LANGUAGE, MODALITY AND THE BRAIN: LOOKING AT SIGN LANGUAGES

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ABSTRACT
Establishing which neural systems support processing of signed languages informs a number of important neuroscience and linguistic questions. First, what constitutes the 'core language system' - what areas of the brain are involved in language processing regardless of the modality? Evidence will be presented from studies of signers with acquired language impairments as a result of stroke and from functional imaging studies of the processing of BSL and English. Second, do sign language sentences encoding spatial concepts differ from more abstract sentences - does sign language recruit non-linguistic conceptual structures? Results of a study on the processing of BSL sentences with topographic and non-topographic structure will be discussed in relation to this question. The conclusion returns to a consideration of the nature of the 'core language system' and spoken language.

Following groundbreaking work by linguists and cognitive scientists over the last thirty years, it is now generally accepted that there are two distinct classes of natural human language: spoken language and signed language, this latter group consisting of the various sign languages of the deaf, such as ASL (American Sign Language) or BSL (British Sign Language)[1]. The most striking difference between these two classes is that signed language operates in a wholly non-auditory, visuo-spatial medium. How does the medium impact on language itself? Meier (2002) lists a number of the 'non-effects' of the modality (p. 2):

- Conventional vocabularies: learned pairing of form and meaning
- Duality of patterning: meaningful units build of meaningless sublexical units, whether units of sound or of gesture:
  - Slips of the tongue/slips of the hand demonstrate the importance of sublexical units In adult processing
- Productivity: new vocabulary may be added to signed and spoken languages:
  - Derivational morphology
  - Compounding
  - Borrowing
- Syntactic structure:
  - Same parts of speech: nouns, verbs and adjectives
  - Embedding to form relative and complement clauses
  - Trade-offs between word order and verb agreement in how grammatical relations are marked: rich agreement licenses null arguments and freedom in word order
- Acquisition: similar timetables for acquisition

[1] ASL and BSL are historically unrelated and mutually unintelligible

Despite these similarities, signed and spoken languages may differ because of the characteristics of the modalities in which they are produced and perceived, in particular the differing properties of the sensory and perceptual systems utilised. Pinker and Bloom (1990) have noted that the properties of the speech apparatus require that "…grammar for spoken language must map propositional structures onto a serial channel…" (p. 713) Since sign languages are conveyed through a multidimensional medium, the question then becomes: to what extent does signed language grammar exploit the spatial and temporal structures available in a visual-spatial modality and what consequences does this have for the nature of linguistic structure?

This in turn opens up new research opportunities. Of particular interest is whether sign languages are processed by the same neural regions as spoken languages. Differences might suggest that processing is sensitive to modality. For example, we might hypothesise that the right hemisphere plays a major role in processing sign, because this hemisphere specialises for visuospatial information. Some early studies of sign lateralisation suggested that this might be the case, in that they either found no hemisphere asymmetries (Manning et al 1977; McKeever et al 1976) or evidence of right hemisphere dominance (Sanders et al 1989). However, these findings have been attributed to confounding factors, like the visual complexity of sign and the variability of subjects (Grossi et al 1996). In their better-controlled study in which Deaf people watched signs presented rapidly to either the right or left visual field, they showed a right visual field/left hemisphere advantage.

Later studies have produced evidence that signed, like spoken languages are underpinned mainly by left hemisphere structures. For example, functional imaging studies show activation of the left Broca's area during the production of signed words (Hickock et al 1995, 1998) and sentences (McGuire et al 1997). Recent imaging studies found bilateral activation during sign comprehension (Neville et al, 1998). However, this may also be the case in speech comprehension (Caplan et al 1996).

If sign language processing is left dominant, this should be reflected in patterns of impairment following brain damage. In other words, sign aphasia, like spoken language aphasia, should follow left but not right hemisphere damage. There is now overwhelming evidence that this is the case (e.g. Poizner et al 1987; Hickock et al 1996a, Hickock et al 1996 b, Hickock et al 1998). Furthermore, symptoms are broadly consistent with those found in spoken language impairments. Thus, some individuals have fluent jargon signing resulting from damage to Wernicke's area, while others have non-fluent, agrammatic signing, resulting from damage to Broca's area (e.g. Poizner et al 1987, Poizner and Kegl 1992).

