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Parallelism and Competition in Syntactic Ambiguity Resolution

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Abstract

A central issue in sentence-processing research is whether the parser entertains multiple analyses of syntactically ambiguous input in parallel, and whether these analyses compete for selection. In this article, we review theoretical positions for and against such competitive parallelism. We then review empirical evidence, primarily drawing on reading time studies, bearing on the prediction made by parallel competitive models that some cost ought to be associated with processing syntactically ambiguous material. We argue that this prediction is not confirmed by the data, and we discuss recent claims that the models in question do not actually make this prediction. We also emphasize the contrast with lexical ambiguity, where there is clearly a processing cost associated with competition between alternate meanings. Finally, we review a different kind of recent evidence suggesting that two syntactic analyses may indeed coexist under specific circumstances.

The question of how readers and listeners resolve ambiguities of the sort found in (1)–(3) has been a central topic for psycholinguistic research for the last three decades, because of the light it can shed on how people recognize words and put them together into sentence meanings.

(1) The specialist examined the organ very carefully.
(2) Someone shot the servant of the actress who was on the balcony.
(3) While the men hunted the deer ran through the woods.

Sentence (1) contains a lexical ambiguity: *organ* has two unrelated meanings. In sentence (2), the relative clause *who was on the balcony* could be interpreted as modifying either *servant* or *actress*. Speakers of English tend to prefer the analysis on which the relative clause modifies the most recent noun (in this case, *actress*), but this preference is not universal across speakers or across individual sentences (Corley 1995; Gilboy et al. 1995). The syntactic ambiguity in sentence (3) is only temporary: at the point of reading *the deer*, this noun phrase could be either the object of the first clause (i.e. the thing that the men hunted) or the subject of the second clause. There is very clear evidence that readers and listeners initially

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construct the first of these analyses (e.g. Frazier and Rayner 1982; Pickering and Traxler 1998), and should undo this mistake when the second analysis turns out to be correct, as in (3) (cf. Ferreira and Patson 2007).

Despite the fact that ambiguity is extremely pervasive in natural language (Church and Patil 1982), its existence seldom causes readers and listeners any conscious difficulty. But research on 'garden-pathing', in which a reader or listener initially mis-analyzes a syntactic ambiguity and later has to correct it at some cost, has provided substantial insight into the factors that govern how a syntactic ambiguity is initially resolved (Frazier 1987; Mitchell 1994; Pickering and van Gompel 2006). The present article, however, focuses on what happens during the processing of the ambiguity itself. In particular, we will ask whether different possible analyses of an ambiguity are entertained simultaneously, and if so, whether they compete for selection.

The use of the word 'competition' that we have in mind is familiar from many areas of cognitive psychology. Adopting an activation metaphor, we assume that two representations compete, if (i) they are simultaneously active, and (ii) the activation of one analysis reduces the activation of the other. Such mutual inhibition may be direct, with the activation of one analysis directly suppressing activation of the other analysis. Inhibition may also be indirect. One version of indirect competition appeals to the existence of a fixed quantity of activation in the system, so that an increase in the activation of one analysis results in a decrease in activation of the second analysis. (Other metaphors are possible. For instance, lowering the position of an item in an ordered search list amounts to increasing the competition provided by items above it in the list; Duffy et al. 2001.)

To make our questions concrete, we may refer back to sentences (1)–(3) above. Is there a stage in the processing of (1) during which both possible meanings of *organ* are activated? In (2), is there a stage at which both attachment sites of the relative clause *who was on the balcony* are entertained simultaneously? Is there a stage in the processing of (3) during which a reader or listener is simultaneously considering the object and subject analyses of *the deer*? In each case, do the two analyses 'fight it out' to be selected? In the present article, we focus on syntactic ambiguities like those in (2) and (3), although we discuss research on the processing of lexical ambiguity in the service of clarifying the empirical issues.

