If a visual probe that was related to the noun "boy" (e.g., the letter string: "girl") was presented at each of the numbered (') positions (in each instance, to different subjects in different experimental conditions), one might expect, *ceteris pan bus,* the following effects on reaction time to make a "lexical decision" to that letter string:[4] First, no priming effects would be expected at test position * 1, as there have been no words related to "girl" heard by the subject up to that point. That is precisely what is found. Second, at test position *2, one might expect that reaction time to "girl" would be speeded (primed) by the subject's just having heard "boy." Again, that is what occurs. Then, at position *'3 (and certainly at position *4), one might predict that there would be no more priming effect of-the word "boy" from the sentence on lexical decision times to the letter string "girl," because sufficient time had passed so that "boy" would have been fully processed and stored away in memory and would no longer be active in immediate sentence processing to be able to exert a priming effect.' This is the prediction of the verb-driven hypothesis about linking discontinuous dependencies, which also predicts that (re)activation of the filler will take place only at test point "5, when the verb requiring a direct object has been processed and a search of the appropriate antecedent filler is undertaken (see above). On the other hand, if the "filler-driven" account of linking antecedent fillers to gaps (discontinuous dependencies) is correct, then continued activation of the filler ("boy") will occur at points * 3 and * 4 in the sentence, as the filler is being kept active while looking for a "gap" site to fill °'5. In short, via the use of CMLP, we are exploiting the fact of priming to provide a basis for an existence proof about the time course of mental activation of some "key" word in the sentence-in this case, the antecedent filler for a structural gap .[6] The CMLP task allows us to know precisely when a "filler"

4. Note that all effects are evaluated in comparison to lexical decision reaction time to a control letter string" presented at each of these test points; a "control letter string" is a word that is associatively/semantically unrelated to the key word in the sentence, but is matched to the "experimental" (related) letter string on the basis of a priori reaction time (lexical decisions taken on the words presented in isolation).

S. The priming that is standardly found to classification of a visual target immediately following occurrence of a "semantically or associatively related" word in an auditory sentence typically lasts between 100 and 700 milliseconds, *ceteris paribus.*

6. McKoon and Ratcliff (1994; see also McKoon, Ratcliff, & Albritton, 1996) have presented arguments in which they have suggested that use of the CMLP technique for examining structural processing contains a confound-namely, char the visual experimental target words constitute better "continuation" (or, a better "fit with") the ongoing sentence than do the "control" target words. Thus, they claim that priming found in these studies is an effect caused by the "goodness-of-fit" of probes into the sentence, and not by "reactivation" or "continued activation" of the filler. For the record, the single example that McKoon and Ratcliff discuss *did* have such a confound. However, in all other studies (including those presented here) the experimental and control probes have been equated for all types of "goodness-of-fit" at each probe point, and hence no such confound exists for any of these results, thus invalidating McKoon and Rarcliff's claims. In short, the CMLP task is a

is active during structural processing and when it is not. Further, it allows us to examine the time course of activation of processing of all possible antecedent fillers (in both structurally appropriate and structurally inappropriate positions), thereby allowing for examination of the role of structural knowledge on this process.

In what follows, we present information using CMLP to detail the time course of information integration and activation during the processing of discontinuous dependencies.

The Processing of Filler-Gap Dependencies by Adults

In a series of studies begun in 1982 using the CMLP technique, we initiated, and further elaborated on, many of the issues raised in the preceding sections about the time course of information integration during processing of discontinuous dependencies. The first of these studies was undertaken in 1982 by Swinney, Ford, Frauenfelder, and Bresnan; and first reported in Swinney, Nicol, Ford, Frauenfelder, and Bresnan (1987); and reported again in Nicol and Swinney (1989). This original study involved presentation of object-relative constructions of the form provided in Example la (reprised here):

(la) "The policeman saw the boy who the crowd at the party" accused
12 of the crime."

