Auditory feedback perturbation as a window into bilingual interactions between speech perception and production

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Auditory feedback perturbation (AFP) is the real-time manipulation of acoustic cues (eg. vowel formants, F0) of a speaker's recorded speech production[2], where the modified sound is cyclically played back to the speaker during their production task. AFP causes the speaker to perceive a change in their own voice and compensate for the effects of the formant perturbation by modifying their own speech production. This compensation is a reflexive adjustment to production, typically (but not inevitably) in the opposite direction to the perturbation. Compensation can persist into longer-term changes in production of the same sounds in a new phonological environment, a process termed adaptation[2]. Compensation and adaptation caused by AFP is also associated with a change in listener's speech sound categorisation, as indicated by perceptual identification tasks[4,8].

Current models of speech production predict compensatory and adaptive responses to AFP, but the mechanisms generating these responses are explained in different ways. The Directions into Velocities of Articulators (DIVA)[10] model proposes a strong relationship between feedback control systems, which respond to auditory perturbations, and feedforward control systems, which issue future speech motor commands in line with the strength of the original compensation response. DIVA therefore predicts a strong correlation between compensation and adaptation magnitudes, because feedback-driven compensation subsequently modifies feedforward speech production commands, inducing adaptation. Meanwhile, in State Feedback Control (SFC)[3], adaptation is caused by the mismatch between predicted and experienced sensory information, without the need for active compensation to correct feedforward commands. It has been shown that the magnitudes and timescales of short-term compensatory responses and longer-term adaptive responses are not necessarily correlated, indicating a possible separation between feedback and feedforward systems[1,5,7].

The existing (relatively sparse) research on bilingual speakers suggests that compensation magnitude is constrained by first language vowel inventory[6]: furthermore, greater experience with a second language is positively correlated with compensation and adaptation magnitudes in that language[9]. However, it is not known exactly how compensation influences adaptation, and its associated changes in perception, cross-linguistically. We address this gap with an experiment involving Spanish/English bilinguals. The test vowels, English /æ/ and /ɛ/ and Spanish /a/ and /e/, occupy similar locations in auditory space. The first session will consist of a period of AFP of monosyllabic /ɛ/ tokens (eg. *head, bed, fed*) and assess the adaptation after-effects on production of /a/ and /e/ in Spanish (eg. *dedo, dado*). The second, identical session of AFP in English will assess the adaptation after-effects on perception, with a 2AFC vowel identification task between Spanish /a/ and /e/.

This cross-linguistic study will help to determine if adaptation can carry across languages as a function of compensation to AFP, as well as the effects of compensation and adaptation on the location of the vowel perceptual boundary. If feedback and feedforward

systems are strongly linked (as in DIVA), compensation and adaptation magnitudes should be positively correlated. If feedback and feedforward systems are separated (as in SFC), compensation and adaptation responses may not be correlated. Furthermore, results from perception tests will show the extent to which speech motor compensation is necessary for perceptual change, and the effects of AFP on perception in a different language. Finally, this experiment will show if two similar vowels share a representation in the bilingual speaker's vowel inventory, depending on how strongly the adaptation after-effect carries across languages.

It is hoped that the results will illuminate the relationship between feedback and feedforward control systems in speech production, especially in bilingual speakers. These results will also provide more information on the relationship between speech perception and production, by highlighting the interactions between production change (compensation and adaptation) and perception change. This research has applications in second language acquisition, language teaching and the study of speech sound variation.

References

[1]Franken, M. K., Acheson, D. J., McQueen, J. M., Hagoort, P., & Eisner, F. (2019). Consistency influences altered auditory feedback processing. *Quarterly Journal of Experimental Psychology*, *72*(10), 2371-2379.
[2]Houde, J. F., & Jordan, M. I. (1998). Sensorimotor adaptation in speech production. *Science*, *279*(5354), 1213-1216.
[3]Houde, J. F., & Nagarajan, S. S. (2011). Speech production as state feedback control. *Frontiers in Human Neuroscience*, *5*, 82.
[4]Lametti, D. R., Rochet-Capellan, A., Neufeld, E., Shiller, D. M., & Ostry, D. J. (2014). Plasticity in the human speech motor system drives changes in speech perception. *Journal of Neuroscience*, *34*(31), 10339-10346.
[5]Lester-Smith, R. A., Daliri, A., Enos, N., Abur, D., Lupiani, A. A., Letcher, S., & Stepp, C. E. (2020). The relation of articulatory and vocal auditory–motor control in typical speakers. *Journal of Speech, Language, and Hearing Research*, *63*(11), 3628-3642.
[6]Mitsuya, T., MacDonald, E. N., Purcell, D. W., & Munhall, K. G. (2011). A cross-language study of compensation in response to real-time formant perturbation. *The Journal of the Acoustical Society of America*, *130*(5), 2978-2986.
[7]Parrell, B., Agnew, Z., Nagarajan, S., Houde, J., & Ivry, R. B. (2017). Impaired feedforward control and enhanced feedback control of speech in patients with cerebellar degeneration. *Journal of Neuroscience*, *37*(38), 9249-9258.
[8]Shiller, D. M., Sato, M., Gracco, V. L., & Baum, S. R. (2009). Perceptual recalibration of speech sounds following speech motor learning. *The Journal of the Acoustical Society of America*, *125*(2), 1103-1113.
[9]Shiller, D. M., Bobbit, S. & Lametti, D. R. (2021). Sensorimotor adaptation in bilingual speech [slide slam]. *SNL 2021 Virtual Edition*, 5-8 October 2021 [online].
[10]Tourville, J. A., & Guenther, F. H. (2011). The DIVA model: A neural theory of speech acquisition and production. *Language and cognitive processes*, *26*(7), 952-981.