Models of Ambiguity Resolution

Some existing 'serial' models of syntactic parsing say 'no' to the questions we just raised (at least regarding sentences like (2) and (3)). The most-studied version of such a model, Frazier's 'garden-path' model (Frazier 1978, 1987; Frazier and Rayner 1982; cf. Crocker 1994; Kimball 1973), claims that with each new input word, a single analysis is constructed on the basis of a race among different grammatical rules or phrase-structure

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templates for adding the word into the structure of the sentence constructed so far (cf. Frazier and Fodor 1978; van Gompel et al. 2005). The simplest structure generally wins, because it requires appeal to the smallest number of grammatical rules. This structure is then used to constrain the semantic interpretation of the sentence, and if syntactic or semantic anomalies appear, the initial structure can be revised (Rayner et al. 1983). This model predicts no processing disruption due to syntactic ambiguity during the ambiguous region itself, as only a single structure is ever completely built. However, the model does predict delayed disruption when later-arriving material conflicts with the initial analysis.

Other 'parallel competitive' models say 'yes' to these questions, and predict that two analyses competing with one another will slow comprehension, both at the point of ambiguity and at the later point where a serial model claims re-analysis takes place. Some models incorporate direct inhibition between different sentence configurations (e.g. McClelland et al. 1989; Vosse and Kempen 2000; cf. MacDonald et al. 1994, for an influential parallel competitive model that has not been implemented). In Vosse and Kempen, the links between different syntactic nodes in a tree structure can directly inhibit each others' activation; in McClelland et al. (1989) the connections that link different 'sentence gestalts', mediated by a group of hidden units, can have negative weights, resulting in inhibition. Other models incorporate indirect competition (e.g. McRae et al. 1998; Stevenson 1994; Gibson 1991). In Stevenson (1994: 303), 'each phrasal node allocates a percentage of its activation to each of its attachment nodes, proportional to their activation levels.' McRae et al. (1998) use a rather similar device, in which 'interpretation nodes' that correspond to distinct analyses receive activation from each of several input constraint (evidence) nodes in proportion to the weights on the links between evidence and interpretation nodes. These activated interpretation nodes feed normalized activation values back to the evidence nodes in a cyclic fashion, again in proportion to the link weights. This increases the activation of evidence nodes that support the more-activated interpretation node and reduces the activation of evidence nodes that support the less-activated interpretation node and results in what appears to be competition among the interpretation nodes. Finally, Gibson (1991) proposes that multiple analyses of an ambiguous sentence are constructed, each with some processing cost. If the summed cost becomes too great, the analyses with the highest cost are eliminated.

Since they assume some time-consuming mechanism for resolving competition (e.g. iterative reduction in activation levels until one analysis is dominant), these parallel competitive models predict disruption when late-arriving information contradicts an earlier resolution of an ambiguity. The late information activates a previously deactivated interpretation, which has to compete with the previously activated interpretation to achieve dominance, slowing comprehension compared with the condition

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in which the initially chosen analysis continues to receive support from information that arrives later. These models also, in contrast to serial models, are thought to predict slowed processing during the ambiguity (but see the discussion, below, of Green and Mitchell 2006, who discuss some cases where an ambiguous input per se should not lead to increased processing time). The models basically claim that a single analysis must become dominant (perhaps to a very small degree) before a reader or listener can move on to begin processing the next word. If two or more distinct analyses are initially active, or are activated by the input, then a competitive resolution process must take place for one to become sufficiently dominant. No such resolution process is needed when no ambiguity is present. Since this process takes time, reading should be slowed during an ambiguity.

To be sure, not every parallel parsing model has to predict slowing during an ambiguous region. For example, a model might posit that the pool of processing resources available to the parser is sufficiently great that two or more analyses can be considered in parallel without any processing cost. In addition, specific parameter settings of competitive models may ensure that disruption is very slight (see Gibson and Pearlmutter 2000, and Lewis 2000, for some discussion). Still, it is illuminating to consider a much-discussed implementation of a competitive constraint satisfaction model, the 'competition-integration' model (Spivey-Knowlton 1996; McRae et al. 1998). Elman et al. (2004) present a carefully worked-out application of this model to a much-studied syntactic ambiguity, the direct object/sentence complement ambiguity, as illustrated in (4):

(4) a. The psychology students found the book in the bookstore.
    b. The psychology students found the book was written poorly.

