"Meaning Through Syntax" in Sentence Production and Comprehension: Reply to McRae et al. (2005)

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The "meaning through syntax" framework (G. McKoon & R. Ratcliff, 2003) proposes lexical, decompositional representations of verb meaning. For several classes of verbs, the proposed representations have successfully predicted 2 types of data that pattern differently: the syntactic structures of sentences that are naturally produced by speakers and writers and the comprehension processing times of verbs and sentences. In addition, the framework assumes that syntactic structures carry meaning, and a particular meaning has been proposed for the reduced relative clause construction. Combining this meaning with the proposed meanings of verbs that might be used in reduced relative clauses explains why reduced relatives with some classes of verbs occur in natural production with near-zero frequency. K. McRae, M. Hare, and M. Tanenhaus (2005) criticized the meaning through syntax framework but offered no explanation for many of the empirical findings that support the framework.

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The goal of the "meaning through syntax" (MTS) theoretical framework (McKoon & Ratcliff, 2003) is to encourage psycholinguistic research that focuses directly on interactions between meaning and syntax. For a verb, MTS specifies the parts of its meaning ("event templates") that control syntactic characteristics of naturally produced sentences in which the verb occurs and also contribute significantly to sentence comprehension. For a sentence, MTS assumes that all of its elements, including words, syntactic structures, and propositions, carry meaning. In the broader discourse comprehension framework in which MTS resides (e.g., Kintsch, 1974; McKoon & Ratcliff, 1992), the meaning of a sentence as a whole reflects interactions among its elements and the general knowledge of the person producing or comprehending the sentence, as well as the syntactic, discourse, and situational contexts in which the elements occur (McKoon & Ratcliff, 2003, pp. 523–524).

Using the MTS framework, McKoon and Ratcliff (2003) addressed a construction that has been a major focus of research in psycholinguistics, the reduced relative clause. We proposed that some reduced relative clauses, such as the one in *The horse raced past the barn fell,* are prohibited in English because the role of the head of the clause in the event template of the clausal verb is inconsistent with the meaning of the reduced relative construction. *The horse raced past the barn fell* is prohibited because the role of

the horse in the racing event is inconsistent with the meaning of the reduced relative. McRae, Hare, and Tanenhaus (2005) criticized this proposal and all its parts. We begin our response by summarizing MTS analyses of two classes of verbs for which reduced relatives are prohibited, and then respond to McRae et al.'s critiques of the analyses.

Event Templates and Sentence Structures

MTS separates the syntax-relevant, event template meaning of a verb from the rest of its meaning. The template lays out the structure of the events that a verb may denote, that is, the structure of the event as it is construed by the linguistic system. Manner-of-motion verbs (e.g., *race*) have an activity template, $x(ACT)$, which represents an entity x engaged in an activity, and internally caused change-of-state verbs (e.g., *erode*) have a simple change-of-state template, $x(BECOME IN STATE)$, which represents x changing into some new state. Event templates can have associated with them features of meaning, such as whether the event denoted by the verb is construed as having a cause and, if it is, whether that cause resides in the entity engaged in the event or in something external to that entity. The event templates of manner-of-motion and internally caused change-of-state verbs both have causality as a feature, both internal causality.

In MTS, each verb has only one template, unless it is truly ambiguous.[1] With only a single template, both manner-of-motion and internally caused change-of-state verbs can appear in both

[1] McRae et al. (2005) suggested that the meanings of a truly ambiguous verb must be unrelated to each other. We disagree; there may well be verbs that are ambiguous between a meaning that has one event template and a meaning that has a different event template, even when the two meanings are related. This issue cannot be addressed without considerable empirical research that investigates a variety of individual verbs, the structures in which they occur, and the processes by which they are comprehended.

intransitive and transitive sentences. According to McRae et al. (2005), MTS offers "no explanation for the syntax" (p. 1024), that is, no explanation for how single-template verbs come to appear in multiple syntactic structures. Here, we reiterate our account. Crucially, we point out how the mappings from template to sentence structures are different for manner-of-motion and internally caused change-of-state verbs.

For internally caused change-of-state verbs (x(BECOME IN STATE)), the entity x is both the cause of the verbal event and the entity that changes state as a result of the verbal event. For the sentence *The beach erodes, x* is the beach. The erosion event is internally caused by *the beach* in that it is characteristics of the beach that allow erosion to take place. Following Dowty (1991) and as described by McKoon and Macfarland (2000, p. 854; 2002, pp. 12–13), for an intransitive sentence like *The beach eroded,* the entity *x, the beach,* is linked to direct object position in the underlying syntax and moves to fill the subject position in the sentence that would otherwise be empty. For a transitive sentence like *High tides eroded the beach,* the second argument, *high tides,* comes from the parts of the verb's meaning outside the template, and as such, it is a participant in the x(BECOME IN STATE) event. Again following Dowty (see McKoon & Macfarland, 2000, p. 854), *high tides* is linked to subject position and *the beach* is linked to object position.

