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Auditory figure-ground segregation using a complex stochastic stimulus

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Outline

- Introduction
- Stimulus
- fMRI study
- Psychophysics
- Temporal coherence model

Auditory scene analysis

Auditory figure-ground segregation

Listeners' ability to extract a particular sound from a background of other simultaneous sounds

Processes:

i. grouping of simultaneous figure components from the spectral array,
ii. grouping of figure components over time,
iii. separation of grouped components from rest of the acoustic scene.

Mechanisms:

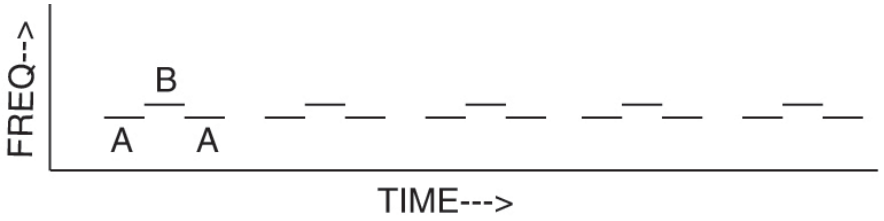
- Segregation is mediated by basic response properties of auditory cells: frequency selectivity, forward suppression and adaptation, resulting in the activation of distinct neuronal populations

Stimuli:

- Studied using relatively simple signals, which lack the rich spectrotemporal complexity of natural signals, e.g. streaming signals

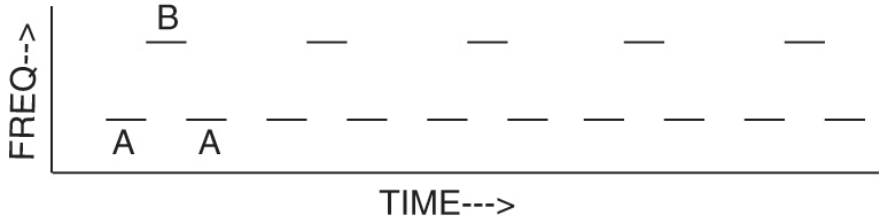
Streaming

ABA_…ABA_ or AB…AB



ΔF: 1 st

Integrated percept

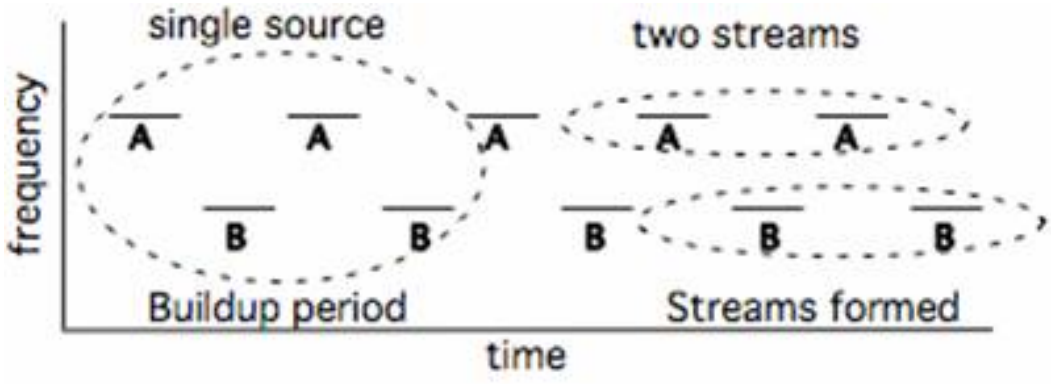


ΔF: 6 st

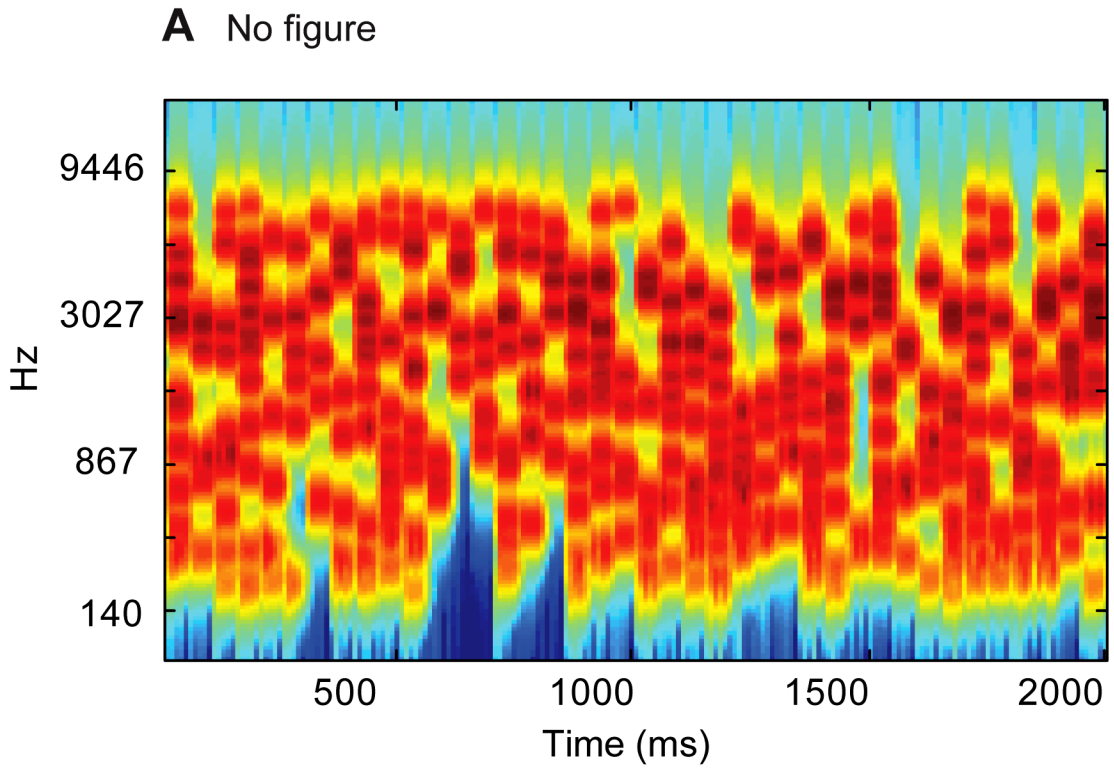
Ambiguous percept

ΔF: 9 st

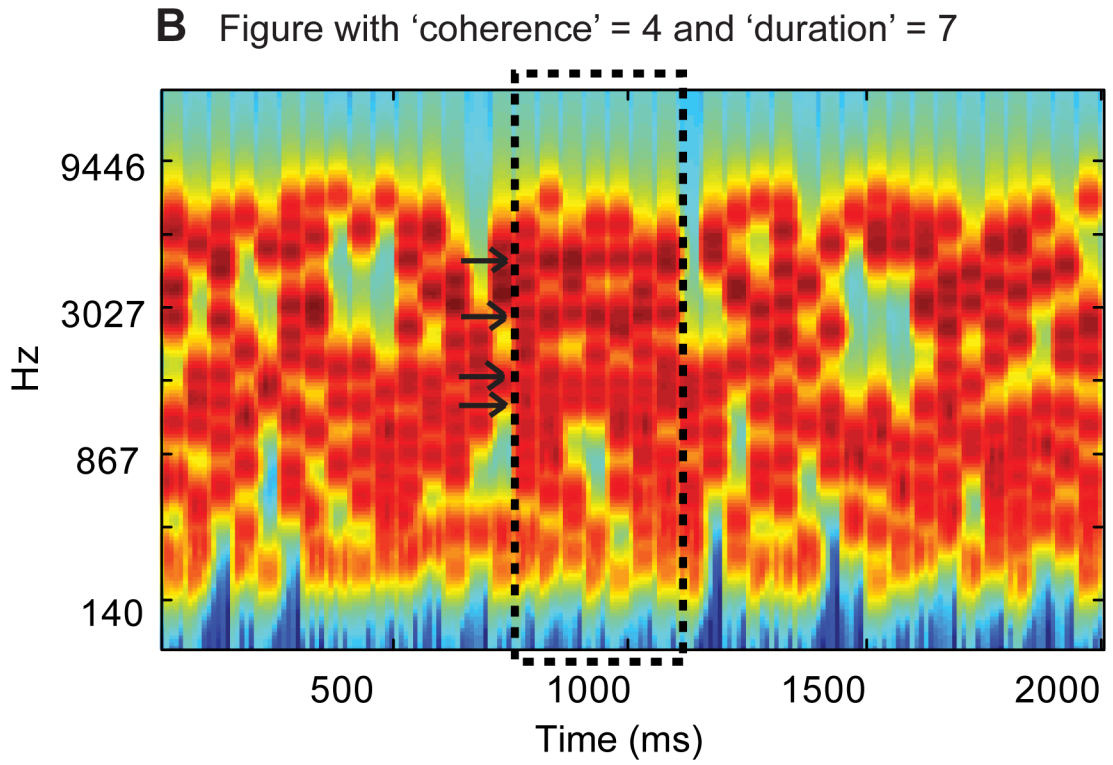
Segregated percept



Stochastic Figure-Ground stimulus



SFG: Figure present



SFG: Stimulus design

Stimulus:

Sequence of random chords consisting of pure tone components

Duration of each chord:	50 ms
Inter-chord interval:	0 ms
Total stimulus duration:	2000 ms (40 consecutive chords)

Chords:

No. of pure tone components:	5-15
Component frequency range:	179 – 7246 Hz
Cosine ramp:	10 ms for onset and offset

Coherence:

Number of different repeating frequencies : **1,2,4,6,8**

Duration:

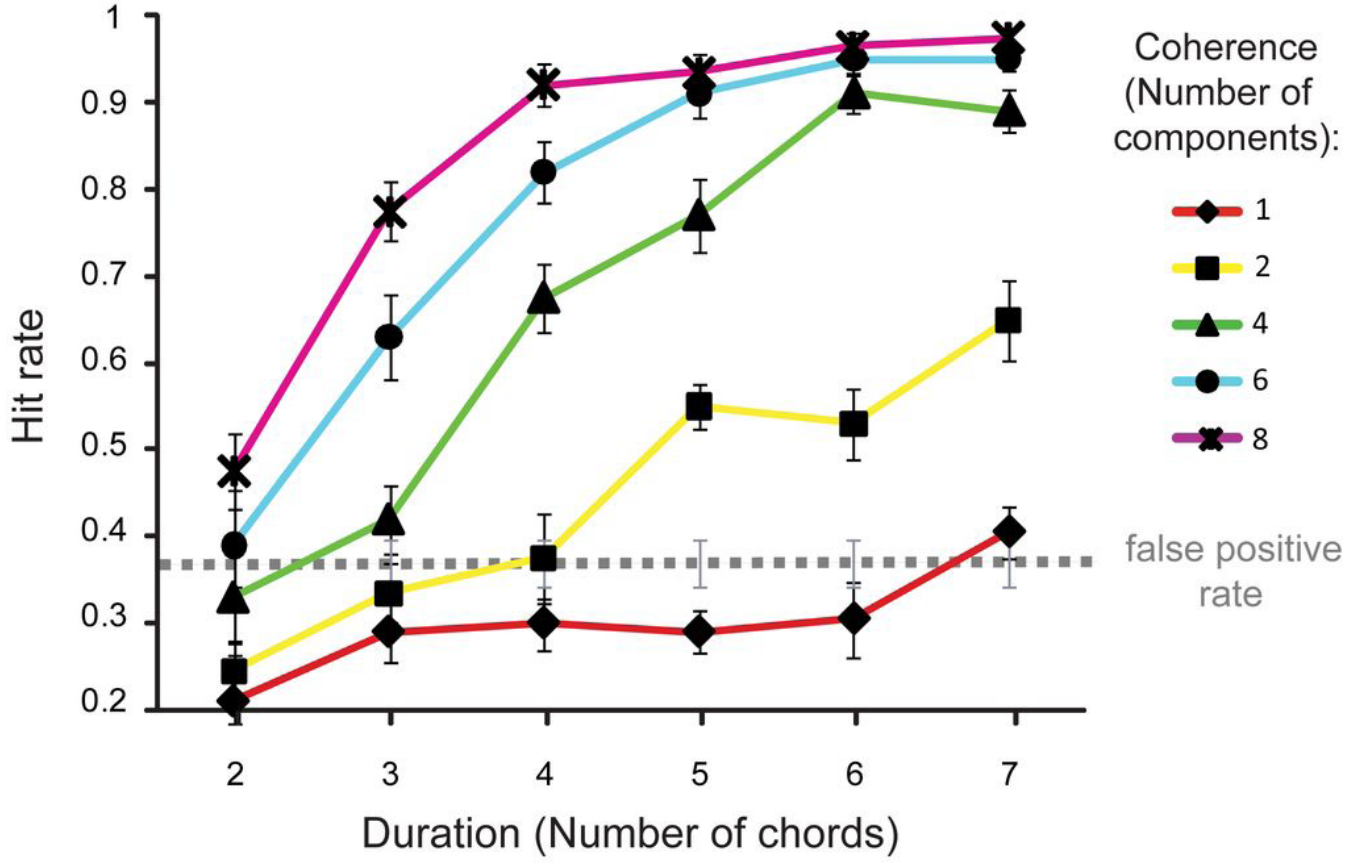
Number of chords over which frequencies repeat : **2-7**

