How do we perceive timbre?

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NIH National Institutes of Health

MRC Medical Research Council

Timbre Perception

1. A *sensory* framework for timbre in the brain
2. Mapping and modelling the *percept* called timbre
3. Timbre gone wrong: dystimbria

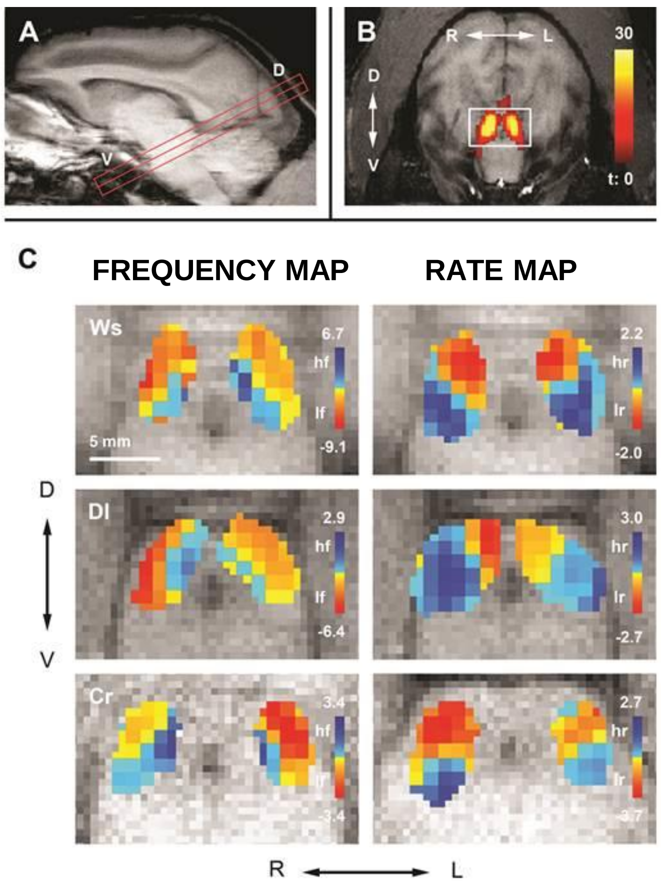
Sensation

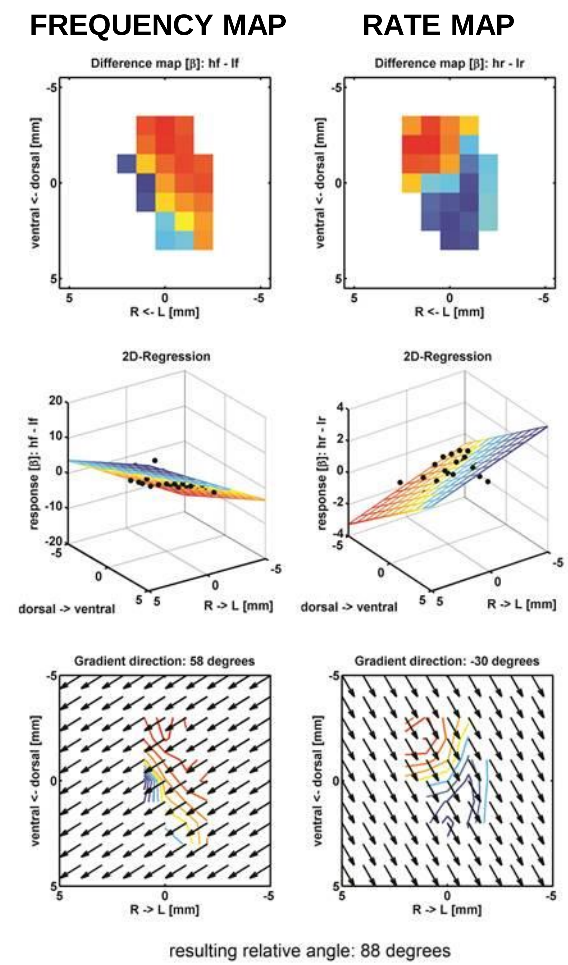
Sensation

1. Timbre is not pitch
2. Timbre is a percept and not a stimulus property
3. All syntheses agree that timbre has dimensions that correspond to time and frequency domain
4. How are sensory frequency and time-domain properties mapped in the brain?

Sensory mapping

Frequency/ time domain mapping in primate brainstem

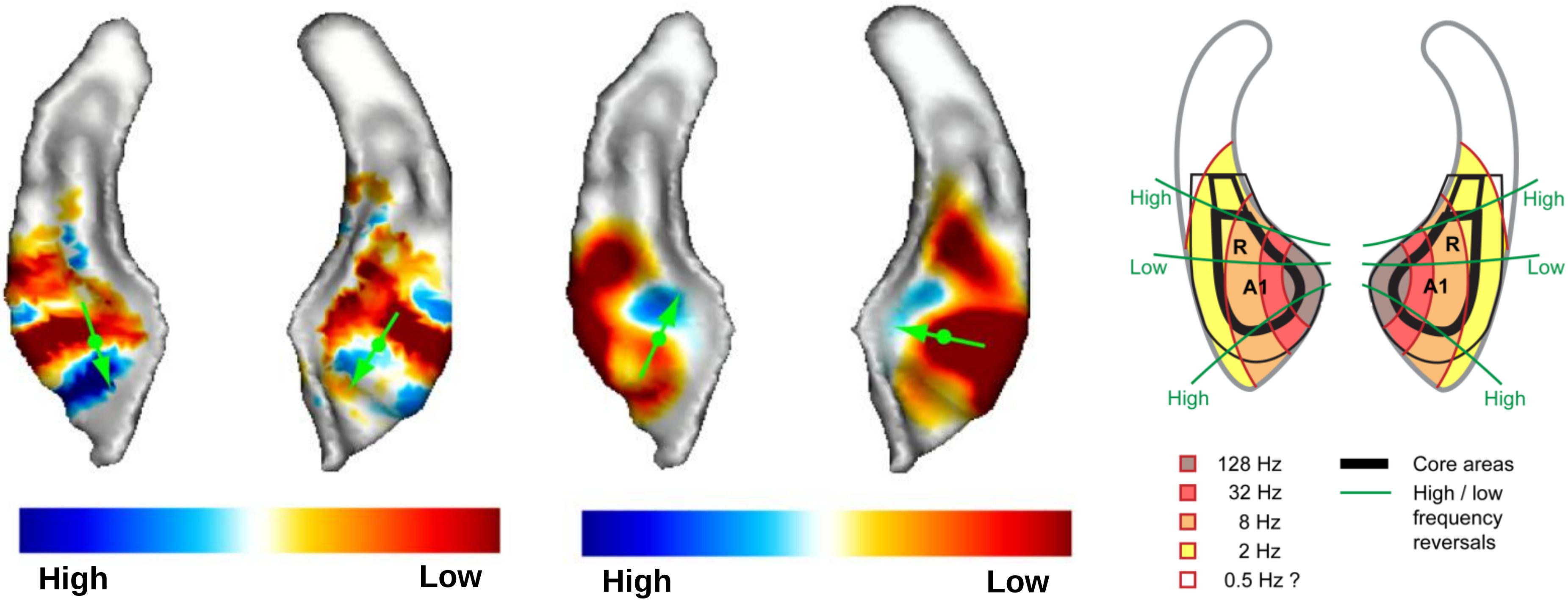




Baumann et al: Nature Neurosci (2011)