For manner-of-motion verbs (x(ACT)), the activity is internally caused by the entity engaged in the activity, *x.* Again following Dowty (1991; also Rappaport Hovav & Levin, 1998, 2001), for an intransitive sentence like *The horse raced,* this entity is linked to subject position in the underlying syntax, and it remains there in the sentence. For a transitive sentence like *The jockey raced the horse, the jockey* plays the role of an external cause, doing something to cause the horse to race. To accommodate *the jockey, race*'s template is augmented through a process not yet fully understood (Levin & Rappaport Hovav, 1995, p. 111; Rappaport Hovav & Levin, 1998, 2001).

For *High tides eroded the beach* and *The jockey raced the horse, the beach* and *the horse* are internal causes of their events (counter what McRae et al., 2005, p. 1024, suggest), and there are no external causes in the verbs' basic templates. Other verbs do have external causes as part of their basic templates, verbs such as *break,* with the template α CAUSE x(BECOME IN STATE), for which the external cause is the subevent α. In *John broke the window, John* represents the external cause, and the change of state is that the window broke. Verbs of this class are called externally caused change-of-state verbs.

McRae et al. (2005) criticized our analyses of manner-of-motion and internally caused change-of-state verbs in several ways. First, they argued against the MTS assumption that a verb has only a single event template. They claimed it is a "well-established" (McRae et al., 2005, p. 1023) result in the lexical semantics literature that most verbs have multiple representations of syntactically relevant information. However, in that literature, the multiple representation notion has been shown repeatedly to be inadequate, as we discussed in detail in McKoon and Ratcliff (2003, pp. 493–494; see, e.g., Croft, 1998; Levin & Rappaport Hovav, 1996; Wechsler, 1997). McRae et al. did not indicate how any of the inadequacies might be overcome.

McRae et al. (2005) further claimed that the occurrence of a verb in more than one syntactic structure requires that it have more than one template (p. 1024). In MTS, *erode* has only the one template, x(BECOME IN STATE), and the template has only one argument. *x, the beach,* is the internal cause in both intransitive sentences like *The beach eroded* and transitive sentences like *High tides eroded the beach*. According to McRae et al. (2005, p. 1024), the entity in subject position of the transitive sentence, *high tides,* must be an external cause and the verb must switch from being an internally caused verb to an externally caused verb. In other words, *erode* must have both internal and external cause templates. However, what McRae et al. overlooked, mentioned above, is that arguments like *high tides* can come from parts of the verbs' meaning outside the event template; they do not have to be an external cause. *Erode* can remain a verb with only one template with only one internal cause argument even though it can appear in transitive sentences. McRae et al. suggested (2005, p. 1023) that this contradicts the views of Levin and Rappaport Hovav, but McRae et al. were incorrect. Levin and Rappaport Hovav and MTS are in agreement that multiple syntactic structures can be determined by the same event template (e.g., Rappaport Hovav & Levin, 1998, p. 111). McRae et al. also erred in taking transitivity as an absolute criterion for external causality (2005, p. 1024), in opposition to many reasons not to do so (see, e.g., Rappaport Hovav & Levin's, 2001, discussions of resultative constructions).

As mentioned, we do not yet understand how the template for manner-of-motion verbs is augmented for sentences like *The jockey raced the horse*. Whatever the process of augmentation, we do not currently believe that the template for *race* changes to an external cause template, even though *the jockey* plays the role of an external cause. The data reviewed below, for which McRae et al. (2005) offered no account, support our view. Also, in arguing for multiple templates for manner-of-motion verbs, McRae et al. (2005, p. 1024) cited Levin and Rappaport Hovav (1995) as agreeing with them but neglected to point out that Levin and Rappaport Hovav have since changed their views on manner-of-motion verbs (Rappaport Hovav & Levin, 2001).

The most important part of the MTS framework is that hypotheses about event templates and sentence structures be subjected to empirical tests that are as thorough as possible. For example, Levin and Rappaport Hovav (1995) had thought that internally caused change-of-state verbs like *erode* could occur only in intransitive sentences and that only a limited range of entities could be subjects of the intransitive sentences. McKoon and Macfarland (2000) showed that both proposals were incorrect, but the demonstration required examination of the distributional characteristics of individual verbs across the syntactic structures of thousands of sentences.