SFG: Figure

Features of SFG:

- Figure and background signals do not differ in low-level acoustic attributes
- No spectral ‘protective’ region between figure and background
- Figure and background signals are indistinguishable at each point in time
- Figure can only be extracted by integrating over time and frequency
- Enables parametric variation of figure salience

Psychophysics (n = 10)



- Listeners are remarkably sensitive to the appearance of figures
- Sensitive to parametric variations of coherence and duration

fMRI study

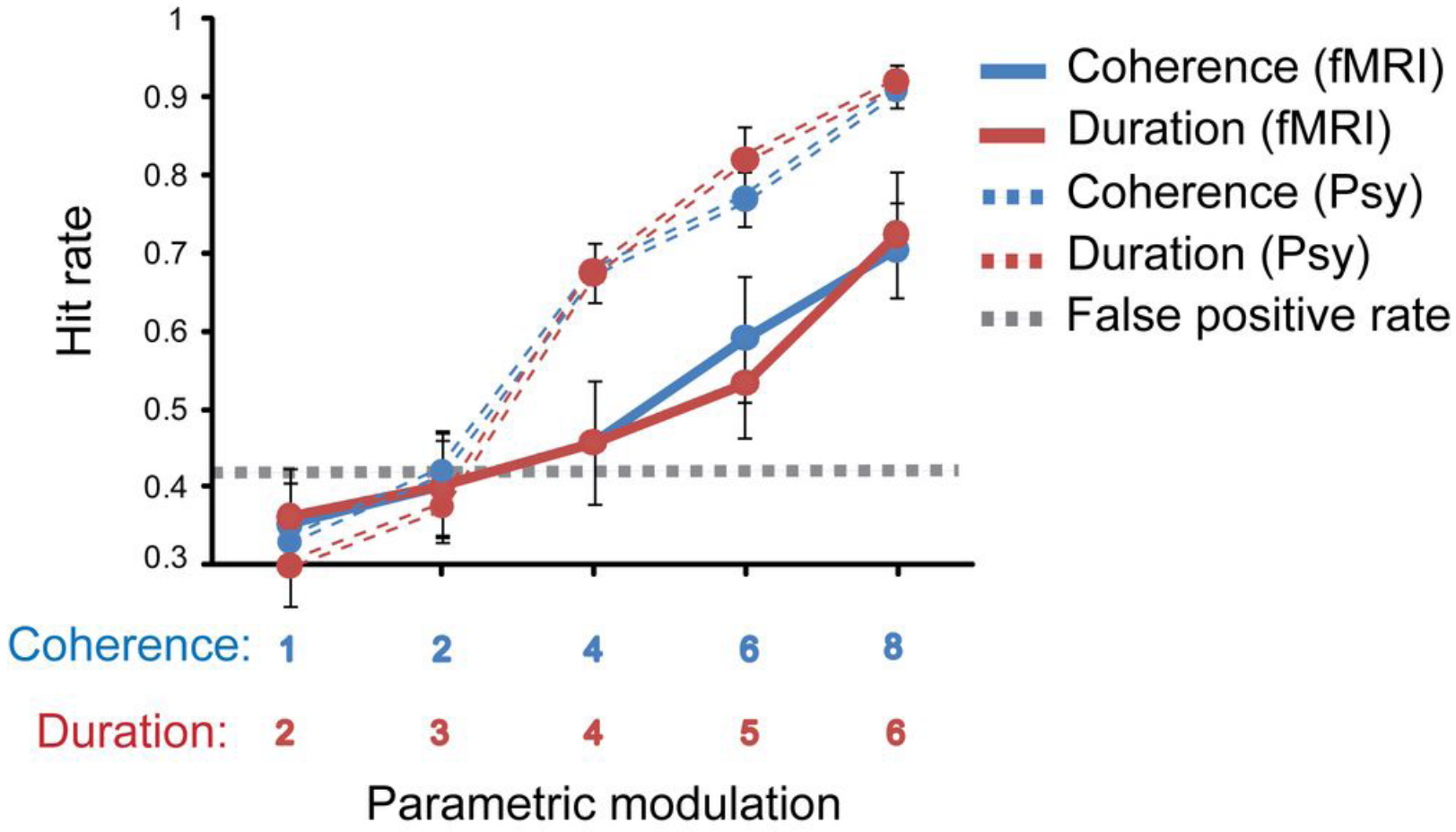
Aim: Identify brain areas whose activity varies with parametric variations in coherence and duration of the figure

Stimulus:
i. Fixed coherence: 4, varying duration: 2-7 chords
ii. Fixed duration: 4, varying coherence: 1,2,4,6,8

= 9 stimulus conditions (x 40 repetitions)

Paradigm:
i. Passive listening
ii. Active figure-detection

Behaviour in scanner



fMRI study

We used the SFG stimulus in a passive fMRI study to identify brain areas whose activity varies parametrically with coherence and duration of the figure

Figure (fixed coh: 4, dur: 2:7)

Figure (fixed dur: 4, coh: 1,2,4,6,8)

Background

Decoy

Task: Detect decoy stimuli (noise bursts; 10% of stimuli)

Results: We found activity in the **intraparietal sulcus** (cf Cusack 2005) and **superior temporal sulcus** to be involved in automatic, stimulus-driven, bottom-up segregation, with no role for the primary auditory cortex.

Teki et al., J Neurosci (2011)

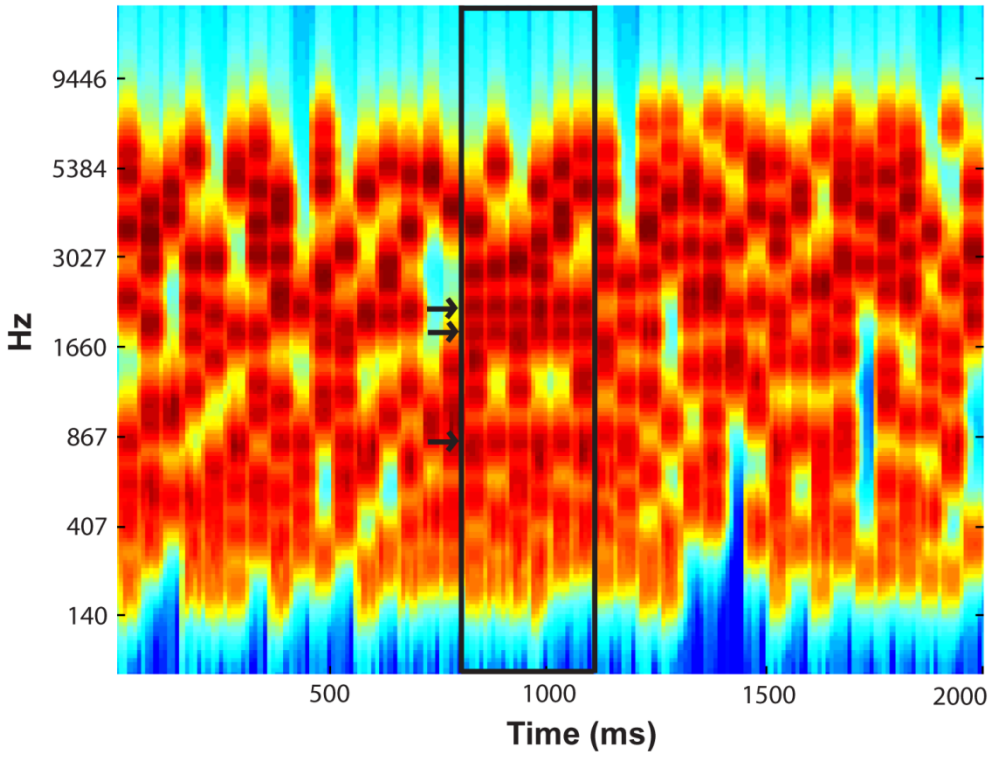
Psychophysics

Aims

- To characterize the brain mechanisms that underlie complex figure-ground segregation through systematic manipulations of the SFG stimulus

Expt. 1: ‘Baseline’ (50 ms)

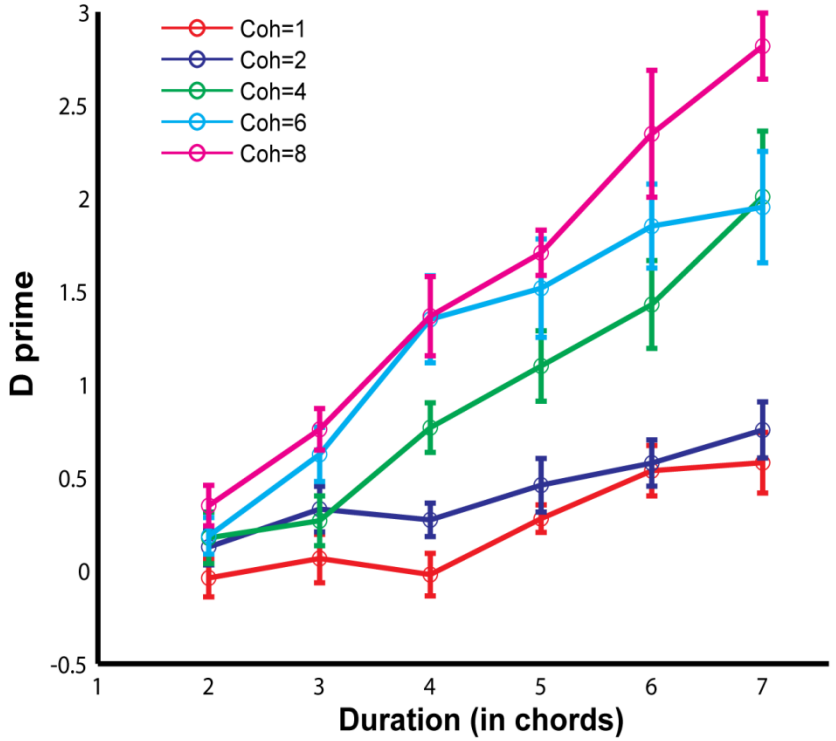
Stimulus consisted of a sequence of 40 x 50ms chords (2 s long)



