Phonology affects statistical learning in artificial speech segmentation: Insights from behavioral experiments and computational modeling

Fabio Trecca[1]*, Fred Callaway[2], Stewart McCauley[2] and Morten H. Christiansen[2,1]

[1] Department of Language and Communication, University of Southern Denmark, Odense, Denmark
[2] Department of Psychology, Cornell University, Ithaca, New York
* fabio@sdu.dk

Overview

* Statistical learning (SL) mechanisms in language acquisition are generally considered robust and reliable.
* However, the cues on which these operate are highly probabilistic and language-specific, which might affect speech segmentation via SL.
* Recent cross-linguistic studies [1], for instance, hint at a possible negative effect of complicated sound structures on SL mechanisms.
* To investigate this idea, we first tested adult subjects with different native languages on a word segmentation task, then simulated our experiment by familiarizing and testing *simple recurrent networks* on the same procedure.
* Our results suggest that both target-language and native-language phonology influence SL in artificial speech segmentation.

Experiment 1: Word segmentation task

Participants

112 adult native speakers of Danish (n=56) and American English (n=56), randomly assigned to one of two artificial language-conditions.

Procedure

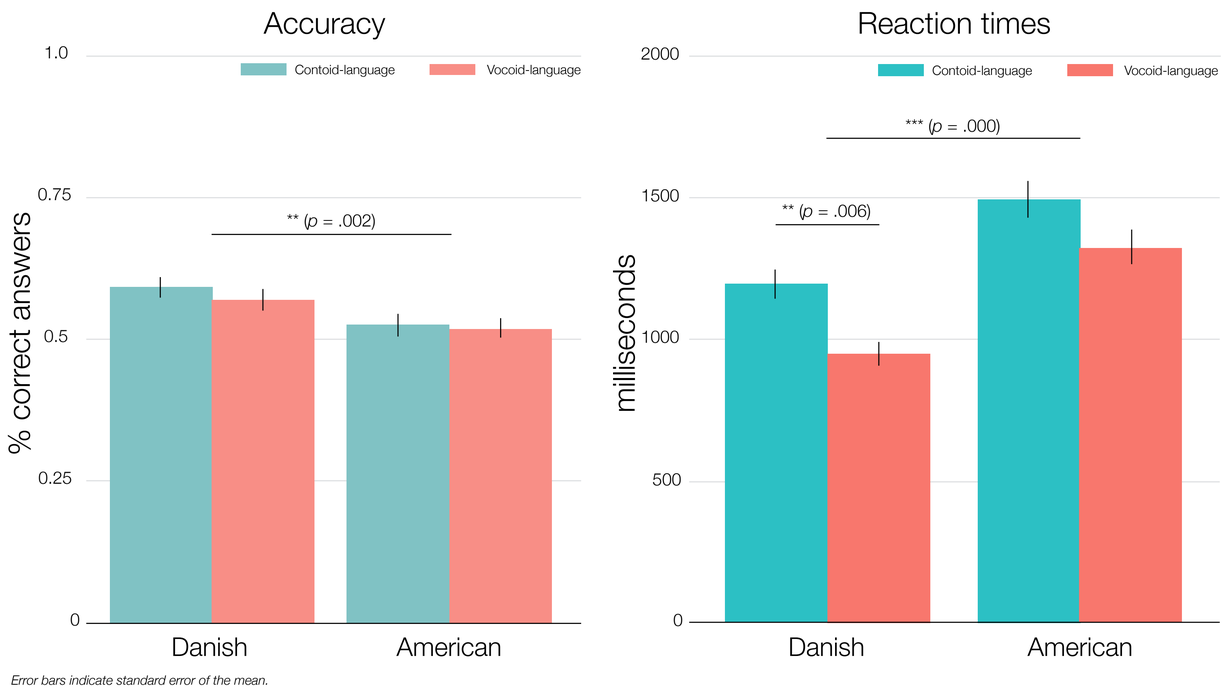
Based on [2], participants were first familiarized with an artificial speech stream, then tested on their knowledge of the language (36 two-alternative forced choice tests).

