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Les llengües de signes com a llengües minoritàries: perspectives lingüístiques, socials i polítiques
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How the brain processes languages in different modalities

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1. Introduction

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 regions are recruited regardless of modality? Second, does sign language recruit non-linguistic conceptual structures (on the right side of the brain)? This chapter describes research which is beginning to answer these questions, and discusses these findings in the context of linguistic theory generally.

Following groundbreaking work by linguists and cognitive scientists over the last thirty years, it is now generally recognised that sign languages of the deaf, such as ASL (American Sign Language) or BSL (British Sign Language[1]) 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? Meier (2002, p. 2) lists a number of the non-effects of modality:

1. Conventional vocabularies: learned pairing of form and meaning.
2. Duality of patterning:
   a. Meaningful units built of meaningless sublexical units, whether orally or manually produced units
   b. Slips of the tongue / slips of the hand demonstrate the importance of sublexical units in adult processing

1. ASL and BSL are historically unrelated and mutually unintelligible.

3. Productivity: new vocabulary may be added to signed and spoken languages:
   a. Derivational morphology
   b. Compounding
   c. Borrowing
4. Syntactic structure:
   a. Same word classes: nouns, verbs and adjectives
   b. Trade-offs between word order and verb agreement in how grammatical relations are marked: rich agreement licenses, null arguments and freedom in word order
5. 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 utilised. Pinker and Bloom (1990, 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 […]". Since sign languages are conveyed through a multidimensional medium, the question then becomes: to what extent do signed languages utilise space and time and what consequences does the use of space 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 visual-spatial 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 can be attributed to confounding factors, like the visual complexity of sign and the variability of subjects. Grossi *et al.*'s well-controlled study in which Deaf people watched signs presented rapidly to either the right or left visual field, demonstrated a right visual field / left hemisphere advantage for sign processing (Grossi *et al.*, 1996).

2. Brain structure and function

Figure 1 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 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, characterised 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 disorganised sentences ('word salad'). This

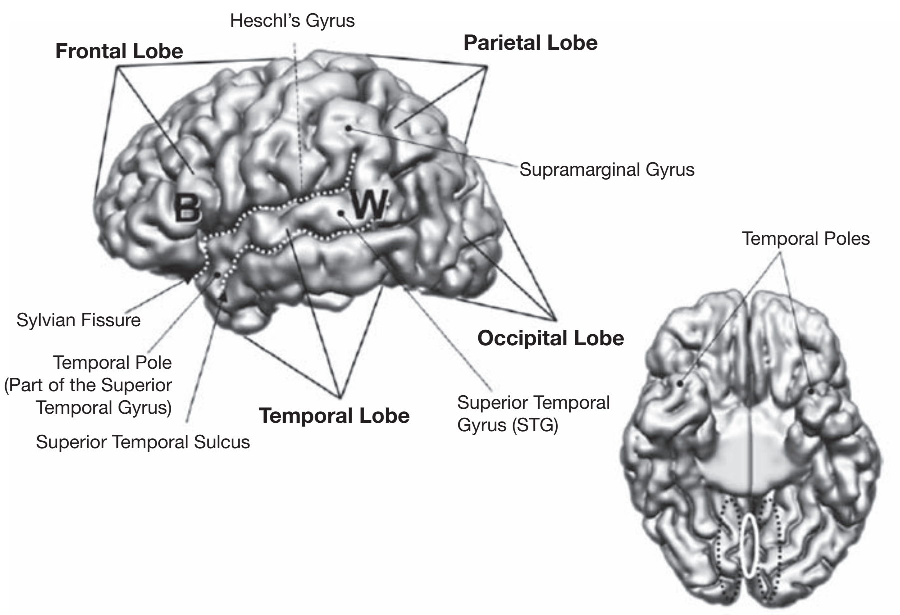

FIGURE 1. The Left Hemisphere (© Campbell *et al.*, 2007)

region also serves auditory processing, so damage to the region is often associated with impaired auditory comprehension.

In the past ten years, a variety of neuro-imaging methods have been employed to explore the neural systems underlying sign language processing. Campbell *et al.* (2008) 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.

2.1. *Similarities and differences between sign language and spoken language processing*

MacSweeney *et al.* (2002*a*) 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 2).

