How the Brain Processes Language in Different Modalities

Bencie Woll

Deafness Cognition and Language Research Centre, UCL, 49 Gordon Square, London WC1H 0PD
b.woll@ucl.ac.uk

Abstract. Establishing which neural systems support processing of sign languages informs a number of important neuroscience and linguistic questions. In this chapter, the linguistic structure of sign languages is introduced with a discussion of common myths about sign languages. This is followed by a more detailed discussion of the linguistics of British Sign Language, with special reference to features which resemble or contrast with spoken languages. The final section describes language and the brain by describing a number of neuroimaging studies with signers and research on signers who have aphasia or other language deficits following strokes. The neuroimaging and aphasia data are used to explore the 'core language system' – the regions of the brains used for language regardless of modality.

Keywords: sign language, neuroimaging, language and brain, modality.

1 Introduction

1.1 What Are Sign Languages?

Sign languages are the languages of the various Deaf[1] communities of the world; (for example, BSL (British Sign Language) is the language of the approximately 50,000 members of the British Deaf community. There are records of deaf people in different countries using sign language going back several thousand years (in Britain, the first records go back to the 1570s). Sign languages arise naturally wherever there are Deaf communities – they have not been invented by hearing people to 'help' deaf people.

1.2 Isn't Sign Language Universal?

It's exciting to think that there might be a universal language that would unite all people in the world, and many people think that sign language is an example of a universal language. But in fact there are many different sign languages in the world (over 100 have already been recorded (www.ethnologue.com)). Some sign languages are related to each other, like British Sign Language (BSL) and Auslan (Australian

[1] The upper case D is used to refer to membership of a sign language-using community. Lower case d refers to hearing impairment.

A. Esposito et al. (Eds.): Multimodal Signals, LNAI 5398, pp. 145–163, 2009.

Sign Language), and users of one can understand the other. But other sign languages – like American Sign Language (ASL) and BSL – are not related, and a Deaf Briton cannot understand a conversation between two American signers. Sometimes people are very disappointed to find this out, but sign languages differ from each other for the same reasons spoken languages differ from each other. Some of these reasons will be discussed below.

1.3 Aren't Signs Just Gestures?

To a person unfamiliar with BSL, signs may appear to consist of random hand and body movements accompanied by facial expressions. Sign languages are of course different from spoken languages because they use the visual, instead of auditory channel. But both spoken and signed languages has a unique set of rules that specifies how words/signs are formed, combined, and understood. All languages have similar grammatical categories, such as nouns and verbs. Every language has the means for indicating time, for forming questions, or negating statements, and so on. All languages are equally complex and capable of expressing any idea.

In spite of the difference in communication channel, linguists find striking similarities between the structure of spoken and sign languages. Additional evidence from functional imaging studies of the brain are described below.

1.4 Are Signs Just Like Pictures in the Air?

Many signs do resemble the concepts they represent (they are 'iconic'), but each sign language uses different icons. People learning a sign language need to learn the signs used in that language. Learning a sign language takes as much time and effort as learning a foreign spoken language. We also know from research that iconicity seems to play very little role in how fluent signers learn and use a sign language.

Sometimes people think that sign languages are like Chinese writing. But the symbols in Chinese writing are representations of spoken Chinese words. Signs are visible representations of concepts. They do not represent either spoken or written words.

1.5 Can Abstract Concepts Be Expressed in a Sign Language?

One of the most common beliefs is that although sign languages can express concrete concepts, they are restricted in their ability to deal with abstract ideas. But all languages are able to meet the communication needs of the communities that use them, and all languages have the flexibility and creativity to meet new needs – the vocabulary of the language expands as new concepts arise. Sign languages are no exception. For example, in recent years, new signs have appeared in BSL for 'fax', 'mobile phone', 'wi-fi', etc. New signs can be borrowed from spoken and written languages, from other sign languages, or new signs can be created. Thus there are no intrinsic limitations on what can be expressed in a sign language. The assumption that sign languages have inherent deficiencies in vocabulary or that they have a simple structure is without basis.

1.6 Are Sign Languages Grammatical?

Word-for-word translations from one language to another often result in ungrammatical or meaningless sentences because each language has its own vocabulary and grammar. The belief that sign languages are ungrammatical, or that they have no grammar, is based on the assumption that a sign language must have a structure identical to that of the spoken language of the community in which the sign language is used. But sign languages are independent languages, not derived from spoken languages and have their own vocabularies and grammar.

