually increased in quite general ways the potentials for adapting to environmental change. Obviously his treatment of such concepts will have to be made more specific, as new knowledge permits, and inevitably a number of his views will require modification, as new research results are attained. Yet certain of his emphases have stood the test of developing knowledge remarkably well, and have provided a model for gaining insight into primate evolution by exploring, where feasible, the more fine grained aspects of neural, behavioral, and fossil evidence, and by seeking in somewhat simpler behavioral and cerebral advances the sources of more complex later adaptations (*8*, *9*).

The immediately preceding claims about Le Gros Clark's syntheses can be made more plausible by indicating, at least in rough sketch, how his ideas on the evolution of substrates for primate intellect complement the views of other writers, and illuminate the consideration of primate visual learning (*10*). He emphasized (*9*) that the particular conjunctions of visual, tactile, and manipulative advances favored by the arboreal existence of primates have two kinds of implications. First, in the development of the individual, the joint effect of information from these sources fosters the ability to understand and react adaptively to the environment, a view having points in common with the contributions of Hebb (*11*) and Piaget (*12*). Second, dur-