Coherence: [1 2 4 6 8] Duration: [2:7]

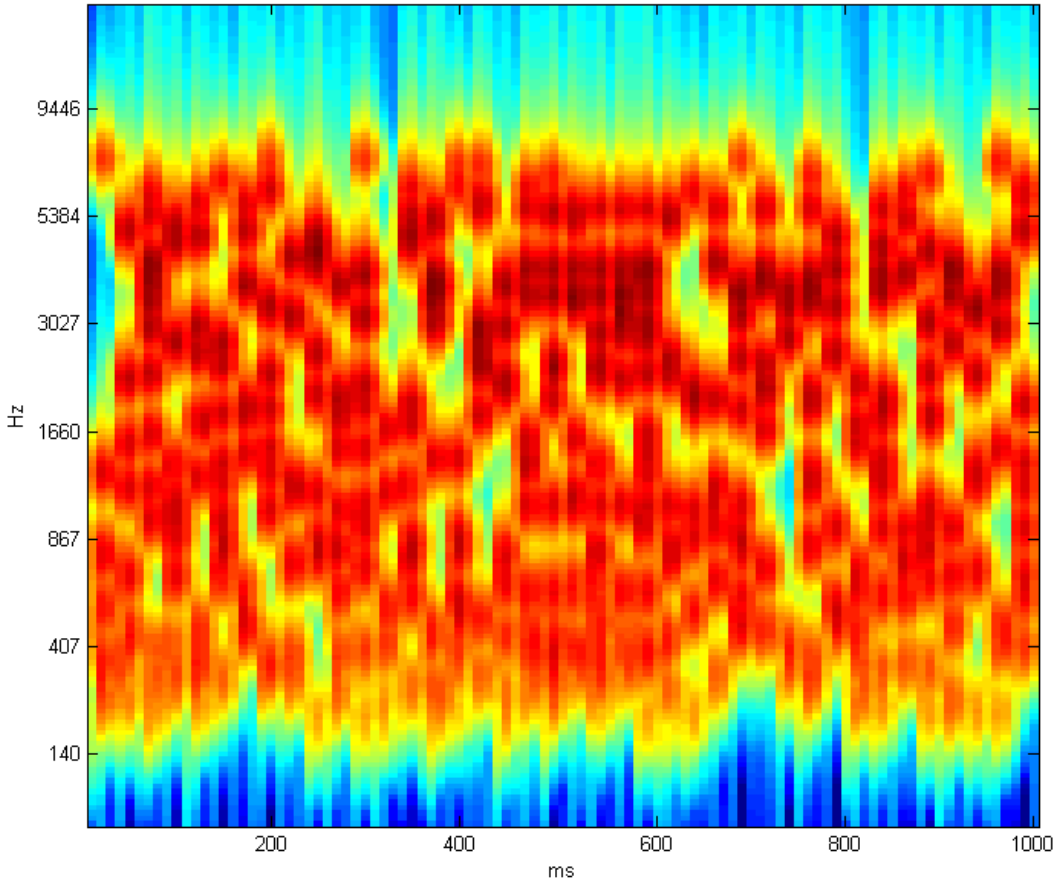
Expt. 1: Results

(n=9)



Expt. 2: ‘Baseline’ (25 ms)

Stimulus consisted of a sequence of 40 x 25ms chords (1 s long)

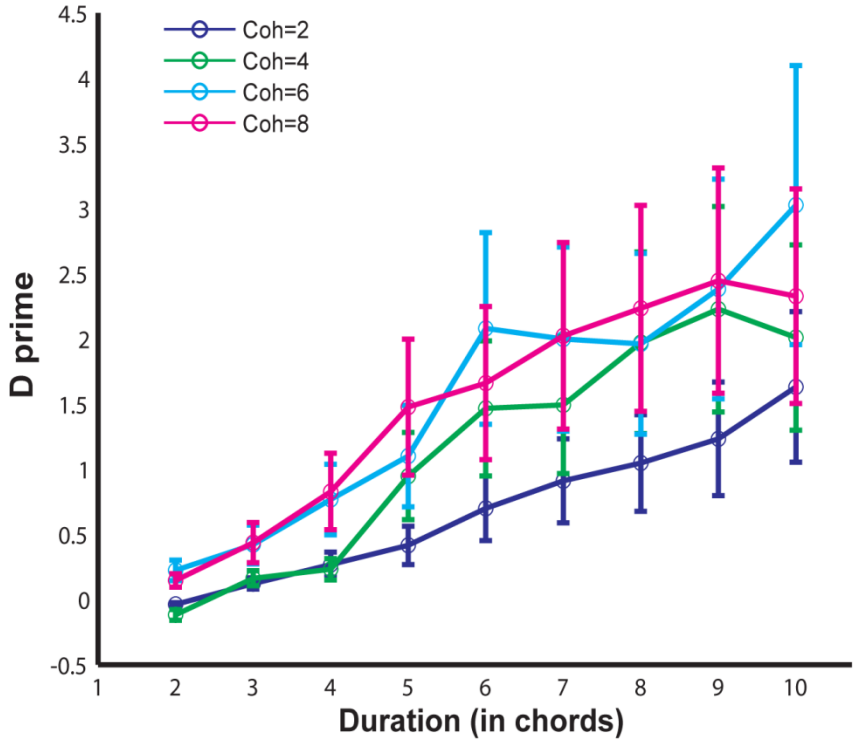


Coherence: [2 4 6 8]

Duration: [2:10]

Expt. 2: Results

(n=8)



Expt. 1 vs. 2

ANOVA

- Coherence and duration as within-subject factors

- Chord length (50 ms vs. 25 ms) as between-subject factor

Results

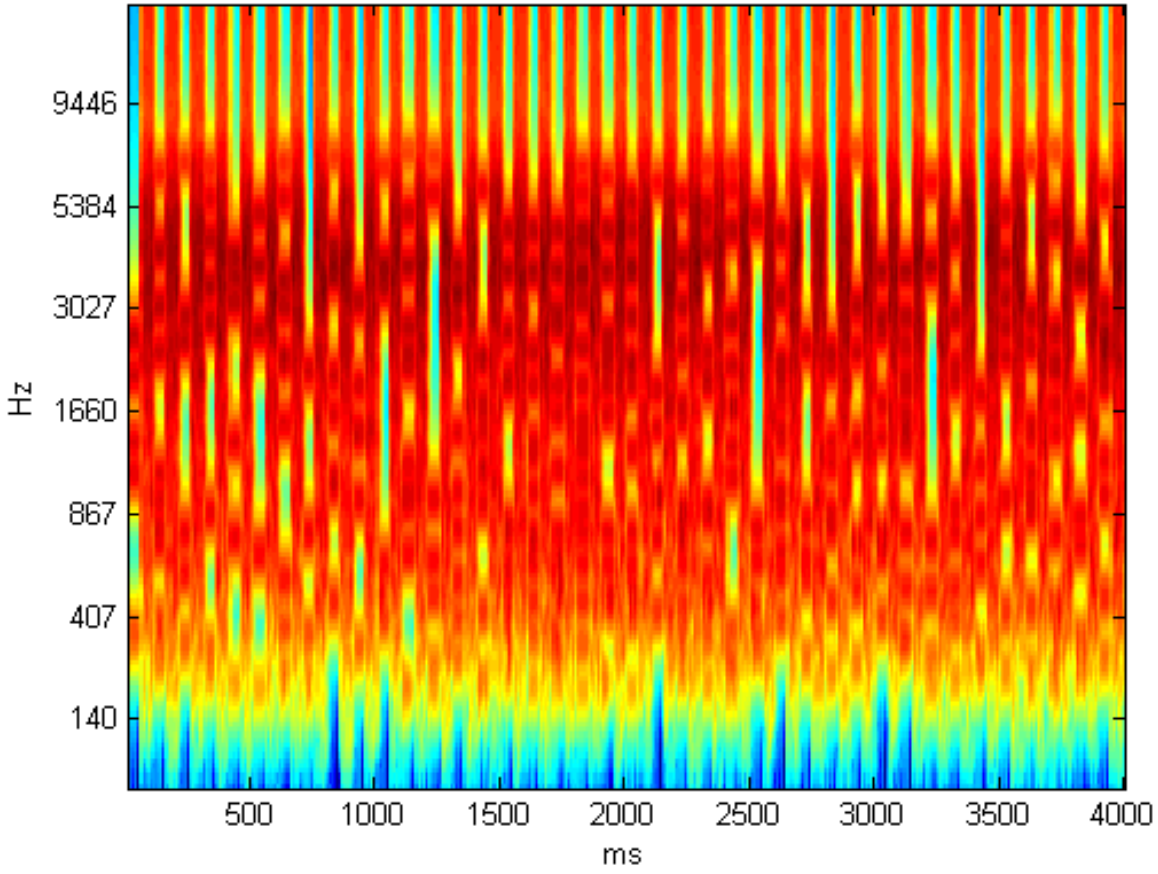
Significant effect of coherence: $F(3, 45) = 77, p < 0.001$

Significant effect of duration: $F(5, 75) = 41, p < 0.001$

No significant effect of chord length: $F(1,15) = 2, p = 0.174$

Expt. 3: ‘SFG/Noise’

Stimulus: SFG with 40 x 50ms chords alternating with 50ms of white noise (4 s)

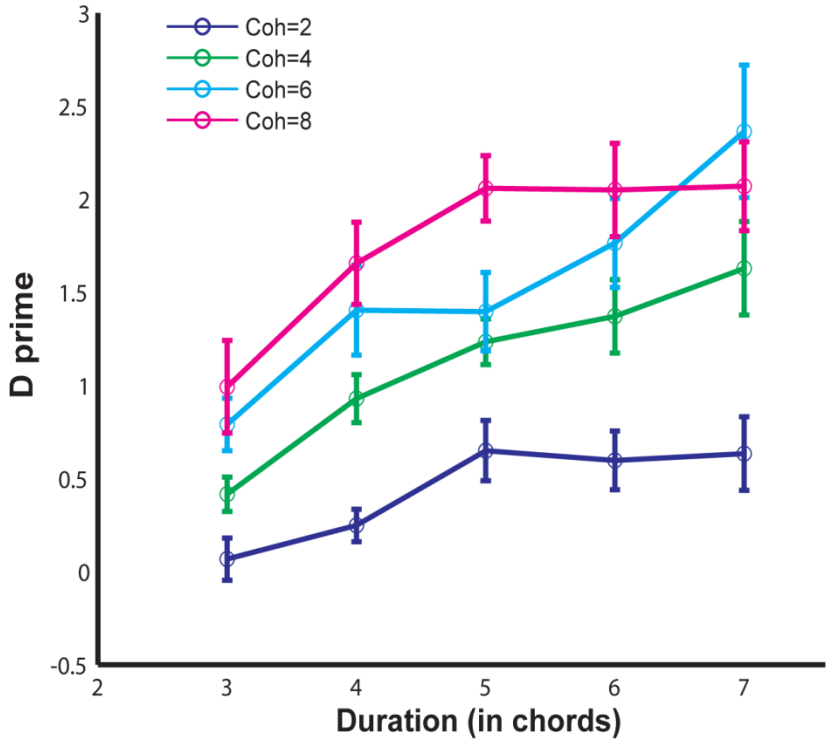


Coherence: [2 4 6 8]