Sensory mapping

Frequency/ time domain mapping in primate cortex

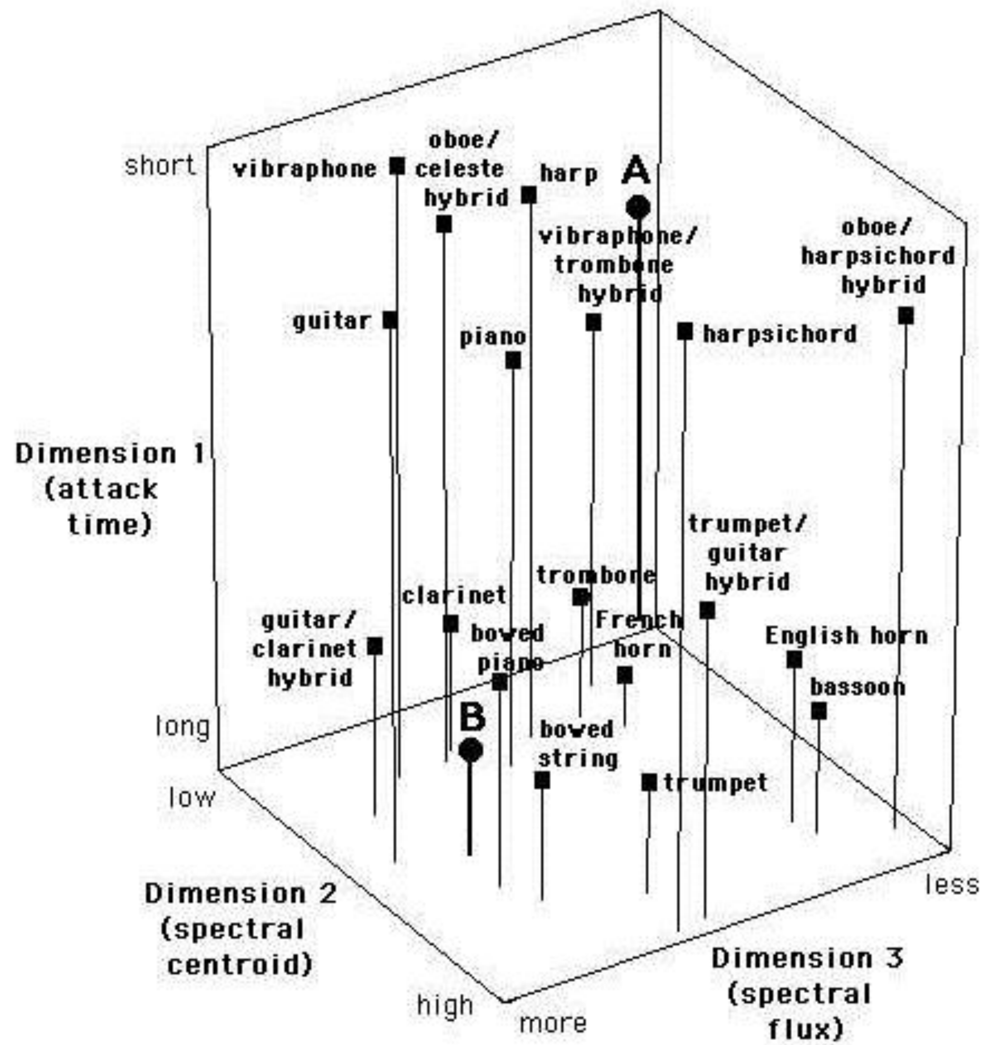


FREQUENCY MAP **RATE MAP** **SCHEMATIC**

Baumann et al: secondary review

Perception

Perception: timbral dimensions



McAdams and Cunible Phil Trans 1992

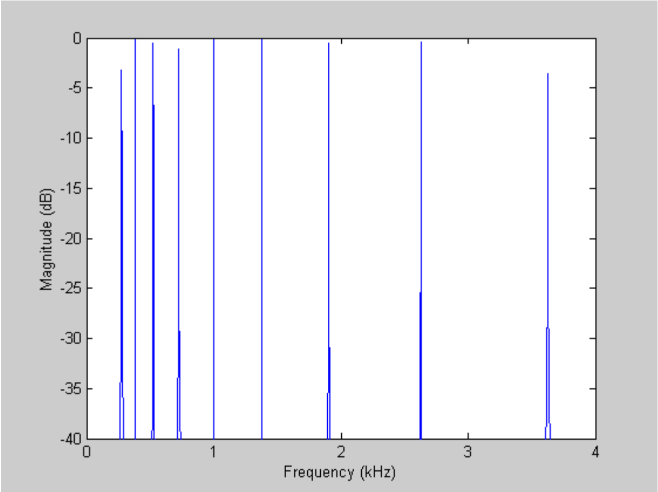
Dimension 1: spectral shape

- Profile Analysis experiments (David Green and others 1980s onwards)
- Alteration of single element in array of spectral components

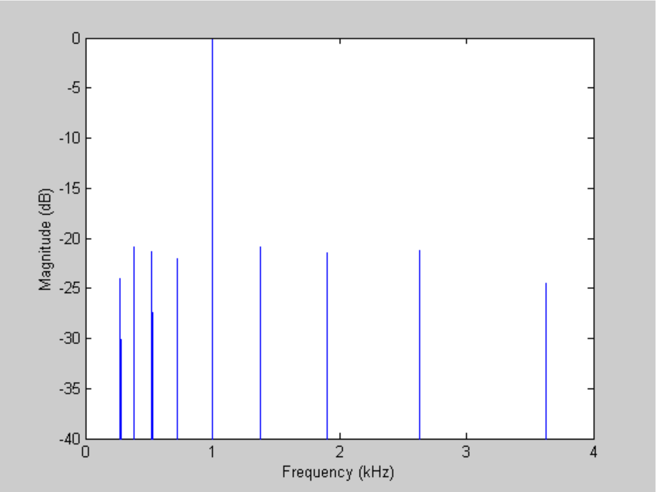
Profile Analysis

[hugely suprathreshold stimuli for illustration]

