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Enactive processing of the syntax of sign language

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Abstract It is unfashionable to suggest that enactive processes - including some that involve the mirror neuron system - might contribute to the comprehension of sign language. The present essay formulates and defends a version of that unfashionable suggestion, as it applies to certain forms of syntactic processing. There is evidence that has been thought to weigh against any such suggestion, coming from neuroimaging experiments and from the study of Deaf aphasics. In both cases it is shown to be unpersuasive.

Keywords Enactive processing · Syntax · Sign language · Parsing · Deafness · Mirroring

1 Enaction and syntax

If a knowledgeable language user has understood an appropriately contextualized utterance of the English sentence "John loved Mary" then, in addition to knowing (1) which string of phonemes was uttered, she will know (2) that John, Mary, and love have all been mentioned; and (3) who it was that is said to have done the loving, and who it was that is said to have been loved. The processing that explains the first of these pieces of knowledge is *phonemic* processing. The processing that explains the second is *semantic*. The processing that explains the third piece of knowledge – the knowledge of who was said to have done what to whom – is *syntactic*.

Embodied and enactive theories of language perception claim that one's capacity to act makes a contribution to one's comprehension of language

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(Fischer and Zwaan 2008). Some of those theories take this to be a contribution to *semantic* processing (Barsalou et al. 2008; Martin and Chao 2001). Others take it as a contribution to *phonemic* processing (Möttönen and Watkins 2009; Pulvermüller et al. 2006). Yet others take it as a contribution to the processing of an utterance's metaphorical and figurative aspects (Gibbs 1994; Gibbs 2005).

All of these theories are controversial, with the controversies about a role for action in the processing of phonemes being the most entrenched. The original source for those controversies is the Motor Theory of Speech Perception (Liberman et al. 1967; Liberman and Mattingly 1985; Ivry and Justus 2001). Unlike some of the more radical enactive theories (Turvey 2004), the post 1985 version of the Motor Theory of Speech Perception postulates a role in perception for one's own *capacity* for action, rather than taking speech perception to involve the actual performance of any actions. And – again unlike some of its more radical successors (Chemero 2011) – the Motor Theory *does* presuppose that perception and action both depend on the processing of representations. The central claim of that theory is that the perception of phonemes depends on a representation of the articulatory gestures by which those phonemes were produced, where this is a representation such as would be involved if one were to have produced those phonemes oneself (Fadiga et al. 2002; Mole 2009; O'Callaghan 2015).

The Motor Theory of Speech Perception does not tell us about the processing by which syntactic roles are identified. Nor could it – or any of its enactive cousins – be plausibly extended to do so. This is an immediate consequence of the fact that it is word order, and not the presence of any articulatory gesture, that marks John as the subject of our sentence, love as the verb, and Mary as the object. Because the syntactic properties of an English utterance do not correspond to any distinct articulatory gestures of the vocal tract, a representation of those gestures could at best be a first step towards knowing which syntactic structures were instantiated. It should therefore be no surprise that, although controversies surrounding enactive theories of phonemic processing are well established (and controversies surrounding enactive theories of semantic processing only somewhat less so (Weiskopf 2010; Hauk et al. 2004)), there is relatively little that has been said about the enactive processing of syntax. Obvious barriers stand in the way of such a theory being tenable, whether in a radical or a moderate form. But these barriers apply only to the case of a language that is spoken.

When we consider the case of sign languages we find that the barriers to an enactive theory of syntactic perception do not apply with full generality. Although sign languages often do employ word-order as a marker of syntactic structure, the syntactic structure of a sign language sentence can also be marked by the spatial organization of the signed gestures (Klima and Bellugi 1979). This spatial organization is given through the active comportment of the signing body. An enactive theory of sign perception could therefore apply, not only to the perception of phoneme-level gestures, but also to the perception of some syntactic properties. The present essay explains the tenability of such a theory, in the face of evidence that has mistakenly been thought to make it untenable.

