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Letter to the Editor

# Articulatory bias in speech categorization: Evidence from use-induced motor plasticity

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Challenging the classical proposal of separate neural/cognitive processes for speech perception and speech production, several neurobiological and psycholinguistic models of speech perception argue for a functional connection between sensory and motor systems (e.g., Liberman and Whalen, 2000; Wilson and Iacoboni, 2006; Skipper et al., 2007; Schwartz et al., in press). In these models, phonetic interpretation of sensory information is determined or constrained by some internal motor simulation based on articulatory procedural knowledge. However, despite accumulating evidence that speech motor regions are activated in processing speech sounds (e.g., Fadiga et al., 2002; Pulvermüller et al., 2006; Sato et al., 2010), the question of whether articulatory processes *mediate* speech perception is still vigorously debated (e.g., Lotto et al., 2009; Sato et al., 2009; Scott et al., 2009). Using a new technique based on use-induced motor plasticity, we here provide evidence that the motor system can bias perceptual performance in auditory speech recognition and plays a mediating role in phonetic decision/categorization process.

To test whether the motor system modulates performance in speech perception, we used a non-invasive behavioral technique based on activity-dependent plasticity in the orofacial motor system, with the goal of recalibrating action controllers that might be tapped by subsequent speech processing (for studies using a similar cross-modal motor-to-perception adaptation paradigm, see Glenberg et al., 2008, 2010; Cattaneo et al., in press). Since short-term training in orofacial motor task has been associated with rapid neuroplasticity of the motor cortex and enhanced corticomotoneuronal excitability (Boudreau et al., 2007), a modulation of perceptual performance after motor training would demonstrate a mediating role of the motor system in speech categorization. To this aim, two groups of participants were required to repeatedly perform 150 lip or tongue movements for 10 min in order to induce changes in the corticomotor control of the orofacial musculature (for details, see supplemental data). More specifically, participants were asked to repeatedly raise and press their tongue to the anterior palate while keeping their mouth closed (tongue training) or to protrude their lips ‘as for doing a kiss’ (lip training). Each articulatory movement consisted of 2 sec of muscle contraction and 2 sec of relaxation. Following the motor training, participants underwent a two-forced choice auditory syllable decision task between/pa/and/ta/syllables that were masked or not with white noise. To test a possible modulation of perceptual performance due to use-induced motor plasticity, a similar perceptual task was performed without prior motor training, with the interval between the two perceptual tasks being half an hour and their order being fully counterbalanced across participants.

Analysis of reaction time to indicate/pa/or/ta/(RTs – see Fig. 1A) showed a large effect of noise [$F(1,34) = 72.14$, $p < .001$], a significant effect of syllable [$F(1,34) = 6.23$, $p < .02$] and a reliable noise x syllable interaction [$F(1,34) = 7.86$ $p < .01$]. No other significant effects or interactions were found, indicating that neither the tongue motor training nor the lip motor training modulated RTs. For identification scores, because of

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0010-9452/$ – see front matter 
doi:10.1016/j.cortex.2011.03.009

