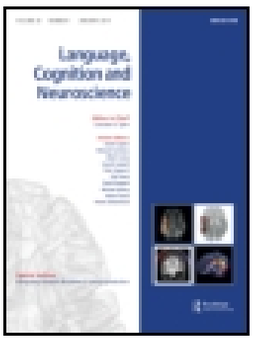

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COMMENTARY

Prediction during sentence comprehension is more than a sum of lexical associations: the role of event knowledge

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Psycholinguistic research, like much of cognitive science, is in the midst of a vigorous inquiry into the role of predictive mechanisms (DeLong, Urbach, & Kutas, 2005; Dikker, Rabagliati, & Pylkannen, 2009; Kamide, Altmann, & Haywood, 2003; Kim & Gilley, 2013; Van Petten & Luka, 2012). This inquiry seeks to explain how language comprehension is not only a process of responding to the linguistic input that arrives at our senses, but also of anticipating that linguistic input based on what we have encountered so far. Given the many combinatory regularities in language that could support such guesses about what is likely to follow, it is not surprising that predictive mechanisms are employed during language comprehension. Prediction may be crucial to explaining how we can recognise and combine word meanings quickly enough to keep up with the rapidly unfolding linguistic input – some of the critical computations are prepared in advance. We comment here on an investigation by Chow, Smith, Lau, & Phillips (2015) into two interesting and important aspects of this larger question: How do we predict upcoming verbs as we comprehend sentences? And how are predictions constrained by limitations in processing resources and available time?

Chow et al.'s experiments

Chow et al. hypothesise that predictions about an upcoming verb, as in sentences such as 1–3 in Table 1, are generated by a mechanism that first identifies the arguments within a clause, and then preactivates verbs that are lexically associated with those arguments. Preactivated verbs are then retrieved from memory more easily than verbs that are not preactivated.

Chow et al. tested this hypothesis in two event-related potential (ERP) experiments. In the first experiment, the authors found that target verbs elicited smaller amplitudes of the N400 ERP component in sentences such as 1a than in sentences containing an argument substitution, such as 1b. This result is compatible with a large literature reporting that N400 amplitude is inversely proportional to that word's offline predictability (Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Kutas & Hillyard, 1984). The authors conclude that retrieval of the verb is facilitated when it is strongly associated with its preverbal arguments, as in 1a (*tenant, landlord*: *evicted*), compared to 1b (*realtor*, *landlord*: *evicted*).

The first experiment also showed, in contrast, that target verbs did not differ in N400 amplitudes when they followed normal vs. role-reversed argument configurations, as in 2a and 2b. The authors conclude that although these two sentences involve different structural roles for *customer* and *waitress* (e.g. *waitress* is subject in 2a but object in 2b), those structural differences failed to influence predictions about the verb, resulting in similar N400 amplitudes.

In a second experiment, target verbs elicited smaller N400s in sentences such as 3a than 3b. Chow et al. again attributed N400 differences to easier retrieval of verbs that are strongly associated with their arguments, as in 3a (*neighbor*, *landlord*: *evicted*) compared to 3b (*exterminator*, *landlord*: *evicted*). The authors further conclude that only verb *arguments* can drive predictions for upcoming verbs. In support of this conclusion, Chow et al. consider an alternative explanation in which predictions are generated from the set of *all* preverbal words. Because this set is identical in 3a and 3b (*exterminator*, *inquired*, *neighbor*, *landlord*), the alternative account is unable to explain the observed N400 differences.

The bag-of-arguments hypothesis

Chow et al. integrate the overall pattern of effects described above within a "bag-of-arguments" account

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Table 1. Stimulus examples from Chow et al. (2015).

1a	*The superintendent overheard which* **tenant** *the* **landlord** *had* evicted *at the end of May*	Argument substitutions (Experiment 1)
1b	*The superintendent overheard which* **realtor** *the* **landlord** *had* evicted *at the end of May*	
2a	*The restaurant owner forgot which* **customer** *the* **waitress** *had* served *during dinner yesterday*	Argument role reversal (Experiment 1)
2b	*The restaurant owner forgot which* **waitress** *the* **customer** *had* served *during dinner yesterday*	
3a	*The exterminator inquired which* **neighbor** *the* **landlord** *had* evicted *from the apartment complex*	Argument substitution with same words (Experiment 2)
3c	*The neighbor inquired which* **exterminator** *the* **landlord** *had* evicted *from the apartment complex*	

Note: Target verbs are underlined and arguments of the verb are in bold.

of prediction. This means two things. First, arguments, and only arguments, influence predictions about a verb. Second, the arguments' lexical meanings but not their structural roles (e.g. subject and object) influence predictions – thus the arguments are in an unstructured collection, or "bag". These constraints are motivated by information-processing limitations. It is assumed that comprehenders can rapidly identify a clause and its arguments, but that identifying the arguments' structural roles takes longer to complete. Because predictions about verbs are thought to be made under extreme time pressure, the account proposes that predictions can only be informed by the lexical properties of the arguments, and cannot wait for structural role information.