The theory that we shall be defending is, like the Motor Theory, enactive and embodied without being radically so. To get a sense of that theory's content, it will be helpful to consider an example. A number of pertinent examples can be found in Scott K. Liddell's *Grammar, Gesture and Meaning in American Sign Language* (Liddell 2003). In one of these a Deaf user of ASL is describing his family to another. Their conversation is slightly artificial, in that the one signer who is being videotaped does almost all of the talking. He establishes first that he is one of five Deaf brothers. These brothers are represented with the signer's non-dominant hand, which functions, in an open five shape, as a 'list buoy' (in Liddell's terminology), to which subsequent information can be attached. When this signer reports that his first brother is forty-five years old, he does so by associating the age of forty-five (signed by the dominant hand) with the first of the fingers on this non-dominant hand. He then goes on to indicate that his second brother is forty-four, no, forty-three; he is forty-four next month. These ages are attributed to the second brother by associating them with the second finger in the same five-fingered list buoy. The speaker then notes that, of the five brothers, these first two are the nearest in age. He does this using his dominant hand, by producing a sign denoting nearness in the space between the first two fingers of this five-fingered list buoy.

Any interlocutor who comprehended these utterances would know (1) which signs had been used, and (2) that brothers, ages, and nearness have all been mentioned. They would also know (3) who it is that is said to have been near in age to whom. The processing that explains our knowledge of these third things is, as in our earlier example, *syntactic*. The hypothesis defended in the present paper is that such syntactic processing employs a representation that is formatted so as to be apt for use in the *production* of the gestures that are being comprehended. This is intended to be a close parallel, at the syntactic level, of the hypothesis that was proposed by the Motor Theory as a claim about the phonemic processing of speech: Whereas the Motor Theory claims that a hearer of speech brings to bear her own capacity for speaking, when representing the phonemes that she hears, our hypothesis would entail that the comprehender of a signed utterance brings to bear her own capacity for acting, in understanding the syntactic relations between the items that are mentioned in a signed utterance, when these relations have been marked spatially, through the active comportment of the signer's body.

Although our hypothesis can be thought of as a natural extension of some more general claims that have been made about the enactive and embodied processing of language, the claim that this hypothesis makes is exclusively about sign languages, and exclusively about their syntactic processing. Our hypothesis is neutral with respect to the phonemic and the semantic processing of sign, such as explain a competent language user's knowledge of an utterance's phonemic and semantic properties (listed above under (1) and (2)). At least for the purposes of the present paper, we wish to leave open questions about these other sorts of linguistic processing. Our focus on syntactic processing should not be taken to imply anything at all, pro or anti, about the hypothesis that these other forms of linguistic processing might also be understood in enactive terms. This focus on syntactic processing motivated by the fact that it is in this syntactic case that sign languages are most plausibly different from spoken ones.

2 Mirroring

Our theory qualifies as ‘enactive’ (although not radically so) because it gives a role to one’s capacity for action, in the explanation of one’s capacity for a certain sort of perception. More specifically, our theory gives a role to one’s *own* capacity for action, in one’s comprehension of the actions produced by *others*. For that reason our theory also qualifies as one in which linguistic processing is, in part, a matter of *mirroring*. Some theories of mirroring are committed to specific claims about a set of anatomically distinct mirror neurons. Other theories characterize mirroring in terms of there being a single capacity that is at work in the representation of first-person and second-person actions, without making any neuron-level claims about the anatomy in which this capacity is realized.

Whichever notion of ‘mirroring’ is in play, there is controversy about any claim saying that mirroring plays a significant role in interpersonal understanding (Hurley 2008; Carpendale and Lewis 2008; Hickok and Hauser 2010). ‘Mirroring’ is regarded with particular suspicion in connection with the comprehension of sign language, both when it is understood as pertaining to particular mirror neurons, and when it is understood as pertaining to higher-level mirroring processes.

These two notions of mirroring were distinguished in a 2006 paper by David Corina and Heather Knapp, entitled ‘Sign Language Processing and the Mirror Neuron System’ (Corina and Knapp 2006). These authors emphasize the importance of:

> a distinction between the more narrowly defined mirror neuron system as originally described in Macaque, and the generalized human action observation/execution system (p. 529).

They go on to raise a number of objections, which we consider below, against hypotheses pertaining to the ‘narrowly defined mirror neuron system’. They describe these as “challenges to conceptualizing sign language comprehension and production representations within a narrowly-construed mirror neuron system” (p. 537). About the more broadly-construed hypotheses they are more equivocal. Corina and Knapp do suggest that “manual languages, in contrast to spoken languages, may provide a more direct route for engaging a human action observation/execution system that has mirror properties” (p. 537). They also “find support for the idea that sign language comprehension and production can be viewed in the context of a frontal-parietal human action observation/execution system” (p. 536). But these last claims are notable for their weakness. Lots of things can be ‘viewed in the context’ of others. Corina and Knapp express reservations about moving to anything stronger. Hypotheses concerning a ‘generalized human action observation/execution system’ may not have been refuted by the data that they review, but they suggest that this is because those hypotheses are too vague to be properly testable:

> the sign language data we present cannot be fully accounted for under a strict interpretation of the mirror neuron system. Moreover, these gaps raise issues about the lack of specificity in current accounts of the human action observation/execution system. (ibid)

Corina and Knapp have expressed similar reservations in more recent work (Corina and Knapp 2008; Knapp and Corina 2010). Others have gone further, suggesting that vague hypotheses about mirroring should not be precisified, but should instead be abandoned, since a mirror-neuron-inspired conception of sign language processing points in altogether the wrong direction. The psychological profile of sign-language comprehension is distinctive, these authors say, in that the mirror-neuron system is *not* involved in it. That is the position taken by Emmorey et al., on the basis of neuroimaging data from a 2010 study, the results of which they summarize by saying:

> The most striking result of this study was the lack of activation within the mirror neuron system […] for deaf ASL signers when passively viewing either signs or communicative gestures compared to a fixation baseline […]. In contrast, hearing non-signers showed robust activation within the [mirror neuron system] for both sets of stimuli [pantomimes and linguistic signs] despite the fact that, for these participants, pantomimes are meaningful and signs are not. […] We interpret these results as indicating that extensive experience with meaningful hand movements […] substantially reduces or eliminates the role of the [mirror neuron system] in passively viewing actions that are communicative, either with linguistic form (ASL signs) or without (pantomimes). (Emmorey et al. 2010, p.1001)

More recently, Rogalsky et al. have taken much the same position, on the basis of evidence drawn from the impairments shown by several sign language users following acquired brain damage (Rogalsky et al. 2013). They take this to be part of a larger case against the idea that mirror processing contributes to the understanding of actions:

> Taken together, the weight of evidence from speech, manual gesture comprehension, and sign language comprehension argues rather strongly against the view that the mirror system is critically involved in action understanding. (p. 1156)

The claim made by these authors is general and negative. There are several ways in which a mirror system might play a role in the comprehension of sign language. Their claim is that mirroring plays *no* such role (and so, a fortiori, that it plays no role in syntactic processing, as we are here proposing). The generality of this negative claim is, we argue, ill-motivated. At least for the specifically syntactic hypothesis that we are proposing, there is no good evidence against there being a role for mirror processes, broadly construed. Nor is there good evidence against there being a role for the ‘narrowly defined mirror neuron system’. Both the strictly neuronal and the looser, system-level mirroring hypotheses are, we claim, defensible.

Our claim is not that mirroring plays a role in every case of signed communication. It does not imply that all syntactic features of sign language depend on mirroring processes for their comprehension, nor that any particular syntactic structures can be communicated only via a mirroring-mediated route. Our claim is just that the mirroring-mediated route is available, and that it plays a role that is sufficiently important to be worth noting.

Although this is not a claim about every instance of syntactic processing, it does not need to be for the purposes that we are hoping to achieve. The view that we are trying to resist is a quite general claim, according to which there is *no* role for one’s own capacity for action, when comprehending the sign language of others. To resist that claim we need only show that one's own capacity for action does have *some* such role. We do not need to show that it plays this role uniquely, or invariably. Nor does the present essay make these latter claims.

This less than fully general claim can still accomplish some theoretically significant work. One of the contexts in which it does so is in discussions about the possible origins of language. Such discussions are inevitably speculative. Partly as a result of this, they have a tendency to go in and out of fashion, but there has recently been a resurgence of interest in them (Everett 2017). One long-standing speculation, plausibly elaborated by David Armstrong, William Stokoe and Sherman Wilcox, is that syntactically structured signing played a role in communication at some crucial stage on the path from our pre-linguistic ancestors to ourselves (Armstrong et al. 1995). This conjecture owes a part of its plausibility to the idea that a person's capacity to act already equips that person with the capacity to comprehend some of the syntactic structure in simple pieces of gesture, thereby providing a rudimentary form of syntactic processing ability, on the basis of which more complex linguistic abilities could then be bootstrapped. The claim that one's capacity to act can function in this way (and so might play this role in the development of language) does not require that it alone performs this function, once the bootstrapped state has been attained. Our less than fully general claim – that one's own capacity to act contributes to *some* instances of sign comprehension – is what this speculation about the origins of language would predict. In debates about the tenability of that speculation (such as those in McNeill 2012), this less than fully general claim is strong enough to be significant.