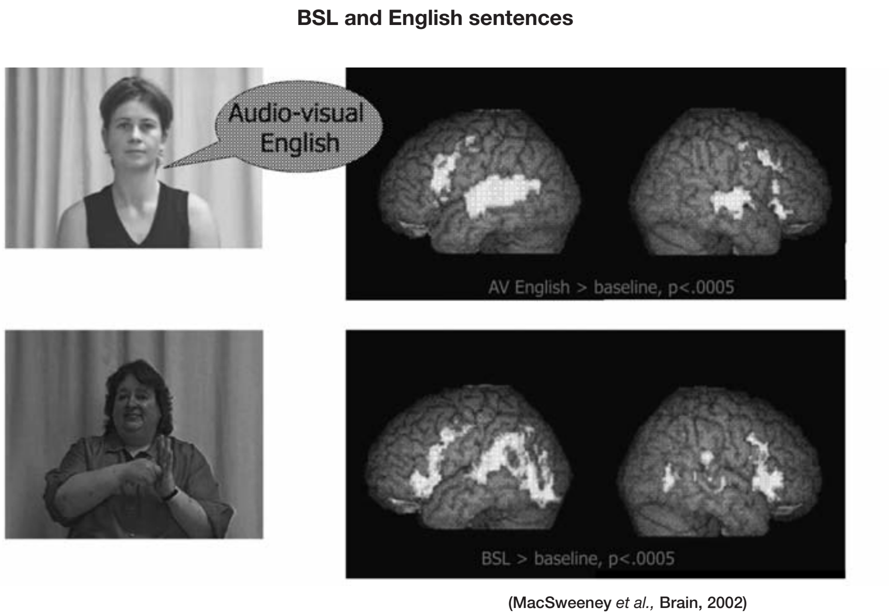

FIGURE 2. Processing of BSL and English

For both BSL and English, although there is involvement of the right hemisphere, language processing is left-lateralised. 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, 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.* 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 are 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 speechreading by hearing people (Calvert *et al.*, 1997; MacSweeney *et al.*, 2000, 2001), and during reading of written words (Haist *et al.*, 2001). Other studies with deaf participants indicate that the auditory cortices can be involved in processing non-auditory stimuli, such as tactile input (Levänen, 1998) and visual (sign language) input (Nishimura *et al.*, 1999; Petitto *et al.*, 2000). 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.

Petitto *et al.* (2000) and Levänen *et al.* (2001) found that deaf native signers showed greater activation in the superior temporal gyri as compared to hearing non-signers. Petitto *et al.* (2000) have suggested that this region is 'polymodal'. MacSweeney *et al.* (2002*a*) support this view, but 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.* 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 specialised for language processing regardless of modality.

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 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*. (2002*b*), in a fMRI study of BSL users, contrasted the comprehension of two types of space in BSL: topographic and non-topographic. In sentences using topographic space, use is made of space in an 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.).

The sentence translated as "The pen is next to the book on the table" (Fig. 3) 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

1. TABLE 2. BOOK 3. PEN 4. CL-PEN

CL-BOOK………………..

FIGURE 3. Use of topographic space

height. Thus the hands form a 'map' of the real world relationships between these referents.

In contrast, in the BSL sentence translated as "The man filmed the wedding" (Fig. 4), non-topographic space is used: the 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. 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.

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

FIGURE 4. Use of non-topographic space

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.

Both studies, then, explored the extent to which precise locational aspects of space, captured by specific language forms (topographic sentences and object classifiers), might activate specific cortical systems. In MacSweeney *et al.*'s (2002*b*) study, the critical region identified specifically for topographic processing was within superior parietal cortex and was left-lateralised. In Emmorey *et al.*'s (2002) study, this region was also activated, but analogous right-sided parietal activation was observed as well.

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.

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 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.

Emmorey *et al*.'s data show that, depending on test conditions, the processing of some sign language classifiers may require a right hemisphere parietal contribution. 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.

4. Lateralisation: sign language and the right hemisphere

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*., 2002). 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; reflected linguistic processes lateralised to the right hemisphere; represented a right hemisphere contribution to a left hemisphere linguistic processing system (Hickok *et al*., 1998; Paulesu & Mehler, 1998); or were an artefact of the experimental design. For example, in Neville *et al*. (1998) it is argued that the right hemisphere plays a more significant role in the processing of American Sign Language (ASL) than in the processing of English. They report that deaf and hearing native signers showed significant activation in perisylvian regions of both the right and left hemispheres while viewing ASL sentences. In contrast, hearing participants showed only left hemisphere activation during reading of English language sentences presented word by word. However, in the ASL condition, participants saw video recordings of signers producing sign sentences, while in the English condition, they saw only written sentences. The ASL input thus included facial expression, and mouth and body actions, as well as prosodic structure, and it is known that perisylvian regions of the right hemisphere are recruited in the processing of (spoken language) prosody (Van Lancker, 1997).

