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# The Processing of Discontinuous Dependencies in Language and Music

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This article examines the nature and time course of the processing of discontinuous dependency relationships in language and draws suggestive parallels to similar issues in music perception. The on-line language comprehension data presented demonstrate that discontinuous structural dependencies cause reactivation of the misordered or "stranded" sentential material at its underlying canonical position in the sentence during ongoing comprehension. Further, this process is demonstrated to be driven by structural knowledge, independent of pragmatic information, aided by prosodic cues, and dependent on race of input. Issues of methodology and of theory that are equally relevant to language and music are detailed.

IT has long been noted that language and music share many characteristics-observations that have led researchers to examine the similarities and differences in both processing and representation of these systems. This article examines the nature of processing of one of the more pervasive and critically interesting properties of language-discontinuous dependency relationships-and proposes similar mechanisms as a potential property of music perception.

There are a number of different types of structurally based dependency relationships in language that are termed ""discontinuous" or "long-distance." All share the characteristic that in some underlying, canonical representation of language, the elements in these relationships are directly linked and tend to be represented contiguously, but they can be (and often are) separated in surface forms of the language. In this article, we focus on one particular form of long-distance dependency in language-the object-relative construction-as found, for example, in the English sentence:

(1a) The policeman saw the boy who the crowd at the party accused of the crime.

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This complex sentence comprises two underlying, basic sentences (concepts):

(1b) The policeman saw the boy
and
(1c) The crowd at the party accused the boy of the crime.

In English, there is a canonical subject-verb-object word order for basic, underlying sentences. Thus, in the preceding example, the underlying word order in the second sentence (1c) of the "basic" sentence pair is

$$\text{Crowd}_{(\text{Subject})}\text{-Accused}_{(\text{Verb})}\text{-Boy}_{(\text{Object})}.$$

However, in the surface form of the complex object-relative sentence of which Example 1c is a part (1a), the direct object (boy) of the verb (accused) occurs *in front of* that verb (along with the relative pronoun "who"). That is, the verb and object are noncontiguous and out of order with regard to the underlying or "canonical" order of basic relationships in the sentence(s). Some linguistic theoretical approaches have held that the surface order of these sentences results from "movement" of the direct object from its canonical position.[1]

A major hypothesis of many language *processing* models is that recovery of the underlying meaning (interpretation) of the sentence is achieved via analysis of the relationships of the sentence in their canonical order. Thus comprehension must involve "recovering" the *underlying* (subject-verb-object) order from the surface arrangement of the sentential elements (among other things, of course). Although such processing hypotheses were derived initially from linguistic formalisms, independent evidence to support several aspects of this approach have existed in the sentence-processing literature for some time (see, e.g., Bever & McElree, 1988; Garnsey, Tanenhaus, & Chapman, 1989; and Nicol & Swinney, 1989).

Thus, a long-standing problem for models of language processing has been that of discovering how the comprehension device links the "moved" components of these discontinuous (long-distance) dependencies to allow for interpretation. This article details evidence about this process.

The question of how the compreherider recovers the underlying relationship in discontinuous dependencies has two essential aspects. One of these concerns *when* during ongoing comprehension the link between discontinuous elements (e.g., verb and direct object) is made, and the other concerns *how* this process takes place.

1. This concept comes principally from formal linguistic theories in which underlying thematic/semantic relationships (meaning) are treated as a constant that is maintained regardless of the superficial form of the sentence (transformational and related linguistic approaches); hence the distinction between deep and surface structure in Generative Transformation Grammar (Chomsky, 1965); see also Government and Binding Theory (Chomsky, 1981).