3 Recent evidence from aphasia and neuroimaging

The hypothesis being defended here is that processes of mirroring play a role in the comprehension of sign language, and, specifically, that they play a role in the syntactic processing of utterances such as those in Liddell's 'Five Brothers' example, in which syntactic relations are marked through the spatial comportment of the signing body, by one sign being directed onto, or placed between the parts of, another.

Because our claim is less than fully general, there are some cases in which it does not apply. One case in which mirroring might *not* play any role is in the syntactic processing of simple commands, in which the only syntactic relation needing to be parsed is that of a main verb to its direct or indirect object. An example of this would be the command "Point to the ceiling".

In a 2013 study of twenty-one aphasic signers, Rogalsky et al. found that "damage to mirror system related regions in left frontal lobe" was not detrimental to the comprehension of commands. Many of the commands that they tested were simple ones. (The example of pointing to the ceiling is theirs.) Rogalsky et al. also tested the comprehension of more complex commands – for which they give the example: "Put the pencil on the paper, then pull it back" – but the results that they report do not indicate how many of these complex commands were successfully comprehended. (Nor is it clear, since the given example is an ambiguous one, what should be counted as success.)

Rogalsky et al. take their aphasic subjects' successful comprehension of these commands to be evidence "against the view that the mirror system is critically involved in action understanding" (p. 1156), but it is evidence that does nothing to refute the version of the mirroring view that is being defended here, according to which mirroring plays a role in the syntactic processing of sentences that depend on bodily comported for the encoding of their syntactic structure. The syntactic marking of such sentences is relevantly different from the syntactic marking of the commands that Rogalsky et al. consider.

Evidence showing that mirroring *sometimes* plays no role in the processing of a sentence cannot refute our present hypothesis. It can weigh against that hypothesis only if it is evidence of mirror processes playing no role in a case from which one could plausibly generalize. To insist on this is not to set the bar on evidence at an inappropriately high level. On finding no evidence for X in conditions C, it may be reasonable to extrapolate to the more general conclusion – that there is never X – or it may be reasonable to endorse only the less general conclusion: that there is no X in C. Even this latter conclusion might generalize too far. The truth of the matter might only be that there was no X in C at the time when one was looking. A number of factors determine the level of generality in the conclusion that it would be rational to reach. One such factor is the extent to which conditions C are conducive to X-spotting. If they are not then one's failure to spot an X gives only weak support to an hypothesis that denies the existence of Xs.

Many of the experiments examining the neural basis of sign language have employed conditions that are not conducive to spotting the involvement of mirror processes in the syntactic processing of sentences in which roles are marked through the spatial comportment of the body. That is because the stimuli used in these experiments have often not been relevantly similar to such sentences. Some experiments have used only individual signs as their stimuli, or have required their participants to produce only a single sign as their response. They have therefore provided no opportunity for syntactic processing. Levänen et al. (2001) asked their subjects (some of who were deaf and some hearing) to passively view a series of individual signs in Finnish Sign Language, presented one every seven seconds (Levänen et al. 2001). Petitto et al. (2000) used a somewhat more complex task, asking their subjects to produce verbs in response to nouns (in either American Sign Language (ASL), or Langue des signes québécoise), but they too had an experimental design in which no single utterance involved more than one sign (Petitto et al. 2000). In neither of these experiments were syntactic relations encoded in the spatial structures of bodily comportment. More recently Okada et al. (2016) also required single signs (in ASL) to be produced and perceived. In some conditions these were verbs, in others nouns (Okada et al. 2016). Again there was no condition in which stimuli with complex syntactic structures needed to be parsed. Such experiments may be informative in any number of ways, but it is clear that no such experiment could threaten the hypothesis that is being defended here, which pertains to a variety of syntactic processing that might be required for the comprehension of stimuli with a greater degree of syntactic complexity.

The 2010 study by Emmorey et al., mentioned above, also used one-verb utterances as its stimuli. It too cannot refute the hypothesis that we are defending, but the results of that experiment might nonetheless be thought to weigh against our hypothesis. We have already noted that the results of this study were taken by its authors to indicate that:

> extensive experience with meaningful hand movements […] substantially reduces or eliminates the role of the [mirror neuron system] in passively viewing actions that are communicative, either with linguistic form (ASL signs) or without (pantomimes). (p. 1001)

Such a reduction in mirror neuron activity might be thought to lower the probability that mirror processing plays a role in the comprehension of complex utterances. Even if it has only been observed in the processing of utterances that are syntactically simple, such an observation would at least point in what is, for the defender of our hypothesis, the wrong direction.