Table 1 summarizes data for naturally produced sentences that support MTS analyses of internally caused change-of-state verbs, manner-of-motion verbs, and externally caused change-of-state verbs. Transitive sentences like *John broke the window* and *High tides eroded the beach* are frequent for both externally and internally caused change-of-state verbs (Table 1, Row 1). For the former, the transitive subject comes from the external cause in its template, and for the latter, the transitive subject is a participant in the internally caused template event. The requirement of being a participant in the internally caused change-of-state event predicts that the kinds of entities that can appear in subject position for internally caused change-of-state verbs are restricted as compared with externally caused change-of-state verbs (Table 1, Row 3), a

Table 1

Empirical Comparisons of Internally Caused Change-of-State Verbs, Manner-of-Motion Verbs, and Externally Caused Change-of-State Verbs

Corpus statistics for naturally produced sentences	Internally caused change-of-state verbs x(BECOME IN STATE)	Manner-of-motion verbs x(ACT)	Externally caused change-of-state verbs α CAUSE x(BECOME IN STATE)
Probability of transitive sentence	.45	infrequent	frequent
Entities in subject position of intransitive sentences	natural entities, artifacts, animate entities, body parts, abstract entities		
Entities in subject position of transitive sentences	natural entities	people, actions by people, natural forces	natural entities, artifacts, animate entities, body parts, abstract entities
Processing time data			
Mean reading times: acceptable intransitive sentences	RT < RT$_{ext}$	RT < RT$_{ext}$	
Mean reading times: acceptable transitive sentences	RT < RT$_{ext}$		
Mean judgment times: unacceptable transitive sentences	RT < RT$_{ext}$	RT < RT$_{ext}$	
Mean lexical decision response times	RT < RT$_{ext}$	RT < RT$_{ext}$	

Note. The data in the table are for the verbs examined by McKoon and Macfarland (2000, 2002) and McKoon and Ratcliff (2003). RT = response time; RT$_{ext}$ = response time for externally caused change-of-state verbs.

prediction verified by McKoon and Macfarland (2000). Transitive sentences for manner-of-motion verbs such as *The jockey raced the horse* are rare (counter McRae et al., 2005, p. 1024) because, according to MTS, *the jockey* must play a role that is outside the basic template of *race* and in conflict with its internal causality. The entity in subject position of such a transitive sentence must dominate the internal causality of the entity engaging in the verbal activity and so is almost always a person, an action by a person, or a natural force (Table 1, Row 3). (Other diagnostics have also been used to distinguish manner-of-motion verbs from other classes of verbs, e.g., Levin & Rappaport Hovav, 1995; Rappaport Hovav & Levin, 1998, 2001; Wechsler, 1997, 2000, 2002; but the table shows only data we have collected.)

Table 1 also summarizes reading and judgment time data for sentences and lexical decision data for verbs that conform to MTS predictions. Predictions for processing times are based on template complexity: x(ACT) for manner-of-motion verbs is simpler than x(BECOME IN STATE) for internally caused change-of-state verbs, which is simpler than α CAUSE x(BECOME IN STATE) for externally caused change-of-state verbs. Because there is only one basic template for each verb, shorter processing times are predicted for the simpler than for the more complex templates for both transitive and intransitive sentences. Several possible mechanisms by which shorter processing times might arise were outlined by McKoon and Macfarland (2002, p. 34).

The data in Table 1 show dissociations among the verb classes for naturally produced sentences: Internally caused change-of-state and manner-of-motion verbs dissociate from each other, and both dissociate from externally caused change-of-state verbs in the probabilities of transitive sentences and the restrictions on the subjects of transitive sentences. Also, the production data dissoci-

ate from the response time data: Neither the probabilities of transitive sentences nor the restrictions on the subjects of transitive sentences can be directly mapped onto the pattern in the response time data. MTS is an attempt to capture all of these dissociations via the theoretical construct of verbs' event templates. The multiplicity of patterns of data give power to MTS, and they keep it from circularity in its explanations of the data. McRae et al. (2005) did not offer an account of these data. Also, when they claimed that MTS is "incompatible with well-established results in the lexical semantics literature" (p. 1023), they did not specify what these results might be.

