The Deaf Brain

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Outline

- Introduction: the multi-channel nature of language
- Audio-visual language
- BSL
- Speech processing
  - Silent speech
  - Auditory processing
- Phonological processing
- Fingerspelling
- Applications to interventions for deaf children

The relevance for those concerned with young deaf children

- Early language & brain plasticity
- bilingualism
- Evidence-based policies and practices

Multi-channel communication

- Human face-to-face communication is essentially audiovisual
- Typically, people talk face-to-face, providing concurrent auditory and visual input
- Visual input also includes gesture
- Sign language is also multi-channel: signs, mouthing, gesture

Audio-visual processing

- Observing a specific person talking for 2 min improves subsequent auditory-only speech recognition for this person.
- Behavioural improvement in auditory-only speech recognition is based on activation in an area typically involved in face-movement processing.
- These findings challenge unisensory models of speech processing, because they show that in auditory-only speech, the brain exploits previously encoded audiovisual correlations to optimise communication

Von Kriegstein et al (2008

Where in the brain is SL processed?

fMRI of BSL – Study 1

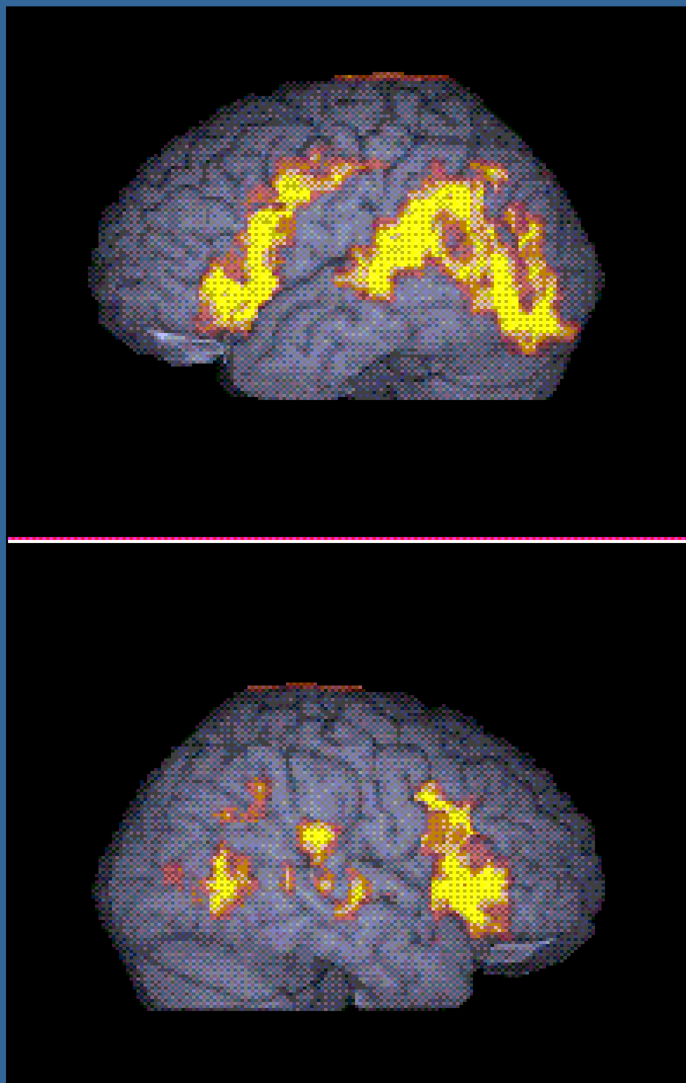
- sentence processing – comparing BSL with English
- Deaf native signers and hearing non-signers
- English translations presented audiovisually
  - Coronation Street is much better than Eastenders.
  - I will send you the date and time.
  - The woman handed the boy a cup.
  - Paddington is to the west of Kings Cross