Stimuli

* Two nonsense artificial speech streams made up of concatenated CV-syllables, with transitional probabilities as the only cue to word boundary.
* The languages differed only in their phonologies (consonants → semivowels).

	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6
Contoid-language (C is a plosive)	gʌ dɔ	də dʌ	dɛ da	gu bɔ gɔ	be bu gə	bæ gæ ba
Vocoid-language (C is a semivowel)	jʌ ðɔ	ðe ðʌ	ðɛ ða	ju wɔ jɔ	we wu jə	wæ jɛ wa

Results



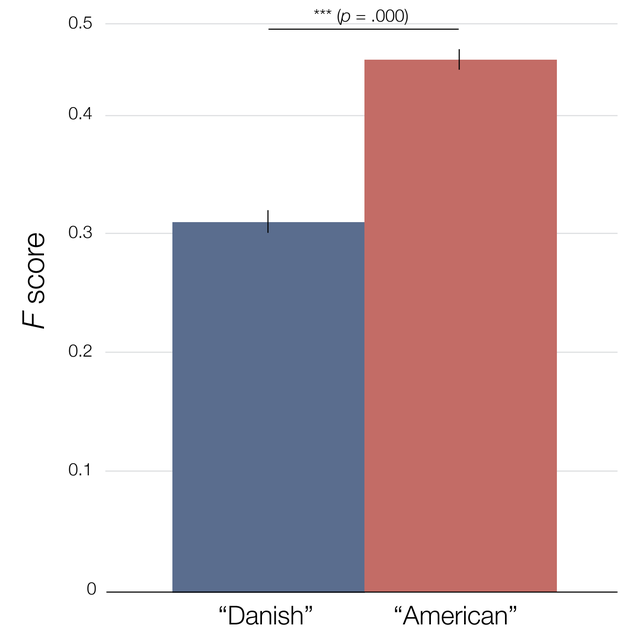
Error bars indicate standard error of the mean.

* Accuracy was above chance in both groups, but Danes scored significantly better.
* Accuracy tended to be higher on contoid-language than in vocoid-language (though not significantly).
* Danes were both faster at choosing the correct word than Americans, and faster in the vocoid-condition than in the contoid-condition.

Experiment 2: Computational modeling

Step 1: Simulation of native language knowledge

* 112 simple recurrent networks (56 for each language) with unique random initial weights, based on [3].
* The nets were trained on either a Danish or US English corpus of child directed speech.
* As input, the nets received phonemes and utterance boundaries, but no word boundaries.
* The nets "learned" their native language by learning to predict upcoming phonemes.
* The nets were better at segmenting American child-directed speech, which is consistent with prior hypotheses about Danish being hard to segment [1].



Step 2: Simulation of word segmentation task

Error bars indicate standard error of the mean.

* To simulate Experiment 1, the nets were trained on the same training stimuli our participants received.
* Two-alternative forced choice tests, as well as reaction times, were simulated by recording prediction errors from each net (in each trial, the net would choose the less 'surprising' word as familiar).
* The results reflect the patterns found in our data from human subjects.

Discussion

* In our study, both accuracy and speed in the segmentation task were affected by native language.
* Speed (and accuracy, albeit marginally) was also influenced by target language phonology.
* Our results suggest that: (a) familiarity with the phonological inventory facilitates the segmentation task; (b) phonological properties of the target language influence SL in artificial speech segmentation (Experiment 2 suggests this might also be the case with natural language stimuli).
* More generally, our results support the idea that **phonology might pose a constraint on the learnability of languages via statistical learning mechanisms**.

References

[1] Bleses, D., Basbøll, H. & Vach, W. (2011). Is Danish difficult to acquire? Evidence from Nordic past-tense studies, *Language and Cognitive Processes*, 26(8), 1193-1231.
[2] Saffran, J.R., Newport, E., & Aslin, R. (1996). Word segmentation: The role of distributional cues. *Journal of Memory and Language*, 35, 606-621.
[3] Christiansen, M.H., Allen, J., & Seidenberg, M.S. (1998). Learning to segment using multiple cues: A connectionist model. *Language and Cognitive Processes*, 13, 221-268.

University of Southern Denmark

Cornell University