

Phonological typicality and sentence processing

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In studies of language, it is widely accepted that the form of a word is independent of its meaning and syntactic category. Thus, the relationship between phonological form and grammatical class would not be expected to affect reading time. However, Farmer *et al.* have now shown that the phonological typicality of a noun or verb influences how rapidly it is read. This finding has implications for both sentence processing and the interpretation of fixation patterns in reading.

Introduction

To a first approximation, natural languages separate form from content [1,2], enabling a finite set of forms to combine to refer to an infinite set of concepts [3]. For example, the phonology of a word determines neither its meaning nor its syntactic category (e.g. ‘cat’, ‘fat’ and ‘sat’ are phonologically similar, but their meanings are unrelated and they belong to different syntactic categories). Moreover, attempts to define syntactic categories in terms of semantic notions (e.g. a noun is a person, place or thing) are notoriously unsuccessful. The form–content distinction is honored both in formal analyses of language structure and in models that show how people build linguistic structure during comprehension. Therefore, phonological factors that are correlated with grammatical category would seem unlikely to influence reading times during sentence processing. However, Farmer *et al.* [4] have recently provided evidence that the phonological typicality of a word with respect to its syntactic category does affect reading.

Determining phonological typicality

Farmer *et al.* measured the phonological typicality of a large set of monosyllabic words that were classified unambiguously as nouns or verbs by translating the phonemic structure of each word into a vector that had a fixed number of phoneme slots, with each phoneme represented by a set of distinctive features. They computed the mean Euclidean distance (a measure of distance in multidimensional space) of each word vector to all nouns and all verbs. Nouns and verbs were closer to words of their own category in terms of their phonology, but individual items varied in terms of how closely they matched the prototypical pattern of their class (Figure 1). The authors then conducted a series of experiments that demonstrated that readers exploit these distributional patterns.

Typicality and reading times

In Experiment 1, the authors reanalyzed an existing database of naming latencies [5] and found that phonological typicality is a significant predictor of time taken to read the word aloud, even after accounting for known factors such as word frequency, word length and orthographic neighborhood size. Because the mapping between sound and spelling is quasi-regular in English, we suggest that the phonological and orthographical typicality of a word for a syntactic category will be highly correlated.

Experiments 2–4 showed that phonological typicality influences reading comprehension. In Experiment 2, participants in a self-paced reading task were presented with structurally unambiguous sentences containing verbs that have strong statistical tendencies to be followed by noun phrases (e.g. ‘The boy saved...’). Participants were presented with sentence frames that contained phonologically prototypical (noun-like) nouns and non-typical (verb-like) nouns. Mean reading times were significantly faster for the noun-like nouns than for the verb-like nouns. Experiment 3 tested the same effects in verbs, using sentence frames that generated strong expectations for a verb (e.g. ‘The girl tried to...’). In this case, reading times were faster for phonologically typical verbs than for noun-like verbs.

Finally, Experiment 4 showed that phonological factors influence the interpretation of noun–verb homonyms such as ‘needs’. Noun–verb homonyms were embedded in sentences that resolved the ambiguity towards a noun interpretation (e.g. ‘...needs were not being met’) or a verb interpretation (e.g. ‘...needs to be more focused’). When the sentence contained a noun-like homograph, there was a significantly greater increase in reading times when the ambiguity was resolved towards a verb interpretation than when it was resolved towards a noun interpretation, which indicates that phonological typicality biased readers to interpret the ambiguous word as a noun. Similarly, for verb-like homonyms, reading times were significantly greater when the ambiguity was resolved towards a noun interpretation rather than towards a verb interpretation. Moreover, readers were significantly more accurate on comprehension questions when the interpretation of the sentence was consistent with the phonological typicality of the ambiguous word.