MacSweeney et al, 2002

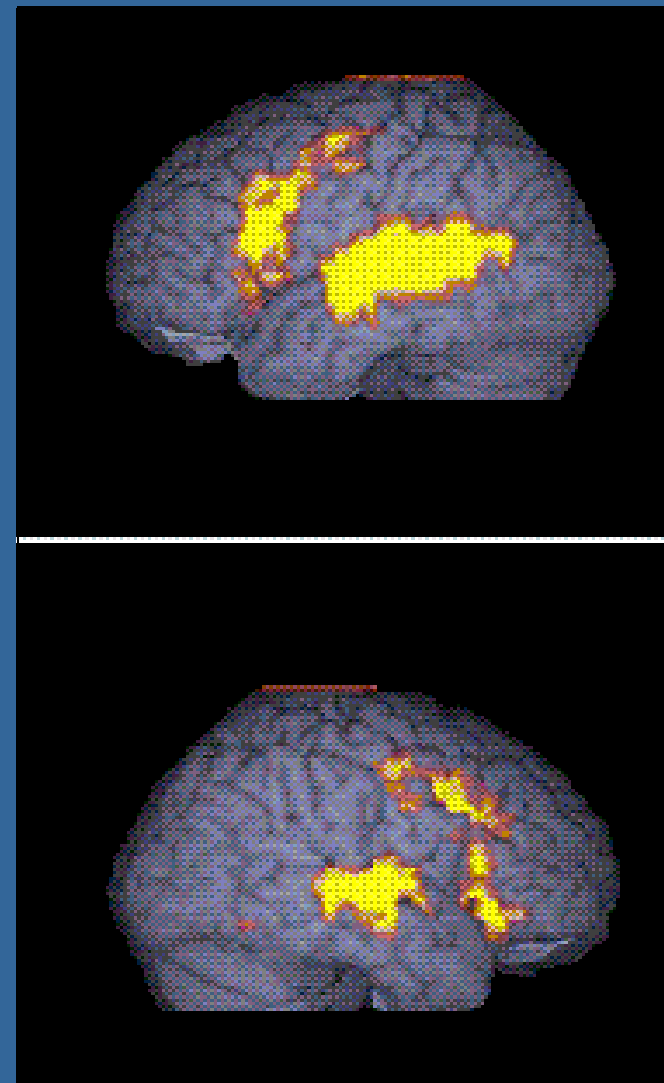
Results

- Sign language and spoken language are both left-lateralised
- More posterior activation during sign language processing than spoken language processing (related to processing of hand movement being posterior to mouth movement)
- Deaf native signers use classical language areas, including secondary auditory cortex, to process BSL

BSL- Deaf native signers



English – hearing native speakers

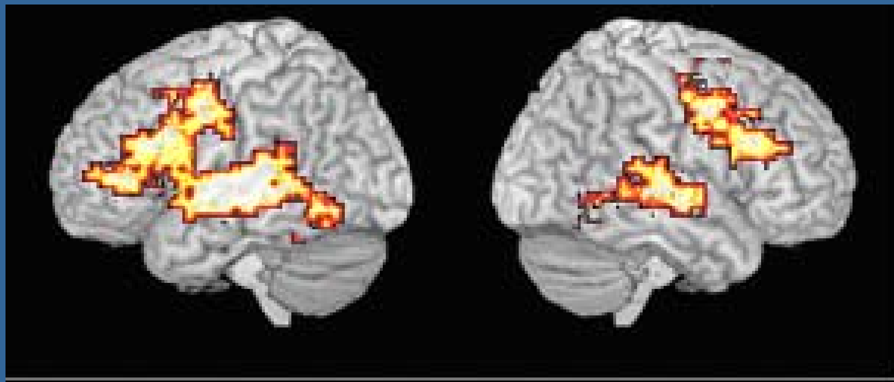


Where is silent speech processed?

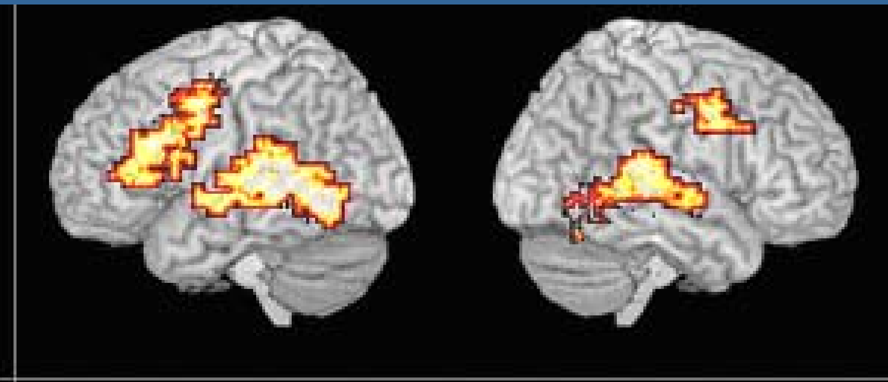
fMRI study 2. Comparing processing of sign, speech and silent speech

- to what extent do the patterns of activation during speech perception and sign language perception differ?
- To what extent do the patterns of activation during perception of silent and audio-visual speech differ?

