Auditory figure-ground segregation in complex acoustic scenes

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Outline

- Introduction
- Figure-ground stimulus
- fMRI study
- Psychophysics
- Temporal coherence model
- Summary

The problem

 # speakers

1 

2 

4 

8 

Auditory figure-ground segregation

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

Processes:

- grouping of simultaneous frequency components
- grouping of frequency components over time,
- separation of grouped components from the rest of the acoustic scene.

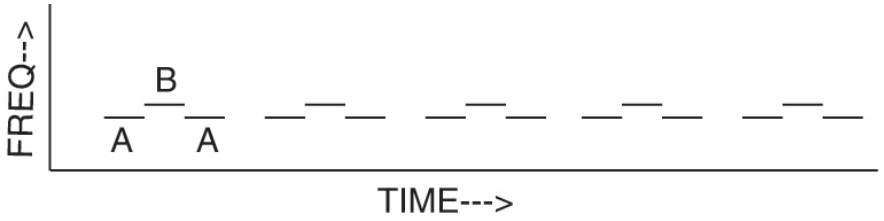
Stimuli:

- Studied using relatively simple signals, e.g. streaming signals

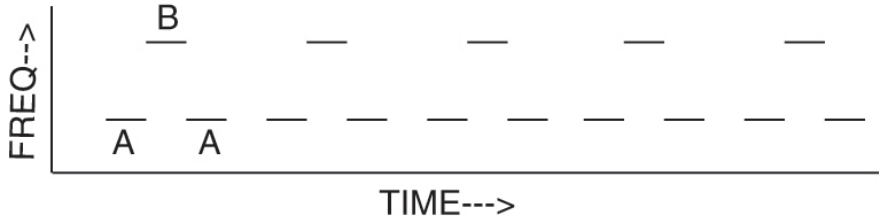
(van Noorden, 1975; Bregman, 1990)

Streaming

ABA_…ABA_ or AB…AB

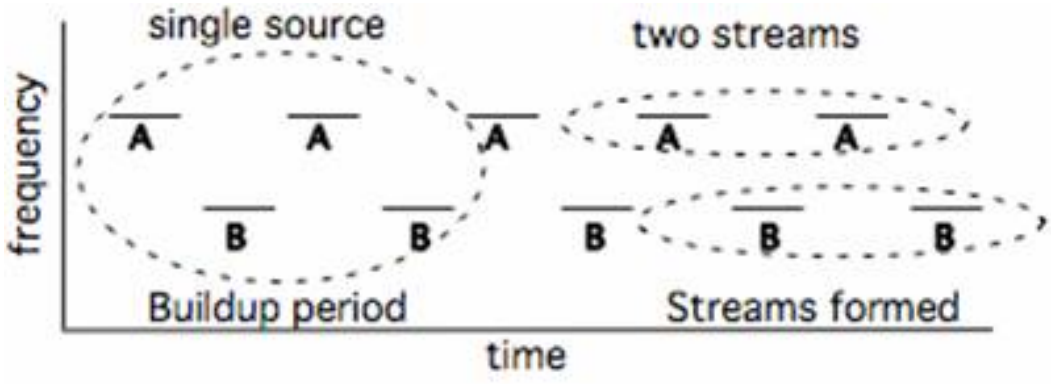


Δf: 1 st **Integrated percept**



Δf: 6 st **Ambiguous percept**

Δf: 9 st **Segregated percept**



Auditory figure-ground segregation

Mechanisms:

- frequency selectivity
- forward suppression
- neural adaptation

cf. Fishman & Steinchneider; Bee & Klump; Micheyl; Carlyon

Auditory figure-ground segregation

Drawbacks of streaming signals:

- lack the rich spectrotemporal complexity of natural signals
- predictable temporal structure
- spectral components do not change with time