2 Sign Language

Following groundbreaking work by linguists and cognitive scientists over the last thirty years, it is now generally recognized that sign languages of the Deaf, such as ASL or BSL are structured and processed in a similar manner to spoken languages. The one striking difference is that they operate in a wholly non-auditory, visual-spatial medium. How does the medium impact on language itself? For some linguistic features there appear to be no effects of modality ([1] p. 2):

- Conventional vocabularies: learned pairing of form and meaning.
- Duality of patterning: Meaningful units built of meaningless sub-lexical units, whether orally or manually produced units
- Productivity: new vocabulary may be added to signed and spoken languages:
- Syntactic structure:
  - Same word classes: 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
- Acquisition: similar timetables for acquisition of signed and spoken language.

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 utilized. Pinker and Bloom ([2] p. 713) have noted that the properties of the speech apparatus require that "[…] grammar for spoken language must map propositional structures onto a serial channel […]" (i.e. the sound stream produced by the vocal apparatus where one word follows another over time). In contrast, sign languages are conveyed through a multi-dimensional medium (two hands + face + body) with the articulators moving in both space and time.

Detailed, empirical linguistic research into sign languages is recent, with modern sign linguistics usually traced back to Stokoe's seminal work on the phonological structure of American Sign Language [3]. Since that time, over 100 sign languages used by Deaf[2] people have been identified and described). The sign languages of Deaf communities have not been invented by hearing people and are independent of - although frequently influenced by - spoken languages. These languages operate

[2] The term Deaf (upper case 'D') is a cultural term, referring to membership of the Deaf community; lower case 'd' is an audiological term, used when referring to hearing loss.

Table 1. Breakdown of impact of modality differences between signed and spoken language

Spoken language	Sign language
Production	
Articulatory rhythm coupled to respiration and oscillating mandible	Articulatory rhythm not coupled to respiration; no oscillator
Articulators largely hidden	Articulators fully visible
Small articulators	Large articulators
Single articulatory system	Paired and multiple articulators
Perception	
Addressee doesn't need to see speaker	Signer must be visible
High temporal resolution: low spatial resolution	High spatial resolution: low temporal resolution
Acoustic events are the object of perception	Visual events are object of perception
Potential for iconic representation	
Auditory representations usually rely on arbitrary symbol-referent links	Visual representations have greater access to iconicity
Co-speech gesture used for pointing	Indexical signs used for pointing
Suitable for segmented, combinatorial, categorical encoding	Possibilities for mimetic, analogue encoding

entirely within the visual modality (with modified forms employing tactile or proprioceptive reception used by deaf blind signers) and reflect the grammatical options available to visual spatial languages. The vocabulary is frequently highly visually motivated and the grammar exploits the possibility of locating and moving signs through space. Unlike spoken languages, in which there is only one major articulator set, signed languages have multiple articulators, allowing two or even more signs to be articulated simultaneously [4].

These articulatory options are available to all sign languages, but unrelated sign languages of different Deaf communities are mutually unintelligible, although it is a common folk belief that the visual gestural nature of sign languages might make them universal. However, even visually motivated signs can focus upon different features of a referent. For example, a sign referring to "tea" might either reflect the way the tea is brewed or how it is drunk. Further, cultural differences between language users will lead to different signs. For example, the form of signs referring to doors may depend upon whether doors in that language community slide open or open on hinges.

2.1 Iconicity in the Sign Lexicon

In spoken language, an arbitrary link between an object and the word that represents it is the norm. In sign languages, while some signs exhibit an arbitrary mapping between their form and meaning (e.g. NOT-YET), many signs exhibit iconicity: a visual relationship to a real world object or concept they express. The majority of signs in BSL, for example, (estimated at 75% of core vocabulary) are iconic (e.g. TELEPHONE).

NOT-YET

TELEPHONE

.As mentioned above, iconicity is often culturally determined [5]. Iconic links often make reference to only part of an object's visual appearance, so some abstraction may be required to see a link. Children who acquire a sign language as their first language seem unaware of the 'etymology' of a sign such as BSL MILK (it imitates the action of milking a cow by hand) and iconicity plays a minimal role in the first stages of sign acquisition in child learners [6] [7]. It is likely that only later, once the core grammar has been mastered, that young children return to the language forms they have learned previously and carry out a metalinguistic analysis akin to what happens when children discover overtly the segmentation properties of their language during the development of literacy. The link between a sign and its iconic root enters the child's encyclopedic knowledge after the sign's phonological and grammatical properties have been acquired.