At each of the test points, activation for all possible antecedent filler nouns (for the gap following the verb "accused") was examined. Thus, words related to "policeman," "boy," and "crowd" were presented at each test point, as were unrelated control words that were matched with the `related" targets for a priori reaction time (lexical decisions to the words presented in isolation). (Subjects, of course, saw only one of the six target words presented at only one of the two test points, for any one sentence). The results (Table 1) were quite straightforward: At test point *1 (the "baseline" position before the verb), there was significant priming for the target related to the NP "crowd," but there was no significant priming for words related to either the noun "policeman" or the noun "boy" (which is the actual antecedent filler for the gap after the verb "accused"). However, at test point *2 (at the structural gap), there was significant priming *only* for the target related to "boy" (the correct antecedent filler) but not for

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sensitive and unconfounded measure of lexical activations during structural processing. See Swinney et al. (in press), *Nicol* et al. *(1997),* and Walenski *(1997)* for further discussion *of* this and related issues.

TABLE 1
Priming Scores (in Milliseconds) for Lexical Decisions Reaction Times to Control Minus Semantically Related Word for Each Potential Referent, at Each Prob_ePoint

	Probe Point	
Referent	1	2
Bov	12	2
Crowd	44*	19

Note-Asterisk indicates significance at $p < .05$ in tests of a priori planned paired-comparisons (t tests).

targets related to either "policeman" or "crowd." Finally, a significant interaction was found between the two test points and related vs control target reaction times (priming) for the word "boy."

Several things can be concluded from the results of this first study. First, it appears that reactivation of the appropriate antecedent for the gap occurs *immediately* at the gap (following the verb). This result is in keeping with results from other techniques (e.g., Crain &. Fodor, 1985; Garnsey et al., 1989; Stowe, 1986), which also suggest that once a verb that requires a direct object is encountered (and no direct object is found), a search for an antecedent filler is undertaken immediately, resulting in reactivation of that filler. Further, these results suggest that the search for a filler is not a random search resulting in activation of all possible prior NPs; rather, *only* the structurally appropriate antecedent NP was reactivated. Thus, the linkage of gap to antecedent filler is guided by structural. knowledge-that knowledge relating to the positions in which appropriate fillers may be found in a sentence. For example, such knowledge dictates that the missing (and presumed fronted) direct object cannot be the subject of the verb for which it is also a direct object (e.g., the word "crowd" in Example 1a). Note that no priming was found for the target related to "crowd" at the gap (in fact, the priming that occurred just after the word "crowd" was first heard in the sentence can be seen to have been suppressed at the gap in these results.) Further, note that, as there was no priming for a target related to the appropriate antecedent filler for the gap ("boy") prior to the gap, it appears that the process that establishes a link between a gap and its antecedent filler is a verb-driven phenomenon (the antecedent filler is reactivated at the gap; if the phenomenon was antecedent driven, one would expect activation of "boy" to be maintained continuously from its occurrence until a gap was found in which it "fit"). In short, this early study strongly suggested that linkage of antecedent filler to a structural gap was an immediate, structurally driven, automatic process in comprehension.

A number of studies using the CMLP technique have been performed to follow up this initial study. For example, Love and Swinney (1996) examined more details of the time course of activation (and/or reactivation) of antecedents during comprehension and also examined whether the search for antecedents was over a surface structure form of the sentence or over.a "deep" representation. In order to examine this issue, Love and Swinney *(1996)* used lexical ambiguities as antecedent fillers-because all meanings of lexical ambiguities are initially activated when the (surface form of the) word is heard (e.g., Swinney, 1979, 1990; Tanenhaus, Leiman, & Seidenberg, 1979). The reasoning behind this study is that if *all* meanings of the antecedent filler are found to be reactivated at the gap, then one could conclude that the search for an antecedent filler occurs over a surface-form (acoustic memory) representation of the sentence; however, if only the contextually appropriate meaning of the antecedent-filler ambiguity is reactivated at a gap, then the search for the antecedent must be over a "deeper" representation of the sentence-one in ,vhich the appropriate interpretation of the ambiguity has been uniquely determined and stored in the structurally appropriate representation for the sentence up to that point. In addition, this study controlled precisely for "fit" of the target probe words at each test point and replicated and extended the original *CMLP* study by examining for activation/reactivation of the appropriate antecedent filler at several points during the processing of the sentence. In this study, subjects hear sentences such as the following:

(2) The professor insisted that the exam be completed in ink, so Jimmy used the new pen that his mother-in-law recently " purchased " _because the multiple *colors* allowed for more creativity.