5. Fingerspelling

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 (Sutton-Spence & Woll, 1999). 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 (Sutton-Spence & Day, 2001) 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 (Boyes-Braem & Sutton-Spence, 2001). 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.* (2007) 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, in both groups. 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.

6. Hands and mouth in sign language

Despite the striking similarities in regions of brain activation, speech and sign do not appear to rely on identical brain networks. MacSweeney and colleagues (2002*a*) did find differences between sign language and audio-visual speech, which they attributed to the modality of the input rather than to linguistic processes. Regions which showed more activation for sign than audiovisual speech included the middle occipital gyri, bilaterally, and the left inferior parietal lobule (BA 40). In contrast, audiovisual English sentences elicited greater activation in superior temporal regions than signed sentences.

As mentioned above, sign languages offer a unique perspective on language, since they embody the structural and communicative properties of spoken language, while existing within a wholly visual-gestural medium. Among other insights, they enable investigators to clarify the core components of language in distinction to those that reflect input or action characteristics of the language system. This difference is reflected in the articulators on which languages in the two modes rely. Sign languages make use of non-manual articulators, including actions of the head, face and trunk (e. g., Liddell, 1978; Sutton-Spence & Woll, 1999). Within the face, eye actions such as eye narrowing, changes in direction of gaze and eyebrow actions (raise/lower) play important roles in SL communication (Crasborn, 2006). In addition, although sign languages are unrelated to the spoken languages used in the surrounding hearing community, sign languages do borrow elements from spoken language (Sutton-Spence & Woll, 1999). Other mouth actions (*mouth gestures*) are unrelated to spoken languages (see Figure 5 below).

Mouthings. Sign languages can borrow mouth actions from spoken words—speech-like actions accompanying manual signs that can disambiguate manually homonymous forms. These are considered to be borrowings, rather than contact forms reflecting bilingualism in a spoken and signed language, since there is evidence that

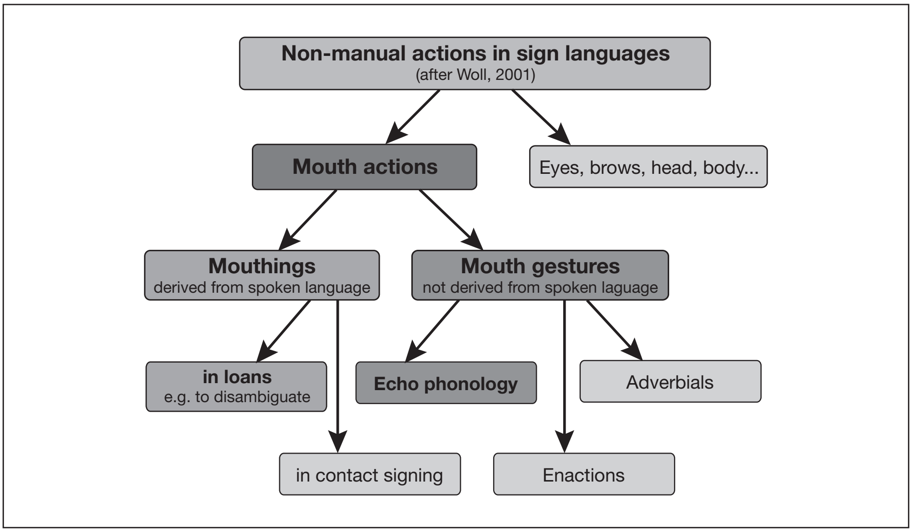

FIGURE 5. Mouth actions in sign language

signers can learn these without knowing the source spoken language. These can disambiguate signs with similar or identical manual forms. For example, the BSL signs ASIAN and BLUE are manually identical (see Fig. 9*c* below). To distinguish which meaning is meant, mouthings are incorporated, derived from the mouth actions used when speaking the words 'Asian' or 'blue'.

Adverbials are arrangements of the mouth which are used to signal manner and degree (e. g. to indicate that an action is performed with difficulty or with ease; to indicate if an object is very small or very large, etc.).

