

Syntactic integration difficulty in language comprehension

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In this presentation, I will present evidence from my lab which evaluates distance-based theories of language comprehension. In the process of understanding a sentence, it is necessary to integrate structures for incoming words into the structure(s) that have been built thus far, such that the potential integrations for an incoming word are determined by the syntactic rules for the language. According to one current theory --- the dependency locality theory (DLT, Gibson, 1998, 2000) --- the processing cost of integrating a new word *w* is proportional to the distance between *w* and the syntactic head to which *w* is being integrated. Structural integration cost has been shown to be an important factor in accounting for on-line processing load. For example, consider the relative clause (RC) structures in (1) and (2):

(1) The reporter who attacked the senator admitted the error.

(2) The reporter who the senator attacked admitted the error.

In (1), the RC pronoun "who" is interpreted as the subject of the verb "attacked", whereas in (2), the same pronoun is interpreted as the object of the verb "attacked". People read the verb "attacked" more slowly in a sentence like (2) than in a sentence like (1) (King & Just, 1991; Gibson, 1998; Gibson & Ko, 1998). This difference can be explained by integration distances. In (1), there is one local integration when processing "attacked": This verb is integrated with the preceding RC pronoun as its subject. In contrast, there are two integrations at the point of processing "attacked" in (2): This verb must be integrated as the verb for the subject "the senator" (a local integration) and the object position of "attacked" must be integrated with the RC pronoun "who", a non-local integration. As a result of the extra non-local integration, the processing load at "attacked" is larger in (2) than in (1), resulting in longer reading times at this word. Furthermore, reading times are slow in both sentence types for the verb "admitted", a point of long-distance integration with the subject "the reporter" in both sentence types. Reading times are relatively faster for the other words in the sentences, because integrations at all other positions are local.

Integration distances are integral in explaining the difficulty of processing nested structures across languages. Consider sentence (3), in which the RC "who John met" has been added to (2) as a modifier of the NP "the senator":

(3) The reporter who the senator who John met attacked admitted the error.

Sentence (3) consists of an RC nested within an RC nested within a main clause. The resultant structure is highly complex, much more complex than (2). The greater complexity is arguably due to the fact that the maximal integration distances required in processing (3) are substantially longer than the maximal integration distances required in processing (2). In particular, the

integration between the verb "attacked" and its subject "the senator" is longer distance than in (2), because the RC "who John met" now intervenes. Similarly, the integration of object position of "attacked" with the RC pronoun "who" is longer distance in (3) than in (2), again because the additional RC "who John met" intervenes. Finally, the main clause subject-verb relationship, between "the reporter" and "admitted" is longer distance in (3) than in (2).

The first set of experiments to be presented here provide more evidence for the distance-based complexity hypothesis from a reading time study examining a range of English sentences. The second set of experiments investigate the question of how distance is quantified. The third set of experiments explore some predictions of the DLT in Japanese, a language with word order properties which are very different from English. The final experiments to be discussed investigate the neural basis of syntactic integration difficulty, using event-related potentials (ERPs).

In the first set of experiments, participants read a variety of nested and non-nested structures as in (4) (Grodner, Watson, & Gibson, 2000). Points of high integration cost occurred primarily at the main and embedded verbs. The magnitude of predicted integration cost was manipulated in two ways: 1) by inserting or omitting modifiers on the matrix and embedded subjects and, 2) by varying the type of modification (relative clause or prepositional phrase). Integration costs were highly correlated with residual reading times accounting for roughly 45% of the variance across regions. Looking only at points of high complexity across conditions, integration costs accounted for 27% of the variance.

(4)

- a. The nurse supervised the administrator.
- b. The nurse from the clinic supervised the administrator.
- c. The nurse who was from the clinic supervised the administrator.
- d. The administrator who the nurse supervised scolded the medic.
- e. The administrator who the nurse from the clinic supervised scolded the medic.
- f. The administrator who the nurse who was from the clinic supervised scolded the medic.

This work emphasizes the role of a resource-based configurational component in sentence processing. The effect of locality dwarfed the contributions of non-configurational factors such as word length, lexical frequency, and the plausibility of intervening material.

An interesting question raised by a distance-based theory of integration cost is how distance is quantified. A series of experiments suggest that the discourse accessibility of the intervening elements may be a large factor in accounting for the complexity of an integration of a new head, w_2 , to a position in the current structure, w_2 (Warren & Gibson, 2000). Evidence from the processing of nested structures supports this hypothesis. Consider sentence (5):

(5) The reporter who the senator who you met attacked admitted the error.

In comprehension ratings, people reliably rate sentences like (5) as less complex than sentences like (4). The only difference between the two is that the name "John" in (4) has been replaced with the pronoun "you" in (5). The complexity difference can be accounted for if integration

costs are determined in part by the accessibility of the discourse structures associated with intervening words. The referent for the pronoun "you" is always highly accessible, because it refers to the reader or listener in a communicative situation. In contrast, the name "John" is new to the discourse in (4), and so building and accessing a referent for this name is more costly (Haviland & Clark, 1974). If distance is quantified in terms of less accessible (new) discourse referents, the longest-distance integrations -- at the verbs "attacked" and "admitted" -- are shorter in (5) than in (4) because one fewer new discourse referent is crossed in each of these integrations. A discourse-based distance metric therefore accounts for the observed complexity contrast.