Duration: [3:7]

Expt. 3: Results

(n=10)



Expt. 1 vs. 3

ANOVA

- Coherence and duration as within-subject factors

- Condition (Baseline vs. SFG/Noise) as between-subject factor

Results

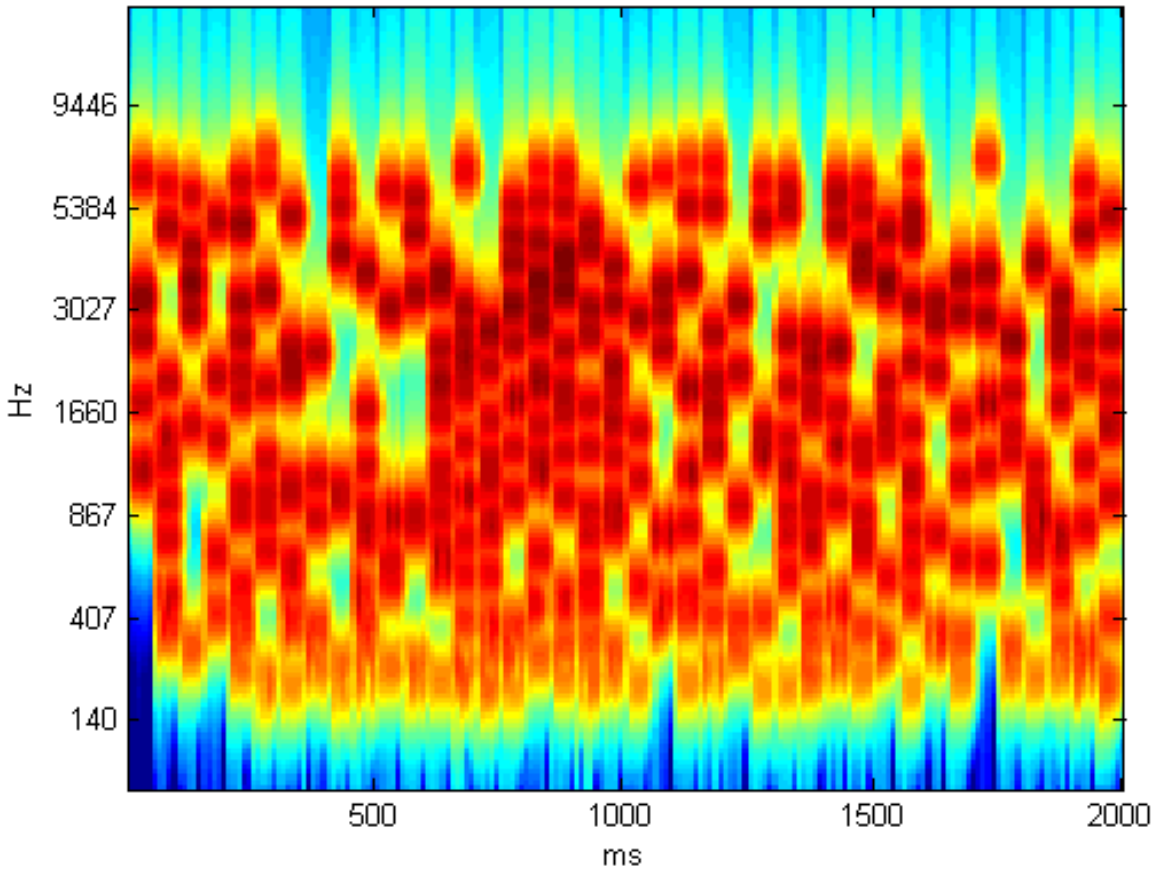
Significant effect of coherence: $F(3, 51) = 23, p < 0.001$

Significant effect of duration: $F(4, 68) = 29, p < 0.001$

No significant effect of condition: $F(1,17) = 0.004, p = 0.953$

Expt. 4: ‘Ramps’

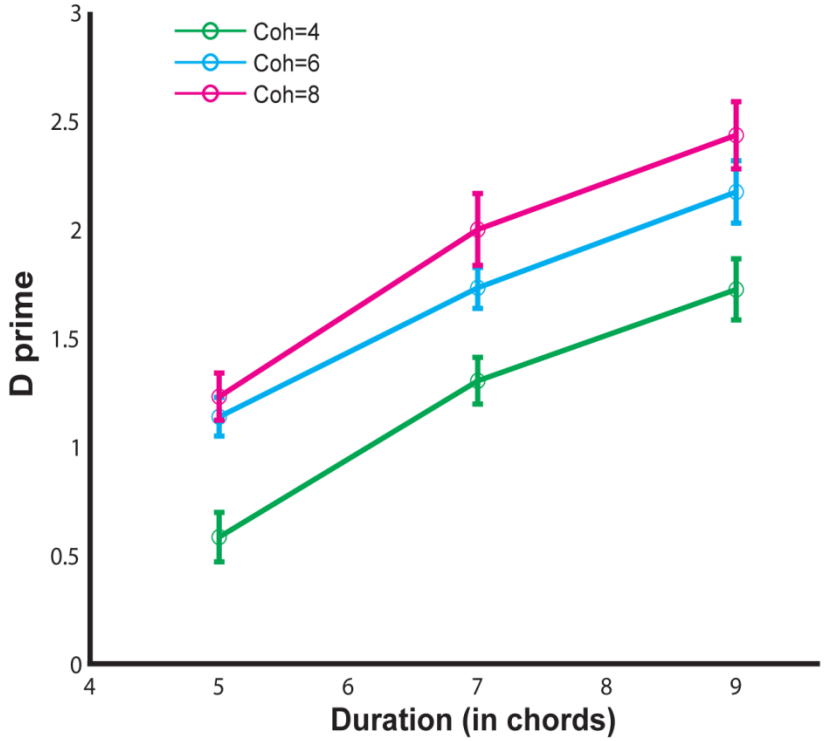
Stimulus: Figures were ramped (successive figure components were not repeating but increasing in frequency in steps of 2*l* or 5*l*, where *l* = 1/24 of an octave is the resolution of our frequency pool; ramps within critical band)



Coherence: [4 6 8] Duration: [5 7 9] Ramp step: [2/5]

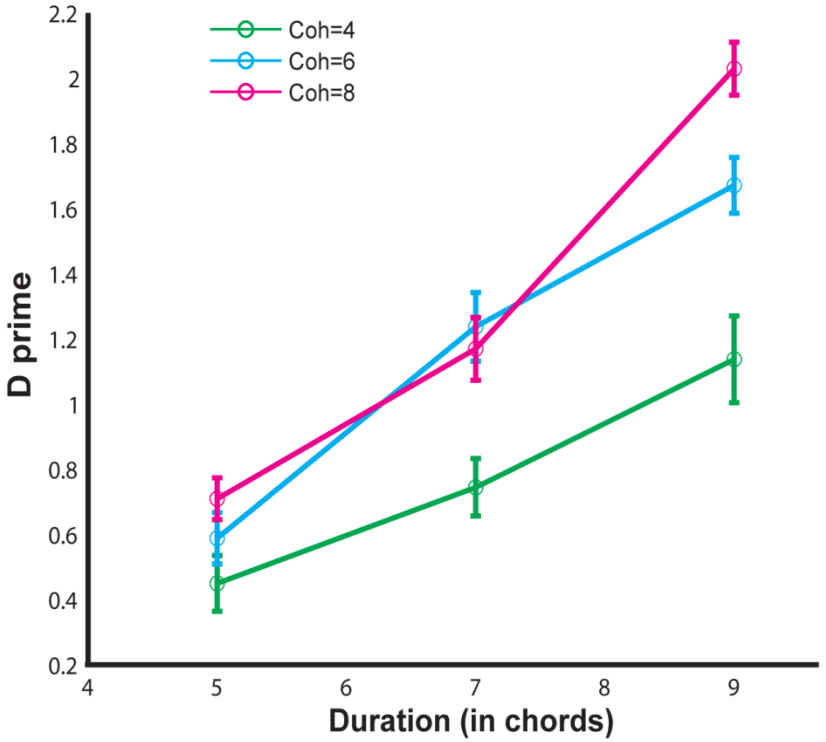
Results: Ramps 2

(n=10)



Results: Ramps 5

(n=10)



Expt. 1 vs. 4a vs. 4b

ANOVA

- Coherence (4, 6, 8) and duration (5, 7) as within-subject factors

- Condition (Baseline vs. ramp of 2 vs. ramp of 5) as between-subject factors.

Results

Significant effect of coherence: $F(2, 50) = 25, p < 0.001$

Significant effect of duration: $F(1, 25) = 110, p < 0.001$

Significant effect of condition: $F(2,25) = 19, p < 0.001$

Expt. 4a vs. 4b

ANOVA

- Coherence (4, 6, 8) and duration (5, 7) as within-subject factors

- Condition (Ramp of 2 vs. Ramp of 5) as between-subject factors.

Results

Significant effect of coherence: $F(2, 36) = 70, p < 0.001$

Significant effect of duration: $F(2, 36) = 198, p < 0.001$

Significant effect of condition: $F(1,18) = 21, p < 0.001$

Expt. 5: ‘Isolated’

Stimulus consisted only of the chords comprising the figure, and the preceding as well as succeeding chords were removed

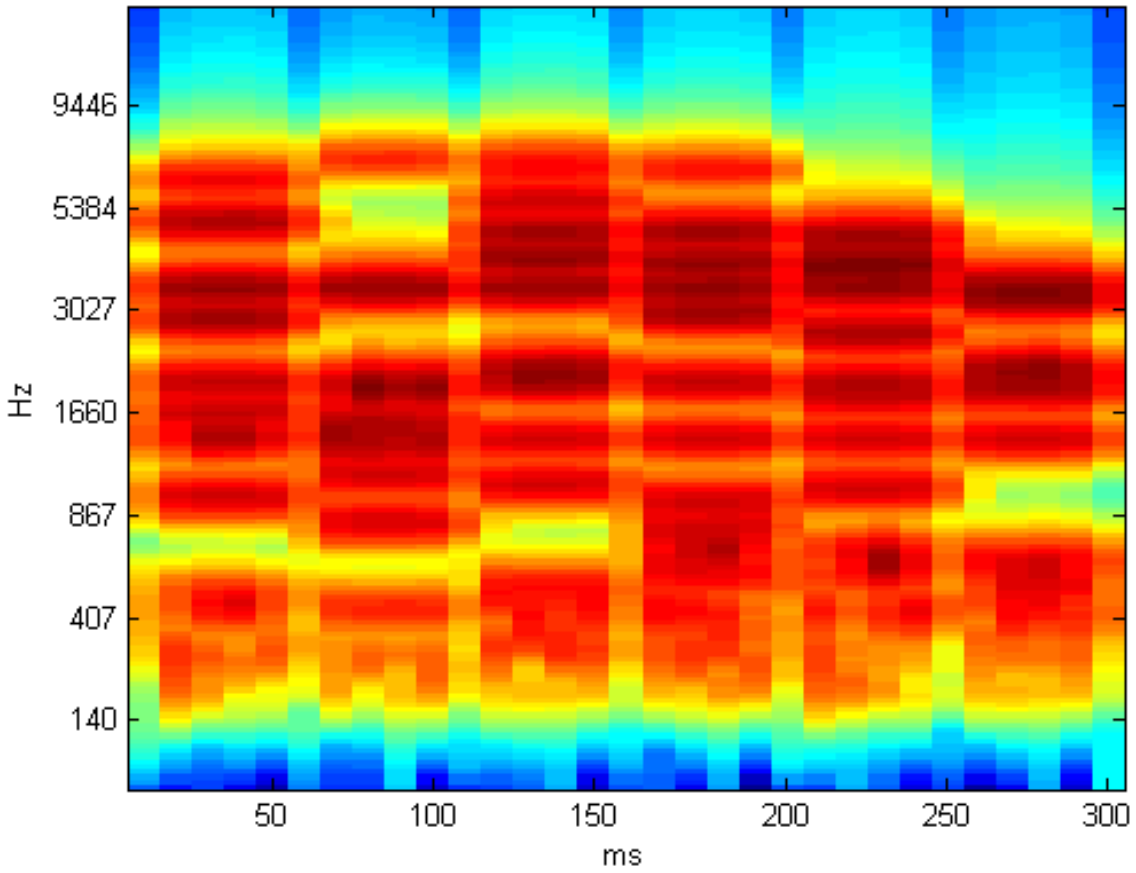


Figure:

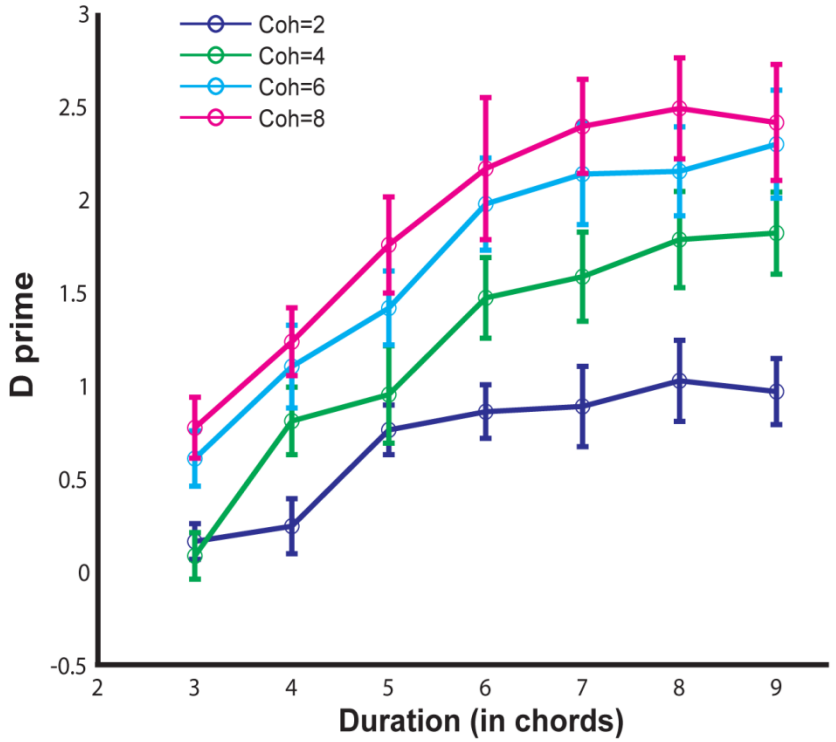
Ground:

Coherence: [2 4 6 8]

Duration: [3:9]

Expt. 5: ‘Isolated’

(n=10)



Expt. 1 vs. 5

ANOVA

- Coherence and duration as within-subject factors

- Condition (Baseline vs. Isolated) as between-subject factor

Results

Significant effect of coherence: $F(3, 48) = 85, p < 0.001$

Significant effect of duration: $F(4, 64) = 69, p < 0.001$

No significant effect of condition: $F(1,16) = 0.033, p = 0.859$

Summary

SFG figure-detection performance is:

- Depends on no. of repeating chords, not duration of figure (Expt. 1 & 2)
- Invariant to disruption by white noise (Expt. 1 & 3)
- Sensitive to shape of figure (continuous vs. ramped) (Expt. 1 & 4)
- Sensitive to size of ramps (2 vs. 5) (Expt. 4a & 4b)
- Invariant to the presence of preceding background (Expt. 1 & 5)

Discussion

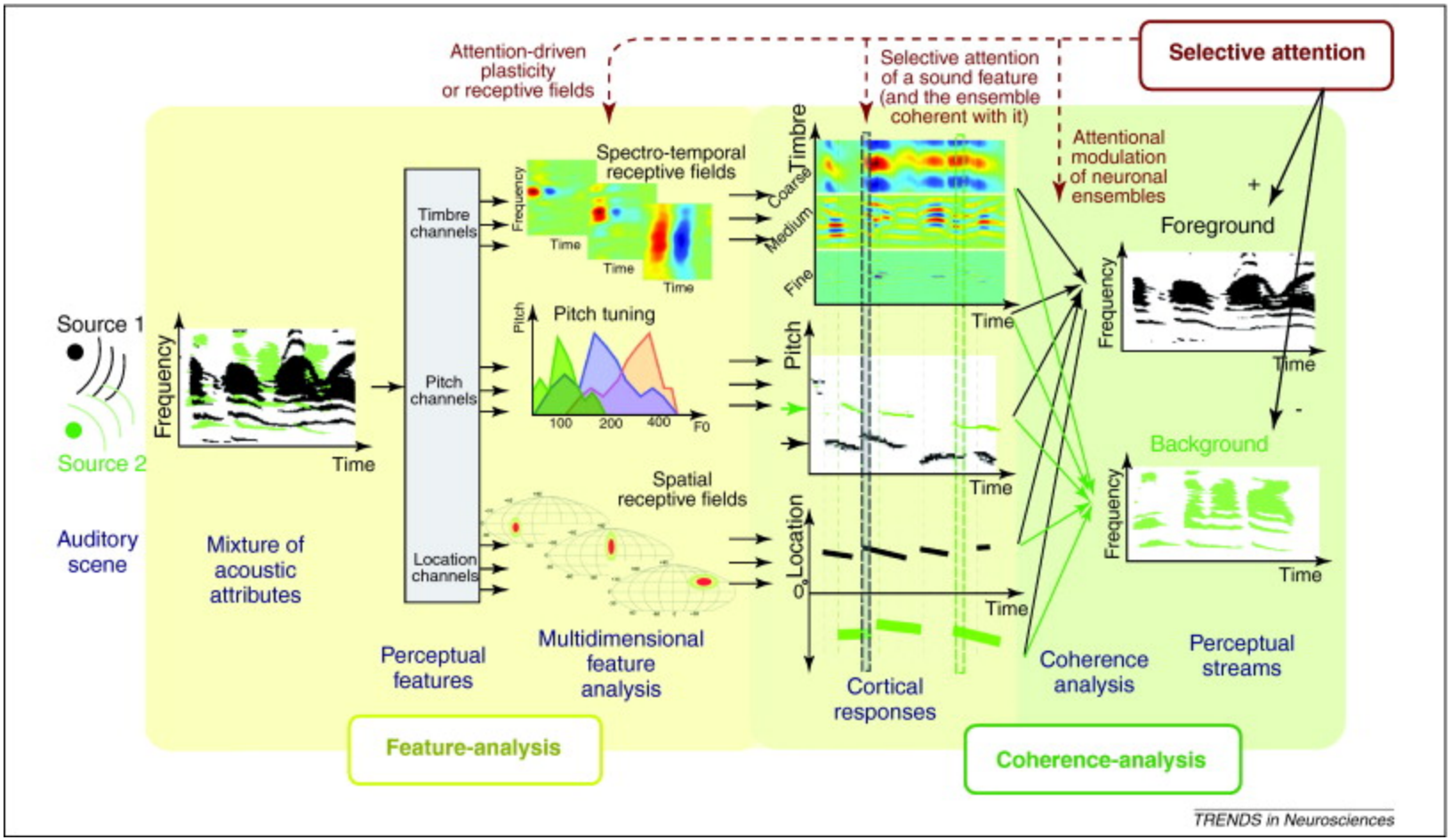
- Listeners can segregate figure from background in the SFG stimulus very well.

- Results suggest that adaptation is not critical for figure-ground segregation.

- We found the behaviour to be congruent with the temporal coherence model of auditory scene analysis which suggests that auditory segregation is based on the computation of cross-channel coherence.

  (Elhilali et al., 2009; Shamma et al., 2011)

Temporal coherence model



Temporal coherence model

The temporal coherence model incorporates three different stages:

1. cochlear processing
2. processing of the signal at the cortical level
3. cross-correlation analysis of multi-scale, multi-rate cortical representations

The cortical model simulates A1 cells that are tuned to a range of spectral and temporal resolutions. Here, we modelled A1 cells tuned to a rate of 20 Hz with a bandwidth of 24 channels per octave.

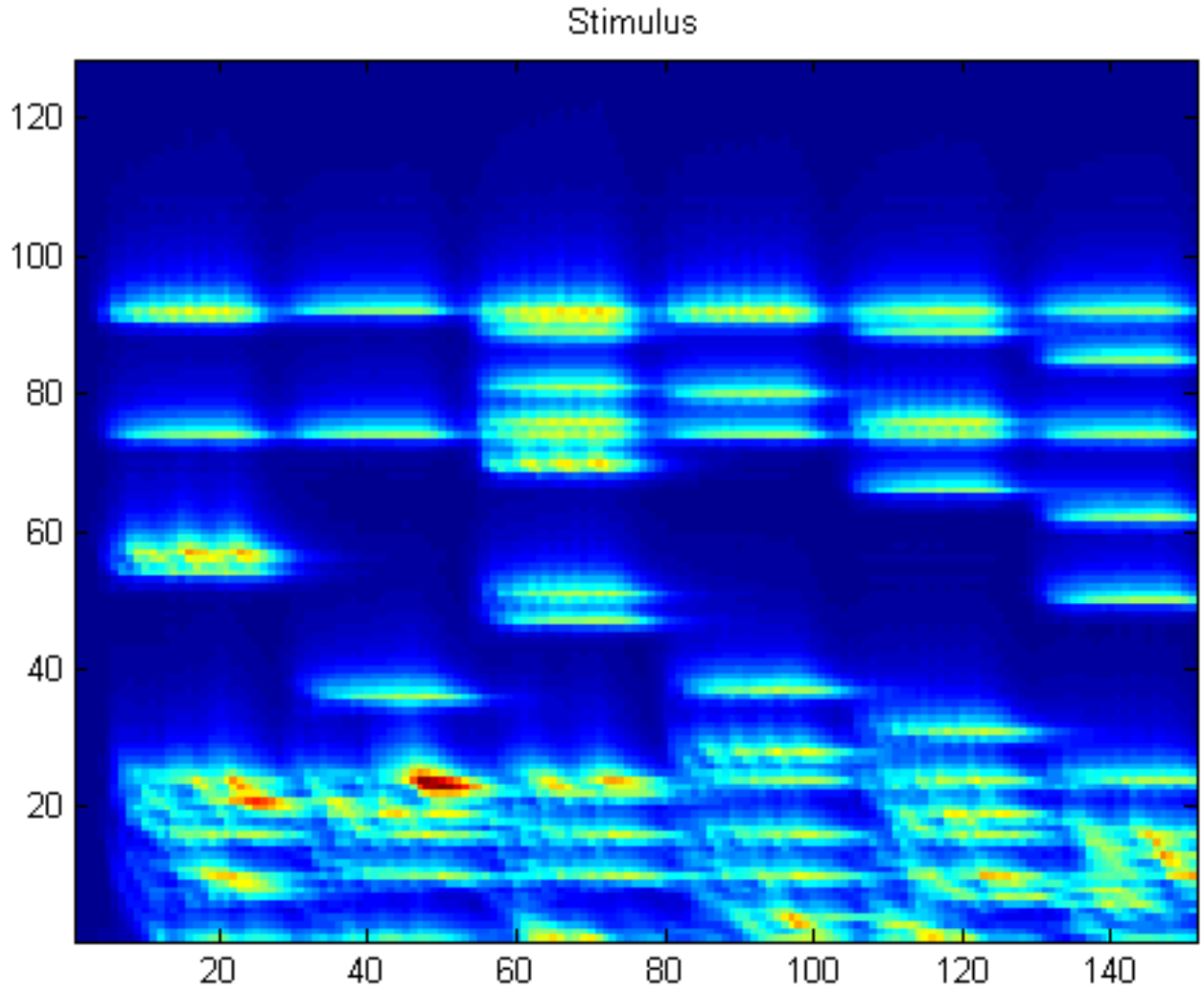
Analysis:

The model was run for 1000 iterations for each stimulus condition for the figure and ground stimuli separately.

