Perceived length of Czech high vowels in relation to formant frequencies evaluated by automatic speech recognition

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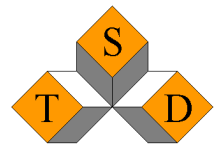
Tomáš Bořil and Jitka Veroňková

Tomas.Boril@ff.cuni.cz

Institute of Phonetics, Charles University

FACULTY OF ARTS
Charles University



Introduction

- Czech vowel system: 5 pairs of short and long monophthongs + 3 diphthongs
- The vowel length is phonologically distinctive
- Improper interchange in L2 speakers' production may lead to misunderstanding
- [kruciː farmaːr̝i] vs [kruːciː farmaːr̝i]
  (meaning *cruel farmers* vs *turkey farmers*)
- [vɪrɪ] vs [viːrɪ] (meaning *viruses* vs *vortices*)

Introduction

Czech high vowels: perceived vowel length is influenced by formant values related to a tongue position[1].

- Bohuslav Hála (1941): [i] and [iː] differ in formant frequencies
- Jana Dankovičová (1997): IPA symbols differentiation [ɪ], [iː]
- Václav Jonáš Podlipský et al. (2009): Bohemians (the western region) – rely more on the spectrum and Moravians (the eastern region) – rely more on the duration
- Šárka Šimáčková et al. (2012): formant shifts between [u] and [uː] in production (the Bohemian region)
- Václav Jonáš Podlipský et al. (2019): formant values play crucial role in a perceptual discrimination between [u] and [uː]
  - A listening test with artificial one-syllable pseudowords

[1] The majority of naive L1 users is not aware of such relations.

Experiment 1

- [ɪ] vs [iː], real-world two-syllable words
- Minimal pair: [vɪrɪ] (meaning *viruses*) and [viːrɪ] (meaning *vortices*)
- Manipulations of the 1st syllable (21 formant steps × 7 duration steps = 147 items) in Praat and rPraat using LPC
  - 1st syllable is not prone to phrase-final lengthening
  - [ɪ] F1–F3 = 405, 2295, 2866 Hz
  - [iː] F1–F3 = 305, 2700, 3000 Hz
  - Duration 90 ms to 300 ms

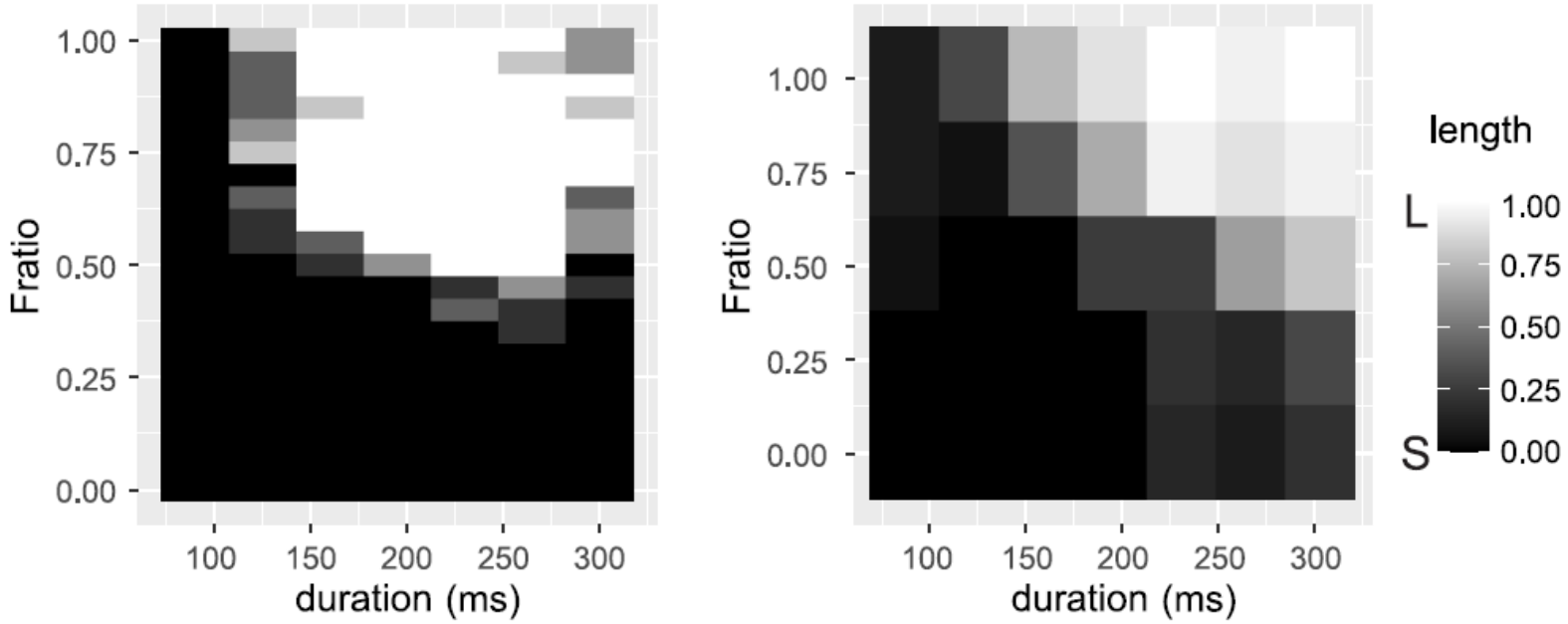
Fratio=1, dur=90ms | Fratio=1, dur=195ms | Fratio=1, dur=300ms