To challenge MTS notions about causality features associated with event templates, McRae et al. (2005, Study 1) asked subjects to rate whether events described in sentences were internally or externally caused. This is inappropriate, because the constructs of internal and external causality are abstract and theoretical ones, defined by how they account for empirical data in the context of a larger framework, not by subjects' or theoreticians' introspections. Given a sentence that most researchers would classify as unacceptable, like *The gardener bloomed the flowers,* with the internally caused change-of-state verb *bloom,* subjects are likely to give *the gardener* a high rating as a cause, which it could be in the real world described by the sentence. However, event templates "are not intended to directly represent events in the world. Instead they express construals of events in the world" by the linguistic system (McKoon & Ratcliff, 2003, p. 495; see also Levin & Rappaport Hovav, 1995). In the linguistic system as postulated by MTS, the immediate cause of the blooming event is internal to *the flowers*. Evidence that speakers are "sensitive to" (McRae et al., 2005, p. 1024) the differences among manner-of-motion, internally caused change-of-state, and externally caused change-of-state verbs

comes from data like those summarized in Table 1, for which McRae et al. gave no explanation.

To be sure, the MTS account of event templates and how they underlie sentence structures is nowhere near complete. Although the generalizations in Table 1 for naturally produced sentences reflect the great majority of the data we have examined, there are exceptions. For example, in *An epilogue jumps us from April to August,* with the manner-of-motion verb *jump* (from McKoon & Ratcliff's, 2003, corpus), the restrictions listed in Table 1 are violated because *an epilogue* is not a person, an act by a person, or a natural force. More important, lexical decompositions like event templates have been proposed only recently, and much work remains to be done. Few classes of verbs have been thoroughly empirically examined, and the rules that link a verb's single event representation to the various sentence structures in which the verb can occur have not been sufficiently worked out. Nevertheless, the data summarized here as well as other data (cited in McKoon & Ratcliff, 2003) suggest optimism.

Reduced Relative Clauses

McKoon and Ratcliff (2003) proposed that the object reduced relative clause construction denotes an entity that is caused to participate in the clausal event by something external to itself. *The horse raced past the barn* is prohibited as a reduced relative clause because the template for *race* attributes causality to *the horse.* McRae et al. (2005, p. 1024) argued that reduced relative clauses like *The horse raced past the barn,* in which the verb is transitive and passive, ought to be possible because simple transitives like *The jockey raced the horse* and simple passives like *The horse was raced by the jockey* are possible. We disagree. Our beginning hypothesis (McKoon & Ratcliff, 2003) is that "a difference in syntactic form always spells a difference in meaning" (Bolinger, 1968, p. 127). Our proposal is that different syntactic forms interact differently with the meanings of verbs. The interaction of *race*'s event template meaning with the simple transitive structure or the simple passive structure leads to acceptable sentences, but the interaction with the reduced relative structure does not. As support for our proposals, we reported probabilities of occurrence of sentences in our corpus: For both manner-of-motion and internally caused change-of-state verbs, reduced relatives occur with near-zero probability, whereas simple passives occur much more frequently. McRae et al. did not offer any explanation of these data.

McRae et al. (2005) pointed out (p. 1029), in criticism, that the MTS-hypothesized meaning for the reduced relative construction is different from the sorts of meanings that construction grammar researchers have postulated for other constructions, and also that we provide different sorts of evidence to support our hypothesis. We see no problem with being different. McRae et al. did not show any way in which construction grammar approaches invalidate MTS claims about the meanings of reduced relatives, and they did not address the empirical evidence provided by McKoon and Ratcliff (2003) to support these claims.

Considerations of the reduced relative clause construction raise an interesting question: Why is it that the head of an object reduced relative cannot be the cause of the clausal event? If *The jockey raced the horse* is acceptable, then why is it that *The jockey, the horse,* and *raced* cannot be coerced into *The horse raced by the jockey fell*? At heart, the question is, why should the reduced relative have the meaning that we claim it does? We believe that this same question—why does it have the meaning it does?—could be asked about any syntactic construction and that answers must await considerably more research.

Ambiguity Resolution and the Reduced Relative Clause Construction

The first issue to be addressed about any possibly ambiguous linguistic construction is whether it is, in fact, ambiguous to the human processing system. The word *lawn* has two meanings in English, but many undergraduates do not know the *kind of fabric* meaning. For MTS, *The horse raced past the barn* is not ambiguous, because only the main clause analysis, not the reduced relative, is possible. For verbs that do not have internal causality as part of their templates, MTS currently has no prohibitions against the reduced relative construction, and therefore it is possible that they can be used in clauses that present a reduced-relative/main-clause ambiguity to the human processing system.