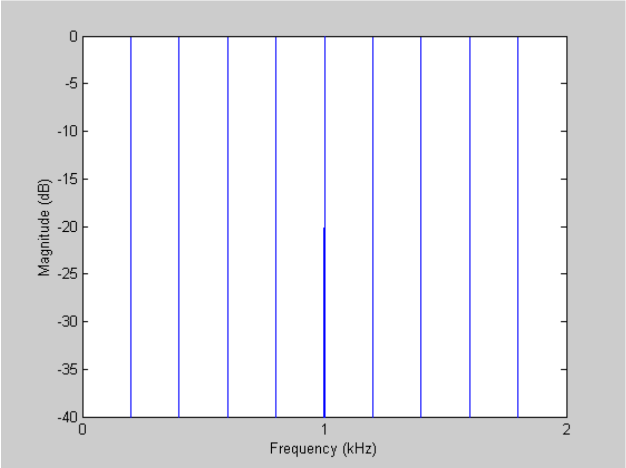
Log Spaced ref



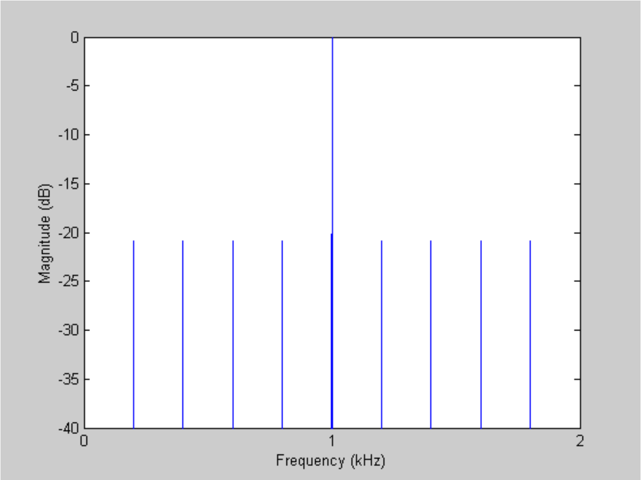
Log Spaced Target



Harmonic ref



Harmonic target



Dimension 1: spectral shape

- First profile analysis experiments used log spaced elements [equal distance on receptor surface] and roved overall level
  - $\Rightarrow$ With roving level you cannot do task by just using output from one peripheral channel or 'critical band'
  - $\Rightarrow$ Detectability improved by elements outside 'critical band'
  - $\Rightarrow$ Requires a central mechanism for 'profile analysis'
  - $\Rightarrow$ Detectability improves with number of components until there are several elements in each critical band when these interfere and it deteriorates

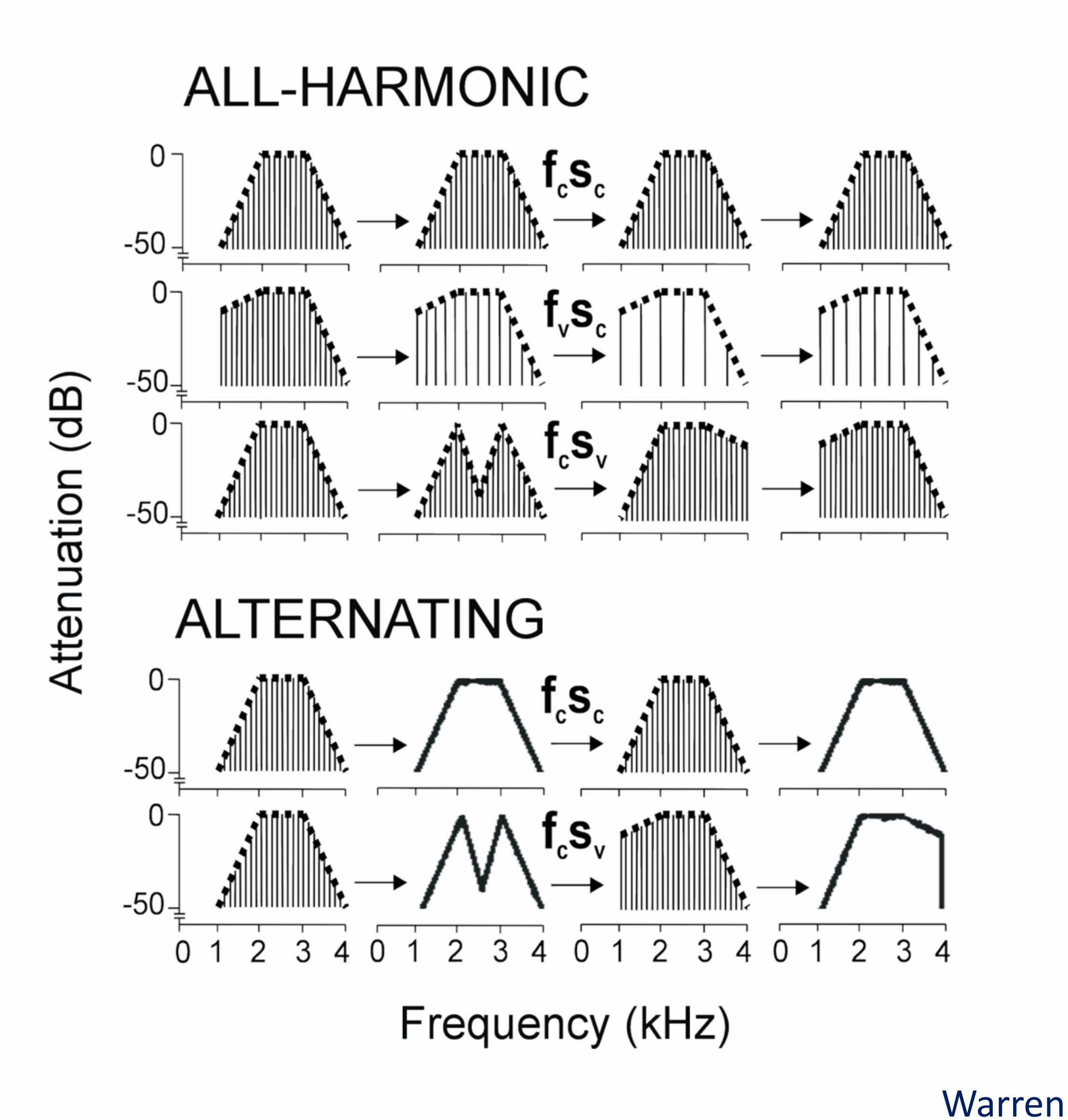
- Experiments with harmonic spaced elements
  - $\Rightarrow$ Similar mechanisms

Dimension 1: spectral shape

- Limitations profile analysis
  - Unnatural stimuli with change in single element
  - Huge amount of training required to produce performance in early Green studies (1000 trials before any data collected)

    Is this relevant to the object analysis that we all carry out continuously and effortlessly for novel stimuli?
  - Results only apply to harmonic stimuli