An alternative account: predictions reflect event knowledge

The Chow et al. experiments produce valuable new evidence about the nature of predictions during language comprehension. However, we disagree with their central conclusion that predictions are based only on unstructured lexical associations. Instead, we propose that predictions are mediated by *event knowledge* – structured knowledge about events and their participants – which is activated automatically during incremental language comprehension (Kim & Osterhout, 2005; McRae, Hare, Elman, & Ferretti, 2005; Metusalem et al., 2012[1]). One way that event knowledge is structured is through the specification of prototypical thematic roles within an event and the relations between them. For instance, an *eating* event involves an eater and something eaten, and the participants that fill these roles, based on the linguistic input, are structurally distinct within the event. The bag-of-arguments hypothesis argues that structural knowledge such as this cannot influence predictions about verbs.[2]

To illustrate how event-based structural knowledge might influence predictions, let's explore what kinds of event knowledge are likely to be activated in each of the examples above. In 1a, the combination of *tenant* and *landlord* drives activation of knowledge related to apartment rental scenarios, which likely includes evictions, paying and collecting rent, and repairing damaged furniture. This facilitates the retrieval of the verb *evicted*. In 1b, by contrast, the arguments *realtor* and *landlord* are more likely to drive activation of knowledge about real estate transactions than about rental scenarios. This eases retrieval of verbs such as *bought* and *sold*, but not *evicted*. Thus, the N400 difference between 1a and 1b is compatible with different patterns of event knowledge activation.

In both 2a and 2b, the arguments *waitress* and *customer* (in any order) are very likely to activate event knowledge about service in a restaurant, which includes serving food, ordering, tipping, etc. Both sentences, therefore, predict the verb *served*, explaining why no difference in N400 amplitude was found between these two conditions.

Although event knowledge activation should not lead to different predictions about subsequent lexical content in 2a and 2b, it should lead to qualitatively different *syntactic* predictions. We expect that before the verb *served* is presented in 2a and 2b, comprehenders would assign *waitress* and *customer* to the predicate-specific thematic roles of Agent and Patient, respectively, in a restaurant-service event. In 2a, these role assignments should combine with the given word order to generate syntactic predictions that are well-matched by the active form of the verb that is ultimately presented. In 2b, on the other hand, the syntactic predictions are more likely to be for a passive form of the verb, as in *The restaurant owner forgot which waitress the customer had been* ***served*** *by*…. This raises an important question about whether the brain is sensitive to the unexpected syntactic form of the verb that is ultimately presented in 2b. We believe that this should be the case, and we address this issue next.

Several previous ERP studies have investigated the brain's response to anomalous sentences that are similar to Chow et al.'s 2b. A key characteristic of such stimuli is that they are derived from plausible sentences by reassigning verb arguments to implausible thematic roles. These studies have found that under the above conditions, target verbs do not elicit an N400 effect (typically associated with semantic processing difficulty) and instead trigger an enhanced P600 (typically associated with syntactic processing difficulty), relative to their plausible counterparts (Hoeks, Stowe, & Doedens, 2004; Kim & Osterhout, 2005; Kim & Sikos, 2011; Kolk, Chwilla,

Van Herten, & Oor, 2003; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003). Thus, such findings have been labelled "semantic P600" effects. For example, Kim and Osterhout (2005) observed this pattern of ERP effects when comparing sentences such as *The hearty meal was devouring …* to *The hearty meal was devoured …*. Why such sentences do not elicit enhanced N400, in spite of semantic anomaly, has become an active area of research, and likely contributes to the motivation for the studies reported by Chow et al. The absence of an N400 effect in virtually all of the above studies is compatible with either the bag-of-arguments hypothesis (e.g. lexical association priming between *meal* and *devour*), or with the event knowledge account (e.g. structured event knowledge about eating drives *meal* to be encoded as the Theme of *devouring*). The finding that such sentences elicit P600 effects, however, is more theoretically constraining. Kim and Osterhout (2005) argued that a structured event-representation, which assigns *meal* as Theme of *devour*, conflicts with the syntactic cues on the verb, resulting in attempts to reanalyse or repair the perceived syntactic anomaly (e.g. *devouring* → *devoured*). Thus, the event-representation account can explain both the N400 and P600 effects in many such examples. In contrast, the bag of argument hypothesis can predict the absence of an N400 effect, but it cannot predict the presence of the P600 effect in brain responses to *devouring* and *devoured* above.

Note that if the event knowledge account is correct, then we might expect event knowledge to clash with syntactic form in Chow et al.'s sentence 2b, leading to a P600 effect relative to 2a.[3] In fact, Chow et al. did observe such an effect (visible in their Figure 2), which appears to be numerically larger and more sustained in duration than the P600 effect observed in 1b. We think that this pattern of P600 effects is likely compatible with attempts to repair these sentences to accommodate the event knowledge activated by the two arguments, but it is not much discussed in the paper.

