The neural basis of sign language processing

Mairéad MacSweeney

UCL Institute of Cognitive Neuroscience *and*
ESRC Deafness, Cognition and Language (DCAL) Research Centre

What do we know about neural basis of speech processing?

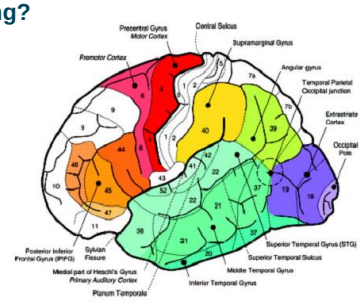


Image from Demonet et al., 2005

Many left hemisphere regions involved, in addition to so called 'Broca's' & 'Wernicke's' areas of the classical model

What do we know about neural basis of speech processing?

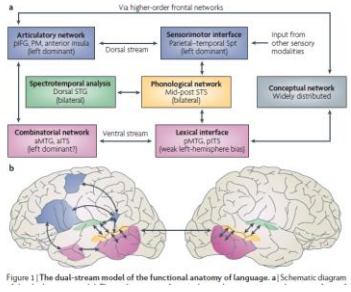


Figure 1 | The dual-stream model of the functional anatomy of language. a | Schematic diagram

From Hickok and Poeppel, 2007

Left hemisphere dominant for language in majority of people, but right hemisphere involved too ..

What do we know about neural basis of speech processing?

Medline search: brain AND speech = 15,603 papers

UCL

What do we know about neural basis of speech processing?

Medline search: brain AND speech = 15,603 papers

What do we know about neural basis of sign language processing?

Medline search: brain AND sign language = 362 papers

UCL

Do signed & spoken languages engage the same brain networks?

It depends on ….

… what you compare sign language *with*:	… **and who you test:**
auditory speech	stroke patients
audio-visual speech	deaf native signers (~10% pop.)
silent speechreading	deaf non-native signers (~90% pop.)
reading	hearing native signers
	hearing late signers
	hearing non-signers

UCL

Do signed & spoken languages engage the same brain networks?

It depends on ….

… what you compare sign language *with*:	… **and who you test:**
auditory speech	stroke patients
audio-visual speech	*But, predominantly late learners of SL*
silent speechreading	
reading	

UCL

Left hemisphere damage = sign aphasia

- evidence of impaired comprehension and production (depending on region)

- better on classifiers ('gestural') than prepositions ('linguistic')

Right hemisphere damage ≠ sign aphasia

- no evidence of impairment on standard language tests

- impaired processing of locatives (prepositions and classifiers). Due to visuo-spatial impairments?

- impaired on processing non-manual negation. Suggests may be prosodic.

(Atkinson et al., 2004; 2005; Marshall et al., 2003; 2005Hickok et al., 1996; Poizner et al., 1987)

UCL

Do signed & spoken languages engage the same brain networks?

It depends on ….

… what you compare sign language *with*:

auditory speech
audio-visual speech
silent speechreading
reading

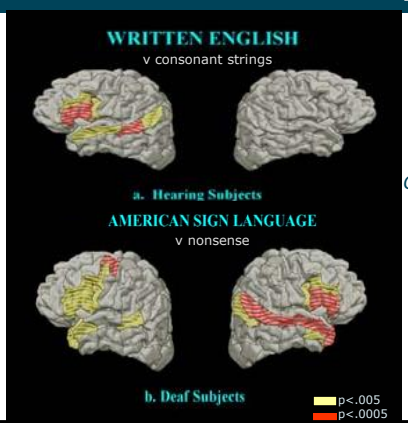
… **and who you test:**

stroke patients
deaf native signers (~10% pop.)
deaf non-native signers (~90% pop.)
hearing native signers
hearing late signers
hearing non-signers

UCL

Neville et al., 1998

UCL



Comparing like with like?

Neville et al., 1998

UCL

Do signed & spoken languages engage the same brain networks?

It depends on ….

