

Title: Gradient perception in English-speaking children: A link to cue-weighting and working memory

Abstract: The present study investigates English-speaking children's (aged 7-9) perceptual manner of being gradient or categorical in identifying category membership of native stops (/d/ vs. /t/) in order to examine its associations with individual children's utilizations of multiple acoustic cues (VOT and *f0*) modulated by working memory capacity (WM). While adults' gradient responses in the stop perception were proposed to reflect listeners' effortful incorporations of linguistic resources (i.e., redundant acoustic details) [2, 3], this relationship cannot be automatically generalizable to children's speech perception due to children's limited linguistic and cognitive resources. That is, children's gradient responses may be attributable to their better utilizations of a redundant cue (*f0*) similarly to adults' perception *or* possibly to immature control of a primacy cue (VOT) or a composite use of both cues reflecting children's developing linguistic capacity [1, 6, 7, 8]. In this study, we tested the two possibilities by employing perception experiments where English-speaking children were given a less category-biased task where they process a set of stimuli combining two acoustic cues. In addition, children's WM scores were measured to be related to individual variations of categorical perception. Ultimately, we aim to refine a developmental implication of categorical/gradient perception in an interaction with multiple acoustic cue processing and cognitive function.

The participants (N=29) were recruited from local visitors to the Language Pod at the Center of Science and Industry in Columbus (Ohio, United States), reporting no speech, hearing and language problems. They were given two kinds of speech perception tasks (Visual Analogue Scaling [5], and 2-Alternative Forced-Choice) and a task for WM (Digit One-Back) [4]. Auditory stimuli came from an existing study: 12 CVs (stop + /a/). Based on the male talker's natural productions of /da/, aspiration duration and post-consonantal *f0* of the stop were systematically manipulated to combine 4-step VOTs (9ms, 19ms, 28ms, and 59ms) and 3-step *f0*s (114Hz, 98Hz, and 130Hz). In VAS, listeners were asked to judge "d"- or "t"- likeness by clicking any locations along a horizontal arrow on the screen whose ends were labelled as "d" (left) and "t" (right). Click response patterns of VAS were quantified to represent individuals' gradient manner of judging stop categories. Similarly, in 2AFC, children identified either "d" or "t" labels upon listening to stimuli. Binary responses from 2AFC were predicted by VOT and *f0* values in mixed-effects regression to numerate perceptual dependency on each acoustic parameter.

Findings showed that some children judged the stop categories more gradiently than others resembling individual differences in adults' categorical perception (Fig.1). Correlation analysis between degrees of gradiency (VAS) and estimated acoustic coefficients (2AFC) showed that children's gradient responses were linked to greater sensitivity to VOT (but not to *f0*) (Fig.2). This relationship not only confirms that phonetic labelling of auditory input is compromised with subtle within-category acoustic information allowing for individual variability, but also suggests that children's utilizations of multiple cues pattern differently from those of adults in that it was a primary cue (VOT) but not a secondary cue (*f0*) that had to do with children's manner of category judgment. Finally, better WM scores were characteristic of more gradient child listeners who expressed phonetic labels of native stops with subtle differentiations, supporting that gradient responses are achieved by successful operation of cognitive control rather than outcomes of processing failure to suppress within-category acoustic details for discrete category identification. Taken experimental findings together, we conclude that gradient responses in children's multiple-cue processing indicate listeners' resourceful usages of fine-grained linguistic storage and do not necessarily represent listeners' lack of linguistic confidence in fitting the auditory signal into phonetic categories.

