Complexity and perceptual factors in phonotactic learning

Evidence from artificial grammar learning

Jennifer Cole and Hahn Koo
Department of Linguistics
University of Illinois at Urbana-Champaign

Phonological knowledge influences speech production and perception

- **Creative behavior**: language games, novel word formation, loanword adaptation
- **Production**: speech errors typically conform to phonotactic patterns (Fromkin 1971)

Phonological knowledge influences speech production and perception

- **Perception**:
  - phonotactically "legal" words are identified more accurately than "illegals" (Brown and Hildum 1956)
  - knowledge of phonotactic constraints influences the identification of speech sounds (Massaro and Cohen, 1983; Dupoux et al. 1998)
  - and aids in the detection of word boundaries (McQueen, 1998; Norris et al., 1997)

Examining speech behavior as evidence of phonological knowledge

- Production is faster when syllables share a common structure (CVC or CVCC). Facilitation due to economy in speech planning.
  - Speeded repetition: *kemp-pilfner*
  - This facilitation effect has been replicated for vowel sequences that share features (CV/CV) (Linebaugh & Cole 2005, Oh & Cole 2006)

Speech processing experience influences phonological knowledge

- Stored representations include token-specific phonetic detail that influences subsequent identification of syllables and word. (Chambers et al. 1999; Fisher et al. 2001)
- High-frequency sound patterns influence speech production and perception differently than low-frequency sound patterns
  - phonotactic knowledge is gradient, reflects usage patterns (Vitevitch et al., 1997)

Speech processing experience influences phonological knowledge

- Phonological knowledge is constructed incrementally and emerges from repeated experience producing and perceiving words.
  - AGL experiments examine the development of phonological knowledge in response to linguistic experience in the laboratory.
The AGL paradigm

- AGL experiments shed light on
  - the learning mechanism
  - the structures of phonological encoding
  - the impact of phonological knowledge on different linguistic behaviors
    - on-line: speech production and perception
    - off-line: metalinguistic tasks (judging phonological similarity)

Do AGL experiments tap “real” processes of phonological learning?

- The effect of learning on production or perception is the same or similar in both cases.
- Dell et al. 2000: speech errors reflect the phonotactic constraints of English and novel phonotactic constraints introduced in the experiment
  - a larger effect for the English phonotactic constraints

Research questions

Q1: Are all kinds of sound patterns equally learnable?
- Are there constraints on learning that relate to the phonological complexity of the sound pattern?
- If so: Learning mediated through phonological grammar.

Q2: Are there constraints on learning that relate to the phonetic naturalness of the sound pattern?
- Specifically, are phonetically optimal structures learned more quickly or accurately than sub-optimal structures?
- If so: A mechanism for the influence of phonetic factors in phonology.

Q3: What are the effects of phonological knowledge on different kinds of linguistic tasks?
- Are online and offline tasks similarly impacted by phonological knowledge?
- If so: Tasks access a common phonological form, and involve grammatical processes in a similar way.

AGL with the auditory repetition paradigm

- Subjects are familiarized with an artificial language of nonsense words constructed over a subset of the syllables of English.
  - no lexical, syntactic or semantic context
  - phonetic inventory and phonotactic constraints inherited from English
  - plus new phonotactic constraints
- Familiarization can involve listening only, or listening combined with speaking (listen-and-repeat)
AGL with the auditory repetition paradigm

- Test phase
  - Subjects are exposed to new words in a listen-and-repeat task
  - “Legal” words conform to the phonotactic patterns of the training set, “illegal” words do not
  - Measurements are taken of latency to response.
- Prediction: subjects will respond more quickly and/or more accurately to legal words than to illegal words.


Phonotactic learning with adults

- Subjects learned simple (1st-order) constraints restricting the distribution of certain consonants to either onset or coda position: C/position.
- Subjects also learned more complex (2nd-order) constraints in which the positional constraints on consonants was dependent on the quality of the adjacent vowel: C/V&position.


Phonotactic learning with infants

- Head-turn preference protocol with 16.5 month old infants
- Infants exposed to CVC words with the same phonotactic constraints as Onishi et al. (2002).
- Infants learned the 1st-order constraint from brief perception experience, under similar conditions of familiarization as the adults experienced.

AGL with infants: Chambers (2004)

Phonotactic learning with infants

- Infants generalize the constraint learned during familiarization to syllables with different vowels in the test phase.
- Generalization in AGL experiments strengthens the parallel with L1 acquisition.

Q1: Are all kinds of sound patterns equally learnable?

- Can subjects learn complex constraints between non-adjacent sounds?
  - /s a l i l u/ -- constrained sounds are non-adjacent
  - cf.) / f ae s/ -- constrained sounds are adjacent

Q2: Are there restrictions on learning that relate to the phonetic naturalness of the sound pattern?