… what you compare sign language *with*:

auditory speech
audio-visual speech
silent speechreading
reading

… **and who you test:**

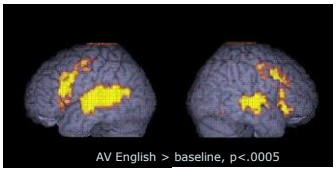
stroke patients
deaf native signers (~10% pop.)
deaf non-native signers (~90% pop.)
hearing native signers
hearing late signers
hearing non-signers

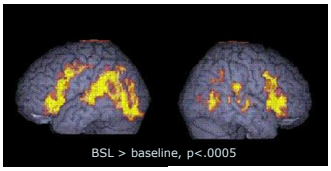
UCL

10 hearing speakers

Baseline: static image + target detection

9 deaf native signers



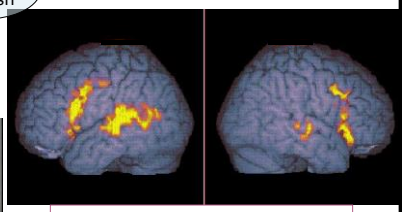


(MacSweeney et al., 2002)

UCL

10 hearing speakers

9 deaf native signers

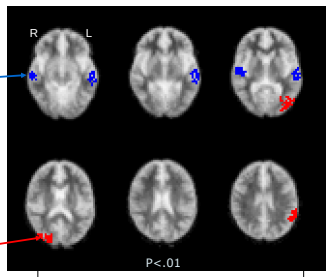


Activation common to both AV English & BSL (p<.0005)

UCL

10 hearing speakers

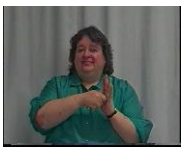
9 deaf native signers

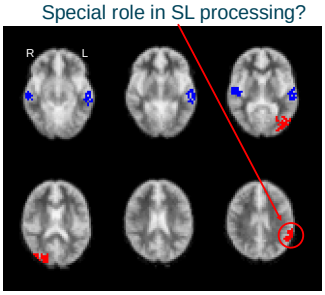


Differences reflect processing requirements of different input modalities

UCL

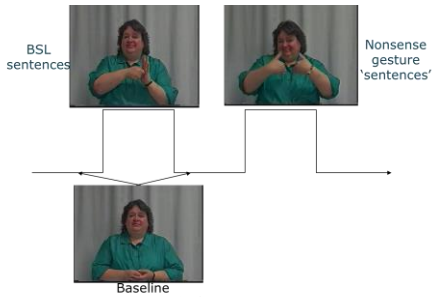
Special role in SL processing?





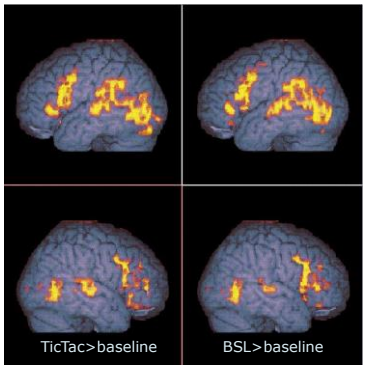
UCL

Contrasts *within* SL and compare to spoken language literature



(MacSweeney et al., NeuroImage, 2004)

UCL



Deaf native signers

UCL

BSL >nonsense

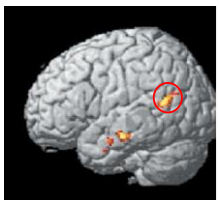
(MacSweeney et al., NeuroImage, 2004)

UCL

BSL >nonsense

(MacSweeney et al., NeuroImage, 2004)

Spoken English >nonsense



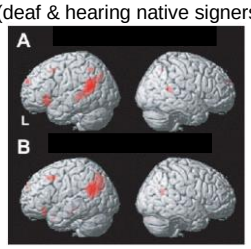
(Narain et al., Cerebral Cortex, 2003)