Capek et al, 2008

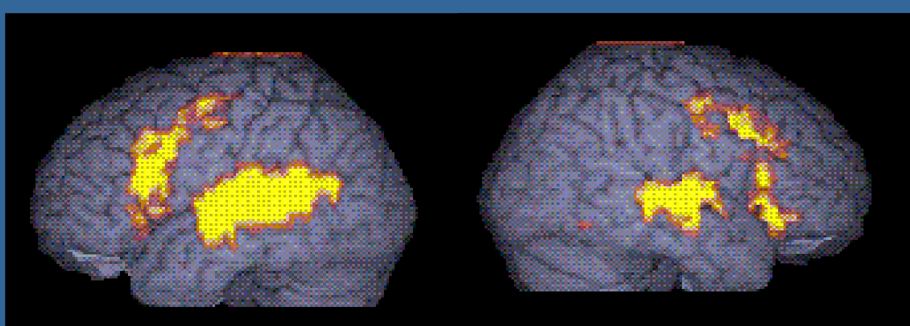


Silent speech (single words)



Single signs

- Signs and words activate a very similar network
- Silent speech activates regions in deaf people's brains that have been identified as auditory speech processing regions in hearing people



Audiovisual speech (sentences)

Auditory cortex and speechreading

- Superior temporal regions activated include areas traditionally viewed as dominant for processing auditory information in hearing people, including secondary auditory association cortex (BAs 22 & 42)
- Some evidence of activation within primary auditory cortex (lateral parts of Heschl's gyrus—BA 41)
- These findings are in agreement with those of Sadato et al (2005) on how lipreading activates the auditory cortex of hearing subjects

fMRI study 3: Signs, text, fingerspelling, pictures

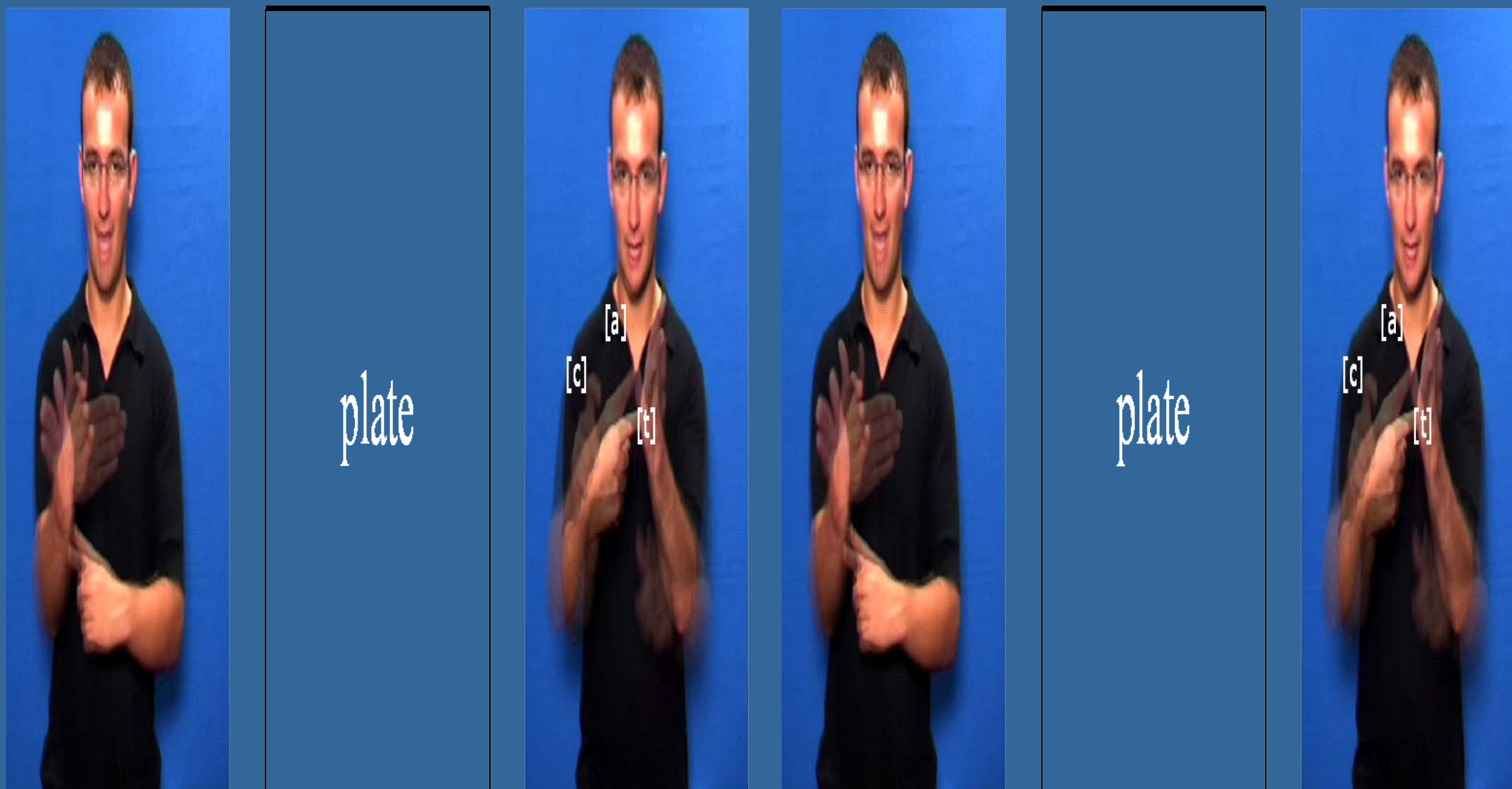
- What are the similarities and differences in the cortical organisation for processing signs (SL), written words (TEXT), pictures (PIX) and fingerspelling (FS)?