Fratio=0.5, dur=90ms | Fratio=0.5, dur=195ms | Fratio=0.5, dur=300ms

Fratio=0, dur=90ms | Fratio=0, dur=195ms | Fratio=0, dur=300ms

Experiment 1

- ASR: 5 replications of random permutation of items
  - Beey by NEWTON Technologies
- Listening test (human perception experiment)
  - 20 participants (Bohemian region, male and female, median age = 23 years)
  - To keep them focused, a subset of items only (5 formant steps $\times$ 7 durations = 35 items)
  - Plus additional 15 two-syllable words with different vowels (distractors)
  - Random order for each participant
  - Praat MFC (multiple forced-choice environment)
  - A short training set (6 items)



(a) (b)

Fig. 1: Evaluation of [ɪ] and [iː] vowels in experiment 1. The vowel is manipulated both in duration and formant values, Fratio stands for ratio on the range between formant values of natural [ɪ] and [iː]. Shades of grey represent mean values of evaluated vowel lengths from (a) 5 realisations of ASR, (b) 20 participants of the listening test (white = long, black = short).

Fratio=1, dur=90ms | Fratio=1, dur=195ms | Fratio=1, dur=300ms

Fratio=0.5, dur=90ms | Fratio=0.5, dur=195ms | Fratio=0.5, dur=300ms

Fratio=0, dur=90ms | Fratio=0, dur=195ms | Fratio=0, dur=300ms

Experiment 1

Statistic significance of duration and Fratio

- Mixed-effects model with logistic regression (binomial family for binary outcome)
- Both fixed effects were centred and standardised, replication was a random effect
- Random slopes included
- p-values obtained by likelihood ratio test

$$length \sim duration + Fratio + (1 + duration + Fratio | replication)$$

- ASR: Fratio and duration effects: $p < 0.001$
- ASR Subset ($duration \geq 160$ ms): Fratio $p < 0.001$, duration $p = 0.2554$
- Humans: both $p < 0.001$

Experiment 2 and 3

- [u] vs [uː], minimal pair: [kruciː] (meaning *cruel* in plural) and [kruːciː] (meaning *turkey* adjective)
- Manipulations of the 1st syllable (19 formant steps × 7 duration steps = 133 items)
  - [u] F1–F3 = 360, 906, 2774 Hz
  - [uː] F1–F3 = 288, 567, 2774 Hz
  - Duration 90 ms to 300 ms
  - ASR, 5 replications of random permutations
- Experiment 3: "zoom in" the transient area
  - Formants: 21 steps covering lower two thirds of Ex. 2
  - Durations: 125 ms – 230 ms in 9 steps