The phrase *the book* is the direct object of *find* in (4a), but is the subject of a complement sentence in (4b). Elman et al. (2004) present an implemented version of the McRae et al. (1998) model to account for data reported by Hare et al. (2003). These authors measured self-paced reading times for sentence-complement sentences like (4b), and modeled them using a connectionist model in which prior sentence context, frequency of usage of the verb with a direct object vs. a sentence complement, and the sense of the post-verbal noun were used as constraints (among other constraints). Their model successfully predicted a disambiguation effect: competition was greatly increased (and human subjects' reading times were substantially slowed) when the words *was written* are read in a temporarily ambiguous sentence like (4b) that followed a sentence context that was biased toward a direct object interpretation (*Allison and her friends had been searching for John Grisham's new novel for a week, but yesterday they were finally successful*). Little competition, and little slowdown in reading, was observed following a sentence-complement biasing sentence (*The intro psychology students hated having to read the assigned text because it was so*

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boring). As the authors state, '. . . when the constraints are balanced among different alternatives, the activation levels of those interpretations are more equal and there is a great deal of competition.'

Of particular interest for present purposes, the model predicted increased competition in the ambiguous region (*found the book*) following the sentence-complement biasing context. Apparently, the sentence-complement and direct-object interpretations of *the book* competed in this condition (but not in the direct-object biasing context, where all evidence including the higher frequency of verb use with direct objects than sentence complements pointed toward the direct object interpretation). That is, the implemented competition-integration model does predict competition, and slower reading, in an ambiguous region of a sentence, as long as there really is some ambiguity.

What Are the Facts?

Before turning to the empirical evidence regarding competition effects in the resolution of syntactic ambiguity, it is instructive to note that the facts are quite clear regarding lexical ambiguity. When alternative meanings of a word are roughly equal in frequency (e.g. *bark*) and occur in a context that could support both meanings, these meanings compete, slowing processing of the word. However, when one meaning is much more common than the other (e.g. *port*) and the context is neutral, competition has negligible effects on comprehension. The best evidence comes from measuring eye fixation durations during normal reading of these words (for a review, see Duffy et al. 2001). When it appears in a neutral context, a 'balanced' ambiguous word is fixated for a longer time than a frequency-matched control word, suggesting competition between its alternative meanings. No such slow-down appears for a 'biased' ambiguous word. Moreover, prior context seems to influence the competition. A context that disambiguates a balanced word to one of its meanings speeds reading of that word, which can be interpreted in terms of reduced competition [or, as Duffy et al. (2001) advocate, changing the order in which the meanings of the word are accessed]. A context that disambiguates a biased ambiguous word like *port* toward its less frequent meaning (*When she finally served it to her guests, the port was a great success*) slows reading of the word (the so-called 'subordinate bias effect'; for example, Sereno et al. 2006), which can be interpreted in terms of increased competition.

Regarding syntactic ambiguity, the empirical picture seems to be very different. Here we focus on reading time data, as in this domain it is clear how processing cost should be manifested, that is, as inflated reading time. In a nearly exhaustive review of eye-tracking studies conducted to the time of writing, Clifton et al. discuss whether reading speed is slowed in the region of a sentence where a syntactic ambiguity is present. They conclude that '. . . there are very few instances of . . . slowing

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in the ambiguous region' (2007: 363). This conclusion is worth a close look.

Consider first the data presented by Elman et al. (2004), following Hare et al. (2003). As noted above, the implementation of the competition-integration model predicted competition in the ambiguous region of sentences like (4b), at least when they occurred in a context that encouraged a sentence-complement interpretation. However, there was a negligible slowdown (when compared to unambiguous sentences, containing an overt complementizer *that*) in the human reading time data (using self-paced reading, not eye-tracking). That is, there was no empirical evidence that the ambiguity that resulted in competition in the model actually slowed readers down.