References:

- [1] Hazan, V., & Barrett, S. (2000). The development of phonemic categorization in children aged 6–12. *Journal of Phonetics*, 28(4), 377-396.
- [2] Kapnoula, E. C., Winn, M. B., Kong, E. J., Edwards, J., & McMurray, B. (2017). Evaluating the sources and functions of gradiency in phoneme categorization: An individual differences approach. *Journal of Experimental Psychology: Human Perception and Performance*, 43(9), 1594-1611.
- [3] Kong, E., & Edwards, J. (2016). Individual differences in categorical perception of speech: Cue weighting and executive function. *Journal of Phonetics*, 59, 40-57.
- [4] Kirchner, W. K. (1958). Age differences in short-term retention of rapidly changing information. *Journal of Experimental Psychology*, 55, 352–358.
- [5] Massaro, D. W., & Cohen, M. M. (1983). Categorical or continuous speech perception: A new test. *Speech communication*, 2(1), 15-35.
- [6] Mayo, C., & Turk, A. (2004). Adult–child differences in acoustic cue weighting are influenced by segmental context: Children are not always perceptually biased toward transitions. *The Journal of the Acoustical Society of America*, 115(6), 3184-3194.
- [7] Simon, C., & Fourcin, A. J. (1978). Cross-language study of speech-pattern learning. *The Journal of the Acoustical Society of America*, 63(3), 925-935.
- [8] Werker, J. F., & Tees, R. C. (1983). Developmental changes across childhood in the perception of non-native speech sounds. *Canadian Journal of Psychology/Revue canadienne de psychologie*, 37(2), 278.

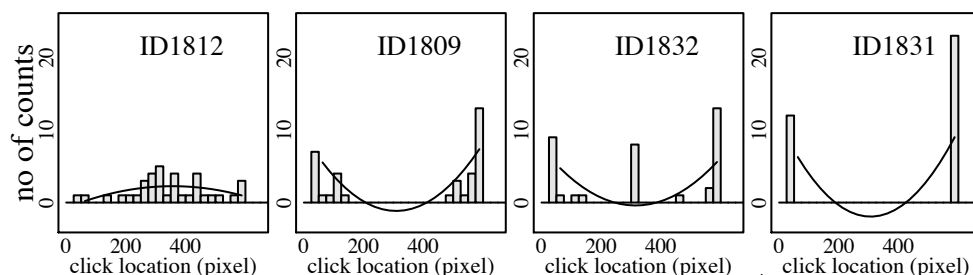


Figure 1. Four individual children’s distributions of click locations in VAS overlaid with polynomial-regression curves. Coefficients of quadratic term were used to represent how gradient the distribution is: Smaller coefficients for more gradient response distributions (flatter curves).

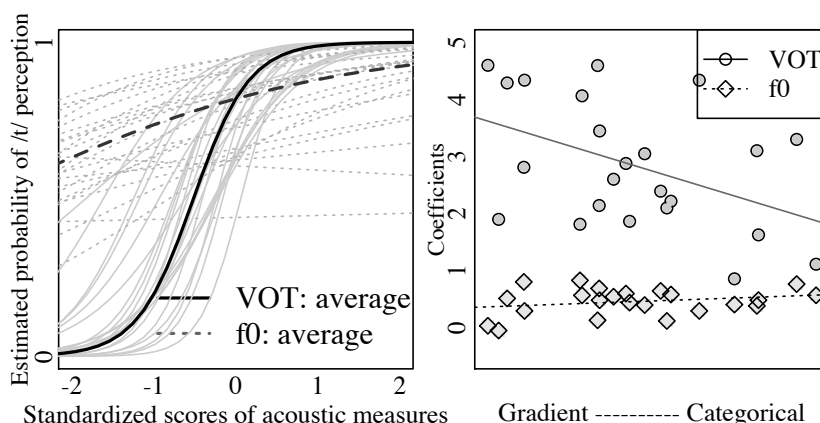


Figure 2. [Left] Logistic mixed-effects regression curves of VOT and f_0 based on 2AFC. [Right] Acoustic coefficients (from the logistic regression model, perceptual reliance on VOT or f_0) as a function of perceptual gradiency (quadratic coefficients based on VAS response distributions). Greater VOT coefficients were associated with gradient manner of category decision in children’s speech perception.