With regard to *when* the linkage takes place, there are some fundamentally different logical possibilities: If the process is a *structurally principled* one (i.e., if it is a procedure built into the comprehension process at *structurally* relevant processing points), then it should occur either *immediately* (e.g., when the absence of a direct object immediately following the verb is discovered-a point referred to as a "gap") or at some later, but principled, point of structural processing (e.g., the end of the clause or sentence containing the dependency relationship, or after a first-pass parse is completed; e.g., Friederici & Mecklinger, 1996). If, on the other hand, the process is based purely on association, frequency, or probability (such as would be found in a generic constraint satisfaction or probabilistic cue-driven account, e.g., Bates & MacWhinney, 1987; MacDonald, Pearlmutter, & Seidenberg, 1994), then verb-direct object linkage should take place only whenever sufficient cues to the process have been accumulated during comprehension to allow appropriate prediction of the nature of relevant linkage. In this latter case, linkage will occur at (highly) varying points during processing, based on strength of the cues available in each different sentence-but it will specifically *not* occur "immediately" or at any *single* structurally principled processing point in the sentence.

With regard to the issue of how the processes underlying linkage of the antecedent filler to the gap operate, there are also several logical possibilities. For example, the linking of the verb to its object may take the form of a *search for a gap*, a search which might be initiated by discovery of a potential antecedent (the "moved" object) in the sentence. Consider again Example 1a:

(1a) The policeman saw the *boy* $_{i}$ who $_{i}$ the crowd at the party accused of the crime.

In this sentence, the direct object of the verb "accused" ("the boy") is standardly marked in English sentences with the relativizer "who."[2] Hence, when a relativizer occurs, it may signal to the comprehension system that the noun phrase (NP) it refers to will "fill" a gap at some point later in the sentence. If this were how the system processes such constructions, one might well expect that the "moved" object NP which is linked to the relativizer ("the boy", in this example) would be activated and *would maintain* its activation until a gap site is found. This hypothesis for linking discontinuous dependencies can be termed a "filler-driven" model.[3]

2. The object NP, the relativizer, and the "gap" have all been labeled here with the same indexical () to indicate that they all co-refer.

3. There exist a large number of potential variants of how a "filler-driven" system might work, one of which has been articulated by Frazier and Flores-d'Arcais (1989) as the "Active Filler Strategy"; we note that the Frazier and Flores-d'Arcais model does not make claims about maintained activation in the way *we* specifically do here.

Alternatively, the linkage occurring in this dependency construction could be "verb driven." In a verb-driven account, whenever a verb that takes a direct object (a transitive verb) is encountered, and no direct object follows the verb, a search is initiated over prior sentential material for the missing constituent. The key to deciding if the search is verb driven will be to determine if there is reactivation of the antecedent at the gap position rather than the *continued* activation that is predicted by a filler-driven account (where, once activated, the filler is kept active until "needed"; i.e., it is not reactivated).

Additionally, should the process be verb driven, the *nature* of the search for the antecedent direct object is a fundamental process that also needs to be understood. It must be determined, for example, whether such a search occurs serially or in parallel over possible antecedents, whether it is made over deep or over surface representations of the sentence, and whether it is guided by syntactic information (e.g., structural knowledge concerning which prior NPs are possible antecedent "fillers" for the gap), or by prosodic information, or by probabilistic preferences.

In the work that follows, we review evidence that strongly supports the view that, for adult listeners, the process involved in interpreting this type of discontinuous dependency (object-relative constructions) involves a search for an antecedent that is initiated by discovery of an element (the verb) that requires a canonically positioned object (the "moved" antecedent); that is, it is a *verb-driven process.* This search involves examination of an *underlying representation* of the sentence, and *actively uses structural knowledge and prosodic information* as a guide to find the appropriate antecedent NP. Further, eye present evidence that this search takes place *immediately* upon encountering a verb which requires a direct object-in other words, precisely at the point when a "gap" is encountered and anticipated by the comprehender.

## Issues for Music Processing

Before we turn to this evidence, however, we wish to briefly point out that much the same set of questions and problems just raised for language potentially exists in the perception of music. Music commonly involves establishment of underlying relationships followed by principled deviations from these and then a return to the basic underlying relationships. There is, for example, a regular pattern in (some) music of establishing a tonic, followed by a principled thematic move from the tonic, with ultimate return. This "movement" both to and from the tonic is often "cued" in the surface form of the music. For the knowledgeable music listener (as for the knowledgeable listener to language), a fundamental question concerns whether the perception and recognition of music involves recovery and (unconscious)