Many published studies of ambiguity resolution do not provide clear evidence about whether reading time is slowed in an ambiguous region. The seminal study of Frazier and Rayner (1982), for instance, only allowed a comparison of first-pass reading time (ms/character) of the ambiguous (boldfaced) region with the preceding region in sentences like *Because Jay jogs* ***a mile and a half*** *seems a short distance to him*. By this measure, reading was not slowed in the ambiguous region, but the comparison is unconvincing, because different lexical items are being compared.

Some later studies (see Clifton et al. 2007) did permit more convincing comparisons of ambiguous and unambiguous regions, and generally showed no slowing in early measures of reading time, such as first-fixation duration (the duration of the very first fixation in a region) and first-pass reading time (the time spent reading a region before first leaving it). For instance, Pickering and Traxler (1998) showed that reading of *the magazine* was not affected by the absence vs. presence of the comma in sentences like *As the woman edited/sailed(,) the magazine about fishing amused all the reporters.* Similarly, Traxler and Pickering (1996) found no effect of adding the disambiguating *that* to sentences like *I recognized (that) you and your family would be unhappy here* on first-pass reading time on the post-verbal noun phrase. Binder et al. (2001) studied reduced vs. unreduced relative clause sentences like *The poet (who was) inspired by his eager students* (and their main clause counterparts) in three eye-tracking experiments and found no evidence of slowing on the initial verb when it was temporarily ambiguous, regardless of verb bias or the presence of discourse context [and, following a test of parallel competitive models suggested by Frazier (1995), noted that a discourse context that supported a normally unpreferred analysis decreased the disruption observed when the sentence was disambiguated in favor of this analysis, but that no corresponding effect was observed when the sentence was disambiguated in favor of the normally preferred analysis].

However, some published eye-tracking studies have shown slowed reading in ambiguous regions. But as discussed by Clifton et al. (2007), most of these effects can be attributed to factors other than ambiguity. For

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instance, Ferreira and Clifton (1986) found slower first-pass reading of the verb in the reduced relative construction (e.g. slower reading of *examined* when the words *that was* were missing from *The evidence (that was) examined by the lawyer turned out to be unreliable*; Clifton et al. 2003 found a similar effect in first fixation duration and a non-significant tendency in first-pass time, probably reflecting a higher rate of regressions out of the verb when *that was* was absent, as was also the case in Trueswell et al. 1994). The first fixation effect is probably due, however, to the implausibility of *evidence* as the subject of *examine*, not to ambiguity per se, since it disappeared when the initial noun was a plausible subject, for example, *defendant*. As another example, there are occasional reports of slower first-pass reading of noun phrases that are temporarily ambiguous between direct object and subject of a sentence complement (e.g. *his sins* in *The criminal confessed (that) his sins . . . harmed too many people*) in the absence of the disambiguating complementizer *that*. For instance, Kennison (2001) found a non-significant difference on the ambiguous noun itself, but a significant ambiguity penalty on a following modifier, and Pickering and Traxler (1998) reported a 36-ms effect but did not report its significance. Although it is possible that this is a true ambiguity effect, it is also possible that the difference simply reflects faster reading or different fixation locations following the short, frequent complementizer *that*.

One study does report slower reading time in an ambiguous region than in a corresponding unambiguous region that cannot be dismissed as an effect of implausibility or superficial factors like a preceding function word (Ni et al. 1996). These researchers measured eye fixations while their subjects read sentences like (5) and found slower reading times for the initial part of the phrase following the initial verb (*money at low, from the parking*) when the verb permitted a main verb object analysis (5a) than when it did not (5b). (The difference disappeared at the last word of the post-verbal noun phrase, *interest* or *lot*). While this is suggestive evidence for an effect of ambiguity, the fact that different lexical items were being compared in different contexts makes the effect less convincing.

(5) a. The businessmen loaned money at low interest were told to record expenses.
    b. The vans stolen from the parking lot were found in a back alley.