In *Enaction* (sometimes called 'mouth-for-mouth'), the action performed by the mouth represents that action directly (e. g. in CHEW, the mouth performs a 'chewing' action, while the sign is articulated on the hands).

The term *Echo Phonology* (Woll, 1996; 2001) is used for a class of mouth actions that are obligatory in the citation forms of lexical signs. In the BSL sign TRUE (see Figure 7*d* below), the upper hand moves downwards to contact the lower hand, and this action is accompanied by mouth closure, synchronised with the hand contact. This type of non-speech-like mouth gesture has been termed 'echo phonology' (EP), since the mouth action is considered secondary to that of the hands (Woll & Sieratzki, 1996; Woll, 2001). That is, the mouth gesture 'follows' the hand actions in terms of onset and offset, dynamic characteristics (speed and acceleration) and direction and type of movement (opening, closing, or internal movement). Thus, these gestures illustrate a condition where “the hands are the head of the mouth” (Boyes-Braem & Sutton-Spence, 2001). EP mouth gestures are not derived from or influenced by the forms of spoken words borrowed into sign; rather, they are an obligatory, intrinsic component of this subgroup of signs, their patterning presumably constrained by common motor control mechanisms for hands and mouth (Woll, 2001). The signs in which they are found require the presence of the mouth gesture to be well-formed, and mouth action includes some movement: either the exhalation or inhalation of breath, or a change in mouth configuration during the articulation of the sign: for example, EXIST (wiggling of fingers, no path movement, accompanied by [ʃʃ]); TRUE (active hand makes abrupt contact with palm of passive hand, accompanied by [am] —see Figure 9*d* below); DISAPPEAR (spread hands close to ‘flat O’ shape, accompanied by [θp]).

The essential dependence of the mouthing on the articulatory features of the manual movement can be seen in three BSL signs all meaning ‘succeed’ or ‘win’. Three different oral patterns of mouthing co-occur with these signs, and one cannot be substituted for the other.

In SUCCEED, the thumbs are initially in contact, but move apart abruptly as the mouth articulates [pa]. In WIN, the hand rotates at the wrist repeatedly as the mouth articulates [hy]; and in WON, the hand closes to a flat O, while the mouth articulates [ʌp].

6.1. *Echo Phonology in Different Sign Languages*

In a study comparing narratives in three sign languages (van der Kooij *et al.*, 2008), the occurrence of echo phonology was compared with other types of mouth action. The chart below shows the percentage of signs accompanied by mouth actions other than mouthings, in narratives of Aesop’s fables. Although there is variability across the data for two signers of each of the three sign languages (Swedish, British, Netherlands) echo phonology is found in all three (Fig. 6).

6.2. *Mouth and hand in the brain*

With these considerations in mind, a study (Capek *et al.*, 2008) explored the following conditions in which lists of single items were presented to deaf native signers in the

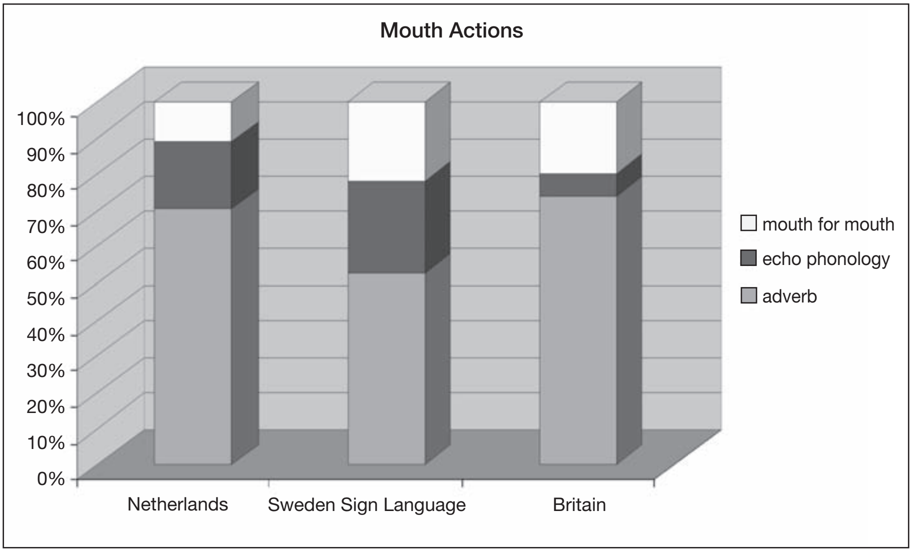

FIGURE 6. Echo phonology in 3 sign languages

fMRI scanner: (*1*) silent speechreading of English (SS); (*2*) BSL signs with no mouth action (hands only – HO); (*3*) BSL signs with mouthings (disambiguating mouth – DM) and (*4*) BSL signs with mouth gestures (echo phonology – EP).

