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Preface

The role of mirror neurons in speech and language processing

The discovery of mirror neurons in the macaque frontal cortex (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti & Arbib, 1998) has sparked renewed interest in the role of the motor system in receptive language processes. This interest has developed primarily around two logically independent, but sometimes conflated, ideas. One is that motor systems involved in speech production are critically involved in perceiving speech sounds (D'Ausilio et al., 2009; Meister, Wilson, Deblieck, Wu, & Iacoboni, 2007; Wilson, Saygin, Sereno, & Iacoboni, 2004), an idea that is clearly related to the motor theory of speech perception (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Liberman & Mattingly, 1985). The other is that the meaning of action-related words are coded, at least in part, in motor regions that control the execution of those actions (e.g., Hauk, Johnsrude, & Pulvermuller, 2004; Wernicke, 1874/1969). These are independent hypotheses in that one concerns the neural basis of perceiving the phonological form of speech sounds while the other concerns the neural basis of a different level of processing/representation, namely the semantics of a word. Thus, the proposals need to be evaluated independently; evidence for or against one idea does not constitute evidence for or against the other.

With this in mind, I would like to introduce this special issue of *Brain and Language*, which brings together seven original papers presenting theoretical and empirical arguments regarding the role of the motor system in these two domains of language processing. Before introducing the papers, however, it is worth laying out some boundary conditions for evaluating the evidence and claims.

1. Role of the motor system in speech perception

The question of the role of the motor system in speech perception has the benefit of decades of research driven by Liberman and colleague's motor theory of speech perception, which has been evaluated from a range of perspectives including neuropsychology, development, and animal research. The outcome of all this work was that a strong version of the motor theory was rejected as a viable theory by a large majority of speech perception researchers. Some of the most convincing evidence that led to the rejection of the strong view of the motor theory came from studies showing that speech perception could be achieved without motor speech ability. Neither damage to the motor cortex related to speech as in Broca's aphasia (Damasio, 1992; Goodglass, 1993) nor cases of congenital failure to develop speech production prevent normal receptive speech ability (Lenneberg, 1962). Developmentally it was shown that infants could discriminate speech sounds that they could not yet produce (Eimas, Siqueland, Jusczyk, & Vigorito, 1971). And research on animals indicated that sophisticated speech perception ability could be achieved even in a model system (e.g., chinchilla) that does not have the capacity to produce any speech (Kuhl & Miller, 1975). More recent evidence supports the earlier findings. For example, it has been shown that acute and complete deactivation of left hemisphere motor regions during the administration of Wada procedures does not preclude impressive speech discrimination performance requiring the resolution of fine phonetic distinctions (Boatman et al., 1998; Hickok et al., 2008). The fact that motor speech is not necessary for speech perception places a significant constraint on motor-based theories of receptive speech processing and falsifies any claim that the motor system is required for speech perception generally.

At the same time, any theory of speech perception must take account of recent observations that motor systems can affect speech perception to some degree. For example, Galantucci et al. review a range of behavioral studies indicating motor influence on speech perception (Galantucci, Fowler, & Turvey, 2006), and studies involving the application of transcranial magnetic stimulation (TMS) to motor areas has shown mild changes in performance in the perception of speech presented in noise (D'Ausilio et al., 2009; Meister et al., 2007) indicating some role for the motor system at least under some conditions (see (Hickok, Holt, & Lotto, 2009; Wilson, 2009) for discussion). Findings such as these place constraints on auditory-based theories of speech perception and indicate that there must be a mechanism for the interaction of sensory and motor systems during perception of speech.

2. Role of motor system in action semantics

Evidence regarding the role of the motor system in action semantics has accrued at a rapid pace in the last few years. This work has generated compelling evidence for an association between motor cortex and action word/concept processing. For example, reading action words activates motor cortex in a somatotopic fashion (Hauk et al., 2004), stimulation of motor cortex via TMS affects response time in a lexical decision task (Pulvermuller, Hauk, Nikulin, & Ilmoniemi, 2005), lesions affecting left premotor/prefrontal regions (as well as parietal and temporal areas) are associated with difficulty in making non-verbal inferences or similarity judgments about statically depicted actions (Tranel, Kemmerer, Adolphs, Damasio, & Damasio, 2003).