Understanding how possibly ambiguous constructions are represented and processed in the human language system requires a model, and testing the model requires separating the effects of ambiguity that are predicted by the model from the effects of other factors. For sentence comprehension, the effects of ambiguity must be picked out empirically from the effects of all the other factors known to affect comprehension, including the factors having to do with meaning that were outlined by McKoon and Ratcliff (2003, p. 523). The MTS framework follows research literature in discourse comprehension in assuming that the meaning of a sentence is made up of interactions among the sentence's elements, a reader's general knowledge, and the contexts in which the elements occur. To emphasize this interactivity, and for brevity, we label this kind of meaning "holistic."

Holistic Meanings

Consider, for example, these two sentences from a study by McRae, Spivey-Knowlton, and Tanenhaus (1998) that was designed to test a constraint-based model for the processing of reduced-relative/main-clause ambiguities: *The hangman executed by the government had been convicted of treason* and *The martyr executed by the government had been convicted of treason.* These two sentences differ only in their first nouns, *hangman* and *martyr.* Reading times at *government* are slower if it is the hangman who is being executed than if it is the martyr. One possible explanation is tied to ambiguity processing: *The hangman* makes the incorrect main clause interpretation more likely, because hangmen are typical agents of the verb *execute.* A second possible explanation has nothing to do with ambiguity processing: The meaning—taken as a whole— of the proposition that a government executes a martyr is more consistent with general knowledge than the meaning of the proposition that a government executes a hangman (e.g., Schank & Abelson, 1977). Because of the existence of this second explanation, slower reading times for the hangman sentence cannot be taken as unequivocal support for constraint-based models like McRae et al.'s over other models (e.g., the two-stage model proposed by Frazier, Clifton, and Rayner; e.g., Frazier, 1978;

Frazier & Clifton, 1996; Frazier & Rayner, 1982; Rayner, Carlson, & Frazier, 1983).

According to McRae et al. (2005), MTS "predicts that the difficulty of a reduced relative should be primarily a function of whether it uses an IC [internally caused] or EC [externally caused] verb" (p. 1025). This is incorrect. McRae et al. overlooked two critical points. First, it is possible to understand strings of words that are prohibited as sentences by the linguistic system. Second, for MTS the difficulty of a sentence with a reduced relative is influenced by all the same factors that affect language comprehension in general, including the frequencies of the words, the number and complexity of the propositional relations, and various types of holistic meaning.

In their Study 2, McRae et al. (2005) asked subjects to rate how easy it is to understand items with internally caused verbs, items like *Dogs walked frequently are usually well behaved* and *The horse raced past the barn fell.* On the basis of the finding that subjects rated some of these items as relatively easy to understand, even easier than some items with externally caused verbs, McRae et al. argued that internally caused verbs in reduced relative clauses are acceptable (p. 1026). However, strings like *The horse raced past the barn fell* can be understood even if they are prohibited, because all the various types of information involved in language processing, such as general knowledge about horses and racing, can be used to put together meanings for them.

To reinforce the point that it is possible to give differential understandability ratings to prohibited strings of words, we conducted a study in which naive subjects rated strings like *Colorless green ideas sleep furiously.* This string has the meanings conveyed by its structures (e.g., adjective–adjective–noun and intransitive modified by adverb) and the words in them. With the same instructions as were used by McRae et al. (2005, Study 2), our subjects rated this string and the others like it as more understandable (mean rating of 5.5 on a 1–7 scale) than randomly ordered strings of the same words (*Green sleep ideas colorless furiously;* mean rating of 6.7), $F_2(1, 2) = 35.7$, $p < .05$.

McRae et al.'s Study 2 (2005) is similar in some ways to Experiment 7 in McKoon and Ratcliff (2003). McRae et al. used a set of sentences with reduced relative clauses that would be prohibited by MTS because of the internal causality of their verbs, and a set of sentences with reduced relative clauses that would not be prohibited. As mentioned, McRae et al.'s subjects rated some of the MTS-prohibited sentences as easier to understand than some of the not-prohibited sentences. However, McRae et al. did not match the sets of sentences on factors known to affect sentence comprehension difficulty, factors such as those enumerated above. For Experiment 7 in McKoon and Ratcliff (2003), we did attempt matching. Like McRae et al., we constructed two sets of sentences, one set with reduced relative clauses that would be prohibited because of the internal causality of their verbs and the other set with sentences that would not be prohibited. For example, *The horse raced yesterday at Del Mar will be sent to stud at the end of the year* would be prohibited, because *the horse* is the internal cause of the racing event. We used instructions slightly different from those McRae et al. used in their Study 2: We asked subjects to rate for each sentence how easy it was to read. There were three groups of subjects. The first group rated only a part of the sentence, specifically, a part that was the same as the whole sentence except that the relative clause was deleted (e.g., *The horse will be sent to stud at the end of the year*). The second group rated a different part, the reduced relative clause, which by itself is a sentence (e.g., *The horse raced yesterday at Del Mar*). For neither of these groups of subjects were there significant differences in the ratings for the two sets of sentences. From this, we assumed that we had done a reasonably appropriate job of matching the difficulty of the parts of the two sets of sentences. When the parts of the sentences were put back together for the third group of subjects (e.g., into the whole sentence *The horse raced yesterday at Del Mar will be sent to stud at the end of the year*), the MTS-prohibited sentences were rated as significantly worse than the other sentences. We concluded that for our Experiment 7, with its sentences, instructions, and method of matching on factors other than the causality of the verbs, subjects' abilities to use general knowledge to understand MTS-prohibited sentences were not sufficient to overcome their unacceptability relative to not-prohibited sentences.