On the other hand, iconicity probably plays a major role in second language-learning: it is plausible that adult learners will use their world knowledge in learning the meaning of a sign or in guessing the meaning for a novel sign, and adult learners may be highly motivated to create such links between form and meaning as BSL has no written script, and forming an imagistic representation may be a useful learning strategy. For example the sign for PARIS in BSL refers to the shape of the Eiffel tower [8]. In other words, iconicity is often apparent only with hindsight.

2.2 A Grammar of the Face

When language is not restricted to manipulations of the vocal tract and to auditory perception, it is free to recruit any parts of the body capable of rapid, variegated articulations that can be readily perceived and processed visually. All established sign languages that have been investigated use non-manual signals – facial expressions and head and body postures - grammatically. These expressions are fully conventionalized and their distribution is systematic.

Early research on ASL showed that certain facial articulations, typically of the mouth and lower face, function as adjectivals and as manner adverbials [9]. Other sign languages have been reported to use lower face articulations in similar ways, although the specific facial expressions and their associated meanings vary from sign language to sign language.

A different class of facial articulations, particularly of the upper face and head, predictably co-occur with specific constructions, such as yes/no questions, WH- questions (questions with words such as 'what', 'when', which'), and relative clauses in ASL and in many other sign languages as well. Some of these facial articulations may be common across sign languages (especially those accompanying yes/no and WH-questions) [10] and some researchers have proposed that they evolved from more general affective facial expressions associated with emotions.

2.3 Space and Vision

Representations of events and ideas by humans can involve either a conceptual structure, coding linguistic representations; and an image structure, coding spatial representations [11]. Spoken languages do not encode spatial distinctions directly, but have developed a range of lexical and pragmatic devices for doing so [12] [13] . By contrast, in signed languages, space can be used directly for linguistic expression [14]. While the syntax of spoken language is primarily organized in a linear fashion, reflecting the temporal organization of the speech articulators and of hearing, syntax in signed languages exploits visuospatial organization.