- We test learning of constraints that mimic assimilation and dissimilation patterns observed in real languages, but which differ in complexity and phonetic naturalness.
Phonotactic constraints

1. Liquid harmony
   /sa.li.la/ /ke.ru.ri/ vs. */sa.li.ra/ */ke.ru.li/
2. Liquid disharmony
   */sa.li.la/ */ke.ru.ri/ vs. /sa.li.ra/ /ke.ru.li/
3. Backness harmony between high vowels
   /sa.li.ki/ /ke.su.ru/ vs. */sa.li.ku/ */ke.su.ri/
4. Backness disharmony between high vowels
   */sa.li.ki/ */ke.su.ru/ vs. /sa.li.ku/ /ke.su.ri/

Naturalness and complexity

- Phonetic grounding: phonetic precursors stronger for V dependencies than for liquid dependencies
- Structural complexity: the liquid dependencies have greater structural complexity than the V dependencies, under some versions of syllable representation.
- Typology: Vowel assimilation is more common than dissimilation. Non-adjacent dependencies are rarer between consonants than between vowels.

Naturalness and complexity

- Prediction: if phonetic and phonological factors limit learning, we expect to see evidence of different outcomes for liquids vs. vowels in our learning experiments.

Q3: What are the effects of phonological knowledge on different kinds of linguistic tasks?

- Our study: learning from perception and production (listen-and-repeat task)
- Tasks for test phase:
  - Auditory repetition– online perception and production tasks
  - Grammaticality judgment– offline, metalinguistic task

Methods for auditory repetition experiments

- 15 adult English speakers per experiment
- Speeded auditory repetition task
- Materials (examples in liquid harmony)
  - /sa.CV.CV/ or /ke.CV.CV/
  - C = {k, l, r, s}, V = {a, e, i, u}
  - Study / legal words – e.g. /sa.le.la/ or /ke.ru.ri/
  - Illegal words – e.g. /sa.le.ri/ or /ke.ru.li/
  - Filler (distracter) words – e.g. /sa.ke.ri/ or /ke.si.ki/
Methods – cont’d (2)

- Latency = stimulus offset to response onset
- Latencies are averaged per type and per block.
- Errors and outliers removed

Results – Liquids

Evidence of learning in both conditions

Methods for grammaticality judgment experiments

- 2 experiments: liquid harmony and backness harmony
- 15 adult English speakers each
- Same materials used in the corresponding auditory repetition experiments
- Familiarization by speeded auditory repetition task

Results – High vowels

No evidence of learning in either condition

Methods – cont’d

- 3 training blocks and 1 test block.

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Methods – cont’d (2)

- Test block
  - Listen to test words (legal, illegal, filler)
  - Yes / No to if each word belongs to the language exemplified by words in the training blocks
- d’-score for each subject
  - Hit rate = rate of “Yes” to legals
  - False-alarm rate = rate of “Yes” to illegals
Results

- $d' = 0.0$ means no discriminability.
- Evidence of learning found in both conditions.
- No significant difference in performance between the two.

Discussion (1)

**Complex constraints are learnable**

- Complex phonotactic constraints involving non-local dependencies were learned on the basis of brief exposure.
- Learning occurs even in the absence of any higher-level linguistic context or communication goal.

Discussion (2)

**Naturalness and complexity do not constrain phonotactic learning**

- We find evidence of learning for both the vowel and consonant dependencies in the grammaticality judgment task.

Discussion (3)

**Task effects on measures of learning**

- A surprising asymmetry
  - evidence of learning for both consonant dependencies,
  - but not for either of the vowel dependencies.
- Why this difference?

Discussion (3)

**A ceiling effect?**

- Phonotactic knowledge facilitates auditory repetition if it reduces perceptual complexity.
- The liquid constraint facilitates perception more than the vowel constraint because liquids are more confusable than high vowels.

Perceptual factors and learning

- Perceptual factors may have an indirect effect on learning through their impact on the faithful transmission of sound patterns from speaker to hearer.
- Phonotactic constraints that improve perceptual salience presumably also improve the transmission accuracy of words that contain the restricted sounds.
- Reliable transmission provides the input for learning to take place, and even sound patterns that are phonetically unnatural or structurally complex will be learned if reliably transmitted from speaker to hearer.
Conclusion

• Adults can learn complex constraints from brief perception and production experience.
• Learning is not constrained by the phonetic naturalness or structural complexity of the constraints.
• Perceptual factors may have an indirect effect on learning through their impact on the faithful transmission of sound patterns from speaker to hearer.

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