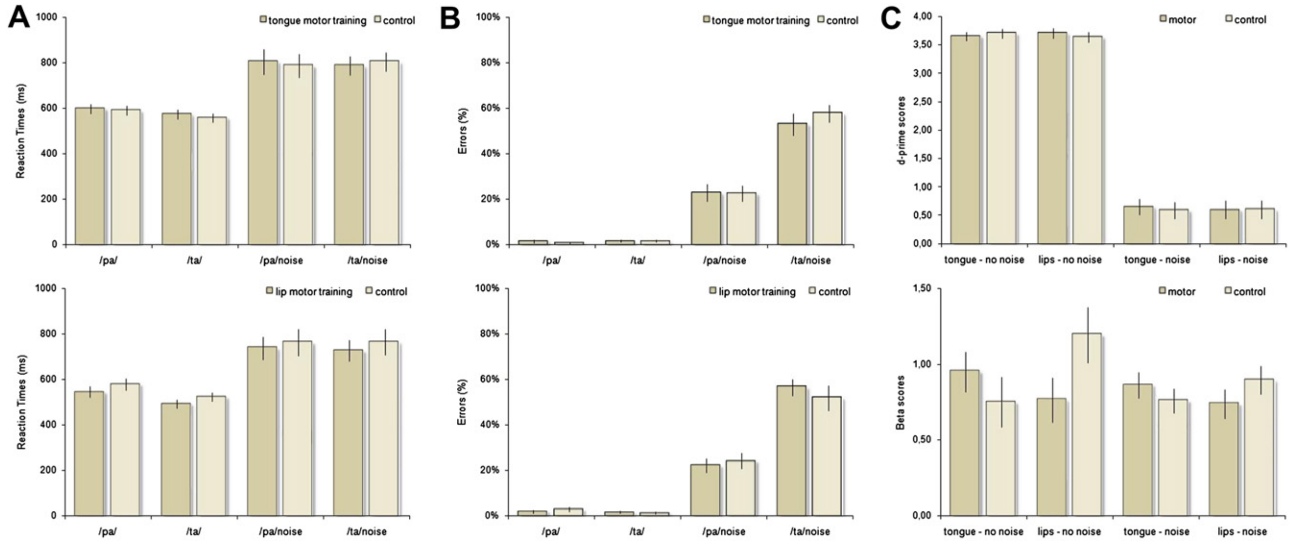


**Fig. 1 – Reaction times (A) and percentage of correct responses (B) observed in the auditory syllable decision task with and without prior motor training. (C) D-prime and beta signal detection parameters computed from identifications scores. Error bars represent standard errors of the mean.**

the large differences in error rates between conditions, we focused on d-prime and beta signal detection parameters (see Fig. 1C). The d-prime measure indicates the ability to distinguish between the two syllables, whereas the beta measure indexes possible response bias. Analysis of d-prime scores showed a strong effect of noise [$F(1,34) = 1278.0$, $p < .001$] but no other significant effects or interactions. For beta scores, a significant experiment × session interaction [$F(1,34) = 6.1$, $p < .02$] was observed. From this interaction, a lower beta score was observed after the lip motor training compared to the control task, that is, participants were more biased to respond/pa/. Just the opposite occurred after the tongue motor training, that is, beta increased so that participants were less biased to respond/pa/(more biased to respond /ta/). No other significant effects or interactions were found.

These opposite modulations of perceptual performance after the tongue and lip motor training suggest that use-induced motor plasticity specifically biases subsequent speech processing in an articulator-dependent manner. However, one alternative might be based on task demands, that is, the participants noted the relation between the articulator used in the motor training and the perceived syllables, and they strategically used that relation to change their responding. Although this alternative cannot be fully ruled out, it appears quite unlikely since the relation between the motor tasks and the articulatory realization of /pa/and /ta/ syllables is far from transparent, and none of the participants reported having noted such a relation when debriefed at the end of the experiment. From our results, it is also worthwhile noting that specific modulations of perceptual performance on an auditory syllable decision task have been previously obtained by temporarily changing the activity of the primary tongue or lip motor cortices by means of transcranial magnetic stimulation (d'Ausilio et al., 2009).

The more likely explanation is based on use-induced motor plasticity conjoined with the claim that the motor system plays a mediating role in speech perception (Schwartz et al., in press). To the extent that the motor training has produced rapid neuroplasticity of the primary tongue or lip motor cortex and enhanced corticomotoneuronal excitability (Boudreau et al., 2007), this plasticity would recalibrate activity of the articulatory motor system in relation to the used articulator. This specific adaptation mechanism then would have affected syllable recognition in the subsequent auditory speech task. Importantly, the fact that analysis of d-prime scores failed to show any significant effect of the motor training, but analysis of beta scores did, allows us to refine how use-induced motor plasticity mediates speech categorization. Our results likely indicate that motor training has no significant effect on the auditory ability to distinguish between the two syllables, but on higher-level, top-down, decision/categorization processes. This conclusion appears in line with recent neurobiological models of speech perception (Wilson and Iacoboni, 2006; Skipper et al., 2007) postulating that phonetic hypotheses are first derived from acoustico-phonetic analyses in the auditory system. These hypotheses are then mapped onto speech motor control commands which, in turn, constrain phonetic interpretation by predicting the acoustic consequences of executing a speech movement through feedback projections to the auditory system. In summary, the observed motor bias after the motor training provides strong evidence that articulatory processes contribute to high-level decision/ categorization processes in auditory speech categorization (Sato et al., 2009, 2010; Schwartz et al., in press).

## Acknowledgment

This study was supported by research grants from CNRS to M.S. and Grenoble-INP (Project BQR 'Modyc') to K.G. and M.S. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agencies.

## Supplementary data

Supplementary data related to this article can be found online at doi:10.1016/j.cortex.2011.03.009

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