Dimension 1: imaging stimuli

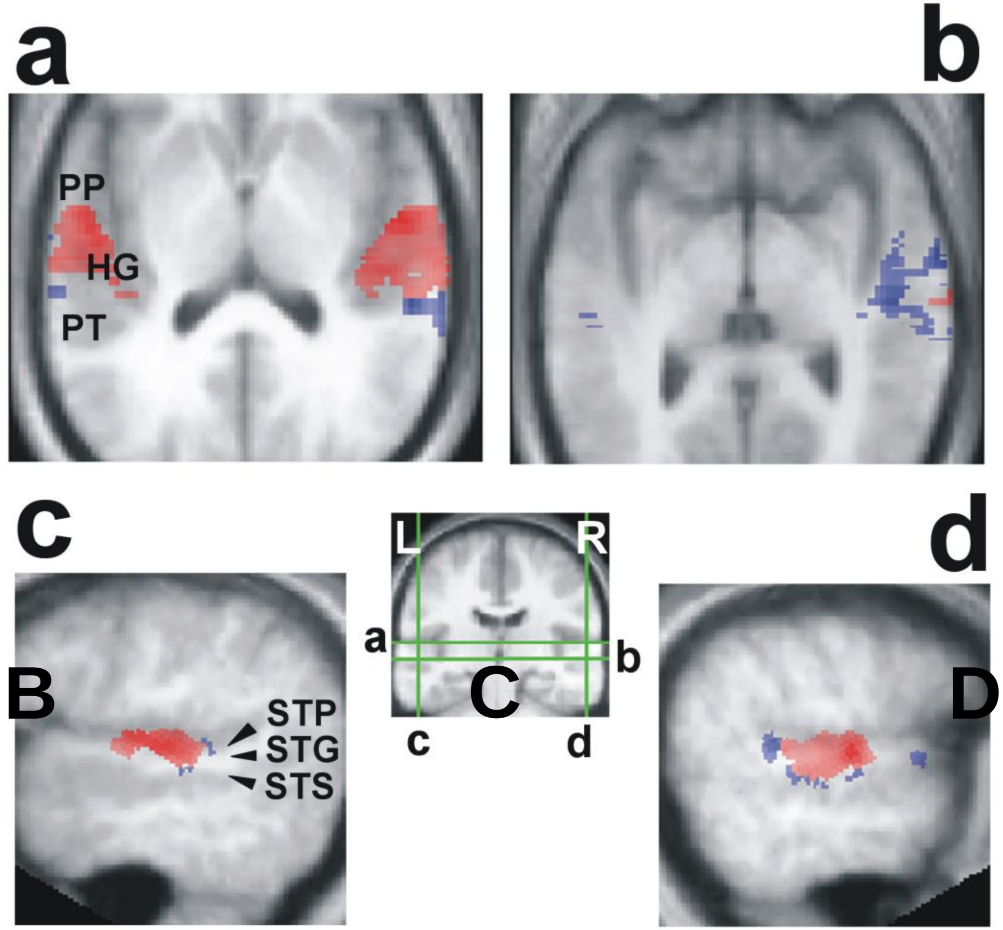


Warren et al Neuroimage 2005

Dimension 1: imaging

STP

STS



x = -52

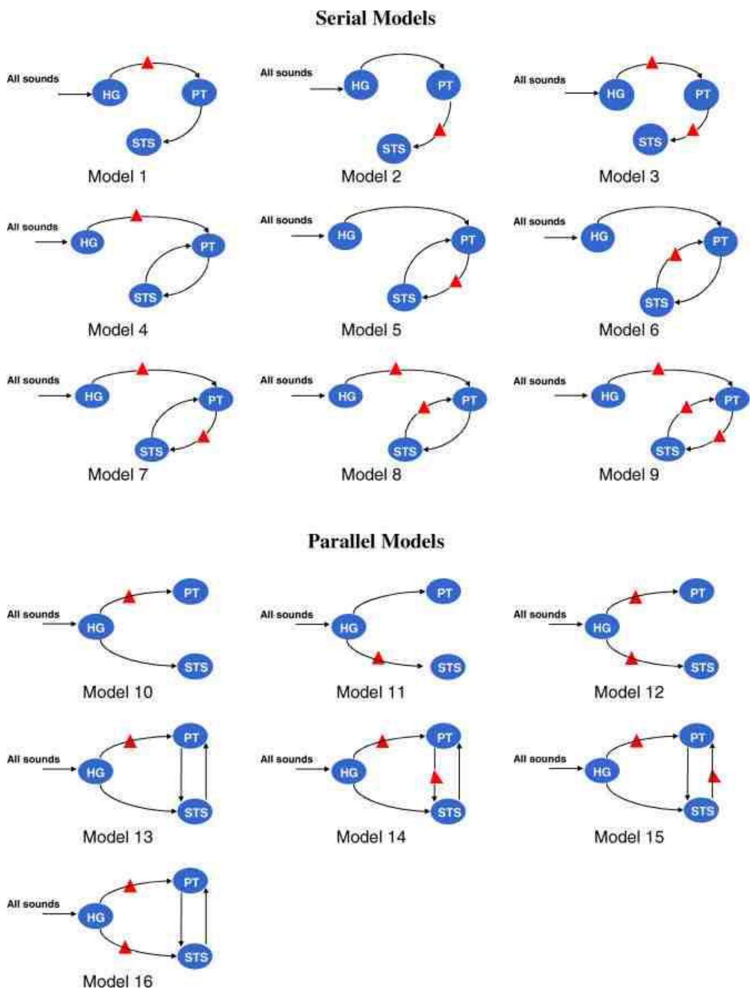
x = 54

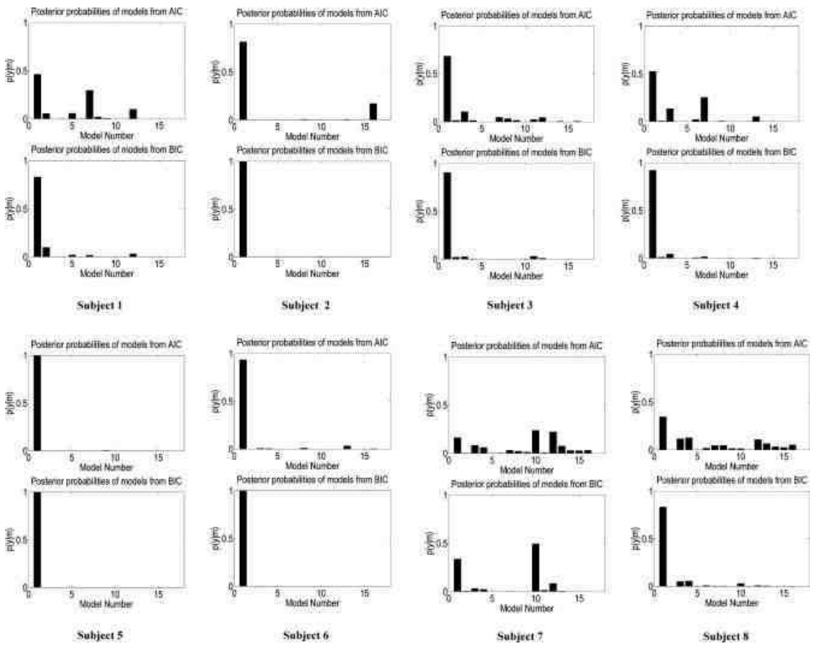
All harmonic: shape or pitch change

Alternating: shape change minus fixed shape

Warren et al Neuroimage 2005

Dimension 1: modelling



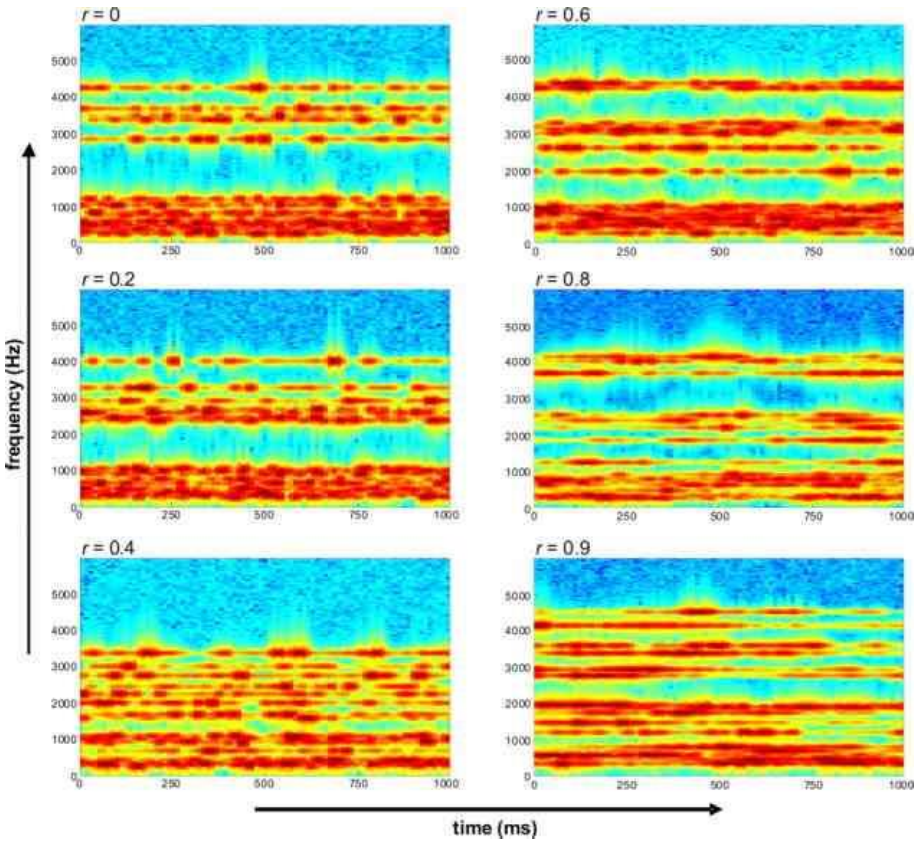