The maximum value of cross-correlation was computed for each stimulus and averaged across iterations to produce the model output.

The average value for ground stimuli was subtracted from the average value for the figure stimuli to obtain the model response.

Isolated: figure with coh=6, dur=6



Isolated: ground with coh=6, dur=6

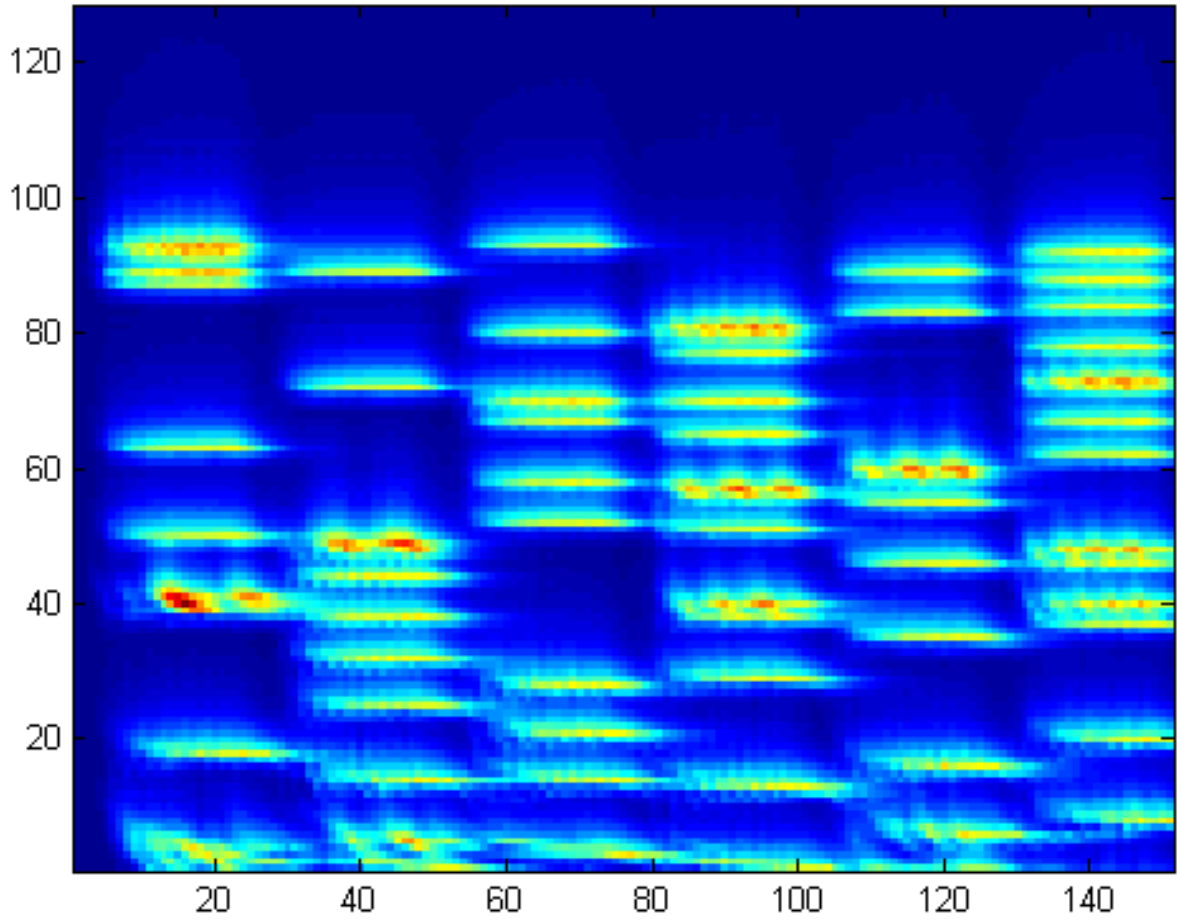
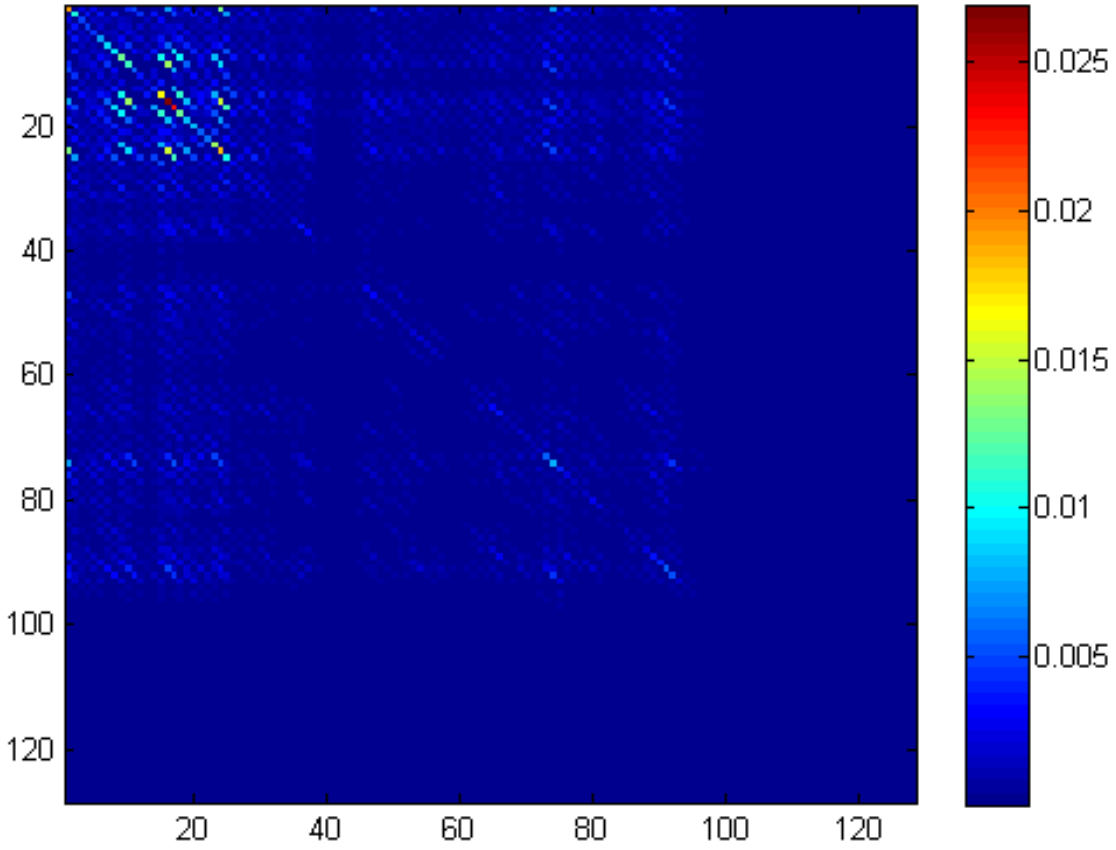
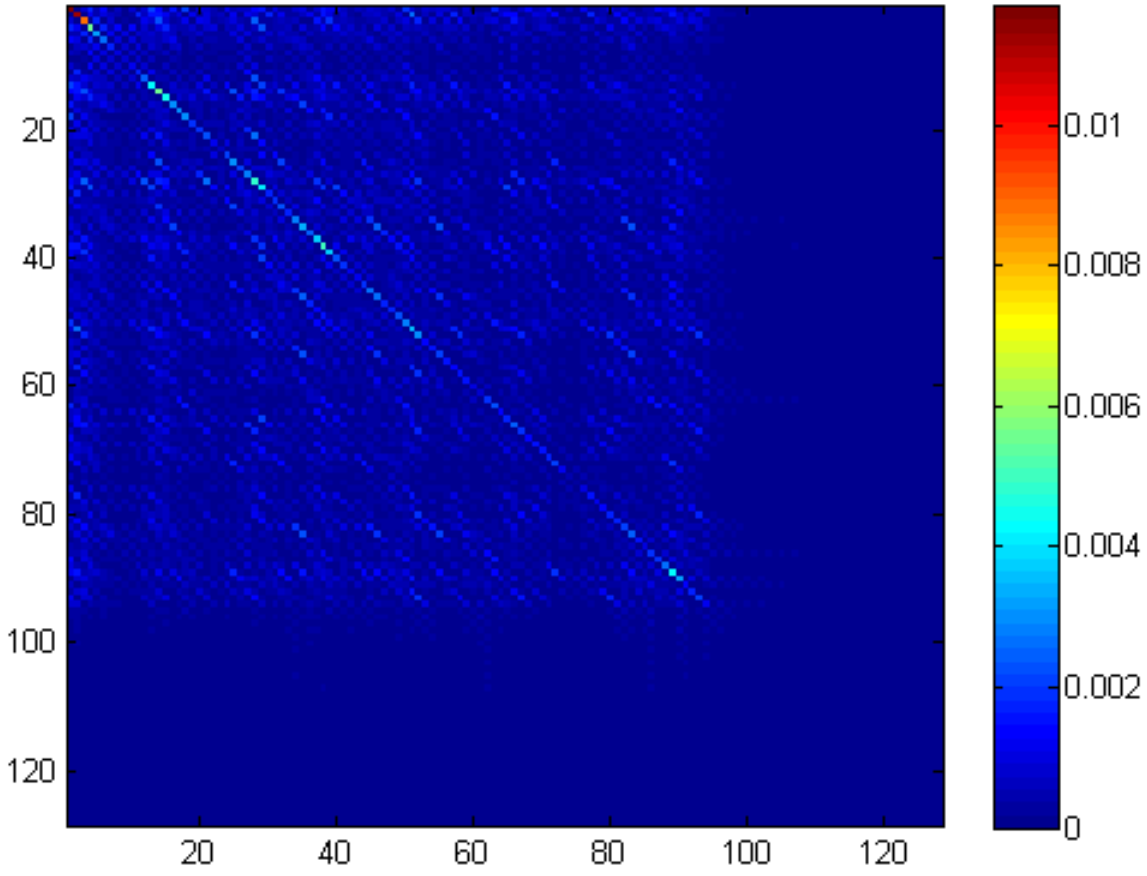


