



A human mirror neuron system for language: Perspectives from signed languages of the deaf

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ABSTRACT

Language is proposed to have developed atop the human analog of the macaque mirror neuron system for action perception and production [Arbib M.A. 2005. From monkey-like action recognition to human language: An evolutionary framework for neurolinguistics (with commentaries and author's response). *Behavioral and Brain Sciences*, 28, 105–167; Arbib M.A. (2008). From grasp to language: Embodied concepts and the challenge of abstraction. *Journal de Physiologie Paris* 102, 4–20]. Signed languages of the deaf are fully-expressive, natural human languages that are perceived visually and produced manually. We suggest that if a unitary mirror neuron system mediates the observation and production of both language and non-linguistic action, three predictions can be made: (1) damage to the human mirror neuron system should non-selectively disrupt both sign language and non-linguistic action processing; (2) within the domain of sign language, a given mirror neuron locus should mediate both perception and production; and (3) the action-based tuning curves of individual mirror neurons should support the highly circumscribed set of motions that form the “vocabulary of action” for signed languages. In this review we evaluate data from the sign language and mirror neuron literatures and find that these predictions are only partially upheld.

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1. Introduction

Arbib (2005, 2008); Rizzolatti & Arbib (1998) propose that a human analog of the monkey mirror neuron system supports a variety of complex socio-cognitive phenomena, most notably human language. This theory is predicated on the notion that the capacity for human language is grounded in neural systems that originally supported manual communication. Specifically, the hypothesized evolutionary route from grasping to language in modern humans includes as a critical way-station *protosign*, a closed set of conventionalized manual gestures that served as the behavioral scaffolding on which ingestive oral behaviors (e.g., lip smacks and teeth chattering) were transformed into the system of complex phonological, syntactic, and semantic contrasts that are the hallmarks of modern language (Arbib (2005, 2008)). Mirror neurons are purported to have enabled this transformation by serving as a physiological cross-modal lexicon that mediated oral and manual behaviors.

Today in macaques, an observed action is said to be assigned meaning when an animal can self-referentially match its distal goal to one stored in its own premotor cortical neurons (e.g., Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Kohler et al., 2002; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; Umiltà et al., 2001). A similar process of self-referential matching is said to occur in humans perceiv-

ing spoken language. If Arbib and colleagues are correct that a mirror neuron system underlies language perception in humans, we would expect it to mediate all human languages, regardless of typology or language family. Natural candidates for the exploration of this hypothesis are signed languages, which possess all the linguistic complexity of spoken languages but are perceived visually and produced manually.

Modern signed languages, which are used by Deaf¹ individuals throughout the world, are fully expressive, natural human languages. Like spoken languages, they can be conceptualized as unplanned but conventionalized repertoires of complex, goal-directed actions whose shared understanding is critical to all members of a given language community. They are subject to the same types of psycholinguistic phenomena—priming, frequency effects, interference effects—that occur in spoken language processing (Carreiras, Gutierrez-Sigu, Baquero, & Corina, 2008; Corina & Emmorey, 1993; Corina & Hildebrandt, 2002; Dye & Shih, 2006). Nevertheless, signed languages exhibit a typologically unique feature that makes them interesting to study in the context of a mirror neuron system. Phonetic aspects of signed languages are seemingly more transparent

¹ *Deaf* is customarily spelled with a capital D when the label refers to those deaf people who consider themselves culturally Deaf – that is, the subset of deaf people who use and value their signed language, lead a lifestyle that places high value on openness and information sharing, and acknowledge a shared history of social marginalization. Typically, regular users of signed languages are culturally Deaf.

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than that of spoken languages. They are perceived visually, and thus forego the successive decoding by auditory association cortices that speech undergoes before making contact with a mirror neuron system (see Hickok and Poeppel (2007) for a perspective). As the paradigmatic case of a linguistic system that circumvents acoustic mediation, signed languages thus serve as an interesting test case for the hypothesis that a mirror neuron system underlies language processing in humans.

1.1. Predictions: properties of a mirror neuron system for sign language

Three predictions emerge from a proposed mirror neuron system for sign language processing. First, the most literal interpretation of a shared mirror neuron system for language and non-linguistic human action predicts a relatively unitary system underlying both of these complex action classes. Presumably, language draws upon a richer set of neural resources than does gesture, but if they share a core neural system for perceptual-motor matching, sign and gesture should rarely functionally dissociate in instances of mirror neuron system damage. Second, because by definition mirror neurons encode both the perception and production of select actions, a great deal of processing overlap between the comprehension and production of meaningful units (i.e., signs, gestures) would be expected within a given domain (i.e., language, non-linguistic action) across all mirror neuron populations. The firing of individual mirror neurons in the macaque is held to represent paired selectivity for individual action schemas – grasping, tearing, holding, and so forth, such that perception and production are in some sense inextricable. Neurophysiological evidence should support this linkage in the human as well. Third, we would expect a human mirror neuron system for language to be attuned to linguistic contrasts. Matching between an observed and a produced linguistic signal could occur conceptually, lexically, or sublexically, and thus demand contrast sensitivity at any or all of these stages. For the linguist, a natural first place to look is at the phonemic level, where psychologically meaningful linguistic contrasts first manifest. In this case, individual phonemic units (in isolation or in particular combinatorial contrasts) would be represented by very sensitive tuning curves of individual neurons, much like orientation or object features have been found to be represented in cortical columns in non-human mammals (e.g., Tanaka, 1993).²