Implications for sentence processing

Are these results so surprising? Recent work has shown that syntactic, semantic, pragmatic and real-world information have rapid effects on syntactic-ambiguity resolution. In addition, adults and infants are remarkably

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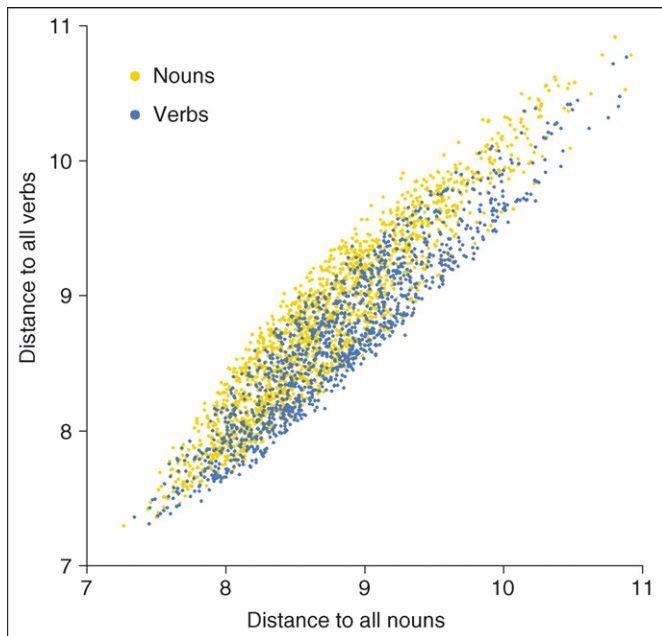


Figure 1. Words in phonological space. Farmer *et al.* [4] plotted words in phonological space as a function of their mean Euclidean distance to all nouns and to all verbs. Nouns are shown in yellow and verbs are shown in blue. Although there is considerable overlap between nouns and verbs, separate clusters of nouns and verbs are also discernible. That is, words tend to sound like other words in their respective grammatical category: nouns tend to sound 'noun-like' and verbs tend to sound 'verb-like'. Figure provided by Farmer *et al.* Reproduced from Ref. [4], with permission from National Academy of Sciences, USA © 2006.

sensitive to distributional regularities in the linguistic input, and large-scale corpus analyses find reliable statistical patterns between the sound of a word and its syntactic category and, more weakly, between the sound of a word and its meaning. However, previous studies on the use of correlated constraints in adult comprehension have focused on ambiguity resolution, and developmental research has investigated the distributional information that might enable infants to bootstrap into the linguistic system in the first place. In each case, the information that is available from the input underdetermines its interpretation, so correlated constraints, even if weakly constraining, would help to resolve indeterminacy. What is unexpected about the results from Farmer *et al.* is that, for skilled adult readers, the speed with which a word is read is influenced by the typicality of its phonology relative to other class members, even when there are unambiguous expectations for a particular grammatical class and the word is unambiguously a member of that class.

Fixation patterns in reading

The results from Farmer *et al.* are a striking example of the importance of distributional patterns in language processing, perhaps, as the authors suggest, as a residue of distributional learning during acquisition. However, the results might also lead to insights into the nature of real-time language processing during reading, including the linking hypothesis between comprehension processes and fixation duration.

The pattern and timing of fixations during reading is a widely used dependent measure in studies of language comprehension, including word recognition, syntactic processing and higher-level interpretive processes. Variables

that map onto aspects of lexical form, such as word length, word frequency (which is correlated with orthographic patterns) and orthographic typicality strongly influence the duration of the initial fixation on a word during reading, which is generally taken to reflect the earliest moments in word recognition. By contrast, syntactic variables and higher-level interpretive variables, such as plausibility, typically do not influence first fixations [6].

Reichle and Laurent [7] show that a reinforcement-learning model that learns to satisfy two constraints can simulate basic patterns of fixation and gaze control in reading. (See Ref. [8] for a discussion of the importance of reinforcement learning for understanding eye movements in natural tasks.) The first constraint is to maintain fixation on a word for a long enough time to retrieve the necessary information from that word. The second constraint is to maximize speed by quickly shifting fixation to the next word. In the Reichle and Laurent model, and other models (e.g. Ref. [9]), the decision to move the eyes is based on an initial shallow assessment of the word that is currently being fixated. If the typicality effects that are reported by Farmer *et al.* in Experiments 2 and 3 influence first fixations (a question that will need to be addressed by future research), then this would resolve a paradox in the sentence-processing literature: namely why higher-level variables that seem to have rapid effects on ambiguity resolution [10,11] rarely affect first fixations. First fixations might be influenced only by expectations that can be translated into form-based estimates of the information that a word is likely to contain. A word that is likely to be informative (i.e. unexpected) would be allotted more fixation time [12,13].

