

## 1. Background

This artificial language learning experiment was conducted in order to study the learnability of *optional* long-distance sound patterns.

### What is consonant harmony?

- A phonological process where one consonant in a word assimilates to another, even when they are far apart. For example:

$C_xV.CV.CV.C_yV \rightarrow C_yV.CV.CV.C_yV$

- In languages with **liquid harmony**, words cannot have both an [l] and an [r].
- In Bukusu (Bantu; Kenya), the applicative suffix [-il] changes to [-ir] when attached to a verb that contains an [r] (Odden 1994):

xam- <b>il</b> -a	'milk for'
- <b>il</b> -te:x- <b>el</b> -a	'cook for'
i:l- <b>il</b> -a	'send thing'
bir- <b>ir</b> -a	'pass for'
- <b>ir</b> -ir- <b>ir</b> -a	'die for'
kar- <b>ir</b> -a	'twist'

### Why are long-distance processes interesting?

- Many sounds can intervene without stopping the process from occurring
- This complexity causes problems for learnability both from a cognitive perspective and for computational algorithms
- A learner would need an enormous amount of memory to keep track of an arbitrarily long sequence of sounds
- In spite of this, long-distance sound patterns are quite common in the world's languages (Hansson 2010), and humans tend to acquire them with ease (McMullin 2016)

### What is optionality?

- Sometimes sound patterns like this are not mandatory, and speakers have two options
- Optional liquid harmony in Bukusu (Hansson 2010):

ruk- <b>il</b> -a	OR	ruk- <b>ir</b> -a	'plait for'
rum- <b>il</b> -a	OR	rum- <b>ir</b> -a	'send for'

- These are *not* "exceptions" or irregularities in the language.
- Native speakers know the distribution of these processes and how to apply them.
- A learner must keep track of the frequency with which pattern occurs.

## 2. Research Questions

- Can humans learn an optional process of liquid harmony that occurs in 50% of their training stimuli?
  - Current computational models will fail when given this type of training as input;
  - The kTSLIA algorithm (Jardine & McMullin 2017) can thus far only account for cases with 100% harmony
- How will the results compare to the control condition where harmony never occurs?
  - Given that harmony occurs only 50% of the time, it is possible that participants in this study would respond similarly to those in the Control (indicating that they do not notice harmony)

## 3. Methodology

### 'Artificial Language Learning' paradigm

- A language was constructed that has an optional pattern of liquid harmony exhibited in 'verb conjugations'
- Participants are exposed to the pattern and then tested to determine whether or not they have detected the pattern.
- Participants completed three phases (using E-Prime 3.0):

#### 1. Practice

- Familiarization with suffixes (headphones on)
- Participants learned that [-li] means past tense and that [-ru] means future tense  
ex: *toke...toke-li...toke-ru*

#### 2. Training

- Participants heard and repeated 192 verb triplets (root...past...future)
- Order of suffixes was counterbalanced
- An l/r in the root sometimes changes to match the suffix:

96 triplets with harmony (root alternation)

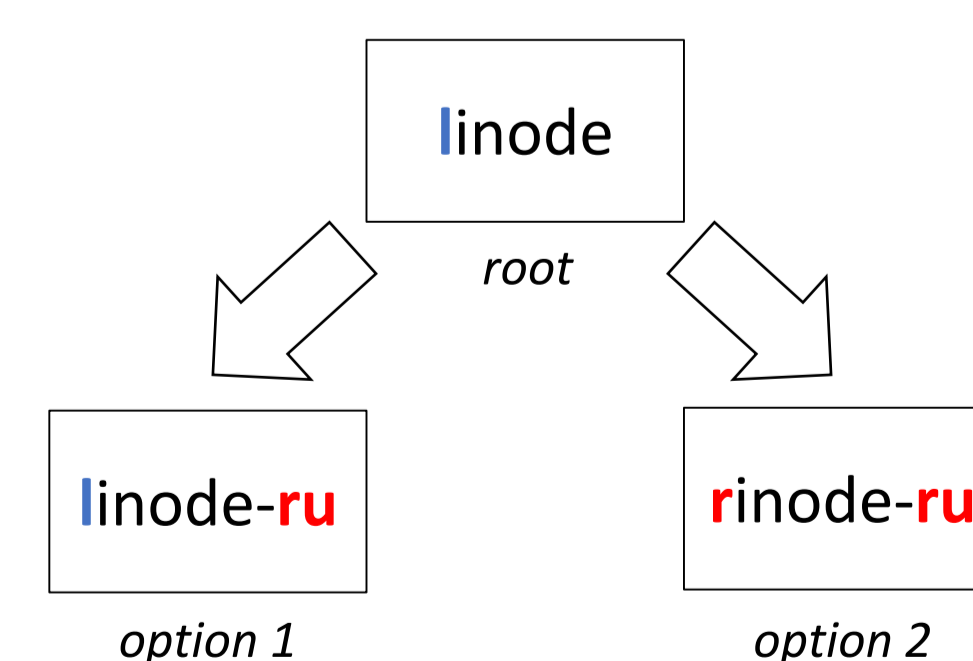
*tukolo...tukolo-li...tukoro-ru*  
*norime...norime-ru...nolime-li*