Whether these three unique demands—a high degree of processing overlap across action class (language, non-linguistic action), a shared neural substrate for perception and production within action class, and a high degree of specificity for action schemas – are met in humans remains to be seen. Here we first review some preliminary evidence for a dissociation of sign language and human action processing, drawing primarily from aphasia and neuroimaging literatures. Within the domain of sign language, we next discuss the anatomical overlap of comprehension and production. Finally, we take a more theoretical approach to the third section and discuss whether currently established contrast sensitivities of mirror neurons could support some of the fine-gained discriminations needed for language processing.

2. A unitary system for sign and action processing?

Historically, much of our knowledge about the neural systems mediating action and language came from apraxia or aphasia case studies, in which individuals who suffered brain injury to discrete

anatomical locations presented with unfortunate, but somewhat predictable, sets of symptoms. Impaired behaviors were inferred to be mediated, in healthy individuals, by formerly functional anatomical loci.

As with spoken language, neuropsychological case studies of deaf signers have provided considerable evidence for dissociations between the processing of sign language and human actions. Several reports have now documented cases in which, following damage to the left-hemisphere, a deaf signer has completely or partially lost the ability to use sign language but has retained an ability to use pantomime and non-linguistic gesture (Corina et al., 1992; Marshall, Atkinson, Smulovitch, Thacker, & Woll, 2004; Metz-Lutz et al., 1999; Poizner, Klima, & Bellugi, 1987). A sampling of this literature cuts a broad swath across patient age and primary language. For example, Metz-Lutz et al. (1999) report a case of a child with acquired temporal-lobe epileptic aphasia who was unable to acquire French Sign Language, but was unimpaired on ideomotor and visuospatial tasks and produced unencumbered non-linguistic pantomime.

Corina et al. (1992) reported that adult patient W.L. demonstrated marked American Sign Language production and comprehension impairment following a lesion in left fronto-temporo-parietal regions, but retained intact pantomime comprehension and production, using gestures to convey symbolic information that he ordinarily would have imparted with sign language.

Marshall et al. (2004) report an interesting case study patient, Charles, whose communicative behavior following a left-hemisphere stroke makes clear that sign and gesture production in British Sign Language can be dissociated, even when the signs and gestures in question are physically quite similar. For example, when asked to produce the BSL sign for bicycle, he substituted a pantomimed bicycling motion.

Although this dissociation of language and gesture is not unique to sign, these cases do emphasize that sign language impairments following left-hemisphere damage are not simply attributable to undifferentiated impairments in the motoric instantiation of symbolic representations, but in fact reflect disruptions to a manually-expressed linguistic system that are not limited to any one modality, language, or stage of language development.

Neuroimaging data also support the neural dissociation of sign and gesture processing. For example, in a recent Positron Emission Tomography (PET) study (Corina et al., 2007), deaf signers and hearing individuals unfamiliar with signed language observed three classes of actions chosen to reflect increasing degrees of meaningfulness: self-oriented, object oriented, and communicative movements, each set against a luminance- and low level motion controlled baseline derived from the sign stimuli.

For sign language-naïve hearing subjects passively viewing these stimuli, few differences between conditions were seen. Primary foci included regions previously identified as critical to a human action recognition system: most notably, superior parietal (BA 40/7), ventral premotor (BA 6), and inferior regions of the middle frontal gyrus (BA 46).

For deaf signers, a different pattern was apparent. While the neural responses to self- and object oriented actions showed a fair degree of similarity to one another, ASL viewing contrasted to non-linguistic movement perception largely engendered neural activity in frontal and posterior superior temporal language areas, including left inferior frontal (BA 46/9) and superior temporal (BA 41) regions and the insula (BA 13) (shown in red in Fig. 1). Thus in this study, as in MacSweeney et al. (2004), the contrast between linguistic and non-linguistic actions reveals the participation of left-hemisphere perisylvian and inferior frontal cortical regions in the perception of signed languages of the deaf.

When non-linguistic actions are directly contrasted with ASL in deaf signers (shown in green in Fig. 1), prominent activity

² This position is at least implicitly shared by Rizzolatti and Craighero (2004), who cite Fadiga et al.'s (2002) comparison of labio-dental [f] and linguo-palatal [l] fricative consonants as evidence of a speech resonance system in humans.

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