Waters et al, 2007

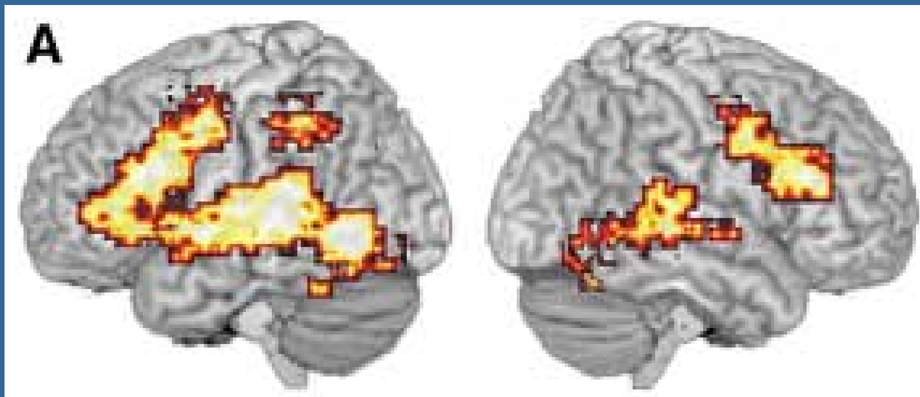
BSL fingerspelling

- hand configurations represent orthographic symbols
- 2-handed manual alphabet
- Used for a variety of functions including representation of ‘foreign’ (English) words
- Source for lexical borrowing from English to BSL

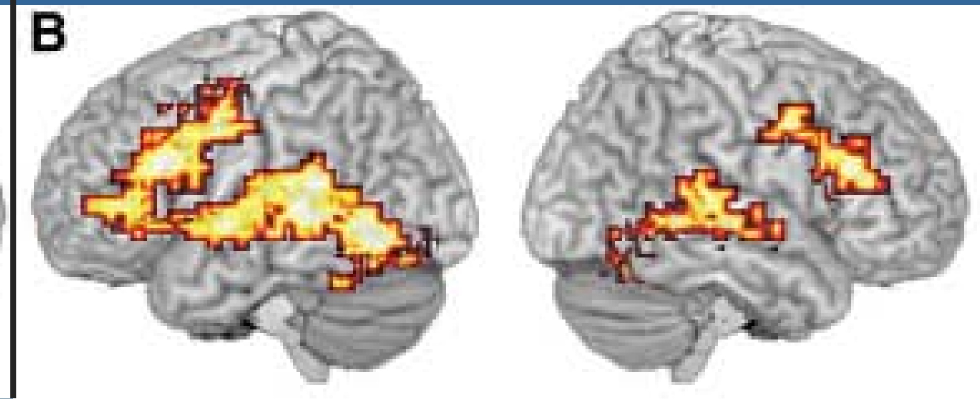
Sign & Fingerspelling



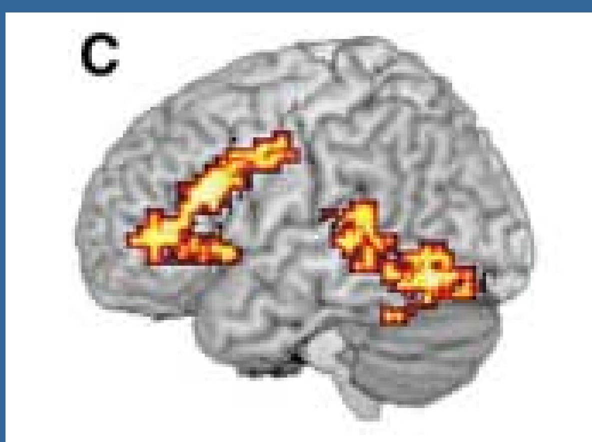
[SL: FLAG] [TEXT: plate] [FS: -c-a-t-] [SL: FLAG] [TEXT: plate] [FS: -c-a-t-]