recognition of these underlying structures. If it does, the question as to whether anticipation and "reactivation" of structures takes place during *ongoing* music perception (i.e., in real time) becomes as fundamental a question for the understanding of music perception as it is for the understanding of language perception. The fact that knowledge of music and structure is consistently (and unconsciously) available suggests that activation of structural knowledge is an active part of music perception (see empirical evidence by, e.g., Besson & FaIta, 1995; Bigand & Pineau, 1997; Bigand, Madurell, Tillman, & Pineau, in press; Chiappe & Schmuckler, 1997; Krumhansl, 1998; Meyer, Palmer, & Mazo, 1998; Patel, Gibson, Ratner, Besson, & Holcomb, in press; Pechmann, 1998; Raffman, 1993). At a different level of analysis, Jackendoff (1991) and Raffman (1993) have provided theoretical accounts of music perception that are quite compatible with this approach. Jackendoff, for example, argues that perceptual processing of music involves a parser that analyzes a piece of music in a consistent, principled (and presumably structure/order-sensitive) manner each time it is heard; that is, the perceptual parser "hears" each piece of music for the "first" time, each time it is encountered). Thus, one could infer that recovery of " interpretation" for music requires recovery of basic and underlying relationships, from both continuous or discontinuously structured input. Givon (1998), among others, has hypothesized an organization of language and of music in which lower levels of perceptual analysis become automatized (and hence unconscious) in much the way that we find processing of discontinuous dependencies in language to be. One might reasonably ask at this point: precisely which of the potential underlying and discontinuous relationships in music are recovered in a manner analogous to that for language? There are a number of candidates, many at different levels of analysis (at one such level we have suggested the example of the tonic and thematic structure, as just mentioned). However, given that there is currently no monolithic account of music representation and structure, and that there is much ongoing, but as yet nondefinitive, empirical work on this issue, one can only speculate as to which of the competing possibilities for structure (and discontinuous structure) will prove to be the critical ones for music perception.

Regardless of which structural analysis proves to be correct in music, the questions of *when* structural knowledge becomes "activated" and "reactivated" during music perception, and precisely which of the various dependencies are important ones for music perception, are critical and intriguing ones.

Fundamentally, answers to these questions hinge on investigating whether recovery of relationships underlying discontinuous dependencies is a structural aspect of ongoing (real-time) music perception. To do so, however, requires development of sensitive on-line methodologies that will not bring conscious awareness of processing into play in examining the underlying

(non-meta-musical) aspects of music perception-a problem as formidable for music perception as it is for language perception.

Before we return to an account of the processing details of how discontinuous dependencies are processed (unconsciously) during language perception, we briefly consider the issue of methodology. Specifically, we discuss how this process can be appropriately examined during ongoing language comprehension.

## Methodology in the Study of Language Processing: On-line vs. Off-line Techniques

Over the years, numerous experimental paradigms have been used as a means of aiding researchers to understand the processes involved in language comprehension. These methods can be broadly divided into two groups-off-line and on-line approaches. Off-line methods are particularly useful in determining the overall comprehension abilities (or disabilities) of listeners. These methods are typically untimed, encourage the incorporation of world knowledge into the subjects' responses, and involve conscious evaluation of the process being studied (e.g., sentence-picture matching tasks, paraphrase tasks, sentence recall tasks). Importantly, all such off-line methods evaluate language comprehension only *after* it has actually taken place-thus often missing rapid, nonconsciously available details of how the process actually took place; data from such tasks is often termed "postperceptual." In contrast, on-line methodologies are concerned with detailing information as it unfolds during ongoing sentence processing. Such methods attempt to capture moment-by-moment operations of the (unconscious) extremely rapid processes underlying language comprehension. It is these on-line techniques that will allow us to establish fine-grain models of language perception.

