

Acquiring segmental and suprasegmental phonology of vowel length: development across the first year of life

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The speech signal is composed of numerous acoustic cues, some of which can be more relevant at the level of individual sound segments, and others can have greater relevance over entire phrases. An acoustic cue that can have linguistic function both at the segmental and the suprasegmental level is duration. Across many languages, duration serves as a cue to linguistic rhythm, through variations in speech rate, phrase-final, lexical-stress, or sentence-focus related lengthening (White et al. 2012). At the same time, in some languages, such as Czech, Finnish, and Japanese, duration cues contrasts between phonemically short and long vowels or consonants. Partly due to the multitude of linguistic roles that it can have, duration is particularly interesting from a developmental perspective. We do not yet know at what age children acquire phonemic length (see e.g. Tsuji & Cristia 2014) and how the acquisition of segmental length phonology interacts with the acquisition of suprasegmental patterns. The research presented here aims to help reveal how the phonemic and prosodic length functions are acquired.

Durational variations are perceptually salient from early on in a child's development. Durational information is veridically transmitted to the intrauterine environment (Graven & Browne 2008); fetuses indeed seem to learn prosodic temporal patterns through exposure and immediately after birth, infants show language-specific processing of temporal variations in rhythm (Granier-Deferre et al. 2011, Ramus 2002, Abboub et al. 2016). Relatively little is known about the early development of duration at the level of phonemes. Duration-cued segmental contrasts are considered perceptually highly salient, meaning that they could be acquired at a rather early age (Burnham, 1976). Empirical studies on perceptual acquisition of vowel length are rare and do not converge in their findings (Sato et al. 2010, Minagawa-Kawai et al. 2007).

We aimed to find out when infants learning a language with phonemic vowel length acquire adult-like sensitivity to length contrasts at the segmental level and how this ability interacts with their processing of durational variations at the suprasegmental level, i.e. rhythm. Our questions were tested with infants exposed to Czech. In speech production, Czech adults realize length contrasts through duration, phonemically long vowels are almost twice as long as their short counterparts (Paillereau & Chládková 2019). The prosodic function of duration in Czech is less clear: duration marks phrase boundaries but not lexical (fixed-position) stress (Dankovičová 1997, Skarnitzl & Eriksson 2017); in terms of the traditional rhythm metrics, Czech seems unclassifiable (Dankovičová & Dellwo 2007). For the acquisition of Czech durational patterns, one might thus predict that with developing length contrasts at the phonemic level, sensitivity to temporal rhythm variations will decline (which aligns with adult speech production in languages like K'ekchi and Hungarian, Berinstein 1979, Vogel et al. 2015). Alternatively, infants may simultaneously develop sensitivity to both phonemic length and language-specific temporal rhythm (in line with a formal description of many languages with quantitative contrasts, Lunden et al. 2017), and rely on durational rhythm cues that had not yet been identified in the speech of Czech adults.

Below we report two experiments. In Experiment 1, we traced infants' perceptual discrimination of the native /fɛ/-/fɛ:/ length contrast (relative to the native /fɛ/-/fa/ vowel quality contrast). In Experiment 2, we tested infants' discrimination of typical and atypical temporal rhythmical patterns. In both experiments, 4 groups of infants were tested: 4-, 6-, 8-, and 10-month olds. Since durational cues are most likely amongst the first ones available (or, audible) to infants, we hypothesized that Czech infants will show a strong sensitivity to phonemic vowel length from the first age tested, i.e. from 4 months (relative to vowel quality,

which typically develops at about 6 months), and that this sensitivity might get enhanced as a result of further perceptual attunement to native-language phonemes. For prosodic duration we, too, expected a strong sensitivity at the early age, 4 months, but hypothesized an age-related decline due to a relatively weak relevance of temporal cues in Czech (adult) prosody.

In Experiment 1, 79 infants were tested and after exclusion due to fussiness, experimenter error, or failure to habituate, data from ten 4-month olds, eight 6-month olds, seven 8-month olds, and six 10-month olds were analyzed. In a central fixation paradigm, infants were tested on their discrimination of a vowel length contrast, /fɛ/-/fɛ:/, and on a spectral contrast, /fɛ/-/fa/. Each trial contained 16 repetitions of naturally produced syllables and was 13 s long. After habituating to [fɛ]-syllables, infants were presented with three types of test trials in a pseudorandomized order. The test trials contained alternations in terms of vowel duration [fɛ]-[fɛ:], spectral change [fɛ]-[fa], or no change [fɛ]-[fɛ], i.e. control trials. We assessed the total looking time in each test trial type (duration, spectrum, control) and compared it to the average looking time of the last two habituation trials. Statistical inferences were done using linear mixed-effects models with Trial type and Age as fixed factors, and per-participant random intercept. There was a trending main effect of Trial type, showing that the duration test trials yielded longer looking times than the last two familiarization trials (by 1 s, $t = 1.789$, $p = .077$). Trial type interacted with Age: in older infants (8- and 10-month olds), spectral test trials yielded longer looking times than the last two familiarization trials (by 1.6 s, $t = 2.003$, $p = .049$).

In Experiment 2, 59 infants were tested, and after exclusion, we analyzed eight 4-month olds, thirteen 6-month olds, nine 8-month olds, and eight 10-month olds. The stimuli were well-formed Czech sentences containing low-frequency content words produced in infant-directed speech by three women. The three women imitated 30 naturally-produced model sentences with typical Czech rhythm, and the same 30 edited sentences with atypical rhythm. The atypical rhythm was realized through altering the duration ratios between stressed and unstressed syllables. Ten different trials were created, 5 trial per rhythm type, each trial containing 9 different sentences (3 from each speaker). Infants were tested in a central fixation paradigm, without habituation, and with pseudo-randomized order of the 5 typical-rhythm and the 5 atypical-rhythm trials (average trial length was 23 s). The dependent measure was first look duration during the typical-rhythm and the atypical-rhythm trials (averaged across trials of the same type). Linear mixed-effects models had Accent and Age as fixed effects, per-participant random intercepts, and per-trial-order random slopes for Accent. Accent interacted with Age, showing that at 4-months, infants looked significantly longer to the typical than to the atypical rhythm (by 2.1 s, $t = -2.30$, $p = .028$). Data collection in both experiments is ongoing (estimated completion by the time of the conference with $n=14$ per age in each experiment).

To sum up, we found that Czech infants between 4 and 10 months discriminate changes between a short and a long vowel duration that cues segmental phoneme identity. The overall sensitivity to segmental duration was not found to differ across development (unlike the sensitivity to spectral contrasts that seemed to rise between month 6 and 8). At the suprasegmental level, the 4-month olds showed reliable discrimination of typical and atypical temporal variations, preferentially listening to the typical renditions of their native-language rhythm. We did not find any rhythm-specific listening at later ages.

In conclusion, early in development, i.e. at 4 months, Czech infants are sensitive to durational changes at both the segmental and the suprasegmental level. However, the subsequent development of duration sensitivity seems to take different paths. Whereas the sensitivity to duration at the level of individual segments remains robust throughout development, perhaps reflecting early-established and maintained short and long phoneme categories, the sensitivity to duration at the suprasegmental level seems to decrease within the 1st year, perhaps reflecting the fact that suprasegmental variations in duration are phonologically little relevant in the infants' native language. Future studies in our lab will examine how durational changes affect Czech infants' perception of lexical stress and how the duration sensitivity interacts with their growing vocabulary.

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