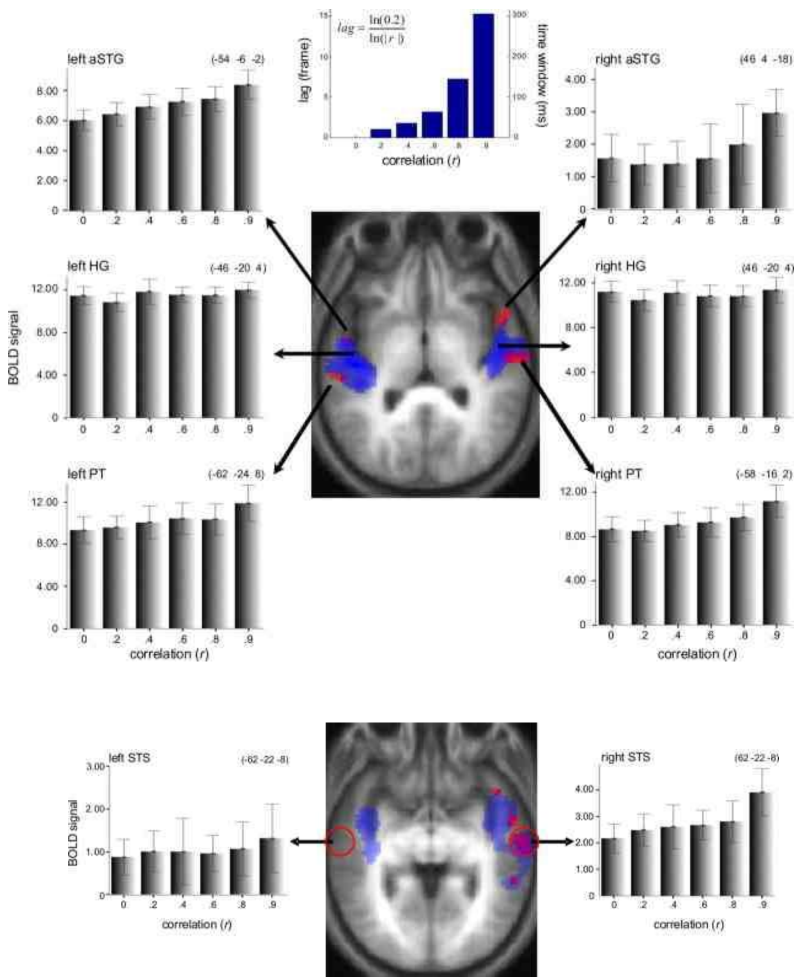
Kumar et al PLoS Comp Biol 2007

Dimension 1: spectral shape

- Psychophysics demonstrates a mechanism for spectral shape analysis that allows the abstraction of spectral shape
- Functional imaging suggests this intermediate level of processing is based on right-lateralised mechanisms between posterior STP and STS
- Modelling suggests a hierarchal mechanism