In summary, there is little or no convincing evidence for slowed first-pass reading time in a syntactically ambiguous region. It is true that none of the studies reviewed were designed to look for such an effect, and it is possible that targeted studies would succeed in uncovering an effect. In fact, there is a series of studies that was directly targeted at searching for such an effect (Traxler et al. 1998; van Gompel et al. 2001, 2005). These studies seem to have found that syntactic ambiguity speeds reading time rather than slowing it. They compared the processing of sentences with adjunct attachments that are globally ambiguous and temporarily

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ambiguous, and sentences whose attachments are unambiguous. Traxler et al. (1998) examined reading times for sentences like:

(6) a. The driver of the car with the moustache was pretty cool.
b. The car of the driver with the moustache was pretty cool.
c. The son of the driver with the moustache was pretty cool.

Sentence (6c) is globally ambiguous, as it is never clear whether the prepositional phrase *with the moustache* is meant to modify the first noun phrase (*the son*) or the second noun phrase (*the driver*), while in sentences (6a) and (6b) only one of these attachments is plausible. Across three experiments, Traxler et al. (1998) found that readers spent less time on the potentially disambiguating word (e.g. *moustache*) in condition (6c) than in conditions (6a) or (6b). van Gompel et al. (2005) confirmed this basic pattern and extended it to adverbial attachment ambiguities. They also found that sentences with a global modifier attachment ambiguity (7a) were not read more slowly than completely unambiguous sentences (i.e. sentences with only one possible attachment site, as in 7b):

(7) a. The guide said that the tower of the castle decaying due to acid rain was very old.
b. The other day the guide said that the castle decaying due to acid rain was very old.

Thus, these experiments demonstrate that a critical word or region is not read particularly slowly when its syntactic attachment is ambiguous. Indeed, it appears that on some eye movement measures, reading time is actually faster when attachment is ambiguous than when one attachment is forced. van Gompel et al. (2005; see also van Gompel et al. 2000) propose a variable-choice model according to which the parser may sometimes initially adopt one attachment, and sometimes the other, so that disambiguation toward either high or low attachment is sometimes costly, while global ambiguity is never costly. Recent research by Swets et al. (2008) suggests, however, that reading times may be especially fast in globally ambiguous sentences because readers do not bother to resolve the ambiguity fully. In any case, these well-controlled experiments do not lend support to the idea that there is costly competition between syntactic alternatives during the processing of an ambiguous region.

Does Parallelism Really Predict Competition?

It has been argued that the parallel interactive models that we have characterized as predicting that ambiguity will lead to competition do not actually make this prediction under the experimental conditions that have been used in the search for competition. Green and Mitchell (2006) provide a very clear example of such an argument. These authors build on the McRae et al.'s (1998) implementation of a competition-integration

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model, in which multiple sources of input information activate different analyses (interpretation nodes) to different degrees, and in which feedback from the level of activation of the interpretation nodes modifies the activation values of the input (emulating competition between the nodes). The original McRae et al. (1998) paper, as well as the Elman et al.'s (2004) modeling extension discussed above, do predict competition in an ambiguous region.

However, Green and Mitchell (2006) note that it is simplistic to say that if an input word provides equal evidence for two (or more) possible interpretations, these interpretations will compete maximally. Instead, they argue that, if there is a strong bias toward one interpretation prior to the presentation of the input in question, a balanced ambiguity will simply preserve this bias, leading to fast resolution of the ambiguity. Competition will occur only when there is no bias prior to the arrival of the input, or if the prior bias goes against the bias of the input. Furthermore, Green and Mitchell argue that the dynamics of the model are such that the relative activations of the interpretations in question will generally be resolved to favor one over the other(s) before processing each word in the sentence, even before the nominally ambiguous word. Attention moves from one word to the next when the relative activation of one interpretation of the earlier word reaches a criterion (which can be relatively low, since the McRae et al.'s model progressively lowers the criterion as time spent attempting to interpret a word increases).