Regardless of whether these conjectures are correct, the results from Farmer *et al.* highlight a central challenge for work on natural language: how can the fact that natural language is sensitive to fine-grained distributional information on multiple dimensions be reconciled with the equally valid observation that language structure, at all levels, seems to be based on relatively categorical representations that abstract away from form?

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Teachers in the wild

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Three recent studies challenge the apparent consensus about the absence of teaching in non-human animals by providing evidence that certain behaviours of ants, birds and mammals satisfy a strict definition of teaching. However, these behaviours, although capable of facilitating information or skill acquisition in youngsters, could not support the transmission of cultural knowledge across individuals, which human teaching arguably serves.

Introduction

Humans are a cultural species whose members generate, maintain and transfer to each other traditions, skills, culture-specific knowledge and values. It has been suggested that there are two main classes of behaviour that accomplish the transfer of these cultural forms across individuals: imitation (or, more generally, observational social learning), in which the recipient is solely responsible for the successful acquisition of knowledge, and teaching, in which the donor has an active role in the transmission of cultural information [1]. Although various forms of observational social learning are widespread in non-human animals [2], it is generally assumed that teaching is a human-specific activity [3–5]. However, this consensus has now been brought into question.

What is teaching?

Although several pieces of anecdotal evidence on teaching in the wild have been cited in the literature [6,7], none of these cases would satisfy the strict criteria that Caro and Hauser [8] laid down as a definition of teaching. According to these criteria, a certain behaviour is teaching if it (i) occurs only in the presence of a naïve observer, (ii) is costly and does not provide any immediate benefit to the teacher, and (iii) facilitates knowledge acquisition or skill learning in the observer. These criteria are not easy to meet. It is difficult to observe natural behaviours in any species that would demonstrably satisfy this definition, and attempts to elicit teaching in the laboratory have repeatedly failed. However, three studies that have been published within the past year challenge the apparent consensus about the

absence of real teaching in non-human animals by providing evidence of behaviours that meet Caro and Hauser's criteria in various taxa.

Evidence for teaching in non-human species

Radford and Ridley [9] observed that adult members of a South African bird species, the pied babbler (*Turdoides bicolor*), produce recruitment purr calls when they find a foraging patch that is abundant in food, and fledglings (youngsters who are not fed any more and have to find their own food) are around. In response, the young birds approach the patch and achieve a greater foraging success than they would have otherwise achieved. According to Rapaport [10], this behaviour satisfies the criteria of teaching because the adults do not produce recruitment calls unless there are fledglings in the group, and they do not themselves benefit from this behaviour, but the youngsters do.

The second recent demonstration [11] of teaching involved an ant species (*Temnothorax albipennis*). In this species, knowledgeable individuals (leaders) guide naïve ants (followers) by running in tandem towards a food source. The leader in the tandem not only directs the follower to a location but also adjusts its behaviour to its pupil: it slows down or even stops to enable the follower to 'memorize' the route. Thus, this behaviour is based on bidirectional signals, and is costly for the teacher while transferring valuable knowledge to the pupil, who will find the food faster with guidance than without it.

The third challenge [12] to the sceptical view on teaching in non-human animals demonstrated facilitation of skill learning, rather than food-source location finding, in meerkats (*Suricata suricatta*). This study provided observational and experimental evidence for a behaviour that had been previously described as 'opportunity teaching' in various predator species [8]. Mature members of the meerkat community (the 'helpers') provision young pups with one of their usual prey, scorpions, either dead, disabled (stings removed) or intact. Dealing with disabled but alive scorpions provides an opportunity for the pups to learn how to kill the prey without being exposed to the danger of being stung or possibly killed by scorpion toxins. Crucially, whether the scorpion is killed, disabled or left intact before being supplied to the pup depends on the pup's perceived age; the older the pup (judged by its begging calls), the more likely it is to be fed intact scorpions. The study also

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