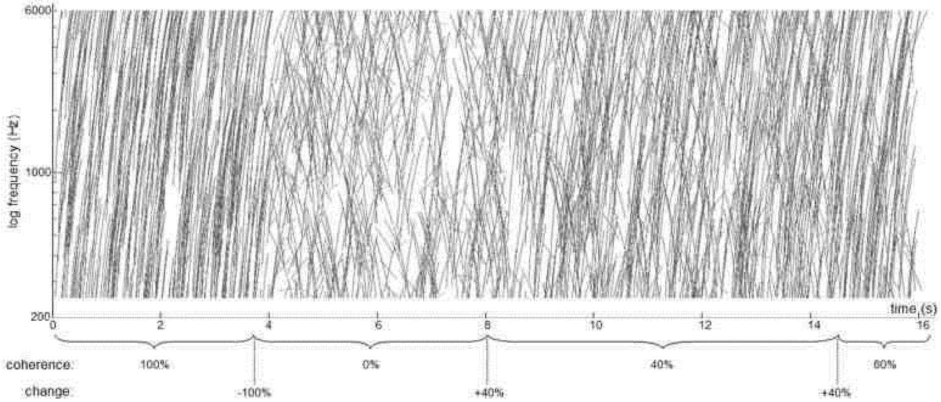
Dimension 2: spectral flux

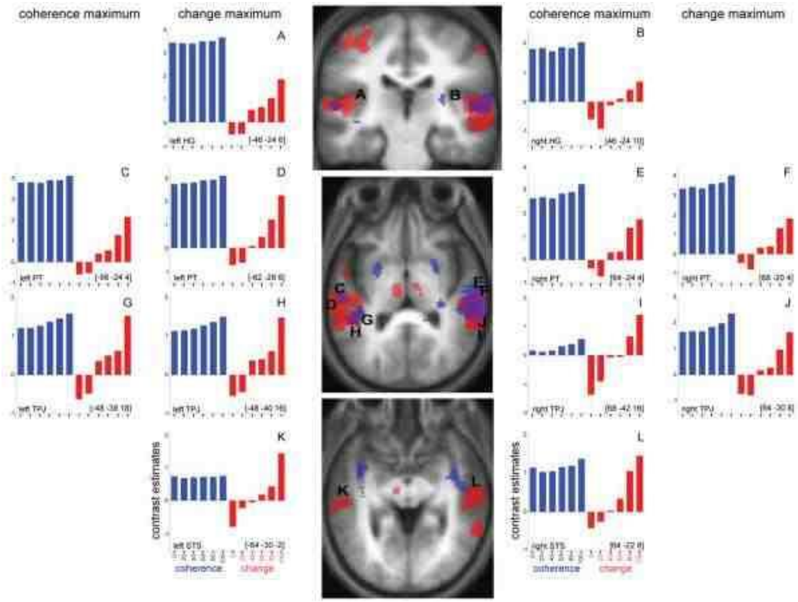




Overath et al J Neurosci 2008

Dimension 3: texture





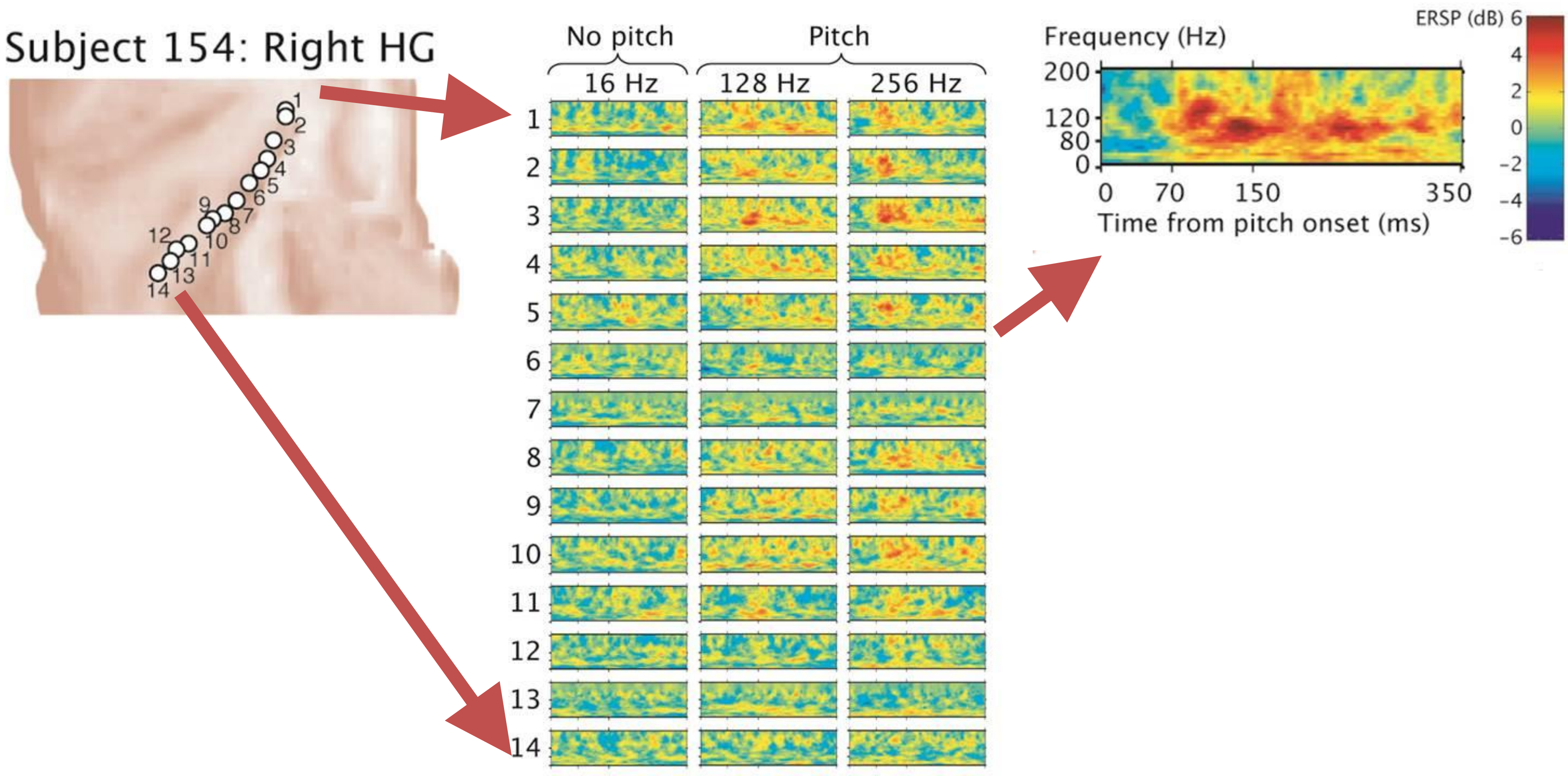
Overath et al J Neurosci 2010

Timbre perception

- Abstraction of timbral dimensions depends on mechanisms in human belt homologues in PT and right-lateralised mechanisms in human parabelt homologues in STS
- Functional imaging suggests this intermediate level of processing is based on right-lateralised mechanisms between posterior STP and STS
- Modelling suggests a hierarchal mechanism with serial processing from human core to belt to parabelt homologues