96 triplets without harmony (no alternation)

*menoli...menoli-li...menoli-ru*  
*korotu...korotu-ru...korotu-li*

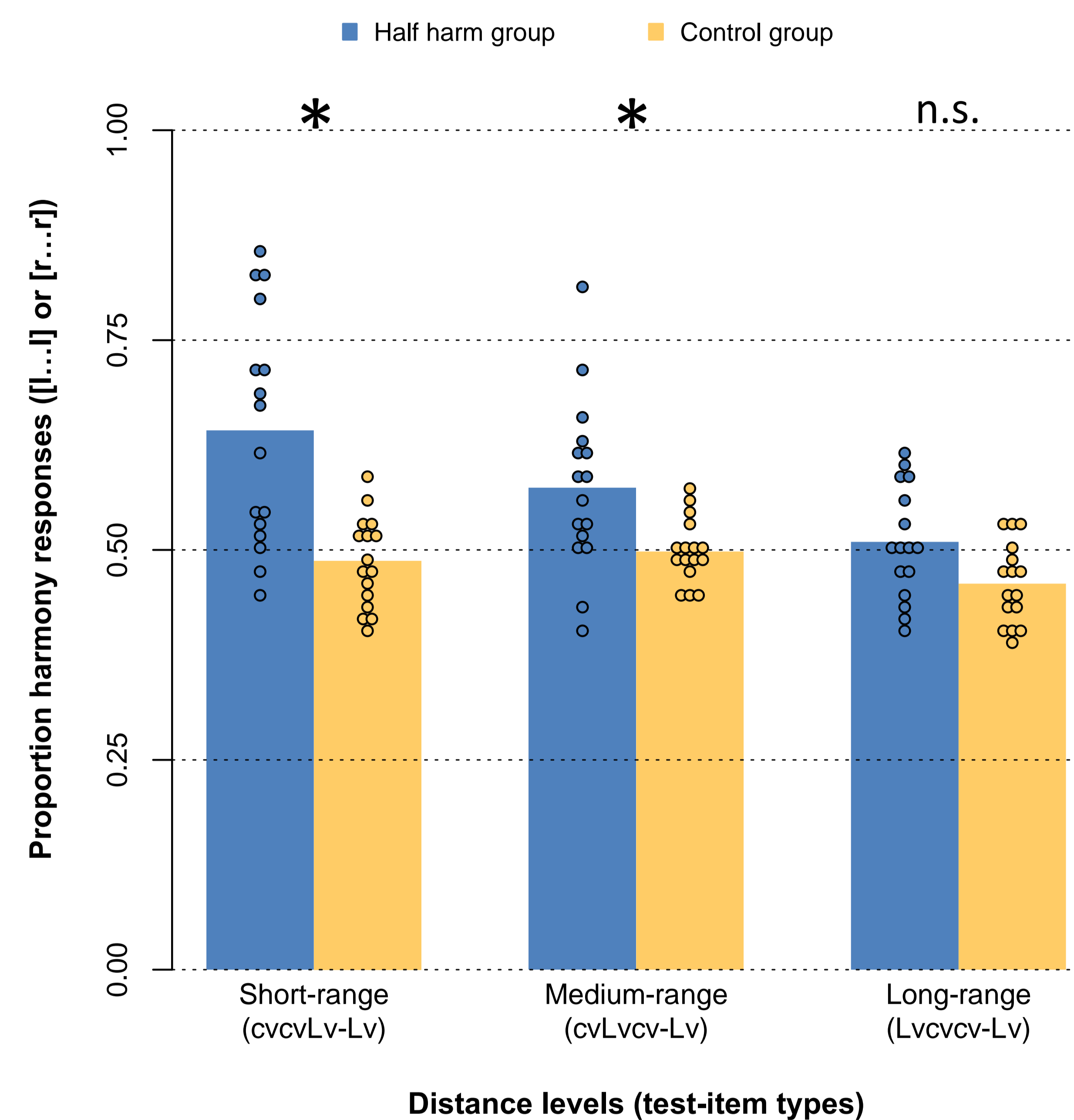
#### 3. Testing:

- 2-Alternative Forced Choice task (2AFC)
- Participant is given a verb root followed by two options with the same suffix
- If harmony is learned, then they are expected choose the option with harmony (on the right below):



## 4. Results and Analysis

- The Control condition, and the baseline for these findings, is data collected in McMullin (2016) for a group who saw no alternations in training.
- Results were analyzed using a mixed-effects logistic regression, in which the dependent variable is whether they chose harmony on each trial.
- Overall, participants in the half-harmony group are about **1.65 times more likely** ( $p > 0.001$ ) to select a test item with harmony.
- This is further broken down into three testing distances in the figure and tables below:



	Short-range	Medium-range	Long-range
Half-harmony vs. Control	OR = <b>2.29</b> $p < 0.001^*$	OR = <b>1.46</b> $p = 0.035^*$	OR = 1.38 $p = 0.067$

Table 1: Odds ratios indicating *how much more likely* the Half-Harmony group is to select the test item with harmony at each of the three testing distances (vs. the Control group)

Coefficient	Estimate	SE	Pr( z )
Intercept	-0.857	0.226	< 0.001*
Harmony in second test option	-0.719	0.155	< 0.001*
Harmony requires no change to root	2.372	0.355	< 0.001*
Short-distance (Control group)	-0.095	0.164	0.564
Long-distance (Control group)	-0.282	0.164	0.086
Half-harmony group (Medium-range)	0.380	0.180	0.035*
Half-harmony x Short-range	0.451	0.222	0.042*
Half-harmony x Long-range	-0.056	0.219	0.799

Table 2: Summary of fixed effects in model with Medium-range baseline

## 5. Discussion and Conclusion

- The results show that learners are still able to detect a pattern of liquid harmony even when it occurs in only 50% of their training
- However, a recently-developed algorithm for learning consonant harmony would fail if given this type of input (kTSLIA; Jardine & McMullin 2017)
- The algorithm must be modified to keep track of probabilities so that it can mimic the distribution of harmony in training
- Note that we cannot simply record the "exceptions" because there is no overlap in training/testing; a generalizing rule is needed.

## 6. Further Research

- More complex harmony patterns where disharmony is motivated by a specific intervening segment
  - For example: *borugu-ru*, but *bolutu-ru*, where /t/ "blocks" the target in the stem from harmonizing to the liquid /r/ in the suffix (i.e. /t/ is opaque)
- The goal of this research would be to investigate when learners start to misinterpret systematic complexity as randomness
- This requires that the algorithm be modified to accommodate a system of opaque segments

## 7. References

- Hansson, G.Ó. (2010). *Consonant harmony: long-distance interaction in phonology*. Berkeley: University of California Press.
- Jardine, A. and McMullin, K. (2017). "Efficient learning of Tier-based Strictly  $k$ -Local languages." In *Proceedings of LATA 11*, 64-76.
- McMullin, K. (2016). Tier-based locality in long-distance phonotactics: learnability and typology. Doctoral Dissertation, University of British Columbia.
- Odden, D. (1994). "Adjacency parameters in phonology." *Language* 70, 289-330.

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