Reply to Gentner et al.:As simple as possible, but not simpler

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In our recent paper (1) we showed that zebra finches, like starlings (2), can learn to discriminate between stimuli generated by two simple formal grammars, but argued that neither study provided a "convincing demonstration" of recursive language learning. Gentner et al. (3) criticize this conclusion and the design of our experiment. Their comments underscore our point that it is critical to exclude that seemingly complex syntactic tasks are solved by applying relatively simple rules.

Gentner et al. (3) correctly point out that both studies differ in how the stimulus sets were created (Tables 1 and 2). They criticize our training set for the presence of bigrams shared between stimuli. Surprising in the light of this criticism and their statement in ref. 3, bigram sharing within and between training and transfer stimulus sets is also present in Gentner et al.'s starling experiment (see the legend of Table 1).

Table 1. Stimulus training schedule for van Heijningen et al. (1)

ABAB				AABB			
a1	b1	a2	b2	a1	a2	b1	b2
a2	b2	a3	b3	a2	a3	b2	b3
a3	b3	a4	b4	a3	a4	b3	b4
a4	b4	a5	b5	a4	a5	b4	b5
a5	b5	a6	b6	a5	a6	b5	b6

Transfer to five novel songs of each type

ABAB				AABB			
a6	b6	a7	b7	a6	a7	b6	b7
a7	b7	a8	b8	a7	a8	b7	b8
a8	b8	a9	b9	a8	a9	b8	b9
a9	b9	a10	b10	a9	a10	b9	b10
a10	b10	a1	b1	a10	a1	b10	b1

Transfer to songs of new element types, but same structure

CDCD				CCDD			
c1	d1	c2	d2	c1	c2	d1	d2
c2	d2	c3	d3	c2	c3	d2	d3
c3	d3	c4	d4	c3	c4	d3	d4
c4	d4	c5	d5	c4	c5	d4	d5
c5	d5	c6	d6	c5	c6	d5	d6

A, B, C, and D indicate element types (1); a, b, c, and d indicate element exemplars. Training began with a single ABAB and AABB stimulus (a1b1a2b2 vs. a1a2b1b2), subsequently extended to all five AABB and ABAB stimuli. ABAB stimuli were composed from six different bigrams, with four present twice, in different positions. Each ABAB stimulus had a matching AABB stimulus constructed from the same elements. Hence, no stimulus could be recognized by learning the constituting elements only, forcing the birds to pay attention to element order. The starling study used eight stimuli per set. Although obtained via a different procedure (2), this did not prevent the presence of repeated bigrams: two AB bigrams were each shared between two stimuli, identical to, e.g., our "a2b2" bigram. If the zebra finches might recognize ABAB stimuli by memorizing three bigrams (one bigram per stimulus, irrespective of its position), then the starlings might do so by memorizing six. The first zebra finch "transfer" set contained two bigrams used before, and eight novel elements (four "a," four "b") The starling set contained four AB bigrams also present in the training set and no novel elements.

Table 2. Subsequent probe session in stimulus schedule for van Heijningen et al. (1)

Structure	Elements
CDCD*	c1 d3 c5 d2
CDCD*	c2 d5 c4 d3
CCDD*	c1 c5 d3 d2
CCDD*	c2 c4 d5 d3
CCCD	c4 c1 c3 d5
CCCD	c5 c2 c1 d4
CCCC	c1 c4 c5 c2
CCCC	c2 c5 c4 c3
DDDD	d1 d3 d5 d2
DDDD	d2 d5 d4 d3
DCCD	d3 c5 c2 d5
DCCD	d4 c3 c5 d1
CDDC	c3 d4 d2 c1
CDDC	c4 d1 d3 c2
CCCDDD	c4 c2 c1 d4 d1 d3
CCCDDD	c5 c3 c1 d2 d5 d4
CCCCDDDD	c3 c1 c4 c2 d4 d3 d1 d5
CCCCDDDD	c4 c2 c5 c3 d1 d5 d4 d2

Our probe testing occurred after transfer to stimuli with "c" and "d" elements and after reaching discrimination. These elements were used subsequently, in novel combinations, in the probe testing phase. The $n = 2$ (AABB and ABAB) probes in the starling study contained several bigrams used in the preceding training phases (2).
*Probes with "ABAB" and "AABB" structure. These, as well as almost all others, shared no bigrams with the training stimuli for this phase.

However, the presence of bigram sharing is inconsequential for the interpretation of our results. Both starling and zebra finch training sets can be distinguished by rote learning, of bigrams or otherwise; therefore, tests of generalization are critical to demonstrate rule learning. The discrimination level for our transfer sets is too high to be explained by the bigram memorization hypothesis, which is thus rejected. This conclusion is reinforced by our probe testing later on; "ccdd" and "cdcd" probes were treated virtually identically to "ccdd" and "cdcd" training stimuli, but shared no bigrams.

Unlike Gentner et al. (2), we also tested for generalization to different element types to examine whether the birds had learned only a *perceptual phonetic* generalization. Failure on this test is not, in itself, evidence against context-freeness, but is crucial for understanding what the birds have really learned. Oddly, Gentner et al. (3) claim that our reasoning is "ungrounded in psychological research." However, spontaneous generalization to novel syllables is a key issue in artificial grammar learning (see ref. 4 and its many citations).

Finally, we did not conclude that the starling data "are best explained by simple perceptual strategies," but stated that "it is still not clear whether the data allow the rejection of the primacy rule." We maintain that statement. The starlings' d' for the primacy probes is lower than for the $n = 2$ probes, but the $n = 3$ and $n = 4$ probes, having lower d' values than $n = 2$, are not tested against primacy. To further evaluate and compare the starling and zebra finch data, they should be subjected to

the same analysis. Unfortunately, Gentner et al. (2) do not provide the number of pecks to the various stimuli, nor the values for individual birds. Regrettably, our requests for this data were rejected and hence this issue remains unresolved.

In sum, we stand by our conclusion (1) that "it remains a challenge to design experiments . . . that unambiguously exclude simpler explanations for discriminating between training structures."

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1. van Heijningen CAA, de Visser J, Zuidema W, ten Cate C (2009) Simple rules can explain discrimination of putative recursive syntactic structures by a songbird species. *Proc Natl Acad Sci USA* 106:20538–20543.
2. Gentner TQ, Fenn K, Margoliash D, Nusbaum HC (2006) Recursive syntactic pattern learning by songbirds. *Nature* 440:1204–1207.
3. Gentner TQ, Fenn KM, Margoliash D, Nusbaum H (2010) Simple stimuli, simple strategies. *Proc Natl Acad Sci USA* 107:E65.
4. Marcus GF, Vijayan S, Bando Rao S, Vishton PM (1999) Rule learning by seven-month-old infants. *Science* 283:77–80.