The stimuli were designed to vary on the dimensions of presence or absence of mouth opening/closing; presence or absence of hand and arm movements; and presence or absence of English-based mouth actions (Fig. 7).

	Mouth opening and closing	*Hand-arm movements (BSL)*	*English-derived mouth*
No mouth (HO)	–	+	–
Echo Phonology (EP)	+	+	–
Disambiguating mouth (DM)	+	+	+
Silent speech (SS)	+	–	+

FIGURE 7. Characteristics of stimuli

Stimuli consisted of single words/signs, examples of which are given in Fig. 8. The list of silently spoken words was based on English translations of the signs below.

Echo phonology	*Disambiguating mouth*	*Hands only*
exist [ʃʃ]	Finland/metal	table
win [hy]	battery/aunt	cherry
none [pu]	wood/problem	butter
success [pa]	Russia/boy	know
end [pəm]	Italy/win	fax

FIGURE 8. Examples of stimuli

Figure 9 shows examples of each of the stimuli types:

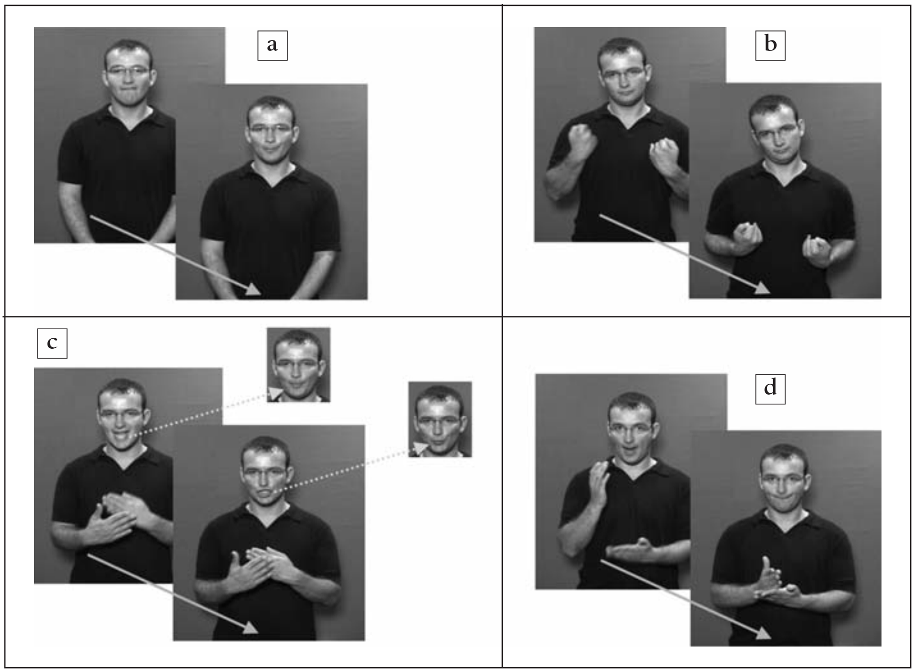

FIGURE 9. Illustrations of stimuli

9*a*. SS. Silent articulation of the English word “football”. The fricative (/f/) (‘foot..’), and the semi-open vowel /ɔ:/ (‘..ball’) are clearly visible.

9*b*. HO. The BSL sign ILL.

9*c*. DM. The BSL sign ASIAN shows the mouthing of /eɪ/ and /ʒ/. The face insets show the corresponding parts of the mouthings for the manual homonym BLUE, where /b/ and /u:/ can be seen.

9*d*. EP. The manual sequence for [TRUE] requires abrupt movement from an open to a closed contact gesture. As this occurs, the mouth closes abruptly.

This experiment was designed to address a number of specific questions: to what extent does the pattern of activation between speech perception and sign language perception differ?; does the processing of mouthings (DM) differ compared to signs without mouth action (HO)?; does echo phonology (EP) generate distinctive activation compared with mouthings (DM)?; how do non-signers differ from signers?