Unambiguous Relative Clauses

In efforts to pick out the effects of reduced-relative/main-clause ambiguities on sentence comprehension from the effects of other variables, researchers have most often compared sentences with reduced relative clauses with sentences that are exactly the same except that the clause is not reduced. However, according to MTS (McKoon & Ratcliff, 2003), reduced relatives differ from nonreduced relatives not only in their ambiguity but also in their meaning: The clausal information and the entity that is the head of the clause are more strongly connected during processing for a reduced relative than for a nonreduced relative. The weaker connection for the nonreduced relative means that any possible discord between the head of the clause and the information in the clause is less evident to the processing system than it would be for a reduced relative. For example, the incompatibility between a government executing a hangman and the standard hanging script (e.g., Schank & Abelson, 1977) would be less evident to the processing system with a nonreduced than with a reduced relative. This difference in meaning means that nonreduced relatives, as they have been used in previous experimental designs, are not appropriate baselines against which to validate models for the processing of possibly ambiguous reduced relatives (McKoon & Ratcliff, 2003, p. 515; counter McRae et al., 2005, p. 1026).

Researchers have also used a second type of experimental design, in which reduced relative clauses with verbs that are ambiguous between their past and past participle forms are compared with reduced relatives with verbs that are unambiguous, as in the first two sentences below. This design has been used in only four studies: MacDonald (1994), Spivey-Knowlton and Tanenhaus (1998), Trueswell, Tanenhaus, and Garnsey (1994), and Spivey-Knowlton, Trueswell, and Tanenhaus (1993).

The dictator overthrown in the coup was hated throughout the country.

The dictator captured in the coup was hated throughout the country.

The dictator who was overthrown in the coup was hated throughout the country.

The dictator who was captured in the coup was hated throughout the country.

The constraint-based notion (e.g., McRae et al., 2005, p. 1026) appears to be that with unambiguous verbs, there is no choice for the processing system to make between a reduced relative and a main clause. *Overthrown* is unambiguous, and therefore *the dictator overthrown in the coup* must be a reduced relative. However, the reasoning behind this notion is not clear. It would seem that constraint-based models (as implemented, e.g., McRae et al., 1998) should choose a reduced relative over a main clause interpretation for unambiguous verbs in the same way as they do for ambiguous verbs, by weighting and summing the various probabilities relevant to the choice via a simple connectionist processing mechanism. The challenge to constraint-based models is to accurately, quantitatively, and simultaneously account for data for both reduced and nonreduced relatives with both ambiguous and unambiguous verbs, that is, data for all the four types of sentences above. To date, in the 10 years that these data have been available, no constraint-based model has met this challenge.

Moreover, in the studies with unambiguous verbs, the ambiguity of the verbs was confounded with the probability that they occur in reduced relative clauses in naturally produced sentences. The unambiguous verbs (like *overthrown*) that were used by Mac-Donald (1994), Spivey-Knowlton and Tanenhaus (1998), Trueswell et al. (1994), and Spivey-Knowlton et al. (1993) occur in reduced relative clauses about twice as often as the ambiguous verbs with which they were compared (McKoon & Ratcliff, 2005).

In short, designs that have been used to examine the effects of reduced-relative/main-clause ambiguity on processing have confounded ambiguity with at least one other factor: For nonreduced relatives, the confounding factor is construction meaning, and for unambiguous clausal verbs, the confounding factor has been the probability of occurring in a reduced relative clause.

