A lexical locus for the integration of asynchronous cues to voicing: An investigation with natural stimuli

Joseph C. Toscano and Bob McMurray
University of Iowa Dept. of Psychology

1pSC29

Multiple acoustic cues in speech

- Multiple cues contribute to phonetic categorization.
  - temporally asynchronous
  - vary in usefulness
  - different units (time vs. frequency).
- Cues must be integrated during phonetic categorization.
- e.g.: Perception of syllable-initial stop consonants depends on later-occurring context information, such as vowel length (VL). (Summerfield, 1981)

Context effects in natural and synthetic speech

- VL contributes to both voicing and manner categorization.
- VL effects found with certain stimuli, but not others:
  - VL effects:
    - Synthetic speech (Miller and Liberman, 1979; Summerfield, 1981)
    - More natural synthetic speech in multi-talker babble background noise (Miller and Wayland, 1993)
  - No (or reduced) VL effect:
    - Natural-sounding synthesized speech (Shinn et al., 1985)
    - Natural speech (for voiceless stops) (Utman, 1998)
- This suggests that synthetic and natural speech may be processed differently from each other.

Issues

- Are synthetic and natural stimuli perceived differently?
- Can we see effects of multiple cues in both natural and synthetic speech?
  - Are multiple cues used in natural speech?
- Are cues integrated in the same way in synthetic and natural speech?
  - When multiple cues are used, how are they integrated?

Questions

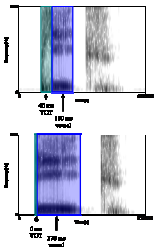
- Under what circumstances are multiple cues used?
  - Synthetic vs. natural speech
  - Background noise
- Does eye-tracking reveal effects of cues that are not detectable in identification responses?
- When multiple cues are used, how are they integrated?
- How are temporally asynchronous cues combined?
  - Integration at a pre-lexical (e.g. cue) level
  - Independent integration at the level of the lexicon

Experimental Design

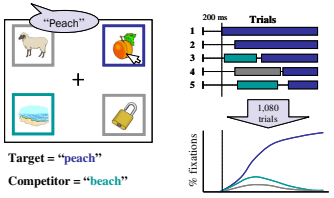
- Previous studies: differences in identification functions to identify contribution of VL.
  - Problem: May not be sensitive to small VL effects.
- Solution: Visual world paradigm is more sensitive.
  - Sensitive to sub-phonemic variation. (McMurray et al. 2002)
  - Sensitive to small effects: could detect VL effects that are invisible to other methods.
  - Sensitive to short-lived, temporal effects.
  - Allows us to evaluate contribution of cues as they are heard: allows us to ask *how* cues are integrated.

- Procedure
  - On each trial, listeners hear the target word and click on its picture with a mouse.
  - Eye movements are recorded via a head-mounted eye tracker (SR Eyelink II) at 250 Hz.
  - Eye-movements reveal unfolding of lexical activation during recognition.
- Why use the visual world paradigm
  - Natural task
  - Subjects are unaware of eye movements
  - Can be used without breaking up speech
  - High temporal sensitivity
  - Reflects activation of lexical items (Allopenna et al., 1998)
  - Eye movements reflect which referents are considered during online word recognition. (Tanenhaus et al., 1995)

- Stimuli
  - Stimuli consisted of recorded speech in which we manipulated voice onset time (VOT) and vowel length (VL)
  - 7 minimal pairs:
    - Beach/Peach
    - Bet/Pet
    - Bath/Path
    - Beak/Peak
    - Best/Pest
    - Bike/Pike
    - Buck/Puck
  - 9 step VOT continua
  - 2 vowel lengths
    - 40% longer or shorter than original vowel length
  - 2 unrelated items per stimulus pair
- Participants
  - 30 undergraduates at the University of Iowa participated in the experiment.