UCL

Sakai et al., Brain, 2005

Japanese SL sentence comprehension > nonsense

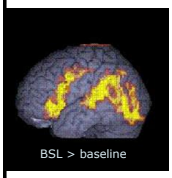
(deaf & hearing native signers)

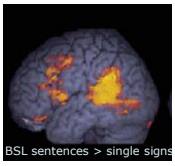


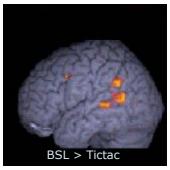
Japanese auditory sentence comprehension > nonsense

(hearing non-signers)

UCL

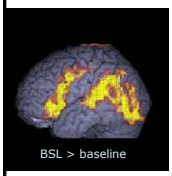

BSL > baseline

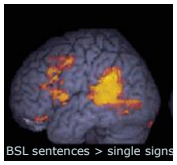

BSL sentences > single signs

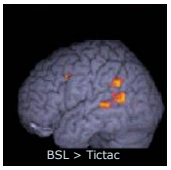

BSL > Tictac

A left-lateralised language network is recruited during syntactic & semantic processing, regardless of language modality.

UCL


BSL > baseline


BSL sentences > single signs

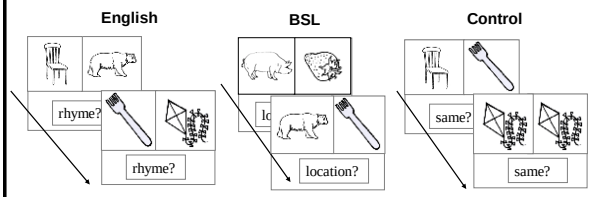

BSL > Tictac

A left-lateralised language network is recruited during sentence processing, regardless of language modality.

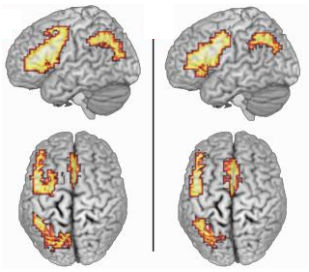
What about a metalinguistic task at the level 'closest' to sensory input - phonology?

PHONOLOGICAL AWARENESS TASK

UCL



PHONOLOGICAL AWARENESS TASK

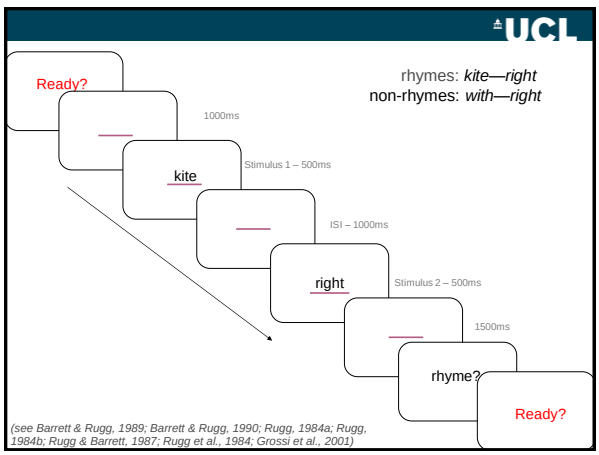


BSL English

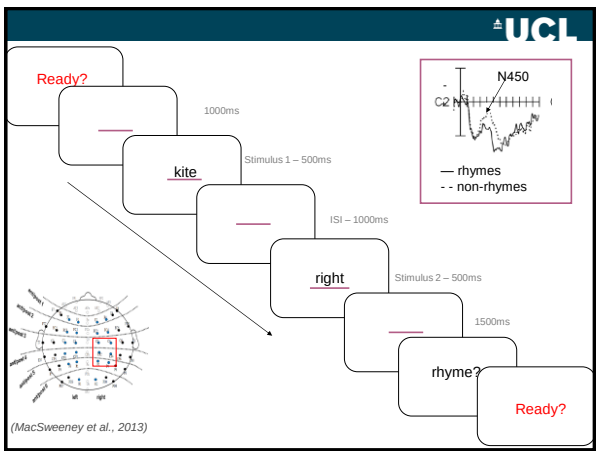
Very similar networks recruited, regardless of language