Figure: cross-correlation matrix



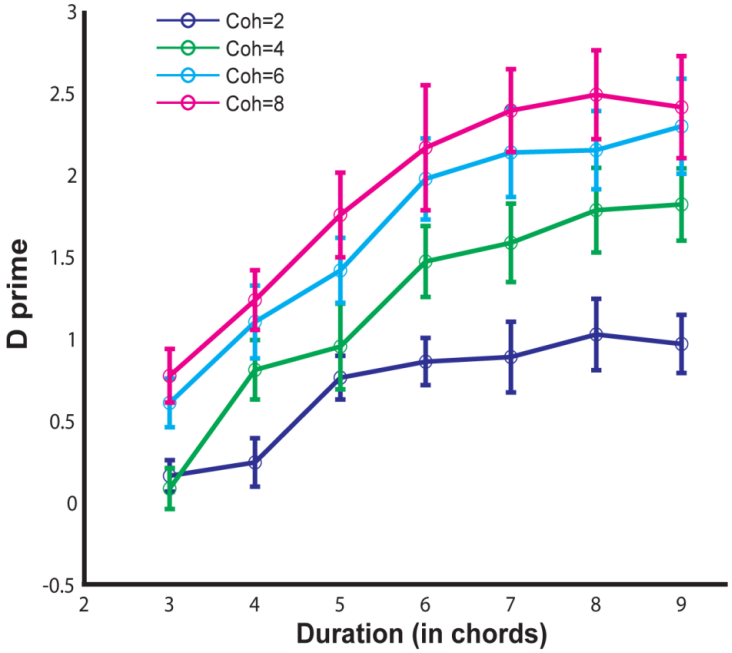
Output: cross-correlation matrix

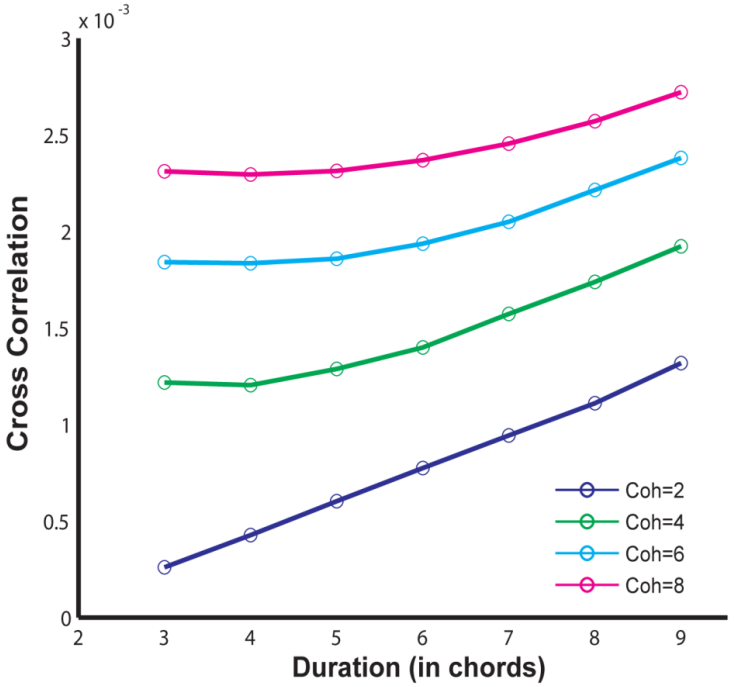
Ground: cross-correlation matrix



Expt. 5: Model

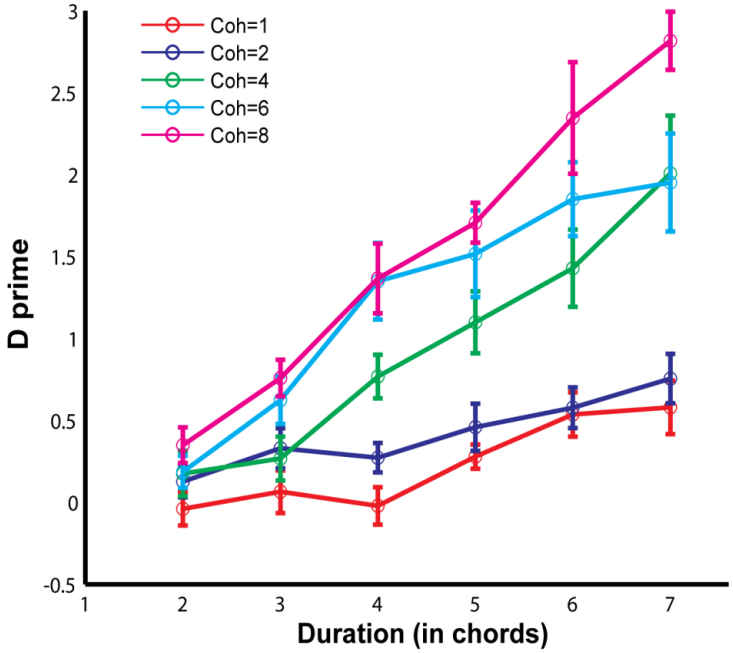
sv=24, rv=20

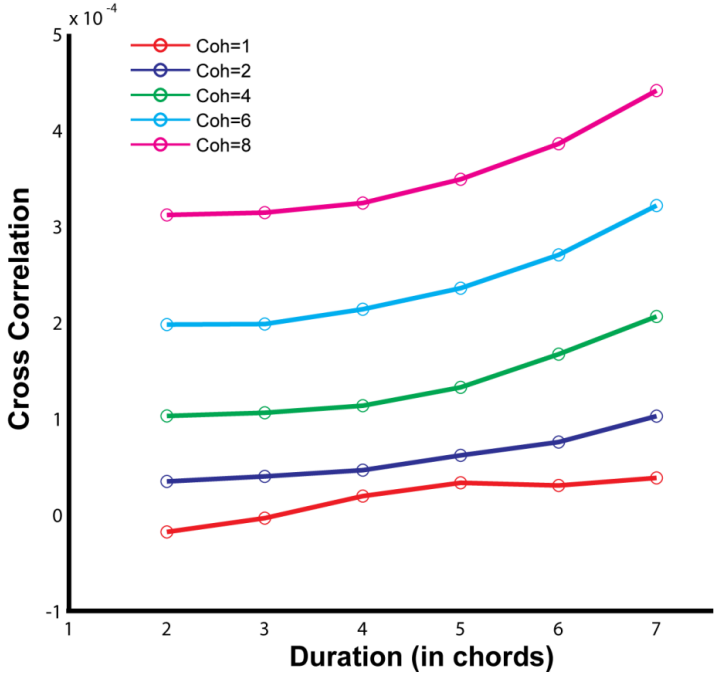




Expt. 1: Model

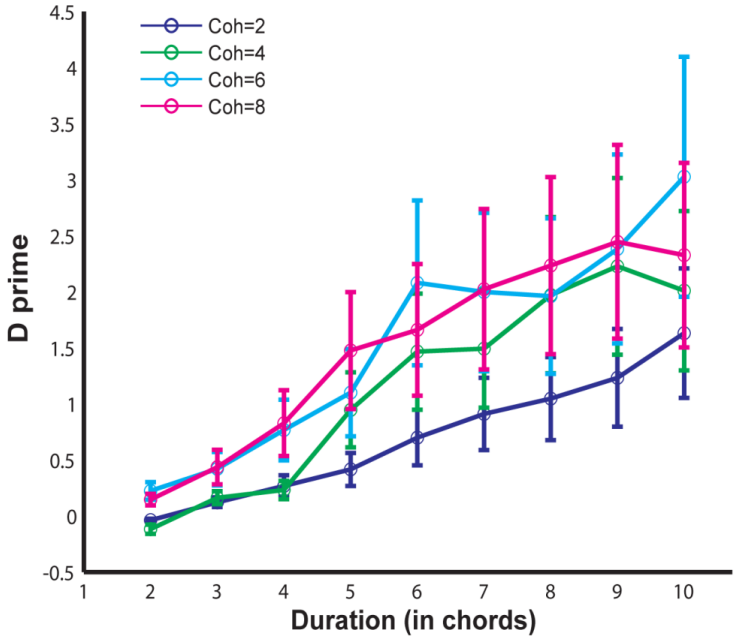
sv=24, rv=20

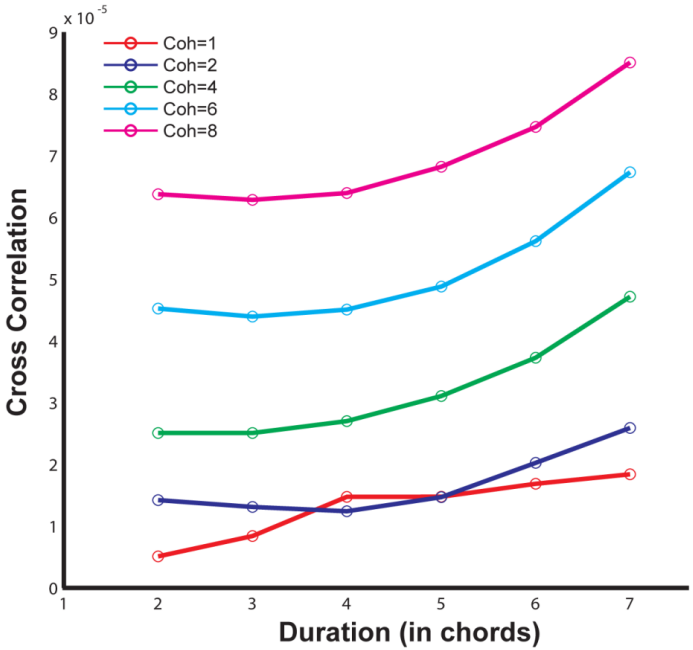




Expt. 2: Model

sv=24, rv=40





Acknowledgments

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UCL Ear Institute

Shihab Shamma

University of Marlyand, College Park

wellcome trust

fMRI Experiment

Aim: Identify brain areas whose activity varies with parametric variations in coherence and duration of the figure

Stimulus:
i. Fixed coherence: 4, varying duration: 2-7 chords
ii. Fixed duration: 4, varying coherence: 1,2,4,6,8

Figure (fixed coherence)

Figure (fixed duration)