Thirteen (6 female; mean age 27.4; age range: 18-49) right handed participants were tested. Volunteers were congenitally, severely or profoundly deaf native signers, having acquired BSL from their deaf parents. Stimuli were presented in alternating blocks of each of the experimental and a baseline condition. Participants were instructed to understand the signs and words and they performed a target-detection task in all conditions, to encourage lexical processing. During the experimental conditions, participants were directed to make a push-button response whenever the stimulus item contained the meaning ‘yes’. This ‘yes’ target was presented in an appropriate form across all 4 conditions, specifically: as an English word with no manual component in the SR condition, as a BSL sign with no mouth action (but BSL-appropriate facial affect) in the HO condition, as a BSL sign with an English mouth pattern in the DM condition and as a BSL sign with a motoric mouth echo in the EP condition.

To what extent does the pattern of activation for speech perception and sign language perception differ?

Speechreading (SS)

The major area of activation was perisylvian (superior temporal and inferior frontal), with somewhat more extensive activation on the left than the right. These findings conform with other recent studies. They confirm that silent speech can activate regions in deaf people's brains that have been identified as auditory speech processing regions in hearing people.

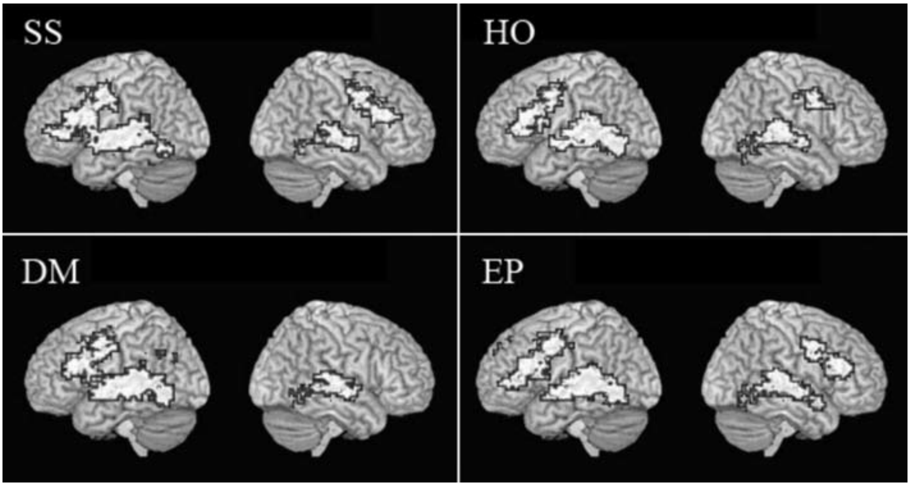

FIGURE 10. Brain activation

10*a*. Activation during silent speechreading (SS).
10*b*. Activation during processing of signs without any mouth actions (HO).
10*c*. Activation during processing of signs with disambiguating mouth actions (DM).
10*d*. Activation during processing of signs with echo phonology (EP).

6.3. *Sign language (HO, DM, EP)*

In all three sign language conditions, there is also activation in perisylvian regions. It affirms that sign language in Deaf native signers activates core language regions that are typically found when hearing people listen to speech. Although both sign language and speech involve perisylvian regions, sign language perception activated more posterior and inferior regions. For this analysis, silent speechreading is compared with the three sign conditions (Fig. 11).

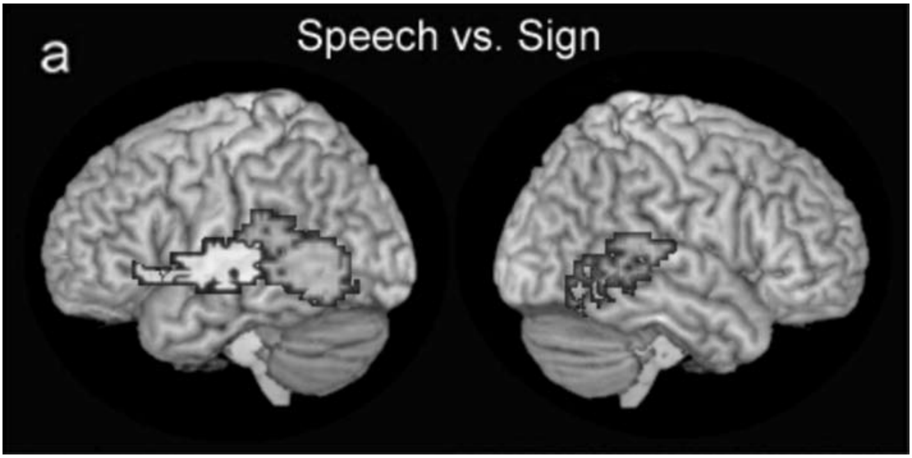

FIGURE 11. Silent speech (white) vs. Signs (EP, DM & HO) (grey)

DOES THE PERCEPTION OF SIGNS WITH MOUTHINGS (DM) DIFFER FROM SIGNS WITH NO MOUTH (HO)?