MacSweeney et al., Brain, 2008

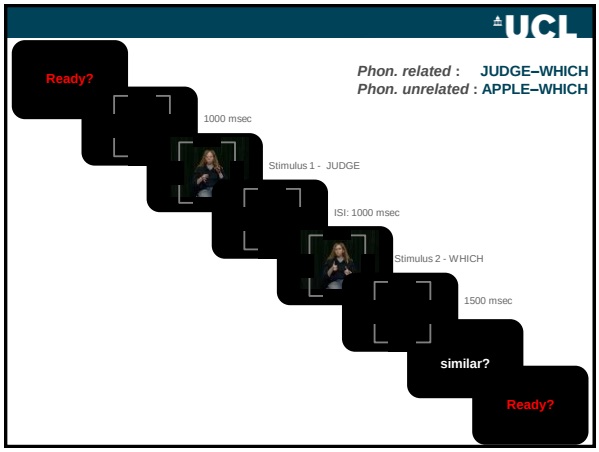
Timing of sign and speech phonological processing is also similar

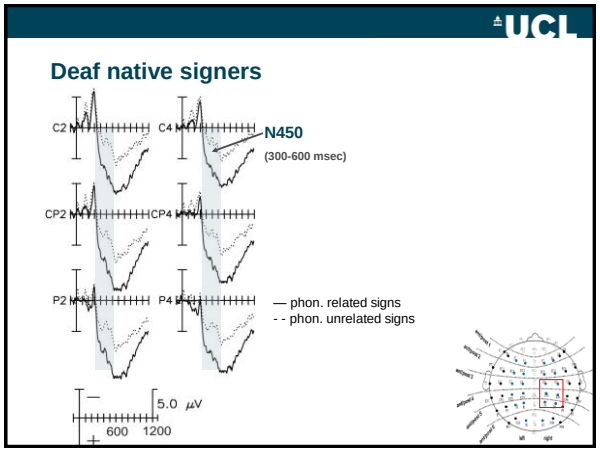


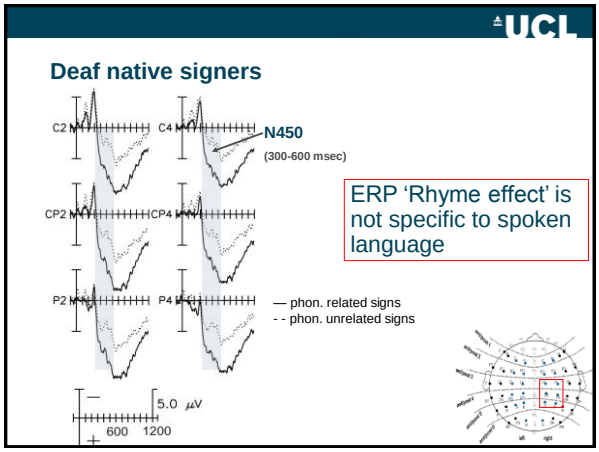
(see Barrett & Rugg, 1989; Barrett & Rugg, 1990; Rugg, 1984a; Rugg, 1984b; Rugg & Barrett, 1987; Rugg et al., 1984; Grossi et al., 2001)

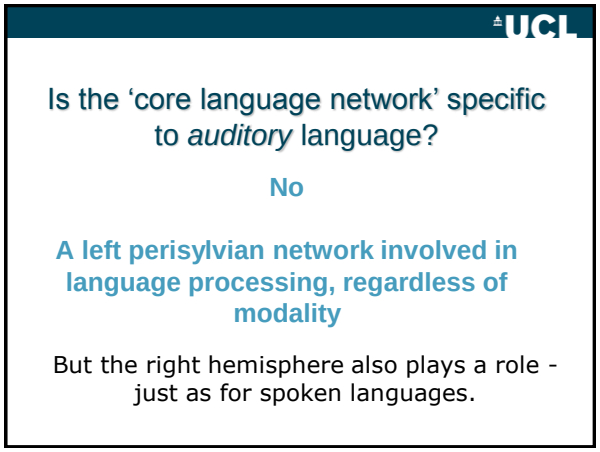


(MacSweeney et al., 2013)


UCL
Ready?
Phon. related : JUDGE–WHICH
Phon. unrelated : APPLE–WHICH
1000 msec
Stimulus 1 - JUDGE
ISI: 1000 msec
Stimulus 2 - WHICH
1500 msec
similar?
Ready?