A further dissociation can be predicted. Since signed language differs from gesture, in that signs exhibit phonological structure and are combined into grammatically governed sentences, dissociations between sign and gesture should be observed following brain damage. Two individuals, WL (an ASL signer) (Corina et al 1992) and Charles (a BSL signer) (Atkinson et al, submitted) have shown just such a dissociation. Although WL had a fluent aphasia and Charles had non-fluent aphasia, both produced and understood gestures well, and often substituted gestures for the signs they could not access. Thus, difficulties with signing could not be attributed to poor motor skills. Rather, it seemed that their lesions had impaired the linguistic system, which controls sign, while leaving non linguistic gesture skills intact. Research with Charles also addressed the question of whether iconicity affected his processing of sign. It is acknowledged that all sign languages include iconic signs, where the meaning of the sign is reflected in its form (eg see Sutton Spence and Woll 1999). An example would be the BSL sign CIGARETTE, which is very similar to a typical smoking gesture. As this example suggests, iconic signs have a degree of transparency, in that people who are unfamiliar with sign language might be able to guess their meaning (eg see Pizzuto and Volterra 2000) or detect a connection between the sign and its referent (Klima and Bellugi 1979). It is possible, therefore, that these signs are processed differently from non iconic signs, ie with greater involvement of gestural systems. However, the available evidence would argue against this. Deaf children acquiring sign language appear to show no advantage for iconic signs (Orlansky & Bonvillian, 1984). Similarly, in tests of sign recall with adults, iconic signs show no advantage over non iconic signs (Klima and Bellugi, 1979).

The study with Charles showed that his stroke impaired his ability to sign, but not his ability to gesture. This dissociation pertained regardless of sign iconicity, or any similarity between the forms of gestures and signs. One task compared Charles' ability to name iconic and non-iconic signs. Ratings of iconicity were first obtained for 56 signs from 17 deaf signers, 4 hearing signers and 15 hearing non signers. Signs were concrete nouns drawn from the South East England regional dialect. For all subjects the procedure was the same, although instructions were given in BSL for the deaf subjects, and in English for the hearing subjects. Raters observed a deaf fluent signer producing a sign on video. They were given the meaning of the sign and asked to rate its iconicity on a 1 – 7 scale. They were instructed to give high ratings if they felt that the sign could be guessed by someone not familiar with BSL, and a low rating if they felt that the sign could not be guessed. From the resulting data 20 iconic and 20 non iconic signs were identified. The mean rating of the iconic group was 4.83 (range 3.9 – 6.2), and the mean rating of the non iconic group was 2.18 (range 1.4 – 3.2). The groups were matched for familiarity (mean familiarity of iconic and non iconic items: 6.28, Toglia and Battig 1978).

Charles was asked to sign the names of these 40 items in response to simple line drawings. Five unimpaired Deaf people were also asked to sign the names of the stimuli. These control subjects had a mean age of 67 (range 48- 81), used BSL as their preferred language and were recruited from Deaf groups in the South East of England.

Overall the control subjects made just 3 errors (mean score 39.4). All errors were due to picture recognition problems.

Charles was impaired in naming both iconic and non iconic items (see table 1). The small numerical difference between the sets was not significant (chi square = .92, $p>.5$).

Table 1: Naming Iconic and Non Iconic Items

	Iconic Items	Non Iconic Items	Total
Correct	13	10	23
semantic errors	2	3	5
phonological errors	4	3	7
finger spelling only	1	2	3
gesture		2	2
total	20	20	40

Charles made a variety of errors. Many were semantically related to the target, eg:

Target Error

tunnel	TRAIN … BRIDGE
factory	WORK

There were also several phonological errors. All but one of these involved handshape errors, eg when SHEEP was produced with a flat hand (an unmarked handshape), rather than a fist with the little finger extended (a marked handshape). There were 3 occasions when Charles could only attempt a finger spelling of the target. One of these was correct (g-a-r-d-e-n); while the others entailed further errors, such as b-o-s for 'bus'. Twice he only produced a non-linguistic gesture, eg when he gestured washing for 'soap'.

To compare Charles' ability to sign and gesture, he was presented with a task in which he was asked to sign the name of, and on a separate occasion, gesture the use of, 50 items. For half the items the signs were similar to a gesture for the item, such as 'toothbrush'. These were termed SLG items (Sign Like Gesture). For the other half, the signs were different from the gesture, such as 'knife' (figure 5). These were termed SDG items (Sign Different from Gesture). Items were represented by single pictures (drawings and photographs), with the same pictures used to elicit gestures and signs.

In the sign condition Charles was shown the picture and asked 'What is the sign for this?'. In the gesture condition he was again shown the picture and asked: 'What do you do with this, can you gesture it?'. Items were blocked, ie in one session the first 25 items were presented for gesturing, and the second 25 items were presented for signing, and in the next session the conditions were reversed. At the start of each block we emphasised that either signs or gestures were now being tested. SLD and SDG items were randomised within the blocks.