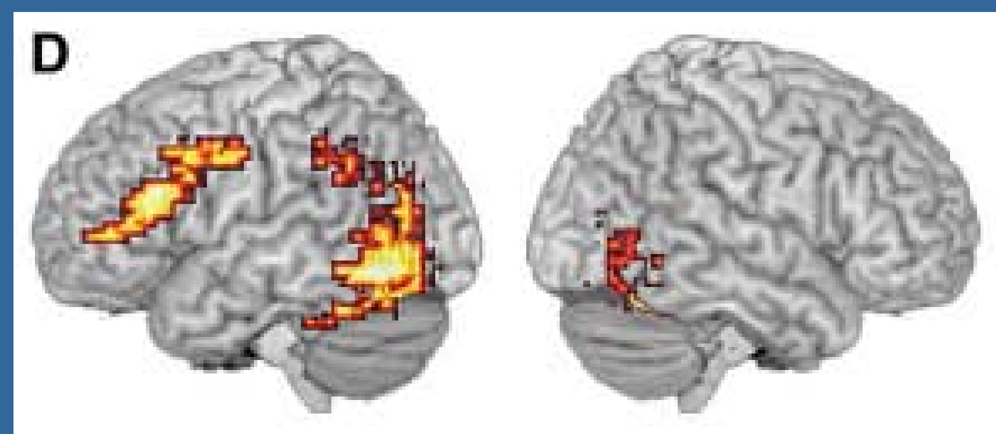
Fingerspelling



BSL



Text



Picture

fMRI Study 4: Phonological processing in deaf signers and the impact of age of first language acquisition

- Does the application of the term ‘phonology’ to signed languages have neurological as well as linguistic and psycholinguistic validity?
- Is similar neural processing involved in phonological analysis of signed and spoken languages?

MacSweeney et al, 2008

Are the neural systems supporting language influenced by the age of *first* language acquisition?

- We predicted differences between deaf native and non-native signers, on both BSL *and* English tasks

- For most deaf children, exposure to a signed language is delayed
  - Deaf native and non-native signers should differ on *sign*-related tasks
- Deaf children's English language acquisition is delayed compared to hearing peers
  - Deaf native signers perform better than deaf non-native signers on written English grammaticality judgments (Mayberry & colleagues, 2002; 2003)
  - Deaf native and non-native signers should differ on *English*-related tasks

Participants

- 20 deaf and 24 hearing participants, matched on age and non-verbal IQ
- All good readers (mean reading age = 15y 6m)
- All deaf participants born profoundly deaf; all had a mean hearing loss >92 dB in the better ear over four octaves from 500–4000 Hz
- The deaf group were skilled speechreaders, outperforming the hearing participants on the Test of Adult Speechreading
- Hearing controls were significantly better readers and had a higher English vocabulary score than deaf participants