UCL
Deaf native signers
C2
C4
N450
(300-600 msec)
CP2
CP4
P2
P4
— phon. related signs
- - phon. unrelated signs
5.0 μV
600
1200


UCL
Deaf native signers
C2
C4
N450
(300-600 msec)
ERP 'Rhyme effect' is not specific to spoken language
CP2
CP4
P2
P4
— phon. related signs
- - phon. unrelated signs
5.0 μV
600
1200

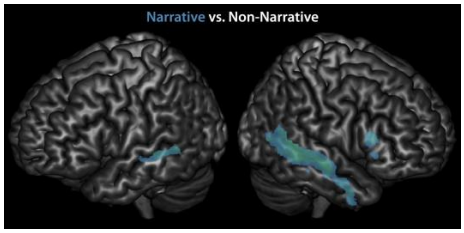

UCL
Is the 'core language network' specific to *auditory* language?
No
A left perisylvian network involved in language processing, regardless of modality
But the right hemisphere also plays a role - just as for spoken languages.

UCL

Contrast of 'narrative' and 'non-narrative' ASL sentences

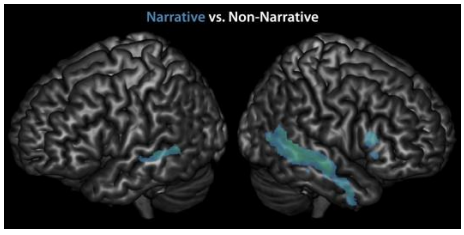
Newman et al., Neuroimage 2010; Newman et al., PNAS, 2011

UCL



Newman et al., Neuroimage 2010; Newman et al., PNAS, 2011

UCL



Same contrast in audio-visual speech (with co-speech gesture) in hearing speakers ??

UCL

Do signed languages recruit the same neural systems as spoken languages?

Very similar…..but are not identical

sign ≠ speech

1. Differential engagement of sensory cortices
2. sign uses different articulators than speech (see - Capek et al., JOCN, 2008; Emmorey et al., 2007)
3. sign uses the face differently to speech (see Atkinson et al., Neuropsychologia, 2004)
4. Space can be used 'linguistically' in sign languages

UCL

A special role for parietal cortex in sign language processing?

(more than spoken language)

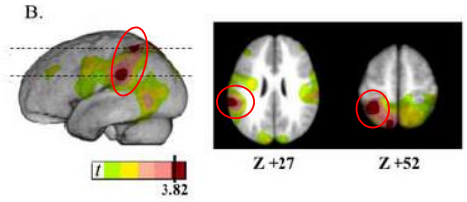
- stimulation of left inferior parietal lobe causes phonological production errors (Corina et al., 1999)

- greater left superior parietal lobe activation for memory for signs than words (Ronnberg et al., 2004)

UCL

Sign production uses different articulators than speech

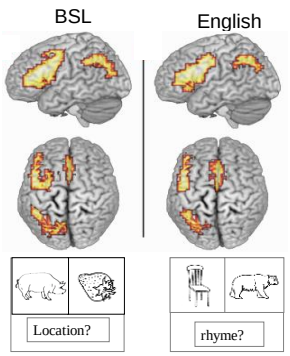
Picture naming by hearing native signers
sign > speech