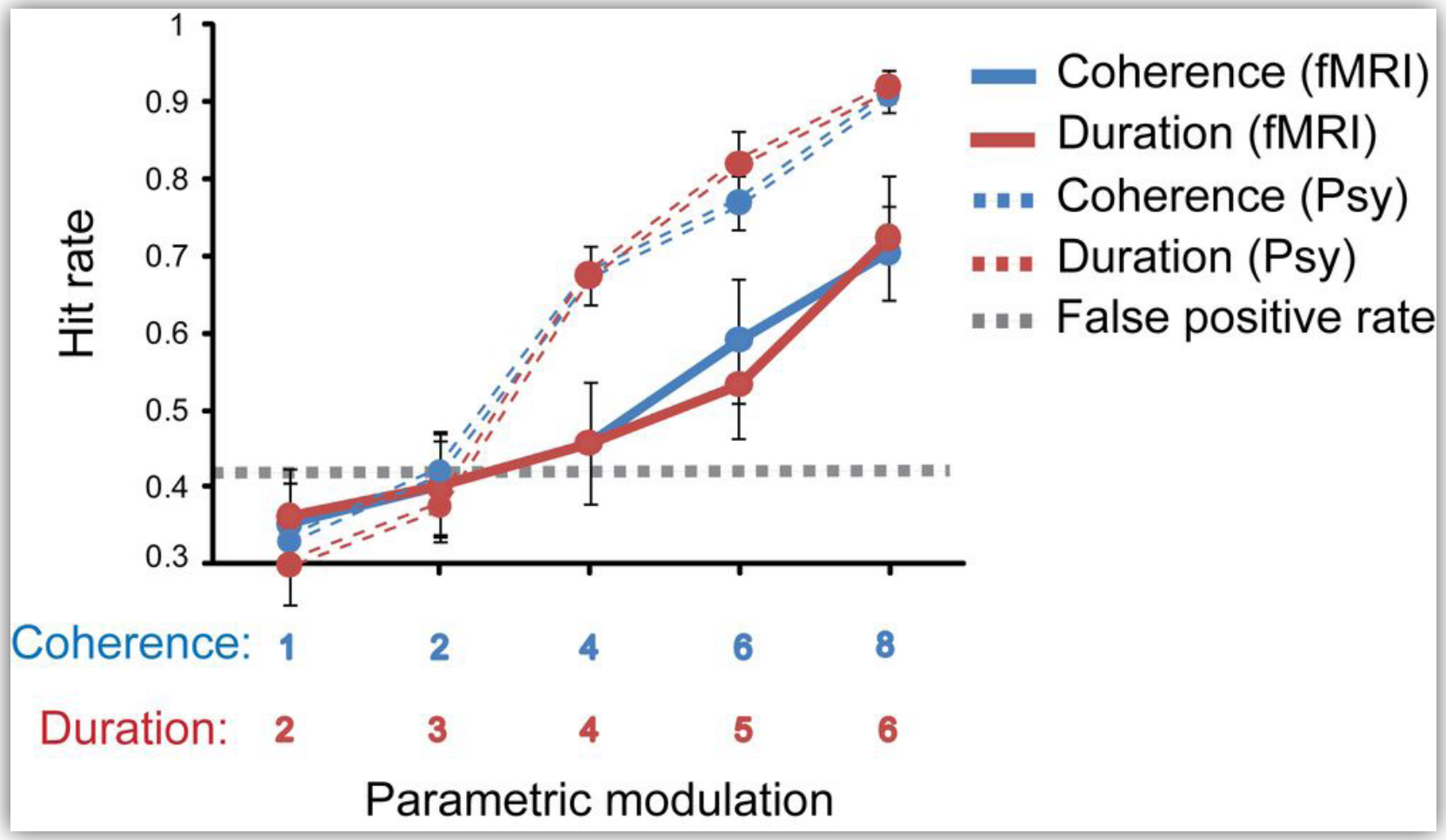
Background

Decoy

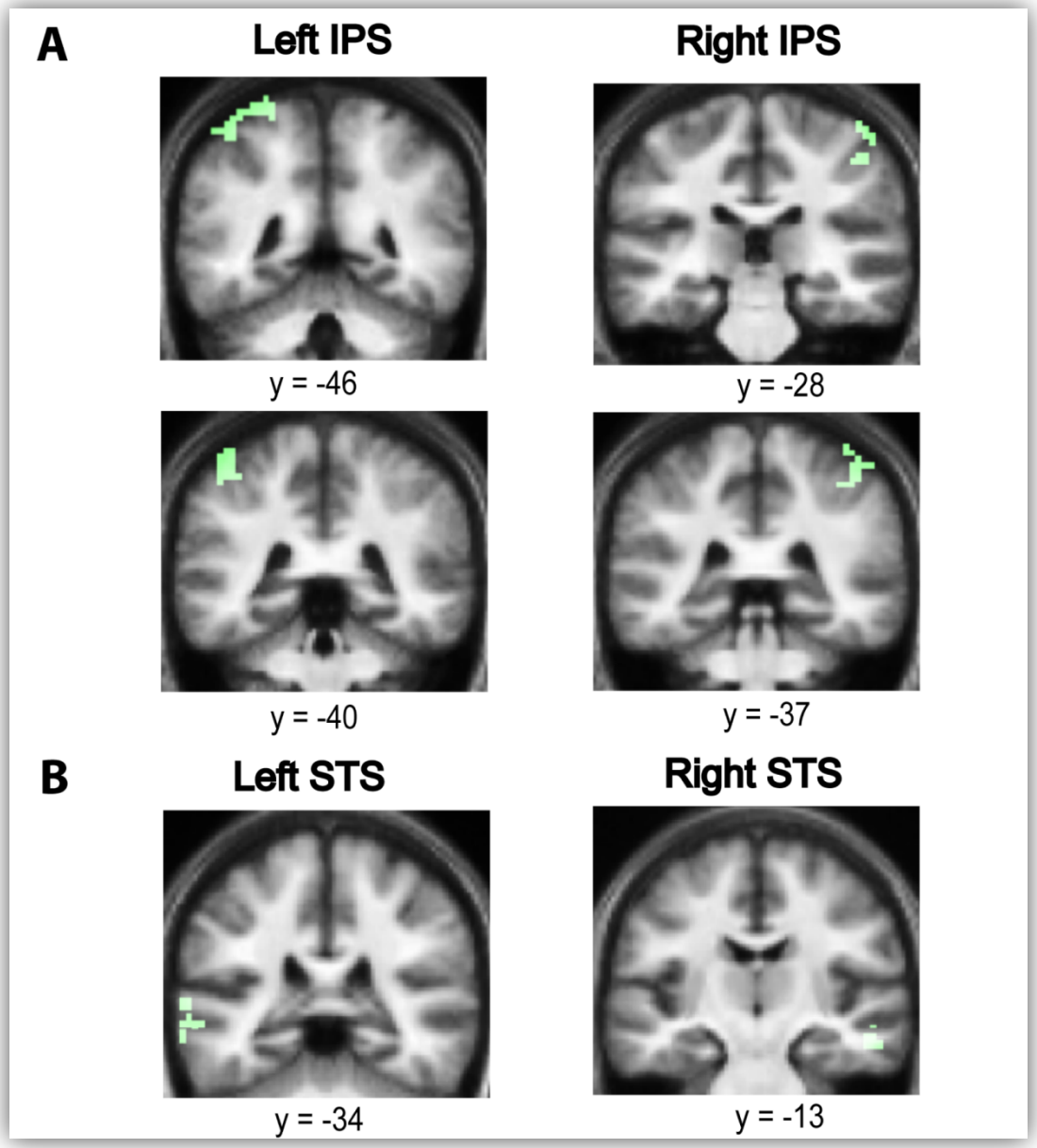
Task: **Detect decoy stimuli (noise bursts; 10% of stimuli)**

- **Subjects were not actively detecting figures**

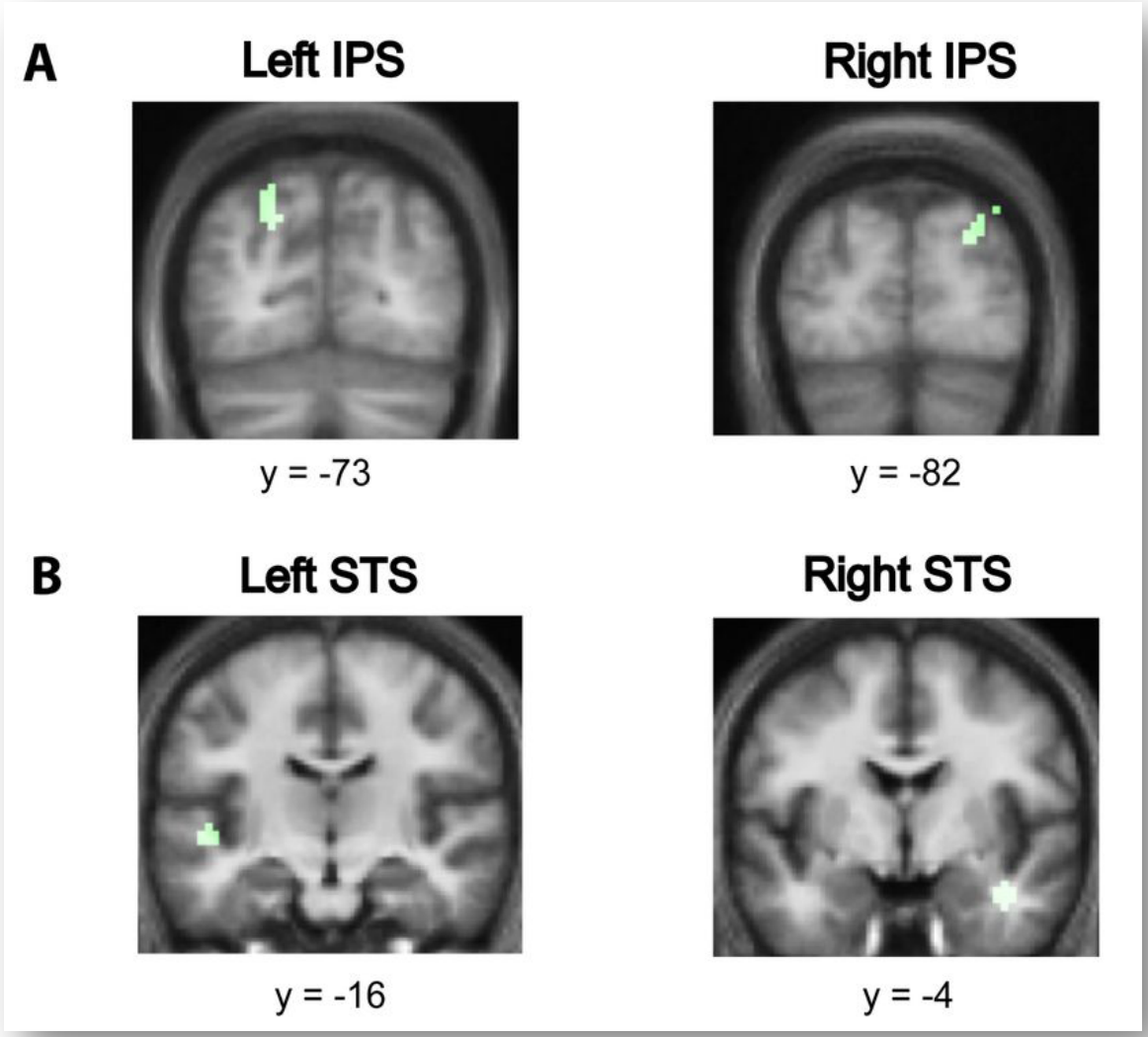
Behaviour in scanner



Effects of Duration



Effects of Coherence



What about the auditory cortex ?

- No activation in Primary Auditory Cortex (PAC) for either contrast
- Confirmed using volume of interest analysis based on PAC maps (Morosan et al., 01)
- Consistent with one previous fMRI study (Cusack, 2005)

Reasons…

- More complex and naturalistic stimulus
- Naïve subjects and short figures
- PAC recruited during active figure-ground segregation (i.e., in behavioural context) with possibly top-down modulation by IPS?

Role of STS

- STS activity modulated by changing duration and coherence of the figure

- Implicated in:
  - analysis of spectral shape (Warren et al., 2005)
  - dynamic changes in spectrum (Overath et al., 2008)
  - detection of increasing changes in spectrotemporal coherence within textures (Overath et al., 2010)

IPS and Perceptual Organization

Role of IPS consistent with Cusack (2005):

- Implicated IPS in perception of two streams vs. one stream, based on the same physical streaming signal that evoked a bistable percept.
- IPS activity likely reflects top-down application of attention (shift between streams)
- Found no activation in primary auditory cortex

IPS is involved in structuring sensory input and perceptual organization:

- Encoding visual object representations
- Binding of sensory features within and across different modalities
- control and shift of auditory attention

What does the IPS activity reflect?

➢ ***automatic, bottom-up segregation of auditory object from stochastic background***

Summary

SFG stimulus

- More representative of the natural complexity of acoustic scenes
- Figure can only be extracted by integrating over frequency-time space
- Shorter build up time (~300ms; compared to ~2s for streaming stimuli)
- Enables parametric approach to study auditory figure-ground segregation

Substrates

- IPS and STS: pre-attentive, stimulus-driven, bottom-up segregation
- No role of primary auditory cortex in such bottom-up segregation

Questions...

- Is IPS involved in active figure-ground segregation ? And PAC?
- Functional connectivity between IPS and the auditory system ?

For complete details, see: ***Teki, Chait et al., J Neurosci (2011)***