Tests of Constraint-Based Models

In the experiments reported by McKoon and Ratcliff (2003), constraint-based model predictions about sentences with the reduced-relative/main-clause ambiguity were disconfirmed. Constraint-based models predict that reading times should depend on the extent to which the head of the relative clause is a typical agent versus patient of the clausal verb, but in McKoon and Ratcliff's data, they did not. McRae et al. (2005) argued that the means of the reading times in McKoon and Ratcliff's data did vary appropriately with typicality, at least for some sets of items. But it is the correlations between typicality and reading time values that are important, not the means. McRae et al. did not mention that for the five sets of items McKoon and Ratcliff tested, with typicality measured exactly as constraint-based researchers have done (McRae et al., 2005, p. 1027), only 4 out of 15 correlations were significantly consistent with constraint-based predictions.

To show that the correlations were not constrained by too narrow a range of typicality or reading time values (see McKoon & Ratcliff, 2003, p. 519, Figure 2), we conducted a simple Monte Carlo study to determine whether there was sufficient power in our experiments to find significant correlations if they were present in the data. According to a constraint-based model, as the difference between the typicality of the head of a reduced relative as an agent and its typicality as a patient increases (McKoon & Ratcliff, 2003, p. 521), reading times should increase. For the Monte Carlo simulations, we assumed a perfect linear increase and then added

measurement error to it. We used a range of typicality differences of 0 to 4 and a range of reading time differences of 0 to 150 ms (McKoon & Ratcliff, 2003, Figure 2), which produces a linear function such that the reading time difference is 37.5 times the typicality difference. The standard errors in the typicality ratings for the sentences in the experiments varied from 0.05 to 2.0, and the average standard error in the typicality differences was 0.65. The standard errors in the reading time differences were reported in McKoon and Ratcliff (2003), and 50 ms is an approximate average of them. Using these average standard errors to add variability to the linear function, we generated 1,000 sets of simulated data and computed the correlation for each set. The average correlation across the 1,000 sets was .58 (close to the split-halves correlation of .48 reported as a check on power by McKoon & Ratcliff, 2003, p. 519). Thus, we conclude that the experiments did have sufficient power to observe the predicted correlations, had they been present in the data. The manipulation of typicality in the studies reported by McKoon and Ratcliff was not "weak," as claimed by McRae et al. (2005, p. 1029).

McRae et al. (2005) also suggested that there were problems with one of the five sets of sentences tested by McKoon and Ratcliff (2003, Corpus Set 1), but even if valid, the problems are too minor to help the constraint-based case. One problem they cited was that for three sentences, it was not clear which of two possible nouns served as the head of the reduced relative, and a second problem was that one clausal verb was used in the less dominant of its two senses. Eliminating these sentences from the correlations changed the data only slightly, not enough to significantly follow constraint-based predictions. McRae et al. also thought that some sentences began with strings of words that were not ambiguous because the words could only be a reduced relative clause—they could not possibly begin a main clause. We think this is incorrect: *The list of 19 directors proposed,* for example, can begin a main clause, as in *The list of 19 directors proposed only those who had had more than 10 years' experience.* McRae et al. also suggested that subjects cannot rate the typicality of *people* or *person* as agents or patients of verbs, but we do not see why not. Finally, McRae et al. objected to calculating correlations on the basis of reading time per word for each sentence; however, switching to calculating them on the basis of total reading time for each sentence did not significantly change the failures to fit constraint-based predictions.

Besides typicality, McKoon and Ratcliff (2003) examined several other constraint-based predictor variables. For example, the verbs in reduced relative clauses are passive, and therefore, according to constraint-based models, reading times should depend on the probability with which verbs occur in the passive (compared with active) voice in naturally produced sentences. Trueswell (1996; McRae et al., 2005, p. 1029) did find the predicted relationship, but McKoon and Ratcliff (2003) tested four other sets of sentences and found that reading times did not vary significantly with passive probability. This was true even though the spread of the probability values for the four sets of sentences was large (from .01 to .88; the mean probability of occurring in passive voice for the high-probability half of the items was .71, and the mean for the low-probability half of the items was .37).

Statistics calculated from a corpus of naturally produced sentences also showed problems for constraint-based models (McKoon & Ratcliff, 2003). For example, reduced relative clauses,

which should be difficult to process according to constraint-based models, occur more frequently than nonreduced relative clauses, which should be easier to process. Reduced relatives in the subject positions of sentences should be more difficult to process according to the models than reduced relatives in object positions, but the former occur more frequently. McRae et al. (2005) did not explain these findings.