A number of "on-line" methodologies are currently in use to those ends. Although many of these methodologies each have revealed important properties of language processing, cross-modal lexical priming (CMLP; Swinney, Onifer, Prather, & Hirshkowitz, 1979) has proven to be a particularly illuminative and sensitive measure of moment-by-moment sentence processing. CMLP comes in many varieties, but all involve the following conditions and properties. First, the sentential material under study is presented auditorily to subjects, who are told that their major job is to understand the sentence(s) or discourse they hear. Subjects are standardly tested for comprehension throughout the experiment-to keep attention on the task of comprehension. Second, subjects are told that they have another task to perform: at some point while they are listening to the sentence(s), a visual item will appear on a screen in front of them and *they* will have to make a

decision about that visual item. This visual item may be a letter string (to which subjects may be required to make a lexical decision, a classifying decision, or a "naming" response) or it may be a picture (again to which some type of classifying response is made, such as "edible/nonedible"). Work with the CMLP technique has shown that most two-choice classification responses work quite well in obtaining basic effects with this task.

Several aspects of this technique should be mentioned: First, presentation of the auditory sentence always continued throughout and beyond presentation of the visual item, and on to the end of the sentence. That is, the sentence is *never ended* with the visual probe; this prevents the probe from being integrated into the ongoing sentential material (provided, of course, that the sentential material is presented normally-see discussion by Swinney, Nicol, Love, & Hald, in press; and Nicol, Swinney, Love, & Hald, 1997). Second, this "secondary" task never requires the subject to make metalinguistic judgments about the sentential material they hear (such as: Was this word in the sentence?). This prevents metalinguistic examination of the auditory sentence, which necessarily involves engagement of conscious (and hence largely nonautomatic) comprehension processes (see Swinney et al., in press, and Shapiro, Swinney, & Borsky, 1998, for more details). Third, at least up to the point of the visual target presentation, processing of the sentence is uninterrupted and "normal." In this regard, the task differs considerably from many other on-line tasks that ask the subject to evaluate each word in a sentence as it appears or to hold a target in mind while the sentence is being processed. Thus, this task is one of the least intrusive behavioral techniques we have for the "on-line" examination of the normal comprehension process.

There is, of course, a planned relation between the two tasks the subject performs (auditory sentence comprehension and visual target classification) in CMLP. On experimental trials (never more than 25% of all trials), the visual target is associatively/semantically related to a critical word in the sentence. Following the principle of automatic semantic priming, occurrence of an auditory word (the prime) in the sentence just prior to processing of an associatively or semantically related item results in speeded processing/classification of the target (priming) (see, e.g., Neely, 1991; Meyer, Schvaneveldt, & Ruddy, 1975). The CMLP task uses the fact that priming occurs between associatively related items (typically words or, for studying children's on-line processing, words and pictures; see Love & Swinney, 1997; Kroll & Potter, 1984; McKee, Nicol, & McDaniel, 1993; Swinney & Prather, 1989) to provide an indication of *when* critical words in the sentence are active during processing. Consider again our Example la, in which subjects hear:

> (la) "The policeman saw $^{*1}$ the boy $^{*2}$ who the crowd $^{*3}$ at the party $^{*4}$ accused $^{*5}$ of the crime."

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 paribus,* 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.[5] 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).

5. 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):

(1a) "The policeman saw the boy who the crowd at the party *1 accused *2 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 Probe Point

| | Probe Point | |
|---|---|---|
| Referent | 1 | 2 |
| Boy | 12 | 27* |
| 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 which 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 *1 that his mother-in-law recently *2 purchased *3 _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 | 12*[a] | 3[b] | 16*[c] |
| Secondary meaning | 8*[d] | 5[e] | 2[f] |

Footnotes provide degree of significance and a priori planned comparison values for each:
[a] $t_{50} = 2.24$, $p < .015$
[b] $t_{87} = .49$
[c] $t_{87} = 3.29$, $p < .0005$
[d] $t_{50} = 1.81$, $p < .038$
[e] $t_{87} = 1.03$
[f] $t_{87} = 0.56$

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[1] hugged[2] _so intensely.

(3b) Everyone watched the enormous heavyweight boxer that the small 12-year-old boy on the corner had[1] beaten[2] _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$_i$ did the supervisor call __$_i$ [2] to get help for his youngest daughter?

(4b) Which doctor$_i$ did the supervisor call [1] to get help for __$_i$ 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 prepositional phrase well after the verb (Example 4b). Similarly, the pitch 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 doctor$_i$ did the supervisor call ___$_i$ [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.[8]

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