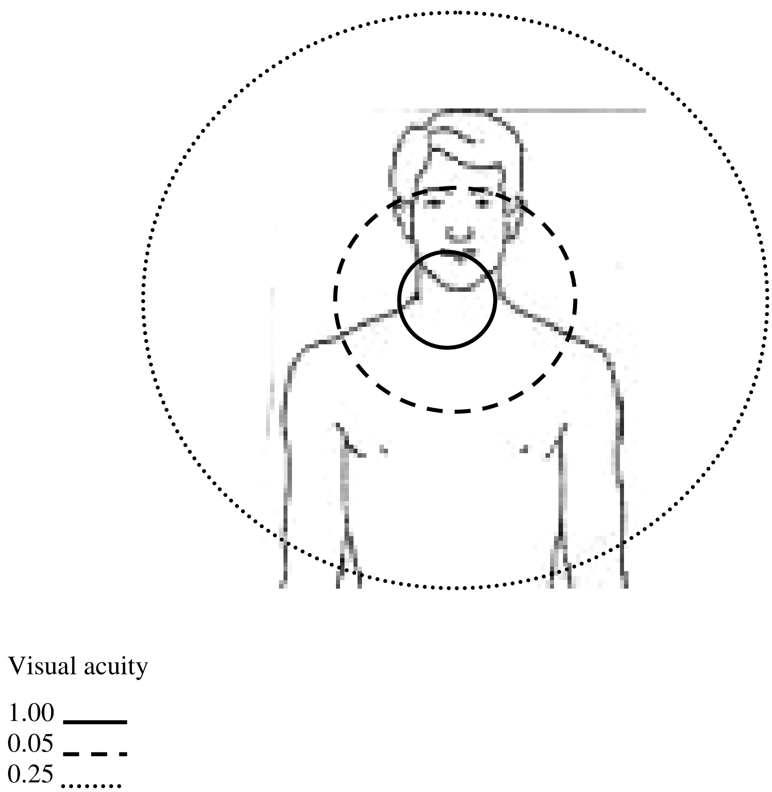

Fig. 1. Sign space and visual acuity

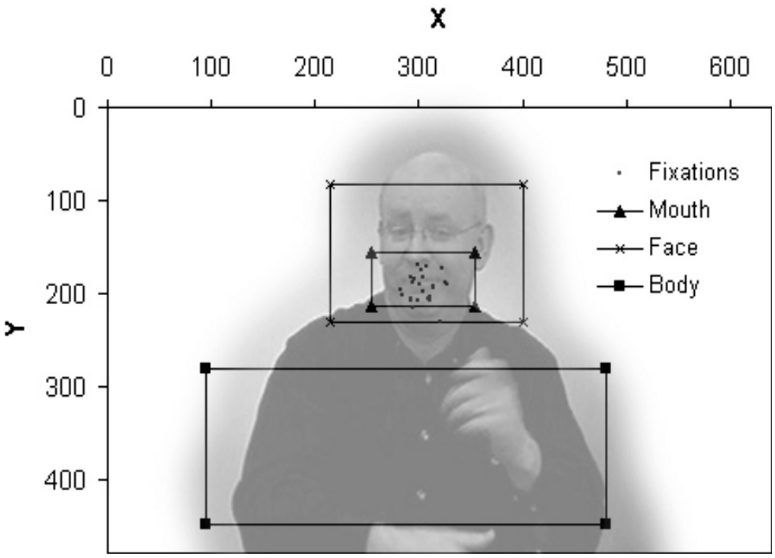

Fig. 2. Eye fixations while observing BSL © [15]

All signing occurs in the "sign space", an area in front of the signer extending from the hips to just above the head, and the width of the extended elbows. Figure 1 shows sign space, with concentric circles indicating relative visual acuity. This decreases rapidly towards the periphery of the visual field.

This decrease in visual acuity towards the periphery is mirrored in BSL by the form of signs. Those signs located towards the periphery of sign space tend to have fewer contrastive handshapes, larger movements, and are more often 2-handed. Signs located in the central visual area have smaller movements, many more contrastive handshapes and are most often 1-handed. In receiving sign language, attention and eye fixations are directed only at the area of central vision (Figure 2).

2.4 Space and Grammar

The use of sign space may be regarded as a continuum. At one extreme, sign space can be employed simply as a region for execution of signs in which the movement or location of signs is purely phonological. Further along this continuum, entirely abstract entities can be represented as spatially related. In the BSL translation of the sentence "Knowledge influences belief", one location in the space in front of the signer is assigned to "knowledge", a second location to "belief", and the verb "influence" moves from the location of "knowledge" to that of "belief". A similar use of space can be applied to more concrete sentences, such as "The man filmed the wedding (see Figure 3 below). In this sentence, he index finger in Frame 2 points to a location associated for referencing purposes to the previous sign, WEDDING; in the 4th frame, the sign BEEN-FILM is directed to the location to which the index pointed.

1. WEDDING 2. INDEX 3. MAN 4. BEEN-FILM

Fig. 3. Referential Space

Although there is agreement within the sentence between the location of the object and the direction of the verb, this is purely linguistic and does not represent real spatial coordinates for where the wedding was or where the camera was located while the filming took place.

Such sentences are regarded as exemplifying *referential* use of space, in which spatial relations are used to differentiate grammatical classes and semantic roles. Space can also be used metaphorically in translations of sentences such as “The professor criticized the students,” where a higher location may be assigned to the higher status role of “professor,” with the verb moving downwards towards “students.” However, the locations of these events in sign space do not represent and are not constrained by “real-life” spatial relations. As concepts move to more concrete meanings, the extent to which real-world spatial features are represented can increase. Thus, at the far end of the continuum, signed languages can convey spatial relations directly: Sentences can be constructed *topographically*. In this case, the space within which signs are articulated is used to describe the position and orientation of objects or people. The spatial relations among signs correspond in a topographic manner to actual relations among objects described. The linguistic conventions used in this spatial mapping specify the position of objects in a highly geometric and non-arbitrary fashion by situating certain sign forms (e.g., classifiers) in space such that they maintain the topographic relations of the world-space being described. [16] (see Figure 4 below).

Signed language grammar requires that the handshapes in verbs of motion and location in topographic sentences agree with real object features or classes (how objects are handled, their size and shape, or their function): These are signed language *classifiers* [17] [18] [19]. In producing the verb in Fig. 4, the sentence translated as “The pen is next to the book on the table” illustrates topographic space. In the third frame the signer establishes a flat-object classifier representing BOOK at the same height as that used for the sign TABLE (Frame 1) and simultaneously produces the lexical sign PEN. In the final frame the thin-object classifier representing PEN is located next to the flat-object classifier and at the same height. Thus the hands form a ‘map’ of the real world relationships between these referents.