This analysis does appear to apply nicely to lexical ambiguity, at least at first glance. If prior context gives no reason to activate one meaning of a word over another, then a balanced ambiguous word will lead to competition. If prior context does bias one meaning over the other, then the balanced ambiguous word will simply allow the bias to continue, resulting in lack of competition. This characterization does open up some serious questions, to be sure, for example, what does prior context activate? It surely cannot be one sense of the ambiguous word. Too many words are possible in the sentences that have been used. For example, in Duffy et al. 1988, the biasing context *Although it was wrinkled and worn, his . . .* preceded the balanced homonym *case*; it seems exceedingly unlikely that the context would actually have activated the particular word *case* or its specific meaning. Perhaps what is activated by the prior context are some semantic features of the appropriate meaning of the ambiguous word, but fleshing this suggestion out will obviously require development of, and commitment to, a sophisticated theory of semantic access in word recognition.

However, we question whether the Green and Mitchell (2006) analysis applies to construction and selection of syntactic analyses in parsing. Their analysis turns on the claim that only two (or a small number) of possible analyses are active prior to the arrival of a syntactically ambiguous input word. In the cases they discuss (taken from Traxler et al. 1998 and van Gompel et al. 2005), the possible interpretations are two different

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attachments of a relative clause. For instance, one target sentence is *I read that the bodyguard of the governor retiring after the troubles is very rich*. The interpretations in question involve whether the reduced relative clause *retiring after the troubles* modifies *the bodyguard* or *the governor*. Mitchell and Green argue that one of these interpretations will generally be dominant after the word *governor* is processed, so that the ambiguity of the relative clause simply permits the bias to continue. Competition between the interpretations is thus not expected, nor is any slowing of reading.

This analysis turns on the assumption that one of the interpretations – a relative clause modifying either the first or the second noun in *the bodyguard of the governor* – is dominant (highly activated) before the beginning of the relative clause. The assumption is implausible: why would the parser activate, for example, the NP1-attached relative clause syntactic analysis upon reading *governor*, before any information arrives that indicates that a relative clause is imminent? Why is not a simple verb, or a modal, or an adverb, or a conjunction, or a second prepositional phrase, or an appositive phrase, or any number of other possible syntactic configurations, dominant? In fact, van Gompel (personal communication) has collected fragment completion norms for the sentences under discussion, and found that such fragments (e.g. *I read that the bodyguard of the governor . . .*) are completed with relative clauses a mere 1% of the time, on average (with another 1% post-nominal prepositional phrase completions). In the absence of any reason to expect one construction, it seems likely that the parser would just wait for input. There is in fact some evidence that when the grammar strongly constrains how a sentence may continue, the parser anticipates a particular syntactic structure (e.g. Staub and Clifton 2006), but there is no evidence that the parser anticipates optional, low-frequency, continuations. Thus, if the two attachments of the relative clause are approximately equally (un)likely, neither is likely to be dominant before the beginning of the relative clause, and the appearance of an ambiguously attached word like *retiring* will lead to maximal competition.

In general, the problem with the Green and Mitchell (2006) analysis (like the McRae et al. 1998 model) is that it models how people choose from two or a small number of alternative interpretations. Parsing is not a matter of choosing between two interpretations. The parser must be able to deal with the arbitrarily large number of possible sentences in the language, constructing syntactic analyses and semantic interpretations on the fly, being prepared for the unexpected. In short, given the implausibility of the Green and Mitchell assumption that the decision about attachment is made before anything arrives to be attached, there is little reason to doubt that the competition-integration model does generally predict competition and slowing of processing of syntactic ambiguities.

Recently, Levy (forthcoming) has suggested a rather different way in which a parallel competitive model could account for the global ambiguity advantage reported by Traxler et al. (1998) and van Gompel et al.

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(2005). Again we may use (6) as a concrete example, repeated here for convenience.

(6) a. The driver of the car with the moustache was pretty cool.
b. The car of the driver with the moustache was pretty cool.
c. The son of the driver with the moustache was pretty cool.