Conclusions

McRae et al. (2005) offered a series of criticisms of the MTS framework advocated by McKoon and Ratcliff (2003). Some were based on misunderstandings of the assumptions MTS makes about verb representations and their relationships to sentence structures. Others concerned ambiguity resolution. One of the latter was that MTS cannot explain how ambiguous sentences are processed. However, MTS is not a processing theory, as was made clear in its initial presentation (McKoon & Ratcliff, 2003). The research strategy of initially developing representational hypotheses and only later developing processing hypotheses is well regarded in psycholinguistics (e.g., Kintsch, 1974; Kintsch, 1988; Kintsch & Keenan, 1973; Kintsch & van Dijk, 1978). McRae et al. also suggested possible problems with data presented by McKoon and Ratcliff (2003), data for which 11 out of 15 correlations predicted by constraint-based models failed to reach significance. Taking the suggested problems into consideration did not significantly improve the fit between the constraint-based models and the data.

According to McRae et al. (2005), McKoon and Ratcliff (2003) implied "that ambiguity is not relevant to reduced relative clauses" (p. 1026). This is not the case. What we did argue is that any candidate model of ambiguity resolution must be supported by convincing data. The effects found in data must be tightly tied to predictor variables identified by the model, and it must be shown that the effects are not confounded by factors outside the model, at least so far as such factors are known to psycholinguistic research.

Contrary to what McRae et al. argued (2005, pp. 1023, 1027), and as McKoon and Ratcliff (2003, p. 510) pointed out, MTS could be combined with the two-stage theory for sentence processing advocated by Clifton, Frazier, Rayner, and colleagues. First-stage, syntactic processes would precede second-stage processes that work with the kinds of meaning information that are the focus of MTS. This combination could be consistent with currently available data on the processing of reduced relative clauses. Processing of *The horse raced past the barn fell* might proceed as follows: *The horse raced past the barn* might be processed as a main clause by first-stage processes, then this analysis rejected by first-stage processes when the main verb *fell* is encountered, then the reduced relative analysis computed by first-stage processes, and then this second analysis rejected by second-stage processes like those suggested by MTS. As Frazier (1995) has emphasized, first-stage processes may proceed so quickly that they are not measurable experimentally.

In their discussion of MTS and the reduced relative ambiguity, McRae et al. (2005) left out a number of relevant findings. First, they claimed that there is no clear distinction between internally caused verbs and externally caused verbs, providing as evidence only the two rating studies we criticized above. They gave no explanation for the patterns of data from production and comprehension presented by McKoon and Ratcliff (2003, summarized in Table 1). In comprehension, processing times are shorter for internally than for externally caused verbs in lexical decisions, in sentence acceptability judgments for transitive and intransitive sentences, and in reading times for transitive and intransitive sentences. In sentence production, there are distributional differences between the two types of verbs across syntactic constructions, and there are differences between them in semantic restrictions across syntactic constructions (McKoon & Macfarland, 2000, 2002; McKoon & Ratcliff, 2003).

Second, McRae et al. (2005) took nonreduced relatives to be different from reduced relatives only in ambiguity, failing to take into account data that show differences in the meanings comprehended from them and the verbs produced in them by naive speakers and writers (McKoon & Ratcliff, 2003). Third, McRae et al. took reduced relatives like *the hangman executed by the government* and *the martyr executed by the government* to be different from each other only in factors directly involved in ambiguity resolution; they failed to offer a methodology for separating ambiguity-relevant factors from holistic factors such as general knowledge. Fourth, McRae et al. took unambiguous past participle verbs to be different from ambiguous past participle verbs only in their ambiguity, not considering that they might differ in distributional patterns of occurrence across syntactic structures. Whether constraint-based models of the kind advocated by McRae et al. could simultaneously handle data of all these sorts is an open question.

Finally and perhaps most significantly, McKoon and Ratcliff (2003) found that reduced relatives with internally caused verbs occur in naturally produced sentences with a probability so close to zero that the few occurrences likely reflect speaker or writer error. The probability of a manner-of-motion verb like *raced* occurring in a reduced relative clause is only about 1 in 3,500, whereas the probability of verbs without the internal causality feature occurring in reduced relatives is about 1 in 16 (in the corpus used by McKoon & Ratcliff, 2003). McRae et al. (2005) did not offer an explanation for this near-zero probability.

Overall, we see a series of challenges for psycholinguistic research: how to define and understand the kinds of meanings that are conveyed by syntactic structures, how to define and understand the interactions of other kinds of meanings (especially propositional, discourse, and general knowledge meanings) with syntactic meaning, how to empirically separate the effects of one kind of meaning from the effects of other kinds of meaning, and how to develop a theory that provides a unified explanation of comprehension data and production data. MTS is intended to stress the evaluation of theory and data in the light of all of these considerations.

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