Signed languages thus appear to differ from spoken languages, not only because space is obligatorily recruited for language, but additionally in that certain linguistic

1. TABLE 2. BOOK 3. PEN 4. cl-PEN
cl-BOOK……………………..

Fig. 4. Topographic Space

structures use spatial characteristics of semantic roles (classifiers) and spatial locations topographically. Such sentences map a number of spatial and image characteristics, both globally in terms of the relative locations of referents and the action paths that link them, and at a relatively fine grain, capturing local relationships [4].

At least one study in American Sign Language (ASL) suggests that this continuum between topographic and non-topographic sign representations has psychological reality. Emmorey et al. [16] showed fluent signers ASL sentences followed by a probe item which could appear at a locus in the sign space that was congruent with the noun phrase in the test sentence or at an incongruent locus. Viewers made a speeded response indicating whether or not they had seen the probe before. Probes that had been indexed incorrectly were slower to process and more error prone, but the effect of probe incongruity was much greater for topographic than for non-topographic material. This study suggests that spatial information is processed and represented differently when space serves a topographic function than when it does not.

3 Sign Language and the Brain

Such differences as those relating to the use of space for grammatical purposes open 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 hypothesize that the right hemisphere plays a major role in processing sign language, because this hemisphere specializes for visual-spatial information.

3.1 Brain Structure and Function

Figure 5 below shows a diagrammatic lateral view of the left hemisphere of the human brain. The four different lobes of the brain and some cortical landmarks for language processing are indicated. The primary auditory cortex lies within Heschl's gyrus. This is hidden from view within the Sylvian fissure on the upper surface of the temporal lobe. The secondary auditory cortex includes surrounding superior temporal

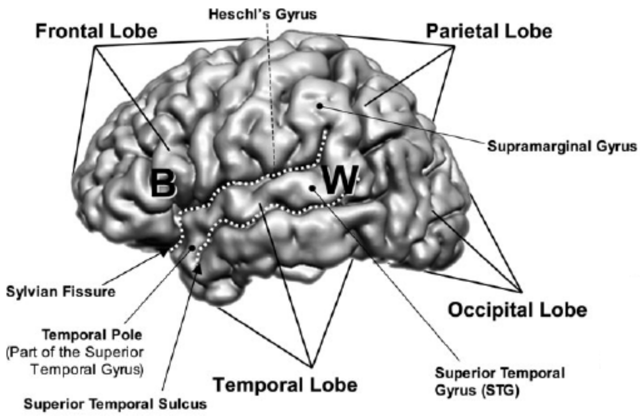

Fig. 5. The left hemisphere of the human brain [20] (©

areas. The area marked with a B is Broca's area, named after the 19th century neurologist who first linked aphasia with a specific area of the brain. Broca's area is located in the anterior region of the left frontal lobe of the cortex, and its function is related to speech and language. When this area is damaged in hearing people, Broca's aphasia, characterized by slow, halting, telegraphic and ungrammatical speech is evident. Conversely, in Wernicke's aphasia, damage is found in the posterior region of the left temporal lobe. Damage to this region does not impair the processing of speech and grammar; instead, it affects the semantic core of language: a hearing patient may speak fluently but often in semantically disorganized sentences ('word salad'). This region also serves auditory processing, so damage to the region is often associated with impaired auditory comprehension.

In the past 10 years, a variety of neuro-imaging methods have been employed to explore the neural systems underlying sign language processing. Campbell et al. [20] provide an excellent description and review of brain imaging techniques and recent functional imaging studies. These studies reveal patterns of activation for sign language processing which are for the most part closely similar to those observed for processing spoken languages, but with some interesting exceptions. In the following section these will be reviewed in some detail.

3.2 Similarities and Differences between Sign Language and Spoken Language Processing

MacSweeney et al. [21] compared hearing non-signers' processing of audio-visually presented English with Deaf native signers' processing of BSL. They found remarkably similar patterns of activation for BSL and English (see Figure 6).

