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Brief article

Sentence processing in an artificial language: Learning and using combinatorial constraints

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ABSTRACT

A study combining artificial grammar and sentence comprehension methods investigated the learning and online use of probabilistic, nonadjacent combinatorial constraints. Participants learned a small artificial language describing cartoon monsters acting on objects. Self-paced reading of sentences in the artificial language revealed comprehenders' sensitivity to nonadjacent combinatorial constraints, without explicit awareness of the probabilities embedded in the language. These results show that even newly-learned constraints have an identifiable effect on online sentence processing. The rapidity of learning in this paradigm relative to others has implications for theories of implicit learning and its role in language acquisition.

1. Introduction

Language comprehenders rapidly weigh and integrate many partially informative sources of information when understanding language. For example, Kamide, Altmann, and Haywood (2003) found that listeners' expectations about direct object nouns were modulated by information from the conjunction of the sentence subject and verb: for a scene with a man, girl, motorcycle, and carousel, listeners' eye movements showed they rapidly anticipated the carousel given the speech context "The girl will ride the..." but anticipated the motorcycle given "The man will ride the...". While both carousels and motorcycles are plausible direct objects of the verb *ride*, their relative plausibility changes when the subject and verb are considered together. Bicknell, Elman, Hare, McRae, and Kutas (2008) obtained similar results in the absence of visual contexts, using sentence reading and EEG measures.

These and many similar results support constraint-based accounts of language comprehension (MacDonald, Pearlmutter, & Seidenberg, 1994; Tanenhaus & Trueswell, 1995), which hold that comprehenders weigh complex long-distance combinatorial constraints in real time to interpret language. Constraints are assumed to be learned from people's prior experiences with events and language, but many studies of artificial grammar learning have suggested that constraints of this sort are extremely difficult to learn. For example, research using the serial reaction time task has shown that learning, evidenced by reaction time to more vs. less predictable patterns, declines precipitously as the number of elements required to make a prediction increases, and with the introduction of irrelevant elements in the sequence (Cleeremans & McClelland, 1991; Remillard, 2008). Similarly, learning relationships between nonadjacent speech sounds (Gomez, 2002; Newport & Aslin, 2004) or tones (Creel, Newport, & Aslin, 2004) appears to require the presence of a perceptual or statistical grouping cue that distinguishes critical elements from interveners. These results are striking in light of the fact that long-distance, complex constraints of this sort are said to be critical in sentence comprehension, challenging both the view of statistical learning as a sufficient mechanism for much of language acquisition and also constraint-based comprehension accounts that assume that such learning has occurred.

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We addressed this conflict by using a paradigm that combined artificial language learning and sentence processing methods (Wonnacott, Newport, & Tanenhaus, 2008) to investigate a combinatorial constraint known to affect sentence comprehension. In our artificial language, similar to the Kamide et al. (2003) stimuli, a particular direct object was predicted by a combination of a subject noun and verb that were nonadjacent to the object, and neither the noun nor verb alone had predictive value. We gave adult participants experience with the artificial language and a cartoon world that provided meaning to the linguistic elements. Participants received feedback on language vocabulary but never about grammar or the contingencies between words in the sentences. We tested participants' knowledge of these combinatorial constraints in a self-paced reading task typical of natural language comprehension studies. If adults can rapidly learn these combinatorial constraints and use them in sentence processing, then reading times on the direct object noun phrase should be shorter when that noun is predicted by the combinatorial constraints than when it is not, as in natural language reading (Bicknell et al., 2008).

2. Method

2.1. Participants

Eighty-one native English-speaking undergraduates received course credit or pay for participation.

2.2. Materials

Our artificial language contained the 18 novel words shown in Table 1. All words were phonotactically and orthotactically probable. Words referring to the (always plural) markings contained the plural suffix *-da*. Sentences had a verb-subject-object structure, with post-nominal adjectives and prepositional phrases. All sentences were six words long, taking the form *Verb monster with markings object color.*

Sentences described events depicted in 450 × 350 pixel bitmap images; a sentence-picture pair is shown in Fig. 1 with its English gloss. Two sets of 81 sentence-picture pairs were created, each with one cartoon monster acting on one nonsense inanimate object. We manipulated the frequency of each verb + monster + object conjunction, holding the frequencies of all other conjunctions constant, as shown in Fig. 2. Specifically, in each set of 81 picture-sentence pairs, each of the three monsters, verbs, and inanimate objects appeared equally often (27

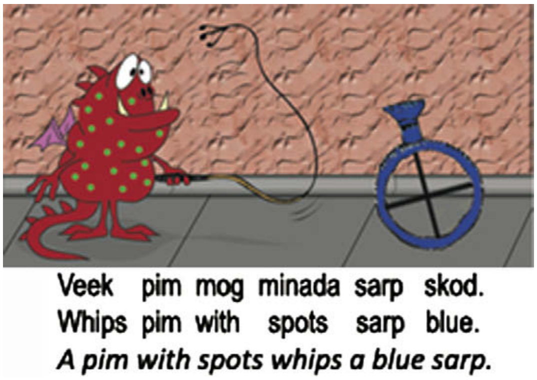

Fig. 1. Sample picture and accompanying sentence, with English gloss and translation.

Table 1
Complete list of words in the artificial language.

Monsters	Verbs	Colors
Pim *Yeen* *Gled*	*Dak* *Grah* *Veek*	*Vorg* *Skod* *Blit* *Peka* *Hoon*
Objects	Markings	Preposition
Sarp *Clate* *Gorm*	*Minada* *Noobda* *Frabda*	*Mog*

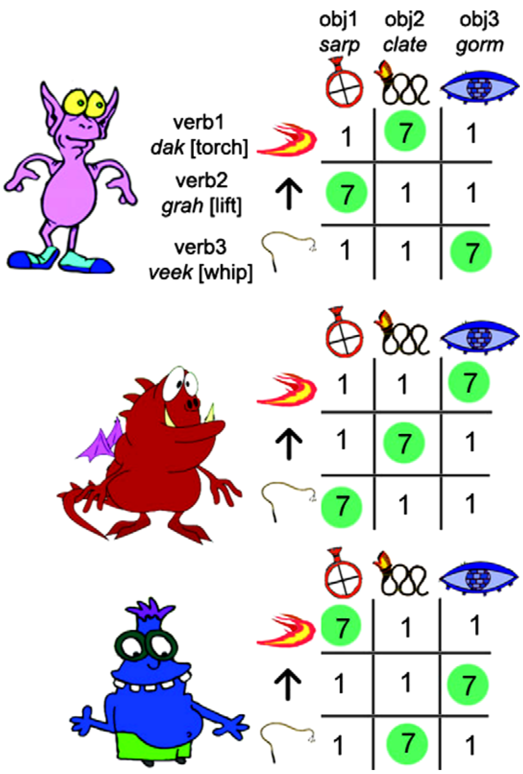

Fig. 2. Frequency in each training block of sentences containing conjunctions of the three critical elements. Monsters (*yeen*, *pim*, *gled*) are shown at left, objects (*sarp*, *clate*, *gorm*) across top of grid, and verbs (*dak* [torch, i.e., breathe fire on], *grah* [lift], *veek* [whip]) are nested within each monster in the grid. For example, in each training set, seven sentences contained the frequent *veek* + *pim* + *sarp* conjunction shown in Fig. 1.