The second experiment investigating the discourse basis for a distance metric varied the referential availability of the antecedent of a definite NP in on-line reading of simpler structures. A target sentence like (7) was preceded by one of three different contexts, as in (6). In (6a), the sentence explicitly mentioned the referent that was the embedded subject in the experimental sentence. In (6b), the antecedent could be identified in the context based on general world knowledge (a bridging inference). In (6c) the target sentence had no context, so all referents were new (null context). The discourse-referent-based distance theory predicts that the condition with explicit reference should have the fastest reading times on the verbal regions, followed by the bridging condition, and then the null context condition. The results confirmed these predictions in self-paced word-by-word moving window reading.

(6)

- a. Explicit: A physicist attended the cross-disciplinary conference at the university.
- b. Bridge: Some scientists attended the cross-disciplinary conference at the university.
- c. Null context

(7) A speaker who the physicist questioned explained the results in more detail.

The third set of experiments evaluates a distance-based theory of syntactic complexity with respect to Japanese, a language with very different word order from English (Babyonyshev & Gibson 1999; Nakatani, Babyonyshev & Gibson 2000). Four conditions in this experiment compared nested structures containing intransitive verbs in the most deeply embedded clauses (as in 8a and 8b) to nested structures containing transitive verbs in the most deeply embedded clauses (as in 8c and 8d). In (8a), the most deeply embedded clause contains a nominative subject and a verb. In (8b)-(8d), the most deeply embedded clause contains a nominative subject and a verb and one additional constituent: an adverb in (8b); an accusative direct object in (8c); and a dative object in (8d). The DLT predicts that the transitive conditions (8c) and (8d) should be more complex than the intransitive conditions because an extra NP (introducing a new discourse referent) separates a number of subject-verb dependencies. The DLT predicts no difference between the two intransitive conditions (8a) and (8b) because the distance metric is based on new discourse referents, and the intervening adverb does not introduce a new discourse referent. The DLT also predicts no complexity difference between the accusative and dative transitive conditions.

(8) NP-topic NP-nom NP-nom (Adv / NP-acc / NP-dat) V comp V comp V

- a. tuma-wa uranaisi-ga otto-ga syoosinsuru to tugeta to zimansita
wife-top fortune-teller-nom husband-nom be promoted comp told comp boasted
- b. tuma-wa uranaisi-ga otto-ga ikinari syoosinsuru to tugeta to zimansita
wife-top fortune-teller-nom husband-nom suddenly be promoted comp told comp boasted
- c. tuma-wa uranaisi-ga otto-ga kakarityoo-o oinuku to tugeta to zimansita
wife-top fortune-teller-nom husband-nom chief clerk-acc surpass comp told comp boasted
- d. tuma-wa uranaisi-ga otto-ga kakarityoo-ni narabu to tugeta to zimansita
wife-top fortune-teller-nom husband-nom chief clerk-dat catch-up-with comp told comp boasted

The results of the experiment bore out the predictions of the DLT: there was no difference between the ratings for (8a) and (8b) or for (8c) and (8d), but there were significant differences for each comparison between an intransitive condition and a transitive condition.

The final experiments investigate the neural basis of syntactic integration difficulty, using event-related potentials (Kaan et al., 1998). One ERP-component that has been associated with language processing is the P600, a positive going wave with a posterior distribution, starting about 600 msec after word onset. This component has been found for words that either are ungrammatical continuations of the sentence (Neville et al., 1991; Hagoort, Brown and Groothusen, 1993; Friederici, 1995), or signal that the preferred interpretation of the preceding ambiguous structure is incorrect ('garden-paths', Osterhout and Holcomb, 1992). This has led some researchers to claim that the P600 either reflects a 'surprise' reaction (Coulson, et al., 1998), or repair processes triggered by an unexpected input word (Friederici, 1995).

An alternative hypothesis is that the P600 reflects a more general computational process involved in sentence processing, namely the process of trying to integrate the current input with yet unsatisfied syntactic predictions stored in working memory. If this hypothesis is correct, it should be possible to elicit a P600 for grammatical, non-garden-path structures as compared with structures whose integration is less complex. To test this hypothesis, we conducted an ERP experiment comparing sentences like (9a) and (9b):

(9)

- a. Emily wondered who the performer in the concert had imitated for the audience's amusement.
- b. Emily wondered whether the performer in the concert had imitated a pop star for the audience's amusement.

When the language processor encounters "who" in (9a), it expects a head which can assign a thematic role to this wh-phrase. This requirement is met at "imitated", at which point "who" is integrated as the patient of the imitating event. In (9b), on the other hand, "whether" doesn't need a thematic role, and no integration takes place between this phrase and the verb. Hence, under an integration account of the P600, a P600 is expected at "imitated" for (9a) vs. (9b). Results demonstrated such a P600.

In a second experiment, we tested whether the P600 found at the verb for "who" questions was indeed similar to a classic P600 elicited by subject-verb agreement violations. We compared sentences as in (10):

(10)

- a. Emily wondered who the performers in the concert imitate for the audience's amusement.
- b. Emily wondered whether the performers in the concert imitate a pop star for the audience's amusement.
- c. * Emily wondered who the performers in the concert imitates for the audience's amusement.
- d. * Emily wondered whether the performers in the concert imitates a pop star for the audience's amusement.

Results suggest that the positivity elicited at the verb by ungrammatical vs. grammatical forms on the one hand, and by "who" vs. "whether" on the other are the same in the sense that they are generated by overlapping neural sources. This in turn suggests that dealing with ungrammaticalities and relating a verb to a "who" phrase involve similar computational processes. Thus it may be that the P600 provides a measurable brain response to syntactic integration difficulty. It remains to be seen whether this response can be modulated by distance.

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