from Emmorey, Grabowski et al 2007

UCL

PHONOLOGICAL AWARENESS TASK

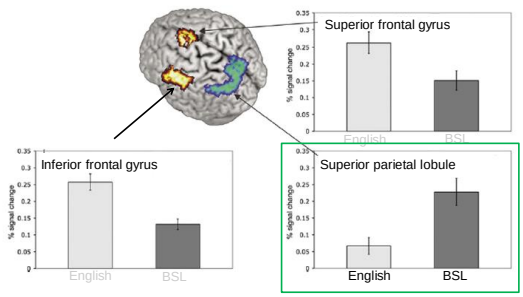


Very similar networks recruited, regardless of language

… but not identical

MAIN EFFECT OF TASK: English V BSL

UCL



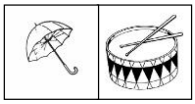
Growing evidence for a greater role of left parietal lobe in signed than spoken language processing

see Corina and Knapp, 2006; 2010; Emmorey, 2006; MacSweeney et al., 2008

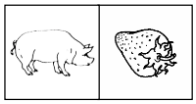
UCL

Influence of sign phonological parameter on sign phonological judgments?

phonological task

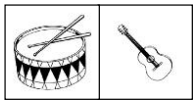


handshape?

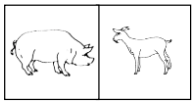


location?

semantic task



related?

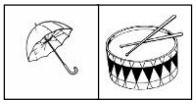


related?

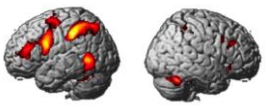
UCL

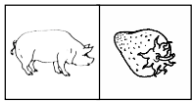
Very little ….

phonology > semantics

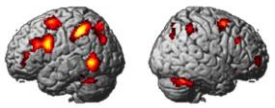


handshape?





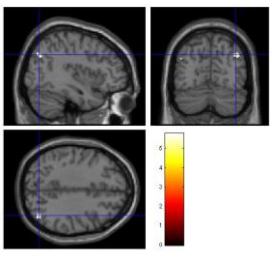
location?



UCL

…. Only in right superior parietal lobe

Location > handshape



UCL

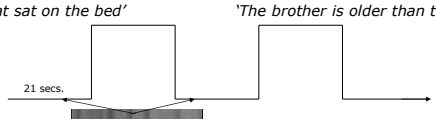
The use of space in BSL

Topographic BSL sentences

'The cat sat on the bed'

Non-topographic BSL sentences

'The brother is older than the sister'

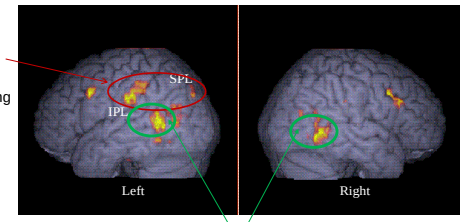


Baseline

UCL

Topographic > non-topographic

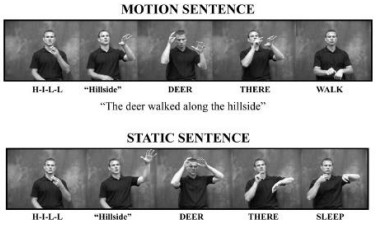
Parietal lobe – spatial processing



V5/ MT - motion processing

(MacSweeney et al., 2002)

UCL



- McCullough et al., 2012

UCL

locative classifier > motion classifier (perception)

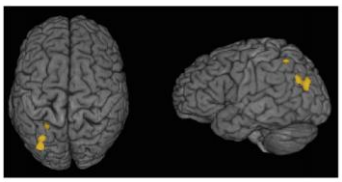
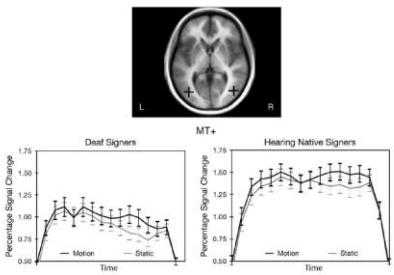


Fig. 3. The clusters in orange are shown on a high resolution TT_N27 human brain atlas and represent brain regions activated for static, locative sentences in contrast to motion sentences, $p = .001$ (corrected). Activation up to 25 mm beneath the surface of the cortex is displayed.