For both BSL and English, although there is involvement of the right hemisphere, language processing is left-lateralized. Also, for both BSL and English there is activation in the inferior prefrontal region, including Broca's area, and in the middle/superior temporal region, including Wernicke's area. There are some differences,

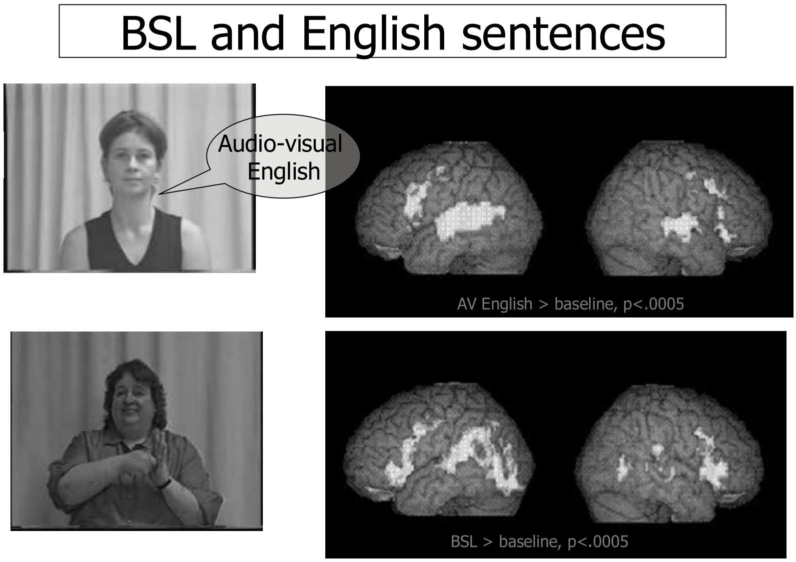

Fig. 6. Processing of BSL and English

however. Although both BSL and English involve processing in auditory cortices, there is greater activation in the primary and secondary auditory cortices for audio-visual English in hearing subjects than for BSL in deaf signers. Conversely, deaf signers show enhanced activation in the posterior occipito-temporal regions responsible for processing of visually perceived movement. In sum, the results of MacSweeney et al. [21] provide evidence both for the modality independent processing of language (whether spoken or signed) but also for some influence of the perceptual channels (visual or auditory). This influence is only partial, since both BSL and English processing involve auditory and visual areas of the brain.

The primary and secondary auditory cortices which process speech in hearing people have often considered to be unimodal; in other words, responding to auditory input only. However, the study above and other recent research suggests that these areas can be responsive to non-auditory stimuli. For example, the primary auditory cortex is activated during silent speech reading by hearing people [22] [23] [24] and during reading of written words [25]. Other studies with deaf participants indicate that the auditory cortices can be involved in processing non-auditory stimuli, such as tactile input [26] and visual (sign language) input [27] [28]. In general, it is clear that many of the areas of the left hemisphere previously considered to be involved in processing of audible speech are also activated in sign language processing.

MacSweeney et al. [21] argue that the region's polymodal potentiality is evident *only* in the absence of auditory input. In their study they looked at deaf and hearing native signers of BSL to ascertain whether hearing status affects sign language processing. Their results indicate that processing of BSL by deaf native signers activated areas in the left superior temporal gyrus; this region includes primary and secondary auditory cortex. Hearing native signers showed much less, and inconsistent, activation in these areas when processing BSL. Consequently, MacSweeney et al. [21] conclude that when there is an absence of auditory input, the region can be recruited for visual language processing. These results suggest that the auditory cortices are potentially plastic, with these left hemisphere areas recruitable for visual (i.e. sign language and speechreading) as well as auditory language processing, and that therefore these areas are specialized for language processing regardless of modality.

3.3 Modality-Specificity

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 specialized for spatial processing. MacSweeney et al. [29], in a fMRI study of BSL users, contrasted the comprehension of topographic and non-topographic space, exploring the extent to which precise locational aspects of space, captured by specific language forms (topographic sentences and object classifiers), might activate specific cortical systems. The critical region identified specifically for topographic processing was within superior parietal cortex and was left-lateralized. This study shows that some aspects of sign language processing require the contribution of cortical regions that are not associated with spoken language comprehension. When English translations of the topographic sentences were presented audio-visually to hearing participants in the scanner, they showed no condition-dependent activation, and none in superior parietal regions. 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 specialized for such mappings are utilized when sign languages capture these relationships.

4 Aphasia Studies

The first understanding that specific areas of the brain might be involved in language processing came from the pioneering 19th century aphasia studies of Broca and Wernicke. Initially, most research on aphasia concentrated on looking at those areas of the brain which are responsible for auditory perception, speech production and language processing. These early studies often equated speech processing with language processing. However, if sign language processing is left hemisphere dominant, this should be reflected in patterns of impairment following brain damage. In other words, sign language 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. [30] [31] [32] [33] [34] [35] [36] [37] [38]). Furthermore, symptoms are broadly consistent with those found in spoken language impairments. Thus, some individuals have fluent aphasias resulting from damage to Wernicke's area, while others have non-fluent, agrammatic signing, resulting from damage to Broca's area.

