Contributions of performance and prediction errors in speech motor learning

Sara-Ching Chao and Ayoub Daliri

Arizona State University

When we perform a movement, we also predict sensory outcomes of the planned movements. We then compare our predictions with incoming sensory information to detect errors in our performance (Guenther, 2016). In our succeeding movements, we try to decrease the perceived error. This process of error reduction is called error-based motor learning, which it includes two learning processes: explicit and implicit learning (Huberdeau, Krakauer, & Haith, 2015; Taylor, Klemfuss, & Ivry, 2010). Explicit learning is the process of change in performance by using instructions. For instance, when we initially learn a new action, we follow a set of instructions or strategies. Our performance improves dramatically at the onset of training. After receiving enough training, we gradually pay less attention to the strategy and start improving our movements without conscious effort. This second process is called implicit learning (Krakauer, Hadjiosif, Xu, Wong, & Haith, 2019; Taylor, Krakauer, & Ivry, 2014). It has been shown that explicit learning is strongly dependent on performance error (i.e. errors between movement outcomes and targets) and implicit learning is strongly dependent on prediction errors (i.e., errors between sensory predictions and sensory outcomes). While these processes have been studied extensively in the limb motor learning domain (For a review, see Krakauer et al., 2019), it is not clear whether these processes play important roles in speech motor learning.

In a recent study (Daliri & Dittman, 2019), we adopted a paradigm that is commonly used in limb motor learning studies (i.e. error clamp) to generate prediction errors independent of performance errors in the speech domain. We developed a formant clamp procedure in which participants would produce a vowel and in near real-time hear a perturbed version of their production. The perturbation (formant clamp) was designed such that there was no correspondence between the participant's speech output and what they heard. For example, regardless of what the participant produced (e.g., "head", "hid", "heed") their production was perturbed so that they hear "had." This procedure is different from the commonly used formant shift in which the participant's production is shifted (e.g., "head" is shifted toward "had") such that the participant can repair the perceived error by changing her production (e.g., producing "hid") (Houde & Jordan, 1998; Villacorta, Perkell, & Guenther, 2007). In our previous study, we applied formant clamps in a gradual manner and participants were not instructed about the perturbations. When we encounter errors that are gradually applied, it is less likely that we would perceive them and therefore less likely to engage explicit learning mechanisms. Additionally, participants were not instructed about the perturbation and therefore, the distinction between sensory prediction errors and performance errors remained unclear. In the present study, we use formant clamp and formant shift procedures to address these knowledge gaps by (1) comparing how participants learn from errors when the errors are introduced gradually vs. suddenly, and (2) comparing how participants learn from errors when they are specifically instructed to ignore errors they hear.

In our previous study (Daliri & Dittman, 2019), we compared learning from gradually applied formant clamp vs. formant shift without instruction. In the present study, we recruited three separate groups (1) to compare gradually applied formant clamp vs. formant shift without instruction to ignore the feedback, (2) to compare suddenly applied formant clamp vs. formant shift without instruction to ignore the feedback, and (3) to compare suddenly applied formant clamp vs. formant shift with instruction to ignore the feedback.

We have recruited 14 participants in each group and the recruitment is ongoing (age range: 19-51 years, M_{age} = 21.46 years, SD = 7.21 years). The experimental setup was like that of our previous study. Participants produced target words while receiving their auditory feedback through insert earphones. Target words were presented for 2.5 s and there was a 1-2 s break period between the presentation of the words. Each participant completed two adaptation tasks that used formant clamp and formant shift perturbations. Each adaptation task consisted of 30 trials of a baseline phase where not perturbations were applied. In the gradual conditions, perturbations were gradually applied over the course of 30 trials. In sudden conditions, perturbation was applied immediately after the baseline phase. The magnitude of the perturbation was participant-specific and was equal to 80% of each participant's ε-æ distance (F1 was increased and F2 was decreased). In each condition, the perturbation remained constant for 60 trials (hold phase). The perturbation was changed to zero in the last 30 trials (end phase).

As a dependent variable, we calculate the average adaptive response over the last 30 trials of the hold phase (i.e., change in formant frequencies in the F1-F2 coordinates in response to the perturbations). Our preliminary results to date show that the difference between adaptive responses to formant clamp and adaptive responses to formant shift was smaller when the perturbations were introduced suddenly and when participants are instructed to ignore the feedback. Overall, these results suggest that speech motor learning may is sensitive to both performance error and prediction error. Using the formant clamp procedure along with the pattern of exposure to perturbations and instruction regarding the perturbations, one can dissociate explicit and implicit mechanisms of speech motor learning.

References

Daliri, A., & Dittman, J. (2019). Successful auditory motor adaptation requires task-relevant auditory errors. Journal of Neurophysiology, 122(2), 552–562.

Guenther, F. H. (2016). Neural control of speech. Cambridge, MA: MIT Press.

Houde, J. F., & Jordan, M. I. (1998). Sensorimotor adaptation in speech production. Science, 279(5354), 1213–1216.

Huberdeau, D. M., Krakauer, J. W., & Haith, A. M. (2015). Dual-process decomposition in human sensorimotor adaptation. Current Opinion in Neurobiology, 33, 71–77.

Krakauer, J. W., Hadjiosif, A. M., Xu, J., Wong, A. L., & Haith, A. M. (2019). Motor learning. Comprehensive Physiology, 9(2), 613–663.

Taylor, J. A., Klemfuss, N. M., & Ivry, R. B. (2010). An explicit strategy prevails when the cerebellum fails to compute movement errors. Cerebellum, 9(4), 580–586.

Taylor, J. A., Krakauer, J. W., & Ivry, R. B. (2014). Explicit and Implicit Contributions to Learning in a Sensorimotor Adaptation Task. Journal of Neuroscience, 34(8), 3023–3032.

Villacorta, V. M., Perkell, J. S., & Guenther, F. H. (2007). Sensorimotor adaptation to feedback perturbations of vowel acoustics and its relation to perception. The Journal of the Acoustical Society of America, 122(4), 2306–2319.