Scoring: Gestures were scored correct if they were judged independently by two researchers to be an accurate demonstration of the use of the object. Sign responses were scored using the same criteria as in previous tests. If Charles produced a gesture rather than a sign during the naming condition we reminded him that we now required him to sign. If he still failed to produce a sign the response was recorded as an error.

Table 2: Results of the Sign vs Gesture Task

	SLG Items	SDG Items	Total
sign score	16/25	9/25	25/50
gesture score	23/35	18/25	41/50

Charles was significantly better at gesturing than signing these items (McNemar chi square = 10.22, p<0.01). This was true, even when the sign was very similar to the gesture (16/25 vs 23/25, Mc Nemar chi square = 4, p<0.05). His few gesture errors consisted of no responses and 3 occasions when he produced the sign but not the gesture. Charles's signing errors consisted of semantic and phonological errors, finger spelling attempts and substitutions of gesture for sign.

Thus despite the superficial similarities between iconic gestures and sign language, they appear to be represented differently in the brain and gesture may remain intact following left hemisphere stroke even when sign language is impaired.

In contrast to the effects of left hemisphere stroke, most features of sign language are still intact after right hemisphere damage, even when there are substantial visuospatial impairments (e.g. Hickock et al 1996a & b). Although space is the medium in which sign language is expressed, spatial debilities following right hemisphere impairment have a minor impact on linguistic processing in ASL. The exception is discourse (Kegl and Poizner 1991; Loew et al 1997; Hickock et al 1999). However, discourse is also vulnerable to right brain damage in hearing people, suggesting that this is one area of language which is not strongly lateralised to the left (Wapner et al 1981, Kaplan et al 1990.

LATERALISATION: DOES SIGN USE RIGHT HEMISPHERE SYSTEMS MORE?

Despite the evidence from right hemisphere stroke, since the mid-1980s Neville and her colleagues, who have pioneered brain imaging studies of ASL, have consistently reported relatively greater contributions of right hemisphere processing to sign language than might occur for processing English (e.g. Neville et al, 1998; Newman et al, 2001). These findings have generated a good deal of debate: Although they demonstrated ASL processing makes use of right hemisphere systems, it was not clear to what extent these were specific to sign language, nor whether they reflected linguistic processes lateralised to the right hemisphere, or a right hemisphere contribution to a left hemisphere linguistic processing system (Hickok et al 1998; Paulesu & Mehler, 1998). More recently, MacSweeney et al (2002a), using a design in which processing of BSL sentences was contrasted with processing of English sentences presented audiovisually, found no greater evidence of the right hemisphere in the processing of a signed language compared to a spoken language (Figure 1). However, questions have remained about the processing of a specific type of sign language sentence, in which the visual-spatial modality is directly exploited to represent real-world spatial relations.

Figure 1: BSL and English processing

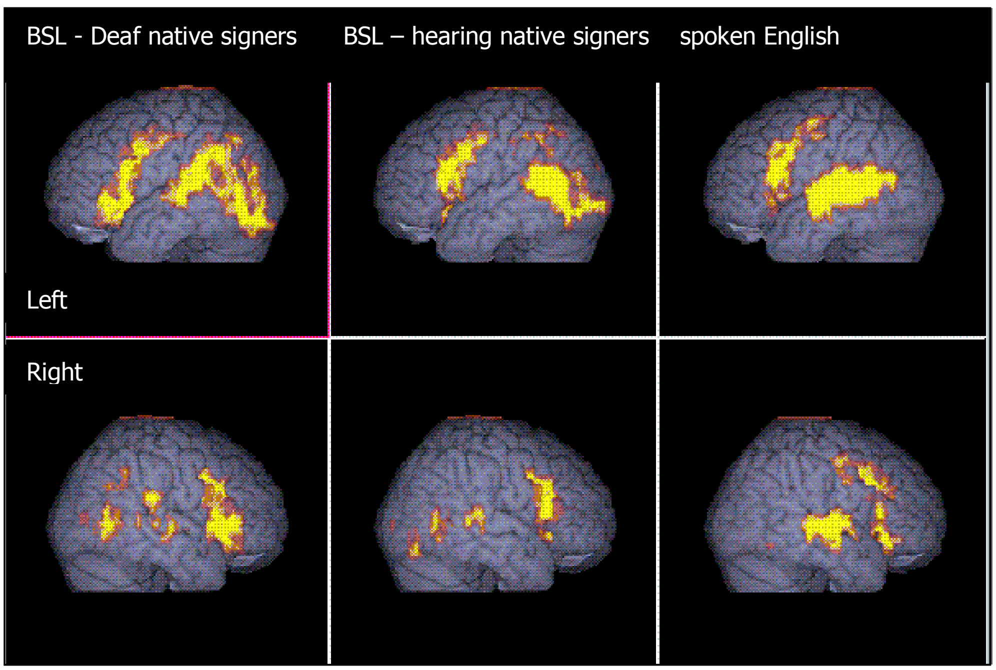

Figure 1: Locations of peak activation during sentence processing in deaf and hearing native signers (BSL) and hearing native speakers (audio-visual English).