- McCullough et al., 2012

UCL

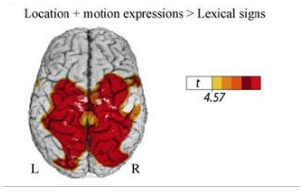
Motion classifier > locative classifier (perception)



- McCullough et al., 2012

UCL

Classifier production



Emmorey et al., 2013

UCL

What is the role of the inferior parietal lobe?

- known to play a role in perception, imagery of hand/ finger movements (see Rizzolatti & Craighero, 2004)
  - therefore likely to play role in all aspects of sign language processing, especially sign language phonology

What is the role of the superior parietal lobule?

- Proposed to be involved in proprioception (Emmorey et al., 2007). However, no direct evidence for this yet.

UCL

Conclusions

•A left-lateralised network is recruited during language processing, regardless of modality.

• In addition - right hemisphere involved in *both* sign and speech processing

• networks very similar, but non-identical.

• special role for left parietal lobe. Function not yet established

UCL

Conclusions

•A left-lateralised network is recruited during language processing, regardless of modality.

• In addition - right hemisphere involved in *both* sign and speech processing

• networks very similar, but non-identical.

• special role for left parietal lobe. Function not yet established

But does this inform theories of language processing or linguistic theory???

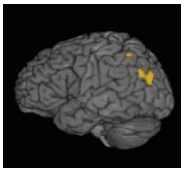
Saygin, et al., 2010 – audio-visual English sentences

static versus motion

The deer slept on the hillside

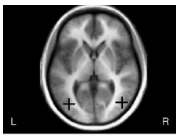
The deer walked up the hillside

parietal differences?



static > motion ASL sentences

MT differences?



Motion > static ASL sentences

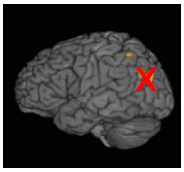
Saygin, et al., 2010 – audio-visual English sentences

static versus motion

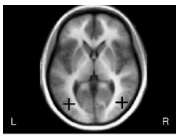
The deer slept on the hillside

The deer walked up the hillside

parietal differences?



MT differences?



Yes

A cautionary note .. .. ..

Is there an influence of age of sign language acquisition?

It depends on who is tested ..

….

hearing native signers

hearing non-native signers

deaf native signers (~10% pop.)

deaf non-native signers (~90% pop.)

UCL

Is there an influence of age of sign language acquisition?

It depends on who is tested .. .

hearing native signers

hearing non-native signers

Newman et al., 2002 'A critical period for right hemisphere recruitment for ASL'
- right parietal lobe – native > non-native

- But, language backgrounds of hearing and deaf late signers are very different.

Not replicated with deaf native versus non-native signers.
(MacSweeney et al., 2008; Mayberry et al., 2011)

ACKNOWLEDGEMENTS

UCL

fMRI studies

University College London

Bencie Woll

Dafydd Waters

Ruth Campbell

Cathy Price

Cambridge University

Usha Goswami

Institute of Psychiatry, London

Mick Brammer

ERP studies

University of Oregon

Helen Neville

University of California, Davis

David Corina

Heather Patterson

Funding: Wellcome Trust, ESRC and National Academy of Education

UCL

UCL

Synthesis – take home messages

- there is a CORE language network that supports both signed and spoken language.
  - this resides in the left perisylvian cortex
- additional 'satellite' regions – both sensory and non-sensory – support sign and speech. Some influenced by modality, others not
- the 'goal' is different for different researchers
  - to use language to learn more about the brain?

  Or
  - to use the brain to learn more about language ?

UCL

Synthesis – questions

- does the brain care about linguistic versus non-linguistic divisions?

- can we actually test for 'amodal' language processing?

- what is the role of right hemisphere in language processing?
    - need 'parallel' studies in sign and speech