Fratio=1, dur=90ms | Fratio=1, dur=195ms | Fratio=1, dur=300ms

Fratio=0.5, dur=90ms | Fratio=0.5, dur=195ms | Fratio=0.5, dur=300ms

Fratio=0, dur=90ms | Fratio=0, dur=195ms | Fratio=0, dur=300ms

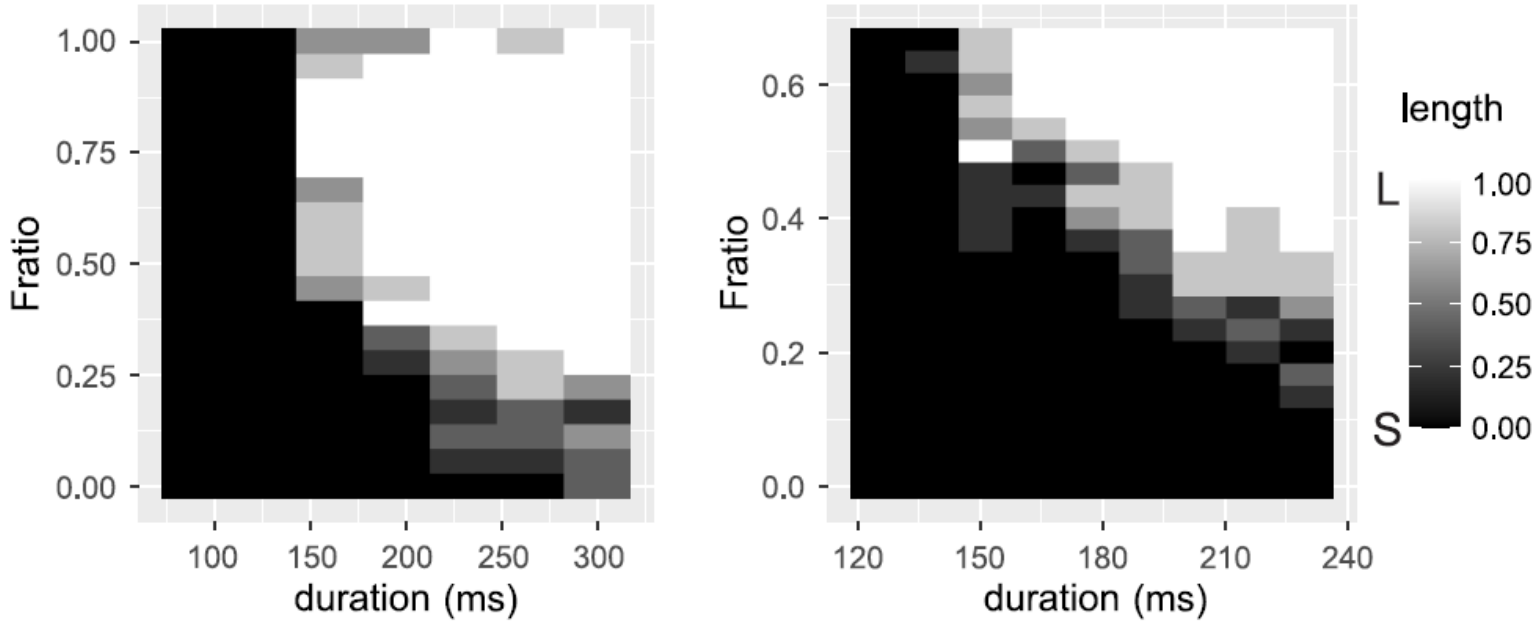


Fig. 2: Evaluation of [ʊ] and [uː] vowels. Fratio stands for ratio of the range between formant values of natural [ʊ] and [uː]. Shades of grey represent mean values of 5 evaluated vowel lengths by ASR in (a) experiment 2, (b) experiment 3 (white = long, black = short).

- Both $p < 0.001$

Fratio=1, dur=90ms | Fratio=1, dur=195ms | Fratio=1, dur=300ms

Fratio=0.5, dur=90ms | Fratio=0.5, dur=195ms | Fratio=0.5, dur=300ms

Fratio=0, dur=90ms | Fratio=0, dur=195ms | Fratio=0, dur=300ms

Conclusions

- ASR trained on an extensive sample of population reached results comparable with listening tests conducted on human subjects
- Advantages of ASR approach: unlimited number of items – parameters covered in much more detail, can be repeated many times with different settings
- Disadvantages of ASR: not possible to control subgroups (region, sex, age), more frequent errors in recognition of a word
- Combination with human perception experiments is recommended
- The results comply with recent study with one-syllable pseudo-words (Podlipský et. al 2019)
- Teachers of L2 Czech learners should be aware that perception of phonological high-vowels length is influenced by the tongue position

Thank you for your attention.