Other studies have explored specific features of sign aphasias. Since sign 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) [39] and Charles (a BSL signer) [35] 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 and other BSL signers with aphasia also addressed the question of whether iconicity affects the processing of sign. For example the BSL sign CIGARETTE is very similar to a typical gesture for smoking a cigarette. 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 (e.g. see [40] or detect a connection between the sign and its referent [41]). It is possible, therefore, that these signs are processed differently from non iconic signs, i.e. with greater involvement of gestural systems. However, the available evidence argues against this. Deaf children acquiring sign language appear to show no advantage for iconic signs [7]. Similarly, in tests of sign recall with adults, iconic signs show no advantage over non iconic signs [41]. Emmorey et al. [42] demonstrate that areas activated in the brain when processing signs or words for tools and their associated actions are the same although the signs are heavily iconic while the words are abstract. The dissociation between signs and gestures in Charles' signing pertained regardless of sign iconicity or any similarity between the forms of gestures and signs.

Charles was asked to sign the names of 40 iconic and non-iconic items in response to simple line drawings. Five deaf BSL signers without any sign language disabilities were also asked to sign the names of the stimuli. Overall the control subjects made just 3 errors (mean score 39.4). All errors were due to picture recognition problems. In contrast, Charles was impaired in naming both iconic and non iconic items (see table 1). The small numerical difference between the iconic and non-iconic signs was not significant (chi square=0.92, $p>0.5$).

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

Target	**Error**
tunnel	TRAIN … BRIDGE
factory	WORK

Charles also made several phonological errors. All but one of these involved handshape errors, e.g. when SHEEP was produced with a flat hand (an unmarked handshape), rather than a fist with the little finger extended (a marked handshape). There

Table 2. Errors in naming pictures

	Iconic items	**Non-iconic items**	**Total**
Correct	13	10	23
Semantic errors	2	3	5
Phonological errors	4	3	7
Fingerspelling only	1	2	3
Gesture		2	2
Total	20	20	40

were 3 occasions when Charles only attempted a finger spelling of the target instead of a sign. 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 produced a non-linguistic gesture in response to a request to produce a sign, for example, 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 either to give the name or 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'. These were termed SDG items (Sign Different from Gesture). Items were represented by pictures, with the same pictures used to elicit both gestures and signs. Table 3 below shows the results for this task.

Table 3. Sign vs. Gesture

	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, McNemar chi square = 4, $p<0.05$). Charles's signing errors consisted of semantic and phonological errors, fingerspelling 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.

5 Lateralization: Sign Language and the Right Hemisphere

Neville and her colleagues, who 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. [43] [44]). These findings have generated a good deal of debate: Although they demonstrated that ASL processing makes use of right hemisphere systems, there are three possible explanations: 1) this reflects linguistic processes lateralized to the right hemisphere; 2) represents a right hemisphere contribution to a left hemisphere linguistic processing system [32] [45]; 3) these findings are an artifact of the experimental design.

The study of signers with right hemisphere strokes can contribute to evaluating the various explanations suggested above for the involvement of the right hemisphere in sign language processing. As already mentioned, 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 visual-spatial impairments (e.g. [31]). Studies exploring impairments in processing of spatial grammatical structures and of facial information will be discussed here.

Although space is the medium in which sign language is expressed, in general, spatial processing disabilities following right hemisphere impairment have a minor impact on linguistic processing. There are exceptions: right hemisphere strokes cause some impairments in the processing of sentences involving the description of spatial relationships [36]. However, in line with the fMRI studies described above [29] [46] , Atkinson et al. [36] found that signers with right hemisphere strokes are equally impaired on topographic and non-topographic constructions, suggesting that the problems of this group with spatial relationships is a result of non-linguistic cognitive impairments which feed into language, rather than specific linguistic impairments. The second exception to the observation that right hemisphere strokes do not cause sign language impairments is discourse [47] [48] [49]. However, discourse is also vulnerable to right brain damage in hearing people, suggesting that this is one area of language which is not strongly lateralized to the left [50] [51]. It should be noted that while the left hemisphere's role is central in the processing of core elements of language: phonology, morphology and syntax, it has always been recognized that the right hemisphere is involved in discourse and prosody. This is true for both signed and spoken language [52].