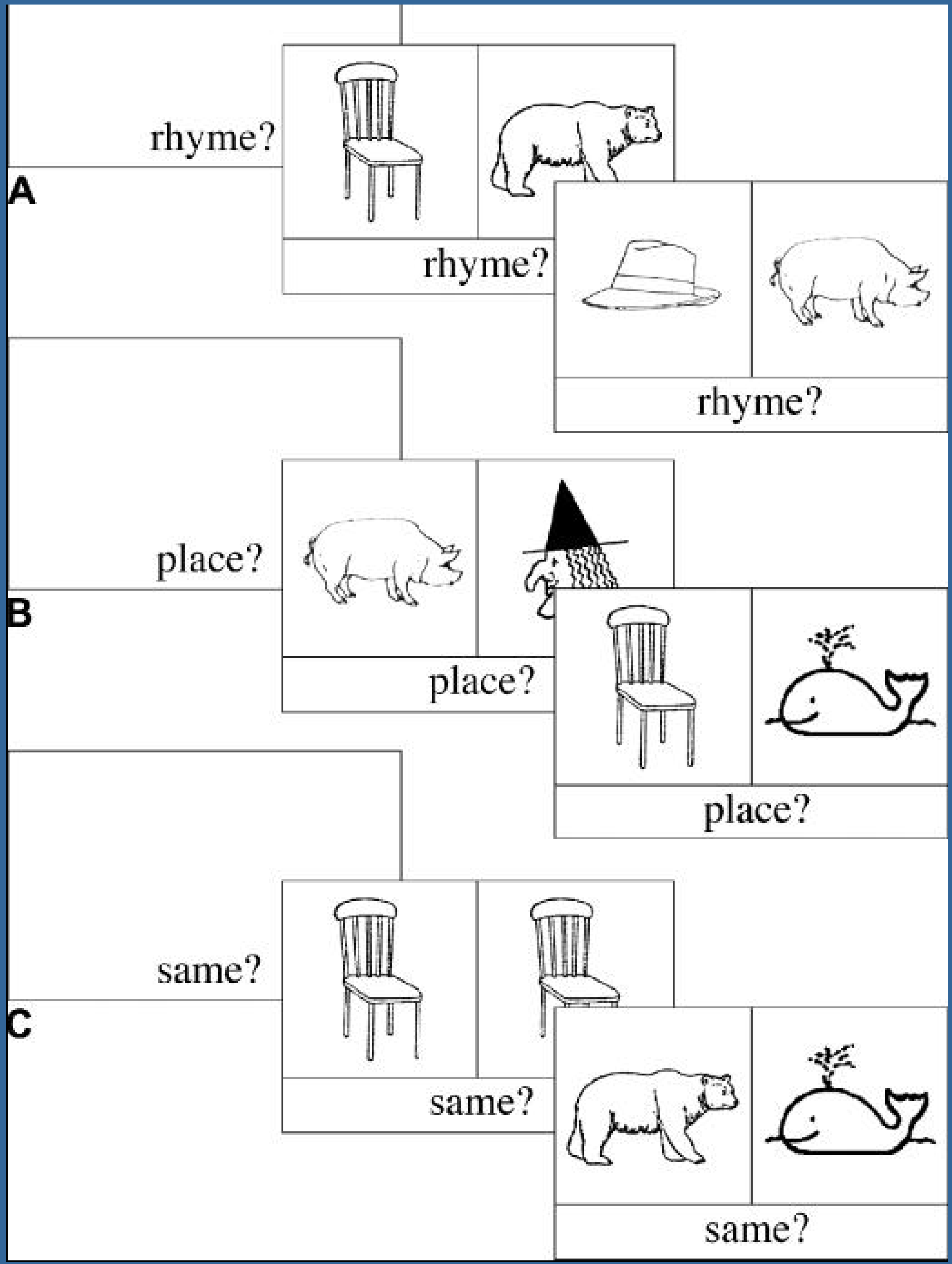
BSL and English experience

- 12 native signers; 8 with hearing parents.
- 18/20 deaf participants attended oral schools
- 5/8 non-native signers learned BSL after leaving secondary school
- 1/8 learned BSL at a Total Communication primary school aged 4-5
- 2/8 learned BSL at oral schools; one aged 4-5, the other aged 11 (These participants learned BSL from deaf classmates)

- In the English phonology task, hearing and deaf participants were required to decide whether the English labels for two pictures rhymed
- In the BSL phonology task, deaf participants were required to decide if the BSL labels for two pictures shared the same location
- In the control task, participants were required to decide if two pictures were the same

The tasks

- If similar processing is required to make phonological similarity judgments about BSL and English, similar brain areas should be recruited during both tasks