Priming for each of two meanings of the antecedent filler "pen" (i.e., "pencil" and "jail") was examined for at each of the three marked target presentation points. The results (Table 2) demonstrated significant priming for *both* the primary (most frequent, "pencil") and the secondary (less frequent, "jail") meanings of the ambiguous word at test point *1 -immediately following initial occurrence of the ambiguity in the sentence. Hence, this replicated a long-established finding, again demonstrating exhaustive access for lexical ambiguities in context. We note in passing that a strong biasing context that exactly replicated the Tabossi (1988) criteria was used in this studs', but it had no effect on lexical access-again strongly supporting the claim of initial contextual independence for lexical access. At test point *2, prior to the matrix verb, but considerably downstream from initial occurrence of the antecedent filler (the lexical ambiguity), no significant priming was found for either the primary or secondary meaning of the ambiguity. Finally, at the critical test point *3 (in the gap), a significant priming effect was found *only for* the primary (and contextually relevant)

TABLE 2

Priming Scores (In Milliseconds) for Mean Naming Reaction Times to Targets Related to Both the Primary and Secondary Meanings of the Ambiguity for Each of the Three Probe Positions

	Probe Position		
Ambiguous Antecedent	1	2	3
Primary meaning	12Y	3b	16*`
Secondary meaning	8' l	5'	2'

Footnotes provide degree of significance and a priori planned comparison values for each:

2.24, $p < .015$

$= .49$

$= 329$, $p < .0005$

$= 1.81$, $p < .038$

$= 1.03$

$= 0.56$

meaning of the ambiguity; there was no significant priming at this point for the secondary meaning of the antecedent filler. Further, the interaction between the nonpriming effect for the primary meaning at test point *2 and the significant priming for this same meaning at test point *3 was significant, indicating that the primary meaning of the ambiguity (but not the secondary meaning) was (significantly) reactivated at the gap.

Thus, this study again confirmed the verb-driven nature of the linkage between gap and filler (reactivation rather than continued activation) and demonstrated that the search is over a deep, nonsurface, representation of the sentence (only one meaning of the ambiguity was reactivated rather than all meanings).

In a related study, we examined the role of plausibility on establishing the antecedent filler-gap link via the CMLP technique. Subjects heard sentences such as:

(3a) Everyone watched the enormous heavyweight boxer that the small 12-year-old boy on the corner had' hugged' so intensely.

(3b) Everyone watched the enormous heavyweight boxer that the small 12-year-old boy on the corner had' beaten' so brutally.

Here, in Example 3a, the NP "the enormous heavyweight boxer" is a plausible filler for the gap (in that a small 12-year-old boy might well hug an enormous heavyweight boxer). However, this same NP is *not a* plausible filler for the gap in Example 3b. It is, however, the structurally correct antecedent filler in both cases. The goal of this study was to determine if gap filling is strictly driven by structural knowledge or if world knowledge (plausibility) would also serve to direct (or preclude) such gap filling. The

results were straightforward. In both Examples 3a and 3b, significant priming was obtained for target probes related to "boxer," but not for those related to "boy" at the gap. Moreover, there was a significant interaction between priming for "boxer" at the two test-probe positions, indicating reactivation of the antecedent filler at the gap, regardless of plausibility constraints. Thus, these results strongly support the view that the linkage between antecedent filler and gap is structurally driven and not top-down knowledge/plausibility driven, and that plausibility effects take place later in processing.

