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The neurobiology of sign language and the mirror system hypothesis

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Abstract

I suggest two puzzles for the Mirror System Hypothesis. First, there is little evidence that mirror neuron populations for words or for signs exist in Broca's area, and a mirror system is not critical for either speech or sign perception. Damage to Broca's area (or to the mirror system for human action) does not result in deficits in sign or speech perception. Second, the gesticulations of speakers are highly integrated with speech, but pantomimes and modern protosigns (conventional gestures) are not co-expressive with speech, and they do not co-occur with speech. Further, signers also produce global, imagistic gesticulations with their mouths and bodies simultaneously while signing with their hands. The expanding spiral of protosign and protospeech does not predict the integrated and co-expressive nature of modern gestures produced by signers and speakers.

Keywords

sign language; gesture; pantomime; Broca's area

0 Introduction

Michael Arbib proposes that the brain got language via the mirror neuron system – hence the title of his book. In particular, he proposes that a mirror system for grasping (a system that matches action observation and execution for grasping actions) evolved into a mirror system that is not tied to praxic actions, but rather relates to actions of speaking (or signing). In addition, Arbib proposes that pantomime preceded protosign, which then provided the scaffolding for protospeech, and an “expanding spiral” between the two led to multimodal protolanguage. I would like to raise two puzzles for this account of the evolution of language: 1) a mirror system for the actions of speaking or signing is not critical for either spoken or signed language processing (Hickok 2008; Corina and Knapp 2008; Emmorey et al. 2010), and 2) pantomimes and modern protosigns (i.e. conventional, more arbitrary gestures) do not co-occur with speech (McNeill 1992, 2012), but gesture (gesticulation) co-occurs with both speech and sign (Emmorey 1999; Sandler 2009).

1 Puzzle 1: The mirror system is not critical for either speech or sign

If the mirror system is key to the evolution and emergence of language in humans, it is puzzling that the mirror system plays such a small role in language processing for both auditory-vocal and visual-manual languages. Although Arbib does not claim that the mirror system alone can support language, he argues that mirror neurons serve as part of the neural circuitry that mediates understanding (2012: 139) and that there are mirror neuron populations for words and signs that encode articulatory form and that these neurons fire when a specific word is heard or uttered (or a sign is either seen or articulated) (2012: 281). Arbib states that the basic idea of the Mirror System Hypothesis for the evolution of language is that “the mechanisms that get us to the role of Broca's area in language depend

in a crucial way on the mechanisms established to support a mirror system for grasping (2012: 174).” The conundrum is that Broca’s area does not exhibit properties associated with a mirror system for either speech or sign, that is, a system that matches action observation (i.e. perceiving speech or sign) and execution (articulation) of speech or sign.

For speech, Hickok and colleagues have laid out several arguments against a speech-based mirror system in Broca’s area (Hickok 2008; Hickok 2010; Hickok et al. 2011; Rogalsky et al. 2011). Although evidence for the role of Broca’s area in speech production is incontrovertible and unquestioned, Hickok and colleagues have provided strong evidence against a critical role for Broca’s area in speech perception. Specifically, lesions to Broca’s area (or to the fronto-parietal human mirror system more generally) do not cause any deficits in speech perception or comprehension. Patients with lesions to Broca’s area perform at ceiling on tests of word comprehension and syllable discrimination (Rogalsky et al. 2011). In addition, the degree of speech fluency (i.e. the degree of integrity of the motor speech system) is unrelated to the ability to discriminate syllables or to word comprehension ability (Hickok et al. 2011). Further, Hickok et al. (2011) cites evidence (not repeated here) that highly accurate and intact speech perception abilities are found for 1) individuals with developmental anarthria (loss of the motor function that enables speech), 2) individuals undergoing the Wada procedure which completely deactivates speech production ability, and 3) infants who have not yet developed the ability to control the speech articulators. Thus, the evidence indicates that if speech-related mirror neurons exist in Broca’s area (or in other motor brain regions), their response plays little role in speech perception.

For sign, there is little evidence that sign-related mirror neuron populations (if they exist) play a critical role in the perception and comprehension of sign language. For example, deaf patients with damage to Broca’s area exhibit sign articulation deficits, but sign perception and comprehension are intact (Poizner et al. 1987; Hickok et al. 1996). Neuroimaging data indicate that Broca’s area is engaged during both sign production and sign comprehension, but given the multifunctionality of this region (e.g. Grodzinsky and Amunts 2005), this result alone does not provide clear evidence that the same population of neurons responds when perceiving and producing signs. Nonetheless, some suggestive evidence is found in Knapp and Corina (2010). These authors conducted a post hoc conjunction analysis with six deaf ASL signers who participated in separate neuroimaging studies that tapped sign production and sign perception, and they reported some overlapping activation in Broca’s area (BA 44). However, several other cortical regions also exhibited overlapping activation for sign perception and production: left superior frontal gyrus, left middle frontal gyrus, left insula, bilateral precentral gyrus, and bilateral superior parietal cortex.