LOOKING FOR SPACE IN SIGN

Two recent studies of two groups of native signers - one of BSL and one of ASL - cast some light on the question of how signed languages may make use of cortical systems specialised for spatial processing. While all sign languages make use of space, there are some constructions in which space is used in a special way. Both studies have focussed on these constructions. MacSweeney et al (2002b), in a fMRI study of BSL users, contrasted the comprehension of two types of BSL utterance: topographic and non-topographic. Topographic utterances make use of space in a veridical, analogue fashion. Action terms within sentences are located and moved in analogy to 'real life' locations of actors and objects, maintaining their relative positions within sign space, while the handshapes (classifiers) represent the physical shape of the object (e.g. the classifiers for flat objects, curved objects, vehicles, etc.). For example, in the BSL sentence translated as 'The car turned left and hit the lorry', the shapes of the hands represent the two vehicles, while the start and end points of the hand's actions for 'car', and the pattern of movement between them, directly represent moving forward, left and stopping (for more examples, see Figure 2, (MacSweeney et al, 2002b) and <http://www.ich.ucl.ac.uk/ich/html/academicunits/behav_brain_sci/bsl/>.

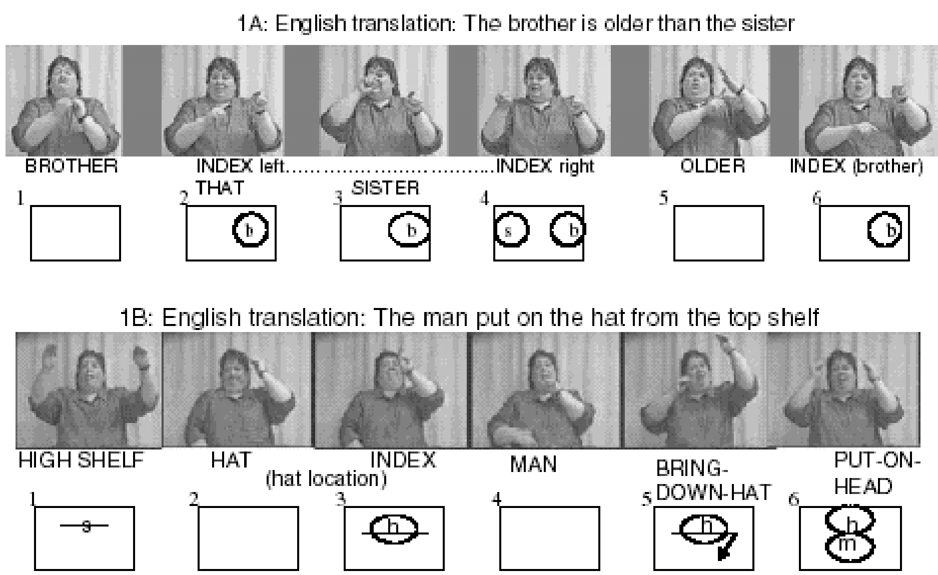

Figure 2.1a and 2.1b

Shown are the English translation of the BSL sentence, video sequence stills, and BSL glosses of the signed sentence and a schematic representation of the location of referents in sign space.

2.1.a: Illustration of non-topographic BSL sentence.

Frame 1— lexical sign for BROTHER (b).

Frame 2— referential location for BROTHER established by indexing to the left.

Frame 3— lexical sign for SISTER (s) is signed while the left hand maintains the location of BROTHER.

Frame 4— referential location of SISTER is established using right hand.

Frame 5—lexical sign for OLDER.

Frame 6—referential location for BROTHER is indicated using left hand while the right hand returns to the rest position.

BROTHER and SISTER use conventional locations: reference is achieved without regard to "actual" spatial relations.

1B: Illustration of topographic BSL sentence.

Frame 1— the sign for SHELF is signed at a high location within sign space indicating the height of the target shelf.

Frame 2— lexical sign for HAT.

Frame 3— precise location of the hat on the shelf is indexed.

Frame 4— lexical sign for MAN.