Levy, too, is skeptical that the parser pre-activates either a high- or low-attached post-modifier analysis prior to encountering the critical material (*with the moustache*). However, his own parallel competitive model also predicts, by way of a different mechanism, that reading time should be faster in (6c) than in (6a) or (6b), beginning at *moustache*. The gist of the idea is that processing difficulty on each word is a function of the conditional probability of that specific word, given the analysis or analyses that are active at the point at which the word is encountered. After having read *with the*, the probability of the word *moustache* as the next word in (6a) is essentially equal to its probability on the high attachment analysis, and the probability of *moustache* as the next word in (6b) is essentially equal to its probability on the low-attachment analysis. In (6c), however, the probability of *moustache* is roughly the sum of these two probabilities, because in this case the word inherits some probability from both analyses.

We see at least two potential problems with the approach. The first relates to the critical assumption relating processing difficulty to transitional probability, at the lexical level. While McDonald and Shillcock (2003) reported that transitional probability affects reading time, Frisson et al. (2005) later found that this effect is eliminated when sentence-level predictability (i.e. cloze probability) is controlled. More importantly, there has never been any direct experimental evidence that transitional probability or cloze probability affects reading time at the level of the vanishingly small probabilities that must be associated with a word like *moustache* in (6). The second problem, in our view, is that Levy's model treats processing difficulty as continuous. Levy notes that a variable-choice model like van Gompel's predicts bimodality in eye movement behavior at the point of reading the word *moustache* in (6a–b): either the reader was already maintaining the correct analysis, in which case she will experience essentially no processing difficulty, or the reader was maintaining the incorrect analysis, in which case she will experience very substantial processing difficulty. Levy's own model does not make this prediction. While we acknowledge that to a great extent this is still an open empirical question, our own view is that bimodality is present in the eye movement record at the point of syntactic disambiguation. It is well-documented that at the point of disambiguation toward a dispreferred analysis, there tends to be a very dramatic increase (i.e. a discontinuity) in the proportion of regressive saccades toward earlier regions of text (see Clifton et al. 2007, for discussion).

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Is There Other Evidence for Parallelism?

We have discussed models claiming that multiple syntactic analyses are entertained in parallel, leading to the possibility of competition. We have argued, however, that there is no compelling behavioral evidence for competition. In addition, we have suggested that Green and Mitchell's (2006) argument that competitive models do not necessarily predict observable competition effects is based on an unlikely assumption, namely, that the parser has partially activated one of the relevant syntactic alternatives before the ambiguous material is encountered. Thus, our own view is that a critical prediction made by competitive models is, in fact, not borne out by the empirical evidence.

However, we have also noted that it is possible for a model to endorse parallelism without endorsing competition. In fact, there does appear to be some recent evidence, not appealing to competition effects, which supports the parallelism claim. Some comes from event-related potential and functional magnetic resonance imaging research that suggests the existence of a response to syntactic ambiguity that might or might not reflect competition between interpretations (Frisch et al. 2002; Fiebach et al. 2004; Stowe et al. 2004; but cf. Hopf et al. 2003). Sticking to behavioral data, several studies (Christianson et al. 2001; Kaschak and Glenberg 2004; Lau and Ferreira 2005; van Gompel et al. 2006; Staub 2007; Sturt 2007) have suggested that an abandoned parse of a sentence may be maintained, with some level of activation, along with the correct parse. For example, van Gompel et al. (2006) had participants complete sentence fragments containing an optionally transitive verb, for example, *When the doctor was visiting.* Across three experiments, they found that transitive completions were more common when participants had just read a garden path sentence in which an incorrect transitive analysis was likely to have been briefly entertained. Similarly, Kaschak and Glenberg (2004) found reduced reading time on a target sentence when the structure of the sentence was likely to have been briefly active as a mis-analysis of an earlier prime sentence.

These results could be explained in terms of parallelism: the incorrect analyses of the prime sentences received some continued activation, along with the correct analysis. On the other hand, it is also possible that participants did not actually complete the re-analysis of the prime sentences, at least on some portion of the trials. But this alternate explanation cannot account for eye-tracking results obtained by Staub (2007) and Sturt (2007). Staub examined the effects of having constructed the correct syntactic analysis just prior to being garden-pathed by the incorrect analysis. For example, participants read sentences like (8a–b) below, which involve the subordinate clause object/main clause subject ambiguity. In (8b), a verb-and-verb structure appears in the subordinate clause, which,

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it was assumed, would induce an early, fleeting analysis according to which the second verb was intransitive.