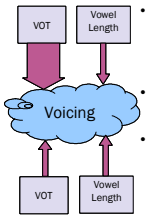


Visual World Paradigm



Cue Weighting

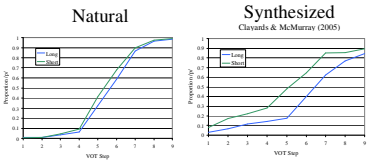
- Previous work: VL may not be used as a cue to voicing in natural speech.
- In contrast: Cues are weighted based on how useful they are.
  - VL effects seen when VOT is less useful.
- Relative weighting determines whether effects of multiple cues are observed.
- Natural speech
  - VOT is usually unambiguous
  - Strong cue to voicing
- Synthetic / noisy speech
  - VOT harder to compute accurately
  - Greater relative weight for vowel length



Predictions

- Eye tracking will reveal influence of VL in natural speech, as differences in fixations to competitors (activation).
  - May be able to see VL effects across entire continuum.
  - Larger effects near the category boundary than at the endpoints.
- Prediction: VL cues are used to determine voicing when VOT is ambiguous.
- VL effects appear as increased looks to competitors when:
  - Short VL for /b/ words
  - Long VL for /p/ words

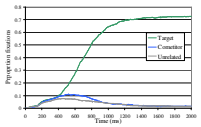
Identification Responses



- Vowel length affects category boundary ($p<0.001$).
- Previous work: larger effects with synthetic stimuli.

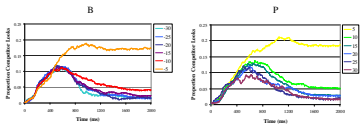
Eye movement results

- Expected pattern of eye movements; similar to previous visual world studies.

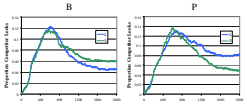


Fixations to target, competitor and unrelated items as a function of time for stimuli with a 0 ms VOT.

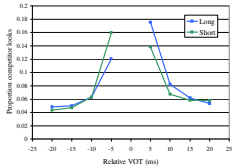
Gradient effects of VOT are seen in fixations to competitor objects over time as a function of distance from category boundary.



VL effect is also seen in fixations to competitor objects over time (for long and short vowels)



Proportion of looks to competitor



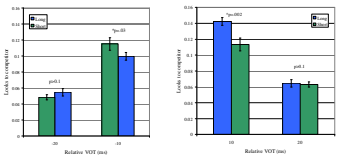
Target /b/:
- VOT: $p<.001$
- Vowel: $p=.059$
- VOT*Vowel: $p<.001$

Target /p/:
- VOT: $p<.001$
- Vowel: $p=.034$
- VOT*Vowel: $p=.018$

Increased looks to /p/-competitor with short VL, and to /b/-competitor with long VL.

Effect of VL near category boundary

Significant vowel effect near category boundary (where VOT is ambiguous), but not at endpoints (where VOT is more reliable).



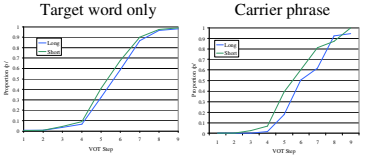
Conclusions

- VL is a cue to voicing in natural speech.
  - VL effects seen near the VOT category boundary.
  - Cues that are normally less reliable (VL) are used when more reliable cues (VOT) are ambiguous.
- Cues may be re-weighted online, as information from different cues is processed.
- When VOT is unambiguous →
  - *Vowel length is weighted low*
- When VOT is ambiguous →
  - *Vowel length is weighted higher*
  - *Contributes more to voicing decision*

Work in progress: Effect of carrier phrase

- Cue weighting may differ in running speech.
  - Insufficient time to compute cues: speed/accuracy tradeoff.
  - Rate compensation more complex: increases importance of temporal cues.
- Cue Weighting Hypothesis: VL effects when the target word is preceded by a carrier phrase.
- Same stimuli spliced onto a series of carrier phrases that instructed the subject to perform a particular task
  - e.g. *Please pick the pointer and click on the peach.*
- Prediction: larger VL effects with carrier sentence.

Responses with Carrier Phrases



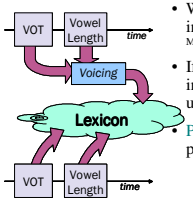
- Carrier phrase creates larger VL effect.
- Suggests that multiple cues are used in more natural contexts when individual cues may be less reliable than in isolation.

