Evaluating models of referring expression production on an emerging sign language

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Redundant modification in referring expression production varies both within language (more redundant color than size modifiers) [1-5] and cross-linguistically (English speakers produce more redundant color modifiers than Spanish speakers) [6-8]. It is an open question whether these asymmetries are the result of asymmetries in the general referential utility of modifiers [3,9,10] or of incremental language processing pressures [11,12]. Cross-linguistic investigations of redundant modification are important to this debate: similar cross-linguistic rates of redundancy would suggest a strong role for general referential utility. In contrast, lower prevalence of redundant modification in languages with post-nominal modification suggests a strong role for incrementality. Here, we test whether differences in redundant adjective use are systematic for a village language: Central Taurus Sign Language [13,14]. As a language in its infancy, CTSL has no established conventions, and therefore provides us with a unique opportunity to explore how redundancy emerges in the initial stages of language formation. We evaluate different computational models of referring expression that each make different assumptions regarding the source of asymmetries in the production of redundant modifiers.

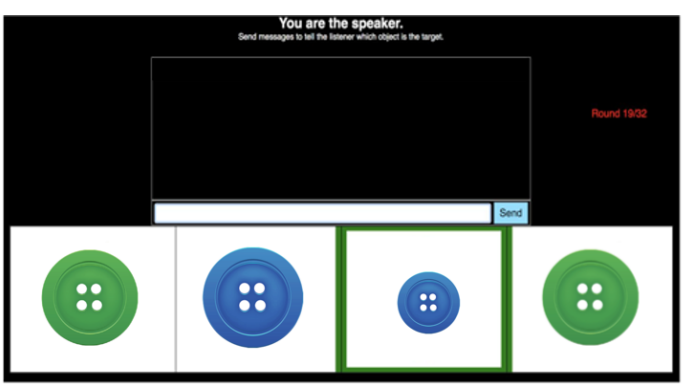
Experiment: Participants (11 CTSL signers, 50 English speakers) played an interactive reference game. On each trial, participants saw a display with 4 objects. The director was asked to communicate the target object (marked by a green border in the speaker's display) to the guesser, who in turn selected an object (Figure 1). On half of the trials, color was sufficient for unique reference, and on the other half, size was sufficient. Participants were recorded during the task and signers' responses were transcribed to English for analysis.

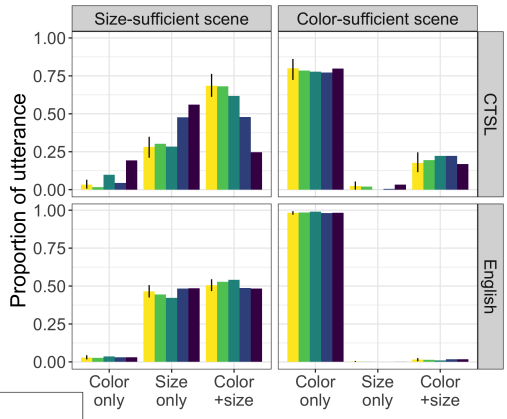
Results (Figure 2)**:** Modification in CTSL was overwhelmingly postnominal (87%). Both CTSL signers and English speakers were more likely to redundantly mention color than size (β=3.24, SE=0.45, $p<.0001$) at rates similar to those previously reported elsewhere in the literature.

Computational Models (Figure 3)**:** Our models extend the Rational Speech Act (RSA) framework [15], in which communication is modeled as recursive reasoning between a speaker and a listener. Models differ as to whether the semantics of words is assumed to be discrete or continuous, and whether an utterance's utility is computed globally (at the level of full referring expressions) or incrementally (word by word).

Model Evaluation: In all four models, size was inferred to have higher cost than color in CTSL. The continuous semantics models best fit the data and correctly predicted more redundant modification in the size sufficient condition in both CTSL and English. In this model, both for the CTSL and English data, the semantic value for size was surprisingly inferred to be higher than the semantic value for color (Figure 4), contrary to previous findings [3].