(8) a. Though the maid mopped the floor would not get clean.
b. Though the maid arrived and mopped the floor would not get clean.

Each of these conditions was compared to an unambiguous control in which a comma was included after the subordinate clause. The results were clear: early measures of processing difficulty upon disambiguation were not affected by the fleeting presence of the correct analysis at an earlier point, but later measures of processing difficulty (i.e. measures that take into account regressive re-reading) were dramatically affected. Thus, 'garden-path' effects of similar size appeared at the word *would* in sentences (8a) and (8b), but the mis-analysis was ultimately easier to resolve in (8b) than in (8a). It appears that as readers progressed through (8b), the correct (i.e. intransitive) analysis was replaced by the incorrect (i.e. transitive) analysis, but the correct analysis was able to 'hang around', and was re-activated or recalled when re-analysis became necessary.

Sturt (2007) compared reading of sentences in which the initial incorrect analysis was consistent in meaning with the correct analysis, as in (9a), and sentences in which the initial analysis and the correct analysis could not both be true, as in (9b).

(9) a. The explorers found the South Pole was actually right at their feet.
b. The explorers found the South Pole was actually impossible to reach.

In both sentences, readers were likely initially to attach *the South Pole* as the direct object of *found*, and to re-analyze to a sentence-complement analysis upon reaching *was actually*, judging from the fact that reading times were inflated on this material compared to disambiguated control conditions. But once the reader's eyes moved into the final region (*right at their feet/impossible to reach*), there was significantly less regressive re-reading in sentences like (9a) than in sentences like (9b). Sturt interpreted this phenomenon in terms of the persistence of semantic commitments, although it is clearly possible that the initial syntactic analysis itself was also retained for some period after it became clear that re-analysis was necessary.

As Staub (2007) notes, a serial model that incorporates a working memory component could account for the persistence of putatively abandoned parses after disambiguation. However, parallel models that assume that the activation of a disfavored parse decays only gradually (e.g. Tabor and Hutchins 2004) may also be able to explain this phenomenon.

Conclusion

In this article, we have examined models of syntactic processing that assume that syntactically ambiguous input results in simultaneous activation of

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multiple parses, which may compete for selection. We have argued that there is interesting evidence suggestive of parallelism, at least in the reanalysis stage of parsing. But there appears to be no compelling evidence for competition during the construction of an initial parse. In our view, the evidence is consistent with models according to which only a single syntactic structure (and hence a single interpretation) is fully constructed when an ambiguity is encountered, or with models according to which multiple analyses may be active without competing.

In closing, we emphasize that the lexical ambiguity results seem to pose a critical challenge to competitive models of syntactic ambiguity resolution. In the domain of lexical processing, increased processing times appear in precisely the circumstances that would invite competition between word meanings. Intuitively, the demands of arbitrating between competing syntactic analyses should be greater, not less, than the demands of arbitrating between word meanings, as syntactic representations are presumably more complex than representations of the lexical items that participate in them. The burden is, therefore, on competitive models of syntactic ambiguity resolution to explain why competition effects are so easy to observe in one domain of language processing, but so difficult to detect in another.

Short Biographies

Chuck Clifton has been doing psycholinguistics since the early 1960s, when he received his PhD under the direction of Jim Jenkins at the University of Minnesota. He has concentrated on questions of sentence comprehension, both in reading and in listening, collaborating with linguists and psychologists at the University of Massachusetts.

Adrian Staub will receive his PhD in Cognitive Psychology from the University of Massachusetts Amherst and will accept a faculty position in the Psychology Department in fall 2008. Most of his published work has used eye movements to investigate syntactic parsing. Recently, he has also studied grammatical encoding in language production. He received a BA in Psychology from Harvard University, and an MA in Philosophy from the University of Pittsburgh.

Notes

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