Finally, the role that prosody plays in on-line sentence processing, particularly structurally related processing such as found in discontinuous dependencies, has been largely unexamined until recently. Several new studies, however, have suggested that the timing and intonation pattern of an utterance can provide important information for resolving syntactic ambiguities. A CMLP study (Nagel, Shapiro, & Nawy,' 1994) used sentences such as those in Examples 4a and 4b, in which the structural interpretation of the ongoing sentence depended on whether or not a gap was posited at the first syntactically licensed position or later in the sentence. Observe the position of the gap in the following sentence:-

(4a) Which doctor, did the supervisor call ___ *[2]* to get help for his youngest daughter?

(4b) Which doctor, did the supervisor call [1] to get help for during the crisis?

The lexical content of the auditory sentences was identical up to (and beyond) the first potential gap, but there were differences in the naturally occurring prosody used in recording the sentences. In an examination of the acoustics underlying these "naturally recorded" sentences, significantly longer duration at the main verb (e.g., *call)* were found when the gap immediately followed the verb (Example 4a) than when it occurred within the ili~t JJ1.1~i1~1 piliaJ: ~\ ~i~ ylt~~ . 'iiui:c: i~ ile pi nn contour showed a significantly steeper decline over the verb in Example 4a relative to Example 4b.

In an on-line comprehension experiment, whether listeners could use this prosodic information to help discern the location of the gap was assessed. Evidence for activation of the potential filler was assessed by prim-

7. One anonymous reviewer of this paper accurately noted that this example from Nagel et al. contains a rationale clause. The reviewer argued that this may have been the cause of the prosodic boundary in version (a) of this example. We note, in response, that such a prosodic boundary *is* maintained even with no rationale clause present (e.g., Which doctorr did the supervisor call __ . *[2]* the day before yesterday: In this example, listeners report that without the prosodic boundary, the tendency *is* to interpret the sentence as though the supervisor *is* calling the doctor a name, namely, "the day before yesterday"). In addition, as far as we can tell, only some of the Nagel examples contained rationale clauses. Thus we think this *is* not an alternative hypothesis for the results of Nagel et al.

ing at point [1), after the main verb. Results showed priming for the potential filler (e.g., *doctor)* only in the gap condition 4a even though the only difference at that point was prosodic. These results suggest, tentatively, that prosodic information may be used by the listener to help recover canonical sentence order, on-line.

Finally, from recent work (Swinney & Love, 1998), we know that the rate of processing (the speed at which the speech arrives to the listener) considerably changes the parameters of this reactivation process-implicating factors of memory and automaticity in the recovery of structurally based discontinuous dependencies.

In all, we know that the processing of discontinuous dependency relationships in natural language is driven by a need to recover an underlying, canonical order of perceptuaUsentential elements during ongoing comprehension (interpretative processing). The process itself is triggered by finding an incomplete structural relationship in the surface form of the sentence, namely, a verb that requires a direct object, where no direct object is found following the verb. We know that the process by which the underlying linkage of the verb to the direct object takes place involves the search of an underlying or deep representation of the sentence, that the search is initiated immediately not at the end of the sentence, but once something is detected as missing), that it is a structurally driven search, that the search is neither changed nor directed by semantic/world knowledge/plausibility, and that the search may be affected/directed by prosodic cues and rate of speech.

Returning to the issue that initiated this article, the question of whether music perception is governed by principles similar to those of language is an interesting and fundamental one. Does music perception involve establishment of fundamental underlying relationships, relationships that are recovered (on-line) by the listener as part of the "understanding" and perception of music? Are these relationships different for different types of music (as they appear ro be for different languages with different canonical orders)? Is anticipation of discontinuous elements in music automatic and structurally driven or is it driven by meaning/plausibility (e.g., mood or emotion in music)? Does rate of music play a significant role of establishing these relationships. either as cue to retrieval or as a parameter-changing variable? These are questions to be considered and examined. However, it is only with the development of adequate on-line techniques, tailored to music processing, that we will develop the type of fine-grained evidence about ongoing music processing that will allow us to create sufficiently detailed models of music perception to answer these questions.'

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