The human mirror system for grasping actions is hypothesized to also include mirror neurons in inferior parietal cortex, and a review by Corina and Knapp (2008) revealed that inferior parietal cortex (specifically, the supramarginal gyrus) is engaged during both sign production and comprehension (in separate studies). However, the conjunction analysis by Knapp and Corina (2010) revealed overlapping activation in the superior parietal lobule, not in inferior parietal cortex. In addition, Corina et al. (1999) found that impairment of the supramarginal gyrus (SMG) via electrical stimulation did not disrupt the ability to imitate signs (which requires matching an observed sign with the execution of that sign), although stimulation to SMG did disrupt sign production alone (elicited via a picture naming task). The Corina et al. (1999) study suggests that if mirror neurons for signs exist in inferior parietal cortex, they are not critical for sign perception.

Finally, my colleagues and I recently investigated the neural systems that were engaged during the perception of pantomimes and ASL verbs by deaf signers and hearing individuals who were naïve to sign language (Emmorey et al. 2010). In that fMRI study, participants

passively viewed video clips of pantomimes (e.g. peeling an imaginary banana) and ASL verbs that were rated as meaningless by non-signers (e.g. TO-DANCE). For hearing non-signers, both pantomimes and ASL verbs (which were meaningless for them) strongly activated the mirror system for human action, i.e. fronto-parietal cortex. However, for the deaf signers there was no activation in the mirror system during the perception of pantomimes, and activation was found only in Broca's area during the perception of ASL verbs. We concluded that the lack of activation within the mirror system for deaf signers did not support an account of human communication that depends upon automatic sensorimotor resonance between perception and action.

In sum, a mirror neuron system does not appear to underlie language perception for either spoken or signed language. Damage to premotor regions or to Broca's area does not disrupt perception or comprehension ability for either speakers or signers.

2 Puzzle 2: The Mirror System Hypothesis is inconsistent with the properties of co-speech and co-sign gesture

At first blush, the ubiquity of co-speech gesture in modern human language users could be taken as support for the Mirror System Hypothesis because the multimodality of modern language could be considered the evolutionary result of multimodal protolanguage, which emerged from the expanding spiral between protosign and protospeech. However, the problem is that the modern equivalent of protosigns – conventionalized gestures that are more arbitrary in form and specific to individual cultures (e.g. the OK gesture, the horns gesture) – are not produced simultaneously with speech (McNeill 1992). In addition, pantomimes are also not produced concurrently with speech, but occur as a type of demonstration or as a “component” gesture produced separately from speech (Clark 1996). In a sense, both pantomimes and modern protosigns (i.e. conventional communicative gestures) actually *repel* speech with respect to both timing (they do not cooccur with speech) and expressivity (they are not co-expressive with speech; see McNeill 2012).

The gestures that co-occur with speech are sometimes referred to as gesticulations in order to distinguish them from pantomimes and conventional gestures. Two decades of research by David McNeill and colleagues have demonstrated that gesticulation is an integral part of speaking (e.g. McNeill 1992; McNeill and Duncan, 2000). McNeill argues that co-speech gestures synthesize several elements of a thought simultaneously, while speech (and sign) express these elements separately and categorically in morphemes, words, phrases, etc. Similarly, he argues that gestures express meanings globally, i.e. the handshape, movement, or location of a gesture gain meaning only as parts of a whole; in contrast, for speech (and sign) meaning is segmented and combined into hierarchical structures. Gestures and speech are bound together in a tight link and are not easily separated – for example, gestures that occur with stuttered speech do not compensate for the reduced content of speech and the onset of stuttering immediately stops a gesture (Mayberry and Jaques 2000).

What is not clear from Arbib's account is why or how this highly synergistic relationship between gesture and speech emerged from the expanding spiral between protosign and protospeech. Protosigns and pantomimes are not synthetic and global (in contrast to gesticulation). In Arbib's account conventional vocalizations (protospeech) became associated with protosigns leading to protolanguage. However, it is not at all clear how protolanguage (a mix of protosign and protospeech) evolved into the integrated semiotic system of speech and gesture observed in modern humans. Under Arbib's account, one would predict that the remnants of the gestural origins of language (i.e. pantomimes and modern protosigns) should co-occur with speech, but they do not.

Another puzzle is that signers also gesture simultaneously while signing (Emmorey 1999; Sandler 2009). As found for speakers, pantomimes and conventional gestures are not produced simultaneously with signs and are produced as components of an utterance (Emmorey 1999). Also like speakers, signers produce synthetic and global gesticulations, but with their mouths and their bodies while signing with their hands. For example, a signer may produce a swaying gesture with his or her body, while producing the sign TO-DANCE; the body gesture conveys the waltz-like manner of the dance (Emmorey 1999). Sandler (2009) presents an elegant analysis of co-sign gestures produced by the mouth, for example, puffed cheeks conveying the round shape of a ball produced simultaneously with the manual sign BOWLING-BALL. She presents evidence that such mouth gestures are global, synthetic, idiosyncratic, and noncombinatoric, and she concludes “speakers gesture with their hands, signers gesture with their mouths (2009: 241).” Why should signers produce these types of co-sign gestures at all? One possibility suggested by Sandler is that all human language users express thought through an integrated system that combines codified, combinatorial meaning structures (expressed in language, either spoken or signed) and global, synthetic, imagistic schemas (expressed in gesticulation with the hands, face, or body). The puzzle for Arbib’s account is how and why protosign evolved into gesticulation and why modern signers produce signs and gesticulations in the same modality.

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