We should, however, be careful when interpreting the data that Emmorey et al. report. Their main discovery is of a difference between the activations that are elicited in the brains of Deaf native signers and the activations that are elicited in the brains of hearing non-signers, when members of these two populations are passively observing manual gestures. Such differences were found both when the observed gestures took the form of ASL signs, and when they took the form of non-verbal pantomimes (with the differences of activation being somewhat more pronounced in the case of pantomimes). For both signs and pantomimes, these differences were entirely on one side: every area that showed activation in the brains of native signers also showed activation in the brains of hearing non-signers, but the non-signers' brains also showed some additional activation, in areas that were not seen to be activated in the brains of the Deaf signers.

One interpretation of these results is as indicating that the brains of the Deaf signers were doing less, and so were performing more efficiently. This interpretation is plausible, given the signers' lifelong expertise in gesture perception, and Emmorey et al. indicate that they put some credence in it (p. 1002), but their results do not support this interpretation unequivocally. That is because their fMRI method requires neural activation levels to be measured relative to a baseline, and this baseline was set separately for each experimental participant. The fact that differences of baseline introduce complications is often acknowledged, but there seems to be a widespread belief that these complications have been dealt with by some mathematical trick in the processing of the data. This is a mistake; one which underestimates the extent of the complications that differences of baseline create.

To see the significance of these differences, remember first that both groups of participants had been placed in an fMRI machine. We would expect the baseline activation in the brains of these two groups to be rather different, partly because this would be an environment of considerable background noise for the hearing participants and not for the Deaf ones, but also – and much more importantly – because once in the scanner, both groups were told:

> You do not need to make any response during the experiment, but please pay close attention to all of the videos. We will have a short test about the stimuli after the scan. However, please do not try to memorize the stimuli. We do not want to see brain responses for memorization. (p. 996)

The hearing participants received this instruction in English. The Deaf participants received it in ASL. In either language the instruction is an intriguing one. It therefore seems likely that the background thinking of the Deaf participants would have included some rumination on this instruction – rumination which would have taken place in ASL. The background thinking of the hearing participants would also have included some rumination on the instruction. This would have taken place in English. We should therefore expect the baseline levels of activation in these two participant groups to be somewhat differently patterned. And, crucially, we should expect this difference to be such that the Deaf participants' baseline activity is closer to the activity elicited during the perception of meaningful gesture (since these participants, but not the hearing ones, are already thinking to themselves in sign). If that is so then we should expect gestural stimuli to elicit a bigger *change* of activation in the brains of the non-signers. And this is just what the data gathered by Emmorey et al. show. Their fMRI observations indicate, not that in response to gestures fewer areas were active in the brains of signers, but that, in response to those gestures, fewer areas of the signers' brains *changed* their activation relative to their baseline activation in that individual.

Standard methods of fMRI analysis do not bring differences of baseline to light, and Emmorey et al. report that "relative increases in activity in one group are not reported unless they also constitute activations above the fixation baseline in that group" (p. 998). Their data show that the brains of non-signers start doing something new when they are shown signs, and when they are shown pantomimes. They show that the brains of signers also start doing something new, but that rather less of what the signers' brains do is different from what they would have been doing anyway, in conditions of internal monologue. Since this pattern of results is something that would be expected if our present hypothesis is true, it should not reduce our credence in that hypothesis.

Nor do other results from the brain-scanning literature point us away from the present hypothesis. On the contrary: activation has consistently been observed in Brodmann's areas 44 and 55 during the production and comprehension of sign (MacSweeney et al. 2002; Emmorey et al. 2002; Emmorey 2003; Emmorey et al. 2016). These are areas in the inferior frontal gyrus, a region of the brain that is believed to contain mirror neurons in humans (Kilner et al. 2009), and that is homologous to premotor area F5, the region of the macaque brain in which mirror neurons were first discovered (di Pellegrino et al. 1992). It is the consistent observation of activation in these areas, over the several studies that they review, that leads Corina and Knapp to allow "that sign language comprehension and production can be viewed in the context of a frontal-parietal human action observation system" (Corina and Knapp 2006, p. 536). A more recent study by Newman et al. corroborates this trend, and it is notable for being a study in which some of the sign-language stimuli did make use of bodily comportment, in the encoding of syntactic properties (Newman et al. 2010).