Locus of cue integration

Are phonetic judgments made after information from all cues is received, or does word recognition begin as soon as a cue is detected?

Cue-level integration
- Information from specific cues is combined prior to lexical access

Lexical integration
- Continuous cues directly access lexicon.
- Lexical activation processes sort them out.

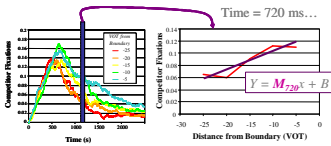


Predictions

- With synthesized stimuli, cues are integrated independently in time. (McMurray et al., 2004; Clayards & McMurray, 2005)
- If cue integration in natural speech is similar to integration in synthesized speech, cues will be used as they become available.
- Prediction: Effects of VOT observed earlier in processing than VL effects.

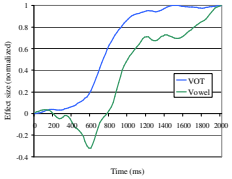
Measuring timing of cue use

- Size of each effect at a given point in time:
  - Slope of the best-fit linear regression across VOT, VL
  - Slope = 0: the effect is small.
  - Slope > 0: large effect.
- *Question: When does slope deviate from 0 for each cue?*



Onset of effects

Size of effect for each cue (VOT and VL) over time



- Onset of VOT and VL is temporally asynchronous
- Effect onset ($p<.05$):
  - VOT: 520 ms
  - VL: 980 ms

Conclusions

- VOT and VL effects observed as each cue is available.
  - Similar to results obtained with synthesized speech.
- Immediacy: Listeners do not wait for all cue information (for a single feature) to become available before accessing the lexicon.
- This suggests a lexical locus for the integration of multiple acoustic cues, rather than a pre-lexical locus of integration.

General Conclusions

- Gradient lexical activation in natural speech.
- Multiple cues to voicing are used in natural speech
  - Cues weighted by their utility.
  - Demands of running speech may change utility.
- Cues are used *as they become available*, suggesting a lexical locus for cue integration.
- Similar results for natural and synthetic speech, suggesting that the two are not perceived differently.

References

- Allopenna, P.D., Magnuson, J.S., and Tanenhaus, M.K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38(4)*, 419-439.
- Clayards, M. and McMurray, B. (2005, November). Can the temporal unfolding of gradient lexical activation reveal the grain of phonological units? Paper presented at the 11th Meeting of the Midcontinental Workshop on Phonology. Ann Arbor, Michigan.
- McMurray, B., Tanenhaus, M., and Aslin, R. (2002). Gradient effects of within-category phonetic variation on lexical access. *Cognition, 86*(2), B33-B42.
- Mitterer, H., Chen, Y., and Zhou, X. (2004, May). Gradient sensitivity to acoustic detail and lexical activation: Evidence from phonetic cues. Poster presented at the 75th Meeting of the Acoustical Society of America, New York.
- Miller, J. L. and Liberman, A. M. (1979). Some effects of later-occurring information on the perception of stop consonant and semivowel. *Perception & Psychophysics, 25*(6), 457-465.
- Miller, J. L. and Wayland, S. C. (1993). Limits on the limitations of context-conditioned effects in the perception of [b] and [w]. *Perception & Psychophysics, 54*(2), 205-210.
- Shinn, P. C., Blumstein, S. E., and Jongman, A. Limitations of context conditioned effects in the perception of [b] and [w]. *Perception & Psychophysics, 38*(3), 397-407.
- Summerfield, Q. (1981). Articulatory rate and perceptual constancy in phonetic perception. *Journal of Experimental Psychology: Human Perception and Performance, 7*(3), 1074-1095.
- Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., and Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science, 268*, 1632-1634.
- Utman, J. A. (1998). Effects of local speaking rate context on the perception of voice-onset time in initial stop consonants. *Journal of the Acoustical Society of America, 103*(3), 1640-1653.

Acknowledgments

- We would like to thank Meghan Clayards for theoretical discussions of these issues, Molly Robinson for assistance with stimulus preparation, and the students in the MACLab at the University of Iowa for helping to run subjects in the experiment.