Event knowledge predictions are distinct from summed lexical associations

We do not intend to argue that lexical associations cannot influence predictions. Rather, we suggest that recognising words activates event knowledge whose predictive effects are greater than the sum of the individual words' lexical associations. In fact, we believe that this sort of dynamic is likely at play in Chow et al.'s study. Consider sentences 3a and 1b, which exemplify strongly and weakly predictive contexts for *evicted*, respectively. If those predictions reflect only lexical associations, then *neighbor* (3a) should be a stronger associate of *evicted* than *realtor* (1b) is (*landlord* cannot cause differences in predictions, because it is an argument in both sentences). But at least one estimate of lexical association strength, latent semantic analysis (Landauer & Dumais, 1997), indicates the opposite: *realtor* is stronger than *neighbor* in terms of its association with *evicted* (LSA cosine 0.2 vs 0.08).[4] Generalising beyond these specific examples – and recognising that these items may not be representative of all the stimuli – we expect that event knowledge would predict *evicted* in many situations, even when *none* of the verb's arguments is a strong associate. Consider, for example, *Jane failed to pay rent for six months and worried that* ***she*** *would soon be* _____ (the verb's argument is in bold). Conversely, we would expect that there are situations when *evicted* is not predicted, even though its arguments are close associates, as in *Jane wondered which* ***landlord*** *the* ***owner*** *had* _____.

Predictions are not always absolute

It is also important to clarify that predictions, as we view them, might not always select a single word with a high degree of confidence. Of course, there are highly predictable situations such as *The pupil remembered that the largest city in France is* _____ . However, in most scenarios, predictions are more likely to be diffuse, low-confidence, and compatible with multiple outcomes. This is what we mean when we say that *customer* and *waitress* predict event knowledge compatible with *served, ordered*, and *tipped*. This sort of low-confidence prediction seems appropriate for the types of stimuli used by Chow et al., where words that were considered highly predictable were produced only approximately 25–28% of the time in a separate cloze-norming study.[5]

Conclusions

Illuminating how language comprehension is constrained by limitations in processing resources and time available to act on the linguistic input is a vital component of the psycholinguistic endeavour. In this spirit, Chow et al. have offered a provocative explanation for some intriguing phenomena that are currently a major focus of psycholinguistic research. We think the authors are likely correct in positing that preverbal arguments have a strong influence on predicting verbs. This idea is consistent with the strong associations between arguments and event knowledge. However, we do not think it is wise to rule out the contribution of any specific class of information, such as event-structural roles or thematic relations, at any point during the processing of sentences. The influence of such knowledge in online

language processing has been suggested not only by recent ERP studies, but also by classic psycholinguistic studies. For instance, people seem to provisionally assign thematic relations to arguments during online syntactic ambiguity resolution within a few hundred milliseconds of reading both the noun and the verb (Trueswell, Tanenhaus, & Garnsey, 1994; cf. MacDonald, Pearlmutter, & Seidenberg, 1994). These studies indicate, fairly clearly, that structured semantic knowledge is rapidly activated, which begs the question why such knowledge would not be available to influence predictions, once computed.

We agree that it is important to identify the ways in which predictions are limited by the time available to compute them. However, we would also emphasise that predictions are, by their nature, a way of "buying extra time". Because predictive commitments are computations that occur prior to the input that demands them, they are under less severe time constraints than computations that respond directly to the current input. In sentences such as 1–3, the preverbal arguments occur many hundreds of milliseconds before the critical verb. By the standards of sentence processing models, this is a generous window of time in which to generate expectations about the event-structural roles and thematic relations those arguments will likely fill. In summary, we believe that the findings of Chow et al., as well as those of many previous studies, are compatible with a model in which predictions during comprehension are mediated by structured event knowledge.

Notes

1. The view here should be understood as influenced by a number of proposals, from a variety of perspectives, in which structured representations of events are a key output of language comprehension (Van Dijk & Kintsch, 1983; Fillmore, 1982; Zwaan & Radvansky, 1998).
2. It should be noted that our use of the term "structure" is somewhat different from the way Chow et al. use the term. We focus on event-structural roles (e.g. the eater, the thing eaten, or at a more generalized level, Agent and Theme), while Chow et al. focus on syntactically defined grammatical roles (e.g. subject and object). Although these various types of structure are theoretically distinct, they are also highly correlated.
3. There is a potentially important difference between Chow et al.'s stimuli and most other sentences that trigger semantic P600s: while the latter are semantically anomalous (meals cannot devour), Chow et al.'s sentences are merely unusual (customers rarely serve waitresses). Given this, the conflict between event knowledge and syntactic form might not be as large in the Chow et al. situation.
4. Calculated by the near neighbours function available at http://lsa.colorado.edu using the topic space derived from the "general reading up to 1st year college" sample.
5. These values of cloze probability are in a range that would typically be considered "low constraint" in studies that manipulate the degree of semantic constraint from low to high (Kutas & Hillyard, 1984).

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