Newman et al. used brief video clips of single sign language sentences, which they presented to Deaf participants who had the task of pressing a foot pedal whenever a sign occurred with content pertaining to some specified semantic category (which might be food, women, clothing, or money). In half of the sentences the contents were signed in an impersonal and prosaic fashion, which the authors refer to as 'non-narrative'. In the other half – referred to by the authors as 'narrative' – the same content was signed in a way that used a fuller range of ASL's expressive resources, including the more enactive marking of syntactic relations, to which our present hypothesis pertains. The authors describe an example of these 'narrative' sentences by saying that:

> in Video 1, a teacher informs students in a sewing class of their grades. In the narrative and non-narrative versions, the same signs are used in the same order. In the narrative condition, however, the signer employs role shifting to assume the point of view of a narrator at the event. This is effected through the addition of eye gaze direction, head tilt, and facial affect cues. (p. 670)

Comparison stimuli were generated from both types of sentence by making the video image of that sentence semi-transparent and then playing it backwards, whilst overlaying it with two other backwards sentences of the same type. The resulting video clips had no discernable semantic content or syntactic structure. The participants were given the task of detecting symmetrical hand shapes in these stimuli, and so were not attempting to extract any linguistic meaning from them. The comparison of the activation elicited by the forward and backwards stimuli is intended to reveal the brain areas in which activity is taking place that implements specifically linguistic processing. The second-order comparison – of how these differences differ in the narrative and non-narrative cases – is intended to reveal the brain areas in which activity is taking place that implements the comprehension of sign-language's distinctively embodied expressive resources.

Newman et al. do not themselves adopt a mirror-neuron inspired conception when interpreting their results, but those results do nonetheless lend themselves to such an interpretation. They indicate that "activation in the IFG and STS was more extensive for the narrative sentences, particularly in the RH" (p. 672). 'IFG' here stands for the Inferior Frontal Gyrus, the brain area in which the evidence of mirror neurons in the human is good. ('STS' stands for Superior Temporal Sulcus, and 'RH' for right hemisphere.)

The non-narrative sentences in this experiment also differentially activated some brain areas more than the narrative sentences: "non-narrative (but not narrative) sentences activated medial cortical and subcortical structures including the supplementary motor area and the basal ganglia" (p. 672). The basal ganglia are mid-brain structures with a number of roles in the production and regulation of movement. The supplementary motor area is an area with direct outputs to the spinal cord. It too is implicated in the production of actions (Roland et al. 1980), and it is thought to have a special role in the adjustments that are required to correct actions that have gone awry (Bonini et al. 2014). The processing resources that enable self-monitored actions to be corrected if they turn out in unpredicted ways therefore seem to be involved in the perception of sign language sentences, especially when the range of communicative devices used in those sentences is impoverished. This evidence concurs with what one would expect if processes that are involved in the production of action do indeed participate in the syntactic comprehension of sign language, as our hypothesis says.

4 Earlier evidence from aphasia

None of the evidence reviewed above weighs against our hypothesis, but these are not the only lines of evidence that have been thought to make such an hypothesis problematic. Further evidence is given by the patterns of impairment that follow from damage to the mirror-processing regions that have been mentioned above. Corina and

Knapp take these patterns of impairment to show that mirror systems are not necessary for the comprehension of sign language:

> the observation that damage to Broca's area does not affect sign comprehension indicates that an intact left hemisphere BA 44/45 is not necessary for the representation of sign language comprehension. (p. 531)

They take this observation to 'run contrary' to the idea that "perceived actions are understood at least in part through a reference to production routines stored in frontal cortex" (*op cit*). A similar line of thought has more recently been put forward by Emmorey, who writes that "deaf patients with damage to Broca's area exhibit sign articulation deficits, but sign perception and comprehension are intact" (Emmorey 2013, p. 207). She takes this (together with some evidence from spoken languages) to weigh against a set of claims that have been made by Michael Arbib (Arbib 2012), including the claim "that mirror neurons serve as part of the neural circuitry that mediates understanding" (op cit).

