Sense of agency is flexible during speech production

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Auditory feedback plays a crucial role in speech production. Speakers monitor auditory feedback during speech production in order to avoid and correct for speech errors. It is well established that speakers compensate for unexpected perturbations of auditory feedback (Burnett et al., 1998; Houde and Jordan, 1998). During motor planning, an internal forward model predicts the sensory consequences of the issued motor commands. This prediction can subsequently be compared to the observed sensory feedback. In case of a mismatch between predicted and observed feedback, an error signal can lead to compensatory responses and/or adaptation learning.

Previous studies have suggested that not only do forward models and auditory feedback play a role in self-monitoring and error correction during speech production, but also in the generation of a sense of agency over vocal output (Haggard, 2017). In other words, the comparison between predicted and observed feedback may not only serve to detect speech errors or update the internal forward models, but also to distinguish between self-generated auditory input and externally generated auditory input and thus generate a sense of agency over the vocal output.

According to this framework, if the predicted feedback does not fully match the observed feedback, this can lead to either (1) a response to compensate for the articulation error (self-monitoring) or (2) the rejection of the auditory input as self-produced (decreased agency). However, it is still unclear how these two functions interact. Logically, in order to use auditory input for error-monitoring, the auditory input has to be recognized as feedback and thus a minimal sense of vocal agency is required. Interestingly, in response to unexpected pitch shifts in auditory feedback, speakers tend to give smaller responses to large shifts (> 250 cents) compared to smaller shifts (Scheerer et al., 2013; Subramaniam et al., 2018). It has been argued that this is the result of the large shifts being too unlikely to be self-generated, leading to less error correction. Therefore, we hypothesize that if the feedback perturbation is large enough, the perturbation leads to a loss of vocal agency. If it is small enough, a sense of vocal agency is generated and thus speakers may use the mismatching feedback for compensatory responses or adaptive learning.

In the current study, we aim to investigate the interplay between vocal agency and speech error correction further. In particular, what acoustic characteristics play a role in establishing vocal agency? In two experiments (N = 36 and N = 38), participants were exposed to unexpected pitch changes in auditory feedback during speech production. The pitch shifts were either small (±100 cents) or large (±400 cents), expected to lead to either relatively bigger or smaller responses, respectively. The feedback voice sounded like their own voice (unaltered except for the pitch shifts) in one condition, or was manipulated by a constant large pitch increase (+500 cents) in a second condition, hereafter the ‘alien voice’. The rationale is that the latter condition makes the feedback sound unlike one’s own voice and thus should lead to a loss of vocal agency. The study goal was to investigate to what extent this large feedback perturbation affects responses to unexpected pitch changes. If the large constant voice manipulation affects vocal agency, smaller

compensatory responses are expected in the alien voice feedback condition, compared to normal voice feedback.

This hypothesis was not borne out. Participants showed clear compensatory responses to unexpected pitch shifts in all conditions, with larger responses to ±100 cents shifts compared to ±400 cents shifts, in line with previous studies. However, responses did not differ between the normal voice condition and the alien voice condition. This was the case both when the voice conditions were administered in separate blocks (Experiment 1) as well as when they were randomly intermixed (Experiment 2). The results suggest that the sense of agency during speech production is highly flexible: participants compensate for unexpected pitch changes, regardless of the feedback voice characteristics. Even when the feedback voice condition was unpredictable (Experiment 2), speakers quickly accepted the alien voice as a new pitch referent for compensatory responses. We suggest that participants' compensatory responses are reactions to unexpected changes in an ongoing feedback pitch contour, rather than responses to the absolute error between actually produced and observed pitch. In addition, these results suggest that differences between voice characteristics of auditory feedback during natural speech production and auditory feedback as observed through headphones may not affect compensatory responses, as speakers quickly adapt to an alien-sounding voice.

In conclusion, the sense of agency is highly flexible in speech production and may derive from temporal covariance between expected and observed sensory feedback, rather than an absolute pitch error. These results raise questions about the content of sensory predictions and the internal representation of one's own voice. With respect to sensory predictions, temporal variation may be more prominently represented than, for example, absolute pitch. Internal representations of one's own voice are more flexible than often assumed, in line with recent studies in non-speech sensorimotor control, showing that the representation of one's body is flexible.

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