What remains to be demonstrated, however, is whether the association between motor areas and action concept processing reflects fundamental involvement of motor cortex in action semantic representation or is merely task-related (d'Honincthun & Pillon, 2008) or even epiphenomenal. As Hauk et al. point out with respect to imaging studies, "previous neuroimaging results have not been able to distinguish between activation evoked by elementary

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recognition processes (accessing the meaning of the word 'hammer', for example) and 'epiphenomenal' post-recognition processes, such as deliberate imagery (e.g. imagining using a hammer) or 'post-understanding translation'" (Hauk, Davis, Kherif, & Pulvermuller, 2008, p. 1856). Another issue is whether the source of action word/concept effects is really motor cortex: this certainly cannot be inferred from studies of neurodegenerative diseases (e.g., ALS, PD), which can be accompanied by diffuse injury. Thus, while much research has indicated some degree of motor involvement in action concept processing, the significance and precise role of motor involvement in action semantics remains to be investigated thoroughly.

3. The present volume

The present collection of papers, representing both favorable and critical viewpoints on motor/mirror-neuron based models, tackles these two major issues and more.

Kotz et al. examine the role of Broca's area in speech perception using TMS and fMRI methods, showing that Broca's area does participate in at least some receptive speech functions such as lexical decision, but only for real words and not for pseudowords. This suggests a higher-order function for speech processing in Broca's area than has typically been assumed by mirror neuron theorists.

Two papers, one by Arbib, the other by Corballis, discuss the implications of mirror neurons for speech and language from an evolutionary standpoint. Both authors argue that mirror neurons are an evolutionary pre-curser for the development of speech. In particular, they suggest that mirror neurons evolved to support an abstract manual gestural system that was then adapted to vocal tract behaviors. Knapp and Corina examine this hypothesis from the unique perspective of signed languages of the Deaf. These authors argue that, in contrast to predictions based on mirror neurons, linguistic and non-linguistic gestures dissociate, as do expressive and receptive aspects of signed language ability. As with similar data from speech, the signed language data places important constraints on mirror-neuron theorizing.

Three additional papers explore the role of the motor system in action semantics. Fernandino and Iacoboni examine the notion of somatotopy in the organization of action-related processing. They note that the presumed somatotopic maps are very coarse and are variable from one study to the next and consider in detail the relation between action processing and motor maps. Using recent data regarding the organization of monkey motor cortex these authors argue that the traditional conceptualization of motor maps may be incorrect in that rather than being organized around body parts, motor maps may be organized around coordinated actions making up the individual's motor repertoire.

Kemmerer and Castillo take on some of the specifics of how the representation of verbs may map onto the motor system. In particular, they propose a two-level theory of verb meaning in which "root" level verb features (those specific to a given verb) may correspond to lower-level (e.g., somatotopic) maps whereas more general features of a verb's meaning may map onto higher levels of the motor system such as portions of Broca's area.

Finally, de Zubicaray et al. question whether indeed there is any unique association between action word processing and Broca's area showing no action word-specific effect. Using fMRI they report equal activation for action and non-action related stimuli, including pseudowords, casting doubt on the idea that action-related processing is action-specific.

As can be seen from this collection of papers, we still lack consensus on the role of the motor system in speech and language processing. As noted above, while it is clear that *something* is happening in motor-related systems during various types of speech processing, it remains to be elaborated the extent to which this *something* fits into current "mirror neuron" models of speech/language. Hopefully, this special issue will help uncover some of the empirical facts and by bringing them together in a single volume will encourage theorists to consider models that explain motor-related effects in language processing as well as whether a motor-oriented framework really does represent the best possible characterization of these facts.

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