These results are consistent with theories of referring expression production that link redundant modification to properties of the lexicon. On speaker-oriented variants of this view, the color/size asymmetry reflects differences in the production cost of size vs. color adjectives; on the listener-oriented view, size and color are lexicalized concepts that differ fundamentally in referential utility. Conversely, these results are in tension with theories that center the role of incremental communicative pressures, which may vary cross-linguistically according to morphemic linear ordering constraints. Contrary to previous findings, we did not observe that redundant modification was attenuated in a language with a tendency for post-nominal modification. This is unexpected on accounts that posit that redundant adjectives, all else equal, are of lower communicative utility and hence less likely to be produced when following rather than preceding sufficiently-informative linguistic units in referring expression production.





Discrete semantics

$$[[u]]^D(r) = \prod_{i \in u} \mathcal{L}^D(r,i) \quad \mathcal{L}^D(r,i) = \begin{cases} 1 & \text{if } i \text{ is true of } r \\ 0 & \text{otherwise} \end{cases}$$

$$\mathcal{X}^D(c,i,r) = \frac{|u{:}[[u]]^D(r)=1 \wedge u \text{ is a continuation of } c+i|}{|u{:}u \text{ is a continuation of } c+i|}$$

Continuous semantics

$$[[u]]^C(r) = \prod_{i \in u} \mathcal{L}^C(r,i) \quad \mathcal{L}^C(r,i) = \begin{cases} v^i & \text{if } i \text{ is true of } r \\ 1 - v^i & \text{otherwise} \end{cases}$$

$$\mathcal{X}^C(c,i,r) = \frac{\Sigma[[u]]^C(r){:}u \text{ is a continuation of } c+i}{|u{:}u \text{ is a continuation of } c+i|}$$

Global production model

$$P_{L_0}(r|u) \propto [[u]](r) \cdot P(r)$$

$$C_u(u) = \sum_{i \in u} C_i(i)$$

$$S_1(u|r) \propto e^{\alpha(\ln P_{L_0}(r|u) - C(u))}$$

Incremental production model

$$L_0^{INCR}(r|c,i) \propto \mathcal{X}(c,i,r) \cdot P(r)$$

$$S_1^{INCR}(i|c,r) \propto e^{\alpha(L_0^{INCR}(r|c,i) - C_i(i))}$$

$$S_1(u|r) = \prod_{j=1}^{n} S_1^{INCR}(i_j | c = [i_1 \ldots i_{j-1}], r)$$

Legend: u : an utterance; r : a referent; $[[\cdot]]$: utterance interp. function; $\mathcal{L}$: lexical interp. function; i : a lexical item; c: a partial utterance; v^i : i's continuous semantic value; $P(r)$: prior over r; $C_{u/i}$: cost function on u/i

Standard RSA: **Discrete** semantics + **Global** production model
Incremental RSA: **Discrete** + **Incremental**
Continuous RSA: **Continuous** + **Global**
Continuous-Incremental RSA: **Continuous** + **Incremental**

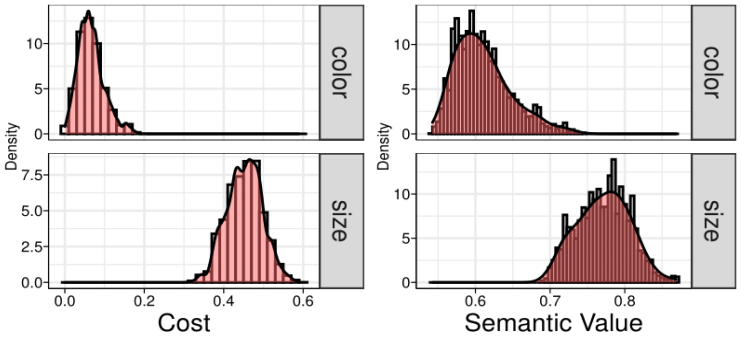


Figure 1 (top left): example display from the director's display on a size sufficient trial; **Figure 2** (top right): Empirically-observed *color*, *size*, and redundant *color and size* utterance proportions in CTSL and English, compared against predictions of the four models under evaluation; **Figure 3** (middle): Summary of models under comparison; **Figure 4** (bottom): Posterior model parameter values of the continuous model on the CTSL data.

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