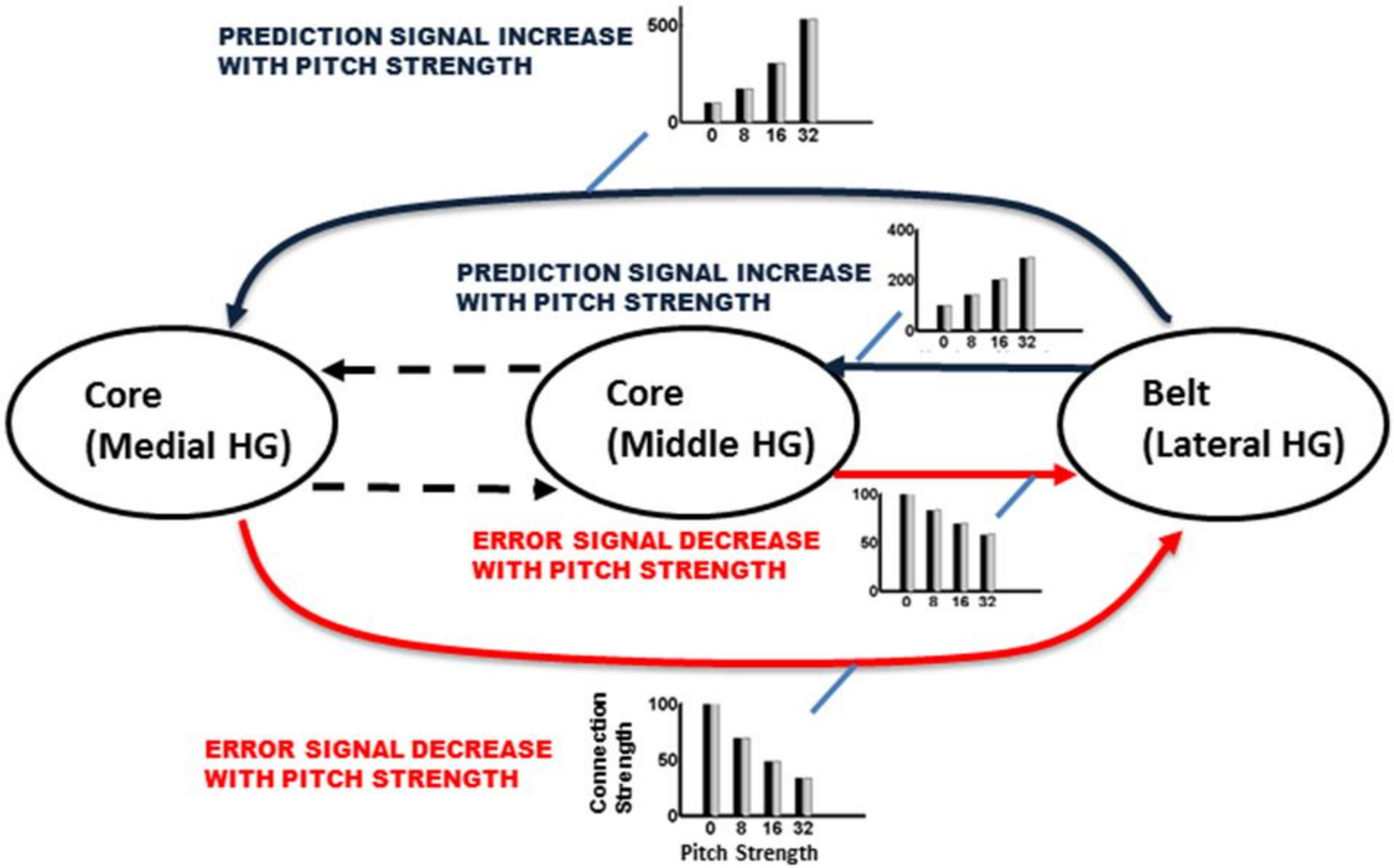
[A note on pitch models]

Human pitch neurophysiology



Griffiths et al: Current Biology 2010 (2 subjects)
Gander et al: submitted (6 subjects)

Human pitch modelling



Kumar et al: J Cogn Neurosci 2011

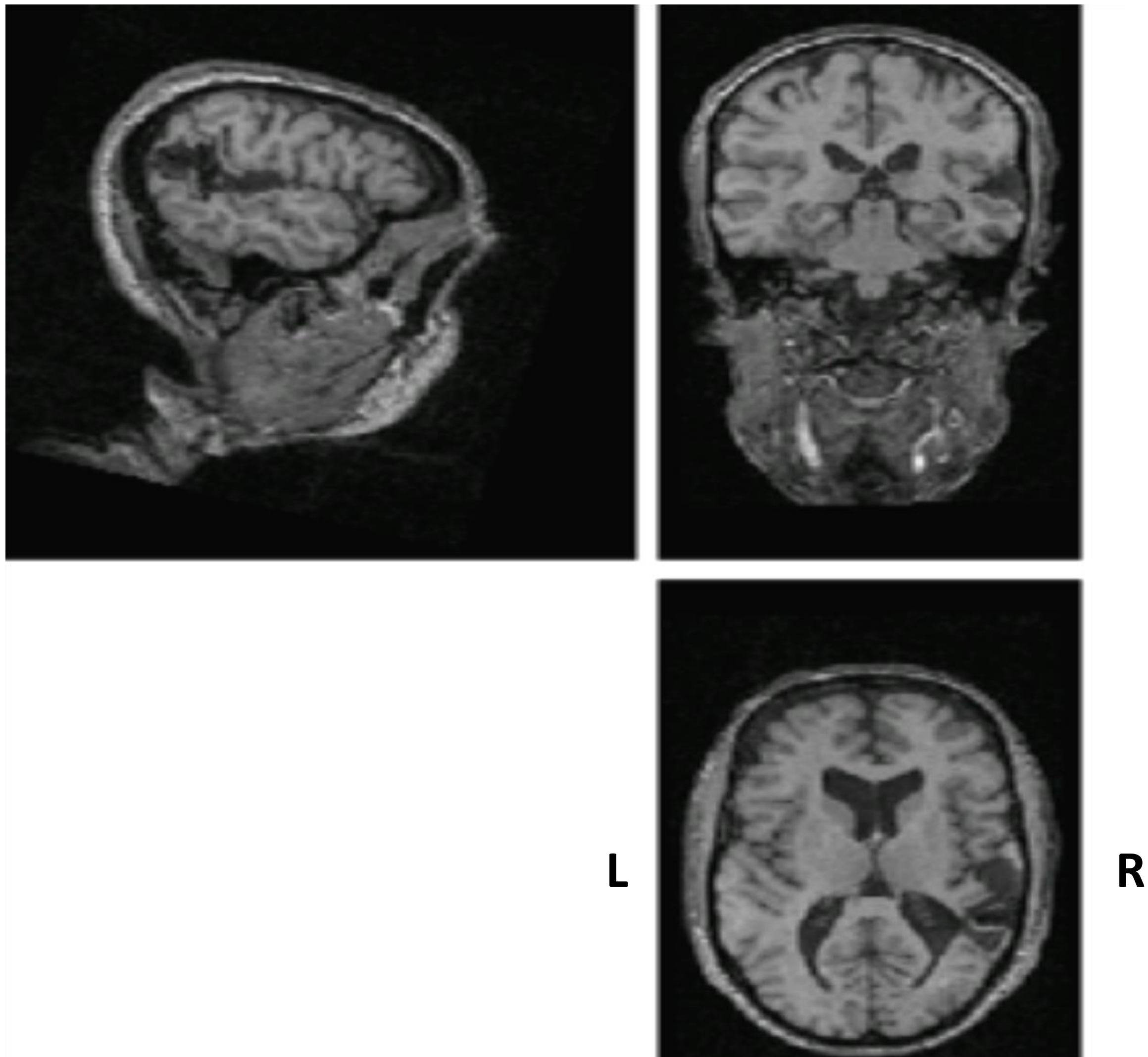
[A note on pitch models]

- Pitch modelling using high-precision neurophysiology data strongly supports constructive models of pitch perception especially predictive coding
- The modelling of timbre using BOLD data supported hierarchal mechanisms but did not show backward effective connectivity to support predictive coding models
- Ongoing work is examining timbre perception in neurophysiological datasets to test hypothesis that timbre perception also depends on predictive coding