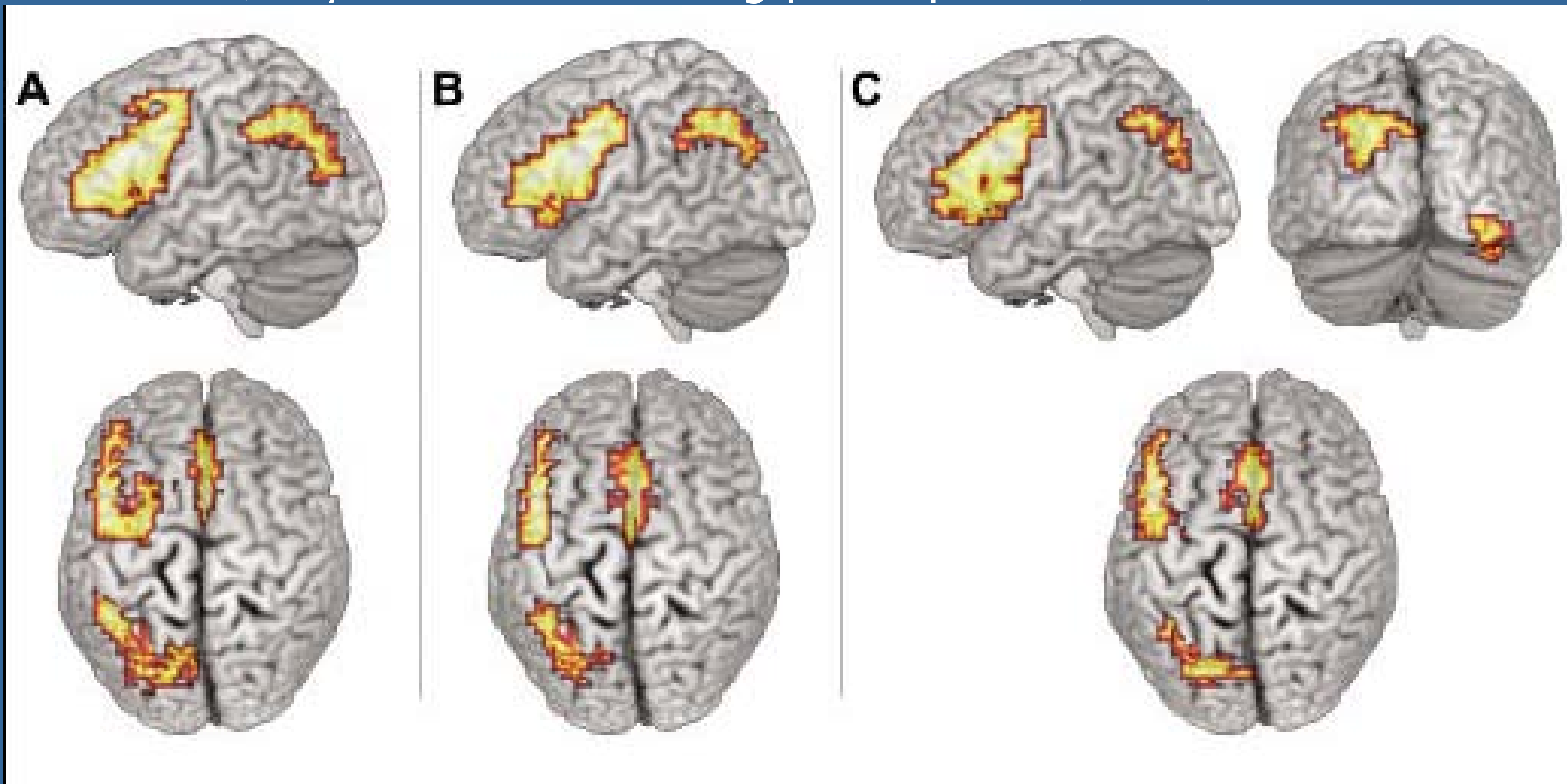

rhyme?
A
rhyme?
rhyme?
place?
B
place?
place?
same?
C
same?
same?

Results I

- a very similar neural network supports phonological similarity judgments in both English and British Sign Language (BSL)
- This phonological processing network is multimodal/supramodal
- It involves representations that in some way ‘transcend’ the sensory modalities

Activation relative to the ‘same picture?’ control task, during the:

A) location task in deaf participants (n=20);
B) rhyme task in deaf participants (n=20);
C) rhyme task in hearing participants (n=24).



A network consisting of the medial portion of the superior frontal gyrus (SFG), the left superior parietal lobule (SPL) incorporating the superior portion of the supramarginal gyrus (SMG), and, most extensively, the left posterior inferior frontal gyrus (IFG)