Emmorey's argument shares the logic of Corina and Knapp's: The mirroring hypothesis takes one's own capacity for action to be drawn upon in some instances of comprehending others, and therefore predicts that a loss of that capacity should impair one's performance in the relevant comprehension-requiring tasks. These authors take the evidence to indicate that this prediction is not borne out. But not all comprehension-requiring tasks are relevant ones, for reasons that we have already seen: the comprehension of simple imperatives – such as "Point to the ceiling" – may be one case to which the capacity for action does not contribute. Our hypothesis is therefore compatible with evidence suggesting that the comprehension of such imperatives can remain intact, even when mirror processing is compromised. One of the two cases cited by Emmorey shows no more than that. She cites a 1996 case study by Hickok et al., of patient RS. Emmorey is right to say that this patient exhibits sign articulation deficits: Hickok et al. document her "relatively frequent 'phonemic' paraphasias (i.e. substitutions of sublexical components)" (Hickok et al. 1996, p. 374). But there is much less evidence of RS's sign perception and comprehension being intact. The evidence offered by Hickok et al. does not show RS to be capable of processing any syntactic structures that are more complicated than that of a simple imperative. What they report is that:

> On the visual confrontation naming and 'sign discrimination' tests […] RS made no errors. Comprehension was largely spared as revealed by our ASL adapted version of the Token Test: RS scored 34 out of 44 correct. […] Repetition was mildly impaired. (p. 374)

The first of these tests – the tests of 'visual confrontation naming' and of 'sign discrimination' – involve single signs. They do not require syntactic processing, and so RS's ceiling performance on these tests does not indicate that her capacity for syntactic processing is intact. Her score of 34 out of 44 on an adapted version of the Token Test is more suggestive. The Token Test is intended to test the capacity for syntactic processing (De Renzi and Vignolo 1962). But the protocol for that test has five equally weighted parts, and it is only in the fifth part that the patient must comprehend sentences other than simple imperatives. A patient whose capacity for syntactic processing was limited to the processing of simple imperatives would therefore be expected to score somewhere in the region of 35 out of 44, even if they never made a lucky guess as to the meaning of a sentence that they could not parse. RS's score of 34 gives no evidence of syntactic comprehension being preserved for the sorts of syntactic processing that are here at issue.

In support of her claim that "deaf patients with damage to Broca's area exhibit sign articulation deficits, but sign perception and comprehension are intact", Emmorey's other citation is to a 1987 book by Poizner, Klima, and Bellugi (Poizner et al. 1987). That book presents six case studies of sign language impairment following stroke. One of the patients considered – Gail D. – does indeed exhibit a deficit of sign articulation, together with intact perception and comprehension of signs. There is no suggestion that her comprehension is restricted to the comprehension of simple imperatives, and there is evidence that her abilities include the intact comprehension of spatially marked syntax. Gail D. is nonetheless quite incapable of *producing* sentences in which syntactic relations are spatially marked. Her signing is limited to the appropriate but non-fluent production of single words, as illustrated in the following example (in which Gail D.'s signs are glossed as English words given in capital letters, her fingerspellings are marked with hyphens; and the responses of the examiner, who was also using ASL, are given in lower case):

> Gail D.: BROTHER … [Mouths "stove."] … C-O-A-T-T … [Mimes "flame burning." … MANY C-A-A-T … FIRE … [Face expresses surprise, gestures.]
>
> [Examiner guesses that she means that her brother burned her on the stove.]
>
> Gail D.: YES.
>
> Examiner: What did the Brother burn?
>
> Gail D.: YES … C-O-A …
>
> Examiner: You mean the cat?
>
> Gail D.: YES. [Nods emphatically.]
>
> (Poizner et al. 1987, p. 76)

When Corina and Knapp argue on the basis of data from aphasia (in Corina and Knapp 2006, p. 530) it is again on Gail D.'s case that their arguments are based. This case study is therefore the crucial one for the evaluation of our hypothesis.

That hypothesis says that the ability to comprehend spatially marked syntax is supported by mirror processes (which generate motor representations). It therefore says that a comprehender's own ability to act is drawn on in the process of comprehension. This claim would be threatened by the existence of a patient in whom the process of comprehension was intact, while the ability for action was absent. But Gail D. is not such a patient.

Although partially paralysed as a result of her stroke, Gail D.'s ability to act in spatially structured ways is intact (Bellugi et al. 1983). Her inability to produce syntactically structured sentences is not explained by a general loss of capacity for spatially structured actions. This inability can instead be explained by other effects of her extensive left-hemisphere infarct. Gail D. performs accurately in naming tasks, and in responding to questions involving one-word answers, but it is clear – in the dialogue quoted above and in longer dialogues reported elsewhere (Poizner et al. 1987, p. 66; Bellugi et al. 1983, p. 168) – that she frequently resorts to fingerspelling during her spontaneous language production, even when the appropriate sign is a common one, requiring no great dexterity. Gail D.'s lexicon may be intact, but her processes of lexical access seem to be somewhat disrupted, both for the accessing of signs, and for the accessing of words in English: Poizner et al. report that she is unable to spell her own name, or the name of the city in which she lives (p. 76).