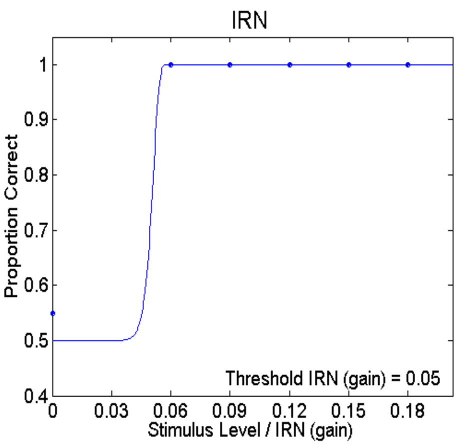
Disorder: Dystimbria

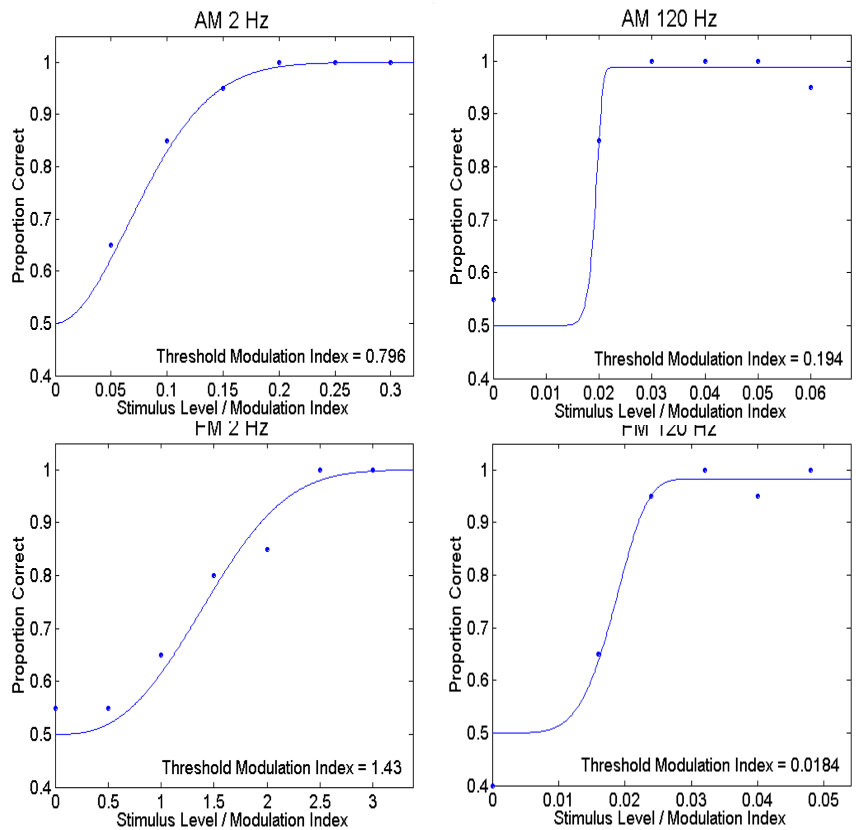
- Television producer with symptoms after right hemisphere stroke
  - No new deafness
  - Acquired amusia
  - Alteration in quality of musical and environmental sounds

Disorder: Dystimbria



Disorder: Dystimbria





Disorder: Dystimbria

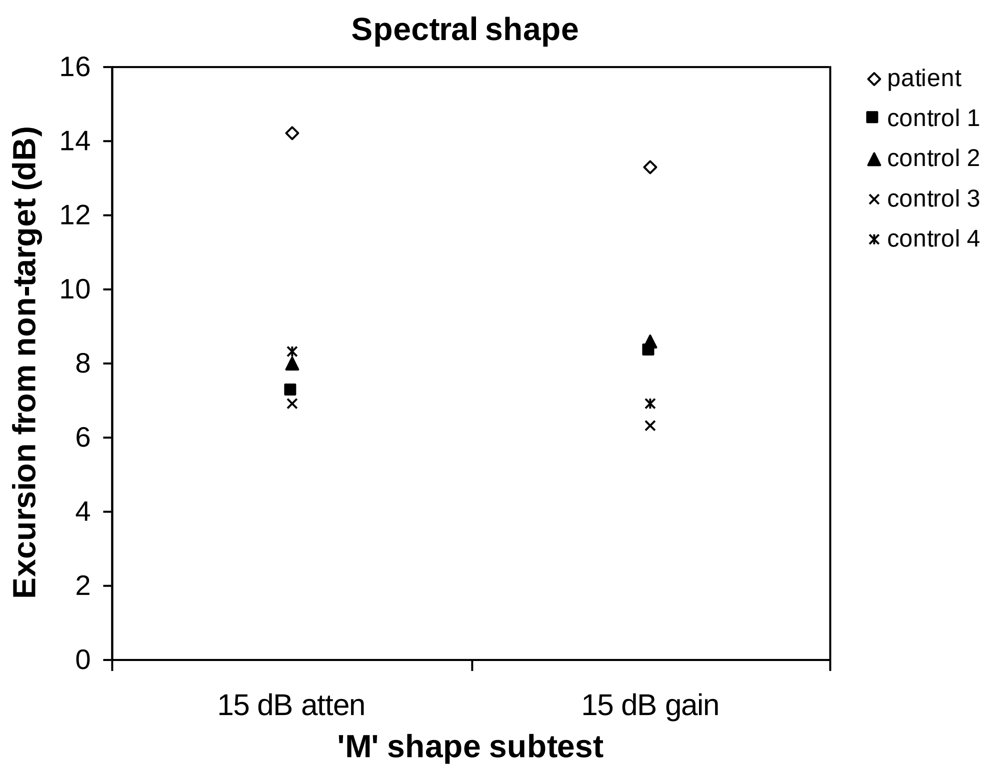
	NAB group mean		Patient DT	
Task	Threshold	S.D.	Threshold	Z score
*2 Hz FM**	*0.0136*	*0.183*	*0.154*	*0.7672*
120 Hz FM	0.0161	0.00758	0.0184	0.3034
*2 Hz AM**	*-1.02*	*0.264*	*-1.0991*	*-0.2996*
*120 Hz AM**	*-1.85*	*0.249*	*-1.7122*	*0.5534*
*IRN (gain)**	*-1.05*	*0.176*	*-1.2984*	*-1.4114*

** LOG transformed values*

Disorder: Dystimbria

	MBEA group mean		Patient DT	
Task	Score	S.D.	Score	Z score
Scale	27	2.3	20	-3.04
Contour	27	2.2	20	-3.18
Interval	26	2.4	17	-3.75
Rhythm	27	2.1	23	-1.9
Meter	26	2.9	18	-2.76
Memory	27	2.3	27	0
Average	27	1.6	21	-3.75

Disorder: Dystimbria



Detection change in ‘M’ shaped envelope applied
to harmonic series: 312AFC AXB design based on
three-down one-up adaptive track yields 79.4% Threshold

Disorder: Dystimbria

- Abnormal timbral perception that dissociates from other tests of complex sound analysis – normal detection pitch of individual sounds
- Structural imaging shows lesion that would disrupt timbral analysis in right superior temporal sulcus

Acknowledgements 1

- **Auditory group Newcastle**: Simon Baumann, Thomas Cope (now Cambridge University), Manon Grube, Amanda Jennings (now Industry), Olivier Joly (now Oxford University), Sukhbinder Kumar, Will Sedley
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Acknowledgements 2

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