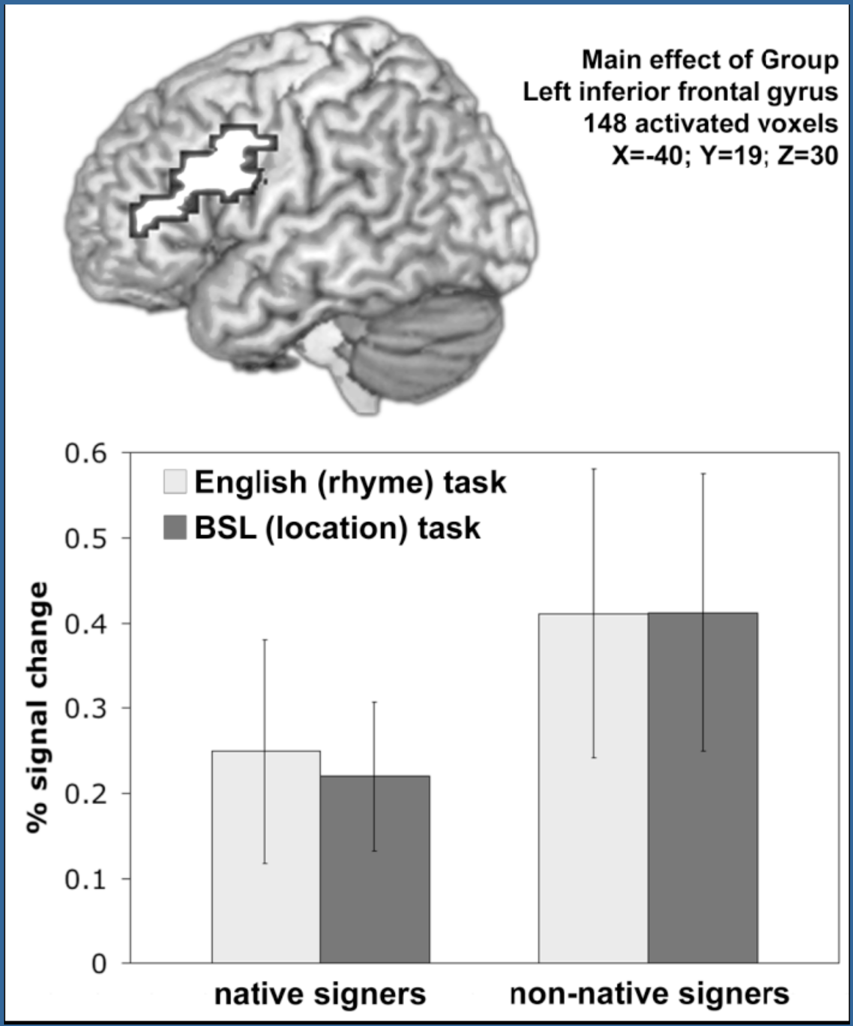
Results II

- Consistent with prior research on semantic and syntactic processing, showing that modality has relatively little influence on the neural systems that support language
- This is very striking in the context of phonological processing since awareness of phonology appears to be more directly linked to sensory input, which differs for sign and speech

Comparing native and non-native signers

- Non-native signers engaged the left inferior frontal gyrus to a greater extent than native signers. Critically this was the case during both the location and rhyme tasks
- Non-native signers recruited the left posterior IFG/precentral gyrus to a similar degree during both rhyme and location tasks
- Native signers engaged this region more during the rhyme task, performed in English which was learned late, than the location task performed in their native language

Non-native signers require greater effort on both rhyme and location tasks



The impact of age of first language acquisition

- Native and non-native signers' brains differed in both the BSL and in the English task
- Limited exposure to a fully accessible language early in life has implications for the neural systems supporting not only that language, but also for languages learned subsequently, whether signed or spoken

Are there reliable indicators (neural, cognitive, behavioural) of individual differences in the ability to benefit from auditory prostheses?

- When auditory cortex is not activated by acoustic stimulation, it can nevertheless be activated by silent speech in the form of speechreading
- Mid-posterior superior temporal regions, potentially including some parts of 'primary auditory cortex' are activated by silent speechreading in prelingually deaf people who have not had experience of heard speech

Auditory/acoustic approaches

- Current practice in speech training pre- and post-CI in children emphasises acoustic processing
- In 'auditory-verbal' training the child's acoustic skills are trained by reducing (hiding) the visibility of oral actions (e.g. Chan et al, 2000; Rhoades & Chisholm, 2001)
- One reason advanced for early implantation is that this makes it less likely that auditory cortex of the deaf child will be “colonized” by visual inputs (Lee et al, 2007)

Cross-modal activation and CI

- It has been suggested that visual-to-auditory cross-modal plasticity is an important factor limiting hearing ability in non-proficient CI users (Lee et al, 2001, Champoux et al, 2009)
- However, as we have seen, cross-modal activation is found in hearing as well as deaf people

- A neurological hypothesis is being advanced which suggests that the deaf child should not watch speech or use sign language, since this may adversely affect the sensitivity of auditory cortical regions to acoustic activation following cochlear implantation

- Such advice may not be warranted if speechreading activates auditory regions irrespective of hearing status and if such activation may be relatively specific to such stimulation

Audio-visual language processing with cochlear implants

- CI subjects present a higher visuo-auditory gain than that observed in normally hearing subjects in conditions of noise
- This suggests that people with CI have developed specific skills in visuo-auditory interaction leading to an optimisation of the integration of visual temporal cueing with sound in the absence of fine temporal spectral information

Rouget et al, 2007

Speechreading

- gives access to spoken language structure by eye, and, at the segmental level, can complement auditory processing. This does not need to be taught or learned explicitly, since infants are highly sensitive to seen speech (Campbell, 2007)
- has the potential to impact positively on the development of auditory speech processing following cochlear implantation

Speechreading

- is strongly implicated in general speech processing (Bergeson et al, 2005) and in literacy development in both hearing and deaf children (Kyle & Campbell, in press)
- capabilities interact with prosthetically enhanced acoustic speech processing skills to predict speech processing outcomes for cochlear implantees (Rouger et al, 2007)
- continues to play an important role in segmental speech processing post-implant (Rouger et al, 2008)

Take-home points: speechreading

- It is highly probable that superior temporal regions of the deaf brain, once tuned to visible speech, can then more readily adapt to perceiving speech multimodally
- This notion should inform preparation and intervention strategies for cochlear implantation in deaf children

Take-home points: sign language

- Age of acquisition of a first language impacts on brain development
- The importance of early exposure to an accessible language for those born profoundly deaf cannot be overstated
- Early learning of a sign language leads to the normal establishment of language systems (e.g. phonology) that can then be used to facilitate the learning of spoken language

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