These disruptions to the process of lexical access could suffice to explain her disfluent signing (Utman et al. 2001), perhaps together with a decrease in some general-purpose linguistic resources (Caplan 2006). Such disruptions can explain that disfluency in the absence of any impairment to the coordination of spatially organized actions. If they do so then Gail D.'s case is compatible with the hypothesis that we are defending, according to which the capacity for such actions contributes to the syntactic processing of sign language. Her case neither refutes nor weighs against that hypothesis. If viewed in the contexts of analogous spoken language aphasias, it even seems to support it, albeit inconclusively, as we shall now see.

A user of spoken language who had suffered from a large infarction in the left hemisphere, affecting Broca's area, would be expected to display Broca's aphasia. Their speech would be limited to the disfluent production of single phrase utterances, just as Gail D.'s signing is limited to the disfluent production of individual signs. Such patients can typically respond correctly to simple instructions, such as "Point to the ceiling". They sometimes retain the ability to produce such forms (Gleason et al. 1975), and they retain some other syntactic abilities, depending on the way in which syntactic roles are encoded in their first language (Bates et al. 1987). But their ability to parse complex sentences is impaired. One of these impairments is that patients with Broca's aphasia are unable to use syntactic markings when interpreting sentences in the passive voice (Caramazza and Zurif 1976; Grodzinsky et al. 1999). Given a choice, they are unable to reliably select the picture corresponding to a sentence such as "The lion is chased by the tiger", being equally likely to identify one in which the lion is chasing the tiger.

Such contrasts in syntactic role can be marked in ASL by the use of spatialized syntax, as marked in the comportment of the signer's body. Such marking allows ASL to generate pairs of sentences in which the sequence of signs is kept fixed, but the syntactic roles assigned to the noun phrases are reversed – as with "The lion is chasing the tiger" and "The lion is being chased by the tiger". Gail D.'s comprehension of such spatially marked sentences has been tested. In one test:

> the experimenter signs a sentence describing an event with two participants, either of which semantically could be the subject or the object of the verb. The spatial indices and order of signs are maintained, so *the movement of the verb between spatial points is the only indicator of grammatical relations*. The subject's task is to answer two questions about the sentence (given in random order): (a) who was the agent of the action and (b) who was the recipient of the action. (Bellugi et al. 1983, p. 164. Emphasis added.)

This test is closely analogous to the test of passive voice understanding, which a Broca's aphasic who was the user of spoken language would typically fail. Gail D.'s responses are correct in 81.1% of cases. In another test:

> the experimenter signs a sentence involving nominals and their associated spatial loci and an action verb, whose spatial endpoints mark subject and object with respect to the spatial loci. The spatial relations indicated in the question involve a shift of spatial reference. […] Gail D. performed extremely well, obtaining a perfect score. (Poizner et al. 1987, p.118)

These data show that an impairment of the sort that prevents users of spoken language from parsing sentences in the passive voice does not prevent Gail D. from parsing analogous sentences of ASL. She therefore seems to have some additional way of identifying the syntactic roles that are being assigned to the things that are being mentioned, when those roles are being marked through the spatial comportment of the signing body. One plausible explanation of this is that her intact capacity for action can be brought to bear in the service of signed sentence parsing, via a process of mirroring. The information that is available about this single case study does not suffice to show that this plausible explanation must be the correct one, but if it is then Gail D's case supports the present hypothesis, rather than weighing against it.

5 Conclusion

The discovery of mirror neurons prompted many claims about the psychological significance of mirroring processes, some of which were poorly motivated. It is therefore understandable that hypotheses involving such processes have gone so thoroughly out of fashion, but we should take care when it is fashion that determines the fate of an hypothesis. In the present case the evidence from neuroimaging experiments, and from the study of lesion patients, is unpersuasive. Neither line of evidence shows mirror processes to play no role in the syntactic processing of sign language. A theory postulating a specifically syntactic role for mirroring in sign language processing therefore remains tenable. Such a theory might be a crucial component in our understanding of the way in which signed and spoken languages relate. This seems to be an instance in which a promising direction for research has been closed off prematurely.

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