If language (speech vs. sign) is the crucial reason for the more posterior activation found in BSL perception, then signs with disambiguating mouth and signs without mouth should be processed identically. On the other hand, if the articulators used determine the areas of activation, then DM and HO signs should differ, with more posterior activation for the HO signs. The data support the first alternative: anterior activation characterised DM and posterior activation, HO (Fig. 12). There was greater activation for signs with mouth actions in superior temporal sulci of both hemispheres; additional activation in the left inferior frontal gyrus; and HO signs activated more right posterior temporo-occipital regions. These may be particularly important for the perception of hand actions. These findings are very similar to those exploring distinctive patterns of activation consequent on observation of hand and mouth gestures that are unrelated to sign language.

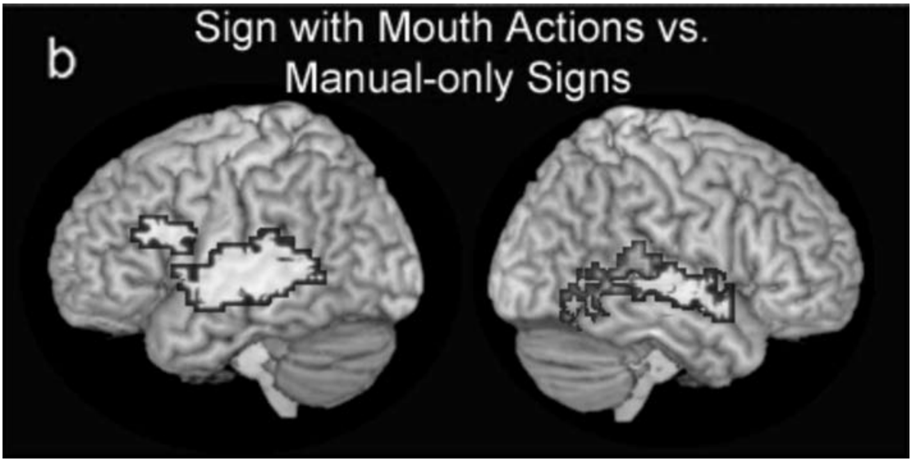

FIGURE 12. Signs with mouth actions (DM & EP) (white) vs. HO signs (grey)

DOES ECHO PHONOLOGY (EP) GENERATE DISTINCTIVE ACTIVATION COMPARED WITH OTHER MOUTHINGS (DM)?

The contrast between the condition that used DM and the one that used EP provides further insight into the cortical correlates associated with observing specific articulators within sign language. Here the pattern differed. DM generated relatively greater activation in a circumscribed region of the left middle and posterior portions of the superior temporal gyrus, while EP produced relatively greater posterior activation. This can be considered to reflect the fact that DM is more 'speech-like' than EP. Thus EP appears to occupy an intermediate position between signs without mouth and signs with mouth actions derived from spoken language (Fig. 13)

These findings suggest a strong conclusion concerning brain organisation for the perception of sign language. The task required participants to process material linguistically. In order to achieve lexical processing, BSL users must integrate perceptual processing of hands and of face/head, and this needs to be achieved fluently and automatically. If the cortical circuitry for sign language processing were driven by a mechanism that is 'articulation-blind', we would expect there to be no systematic differential activation between, for example, signs with mouthings (where the mouth information is non-redundant), signs without mouthing (where there is no mouth information, or signs with echo phonology, where the information on the