This issue was explored in a study investigating the linguistic function of negation in six BSL signers with unilateral brain damage [35]. We have already noted that syntactic processing in signed languages appears to engage the same left perisylvian regions as syntactic processing in spoken languages. In BSL, headshake, a furrowed brow, and a frowning facial gesture are the nonmanual actions constituting the unmarked way of expressing negation. Because negation is considered syntactic, the investigators predicted that processing nonmanual negation ought to be difficult for left hemisphere lesioned patients who had language impairments. Contrary to prediction, however, all three patients with left-sided lesions, who were aphasic for signed language, understood negation perfectly when it was expressed nonmanually.

Negation can also be expressed in BSL by a manual negation marker such as the sign NOT. The patients with right-sided lesions had no difficulty in recognizing negation when the manual sign NOT was present, but failed to understand nonmanual (facial) negation. This unexpected finding alerts us to the possibility that non-manual negation is not syntactic at the surface level, but instead is prosodic.

6 Associated Language Issues

British Sign Language is fully independent of English, both lexically and grammatically. There is no doubt however that English has influenced BSL. This influence is to be expected when any powerful majority language surrounds a minority language. Given that BSL and English have been in such close proximity for many generations, signers have come to use certain forms derived from English.

We would expect BSL to borrow from English for new terminology, and we see this occurring, especially through the use of fingerspelling [4]. Signers can also borrow from any written language using fingerspelling. BSL also reflects the influence of English in its use of mouth patterns derived from spoken English (*mouthings*). BSL uses mouthings in a wide variety of ways [53] and in conjunction with other mouth patterns unrelated to English (*mouth gestures*). The use of mouthings varies with the age and social and linguistic background of the signer, as well as with the situational variety. Comparative research on a range of European sign languages, as well as other sign languages including ASL and Indo-Pakistani Sign Language shows that mouthings feature in all languages, and function in similar ways [54]. However, the amount of use and the exact functions of these components vary.

Recent imaging studies have explored both fingerspelling and the role of the mouth. Waters et al. [55] used fMRI to compare cortical networks supporting the perception of fingerspelled, signed, written, and pictorial stimuli in deaf native signers of BSL. All input forms activated a left fronto-temporal network, including portions of left inferior temporal and mid-fusiform gyri. To examine the extent to which activation in this region was influenced by orthographic structure, orthographic and non-orthographic stimuli were contrasted: fingerspelling vs. signed language. In the fingerspelling vs. signed language contrast, there was greater activation for fingerspelling than signed language in an area of the brain known to be activated when processing orthography – the visual word form area – indicating that fingerspelling, despite existing in the visual-manual modality, is still processed as orthographic, reflecting its role in representing written language.

Capek et al. [56] investigated mouthings and mouth actions. In an fMRI study they established that differential activation from superior temporal to inferior/posterior temporal regions reflected the relative presence or absence of speech-like mouth gestures. While a common perisylvian network is activated by sign language and by seen speech in native deaf signers, differentiation of activation can be sensitive to the type of articulation seen in the stimulus: speechlike orofacial patterns (whether within speech or sign language) consistently activate more superior temporal regions; manual actions more posterior temporal regions. McCullough et al. (57 2005) have studied facial actions in ASL, using fMRI to investigate the neural systems underlying recognition of linguistic and affective facial expressions, and comparing deaf ASL signers and hearing non-signers. Within the superior temporal sulcus, activation for emotional expressions was right lateralized for the non-signing group and bilateral for the deaf group. In contrast, activation within STS for linguistic facial expressions was left lateralized only for signers, and only when linguistic facial expressions co-occurred with verbs. The results indicate that function (i.e. linguistic or non-linguistic) in part drives the lateralization of neural systems that process human facial expression.

7 Summary and Conclusions

The research which has taken place over the past 20 years has confirmed that sign language for the most part uses the classic language processing areas associated with spoken language. Differences are found, and these for the most part relate to the different modalities in which signed and spoken language exist. As Campbell et al. [20: p. 15] state:

> The specialization of cortical networks for language processing does not appear to be driven either by the acoustic requirements for hearing a spoken language or by the articulatory requirements of speaking. It seems likely therefore, that it is the specialized requirements of language processing itself including for instance, compositionality syntax, and the requirements of mapping coherent concepts onto a communicable form, that determine the final form of the specialized language circuits in the brain.

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