Frame 5— the handling classifier handshape for HAT (holding a hat brim) is used to represent "bringing-down" the hat from the (position on the) shelf located in Frame 1.

Frame 6—HAT classifier used to indicate putting hat on MAN's head.

In 1b the actual relative positions and movements of the event are indicated by signed actions.

Emmorey et al. (2002) explored space in a different way, adapting a PET paradigm developed by Damasio et al. (2001) that required signed production of pictured static spatial object relations. There are two ways to 'name' such object relations – by the spatial arrangement of classifiers ('cup on table' – the hand representing the cup (curved object) is placed above the hand representing the table (flat object), or with lexical forms (prepositions such as ON, IN, etc.). Unlike lexical prepositions, the sentences with classifiers signal spatial relationships *directly* by their topographical relationships.

In both studies, then, the contrasts of interest were internal to the task, for they explored the extent to which precise locationary aspects of space, captured by specific language forms (topographic sentences and object classifiers), might activate specific cortical systems.

SPECIAL SPACE FOR SPATIAL SIGN; PARIETAL INVOLVEMENT

In MacSweeney et al's study, the critical region identified specifically for topographic processing was within superior parietal cortex and was left-lateralised (see figure 3). In Emmorey et al's study, this region was also activated, but analogous right-sided parietal activation was observed as well.

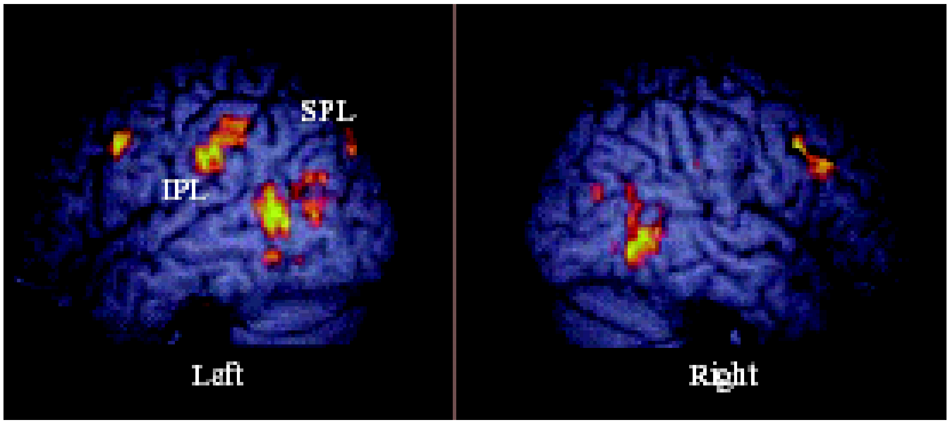

Figure 3: Activation during processing of topographic sentences

Locations of peak activation during topographic relative to non- topographic sentence processing in deaf native signers of BSL. Activation up to 5 mm beneath the surface of the cortex is displayed. IPL = inferior parietal lobule (BA 40); SPL = superior parietal lobule (BA 7). Activation in occipito-temporal boundary regions can also be seen, including V5/MT

Why was there bilateral activation specific to processing spatial classifiers in Emmorey's task, but only left-sided activation in MacSweeney's? Emmorey's task required matching of observed images of objects in relation to each other - a pictorial component that may have made greater demands on image analysis, or on mapping the products of such analyses to the classifier forms in production. In MacSweeney et al's study, participants were more passive: their task was simply to detect a semantically anomalous utterance in a series of five semantically appropriate ones, where topographic structure was varied in different experimental blocks. Task differences were likely to have driven the different patterns - but it is not at all clear which task differences may be critical.

How have these findings advanced the arguments about space in sign? They show that some aspects of sign language processing require the contribution of cortical regions that are not associated with spoken language comprehension. When translations of the topographic sentences were shown as videos to hearing participants in the scanner, they showed no condition-dependent activation, and none in superior parietal regions. This left parietal region identified by MacSweeney et al. is activated in biological action recognition, but not in speech comprehension.

Depending on test conditions, the processing of some sign language classifiers may require a right hemisphere parietal contribution. This also fits with the report of a single patient, DN, with a focal right hemisphere lesion and ASL as a first language, whose only detectable sign language deficit was in the use of such classifiers (Emmorey et al, 1995).

Since the visual medium affords the identification of objects and their spatial locations as a function of their forms and locations on the retina and sensory cortex, it is not surprising that cortical systems specialised for such mappings are utilised when sign languages capture these relationships. An interesting and as yet unanswered question is how might we characterise the auditory world so that the ways in which it delivers acoustic properties (timbre, intensity, pitch) might show analogous cortical dissociations within heard-and-spoken language?

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