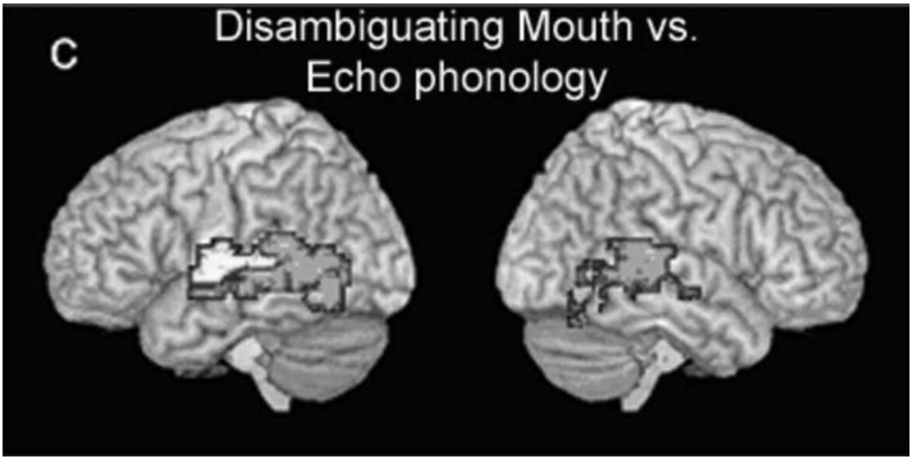

FIGURE 13. DM (white) vs. EP signs (grey)

mouth is redundant. Yet the contrasts analysed here suggest this is not the case. It appears that mouth actions, when they are a required component of the sign differentially, activate a circumscribed region within the middle and posterior portions of the superior temporal gyrus. More generally, there is a strong similarity between the patterns of distinctive activation for mouth actions and for hand actions. This suggests that when the language processor is engaged, it requires ongoing access to visual information about the articulators that deliver information to it, and that this information can be distinguished in terms of relative cortical location. The core language processes themselves appear to be similarly constituted for sign language and for speechreading in Deaf native signers.

6.4. *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. Poizner *et al*., 1987; Hickok *et al*., 1996; Hickok *et al*., 1998; Corina 1998*a*, 1998*b*; Atkinson *et al*., 2004, 2005; Marshall *et al*., 2004, 2005). 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) (Corina *et al*., 1992) and Charles (a BSL signer) (Atkinson *et al*., 2004) 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. All sign languages include iconic (visually motivated) signs, where the meaning of the sign is reflected in its form (Taub, 2001). 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 Pizzuto & Volterra, 2000) or detect a connection between the sign and its referent (Klima & Bellugi, 1979). 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 (Tolar *et al*., 2008). Similarly, in tests of sign recall with adults, iconic signs show no advantage over non iconic signs (Klima & Bellugi, 1979). Emmorey *et al*. (2004) 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, $p > 0.5$).

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, e. g.:

Target	Error
tunnel	TRAIN … BRIDGE
factor	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 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 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'. These were termed SDG items (Sign Different from Gesture). Items were represented by pictures, with the same pictures used to elicit gestures and signs. Table 2 below shows the results for this task.

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, McNemar chi square = 4, $p < 0.05$). 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 (MacSweeney *et al.*, 2004) and gesture may remain intact following left hemisphere stroke even when sign language is impaired.

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. Hickok *et al.*, 1996). 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 two exceptions: right hemisphere strokes cause some impairments in the processing of sentences involving the description of spatial relationships (Atkinson *et al.*, 2005). However, in line with the fMRI studies described above (MacSweeney *et al.*, 2002*b*; Emmorey *et al.*, 2002), Atkinson *et al.* 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 linguistic impairments. The second exception to the observation that right hemisphere strokes do not cause sign language impairments is discourse (Kegl & Poizner, 1997; Loew *et al.*, 1997; Hickok *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). 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 recognised that the right hemisphere is involved in discourse and prosody. This is true for both signed and spoken language (Rönnberg *et al.*, 2000).

This issue was explored in a study investigating the linguistic function of negation in six BSL signers with unilateral brain damage (Atkinson *et al.*, 2004). 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 non-manual actions constituting the unmarked way of expressing negation. Because negation is considered syntactic, the investigators predicted that processing non-manual 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 non-manually.

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 recognising negation when the manual sign NOT was present, but failed to understand non-manual (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.

7. 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 (Sutton-Spence & Woll, 1999). 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 (Sutton-Spence & Day, 2001) 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 (Boyes-Braem & Sutton-Spence, 2001). 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.* (2007) 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, in both groups. 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.* (2008) 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.* (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 lateralised for the non-signing group and bilateral for the deaf group. In contrast, activation within STS for linguistic facial expressions was left lateralised 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 lateralisation of neural systems that process human facial expression.

8. 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*. (2008, p. 17) 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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