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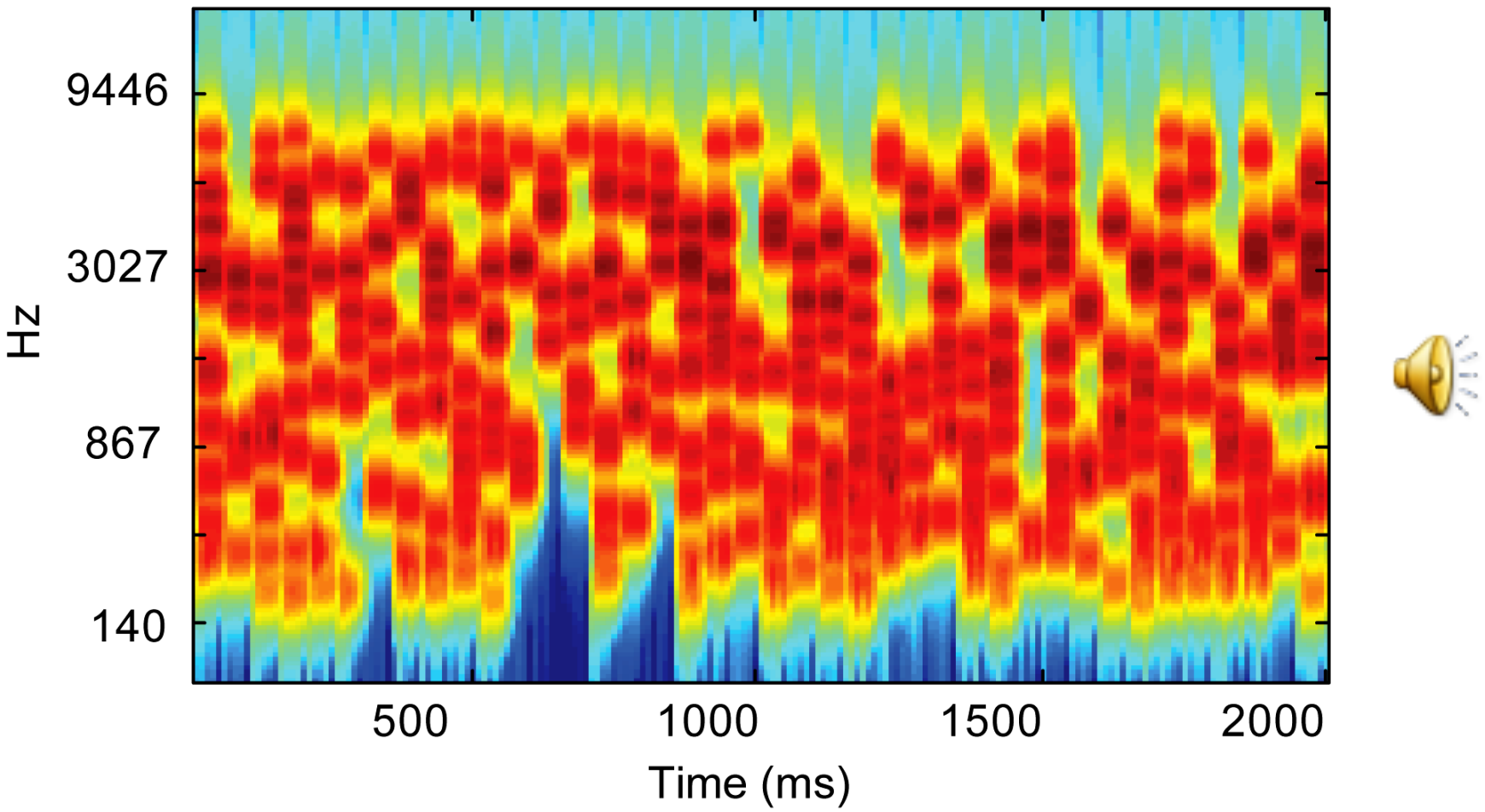
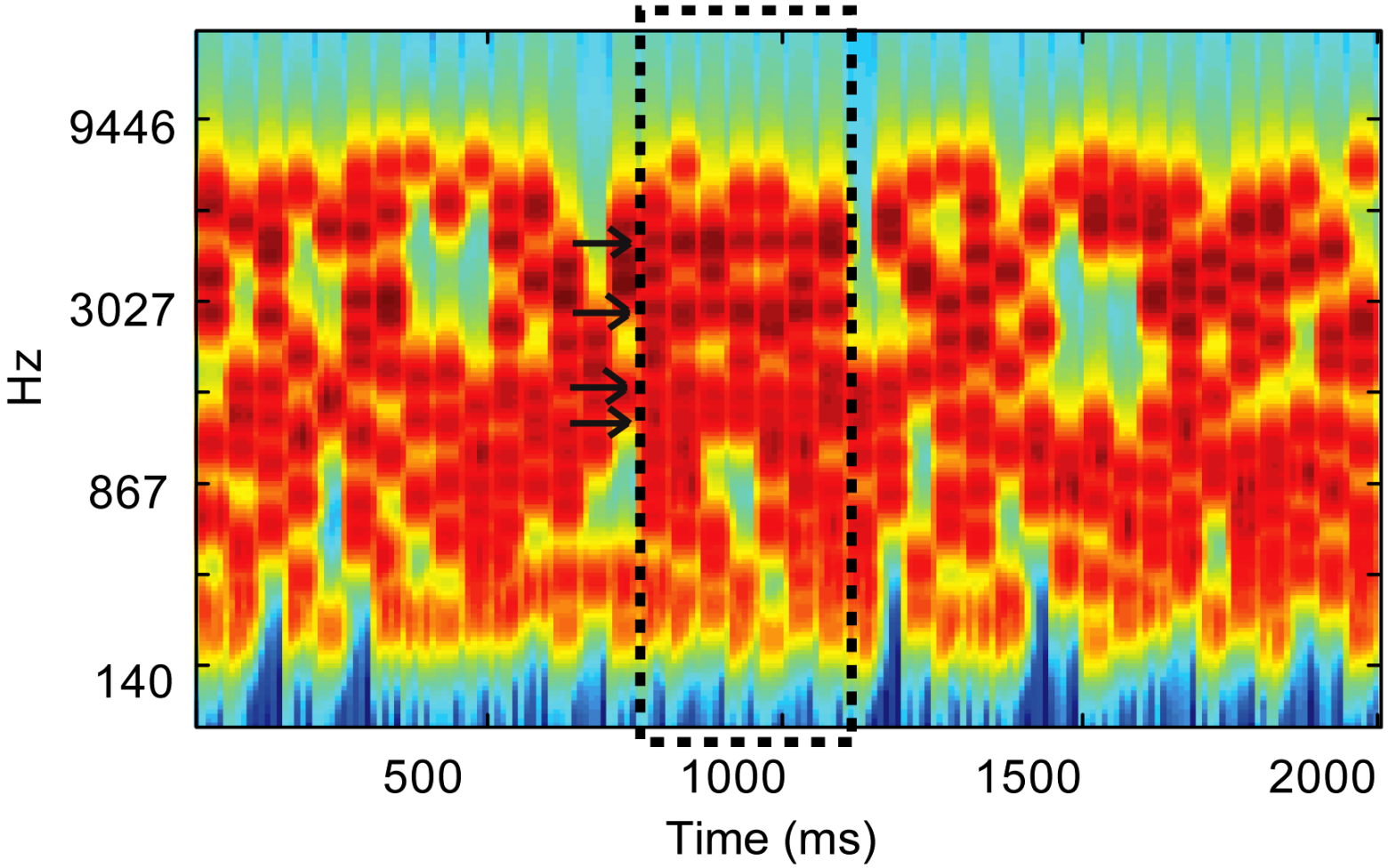
Stochastic Figure-Ground (SFG)



SFG: Figure present

Figure with ‘coherence’ = 4 and ‘duration’ = 7



SFG: Stimulus design

Stimulus:

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
Resolution of frequency pool:	1/24th of an octave
Cosine ramp:	10 ms for onset and offset

Coherence:

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

Duration:

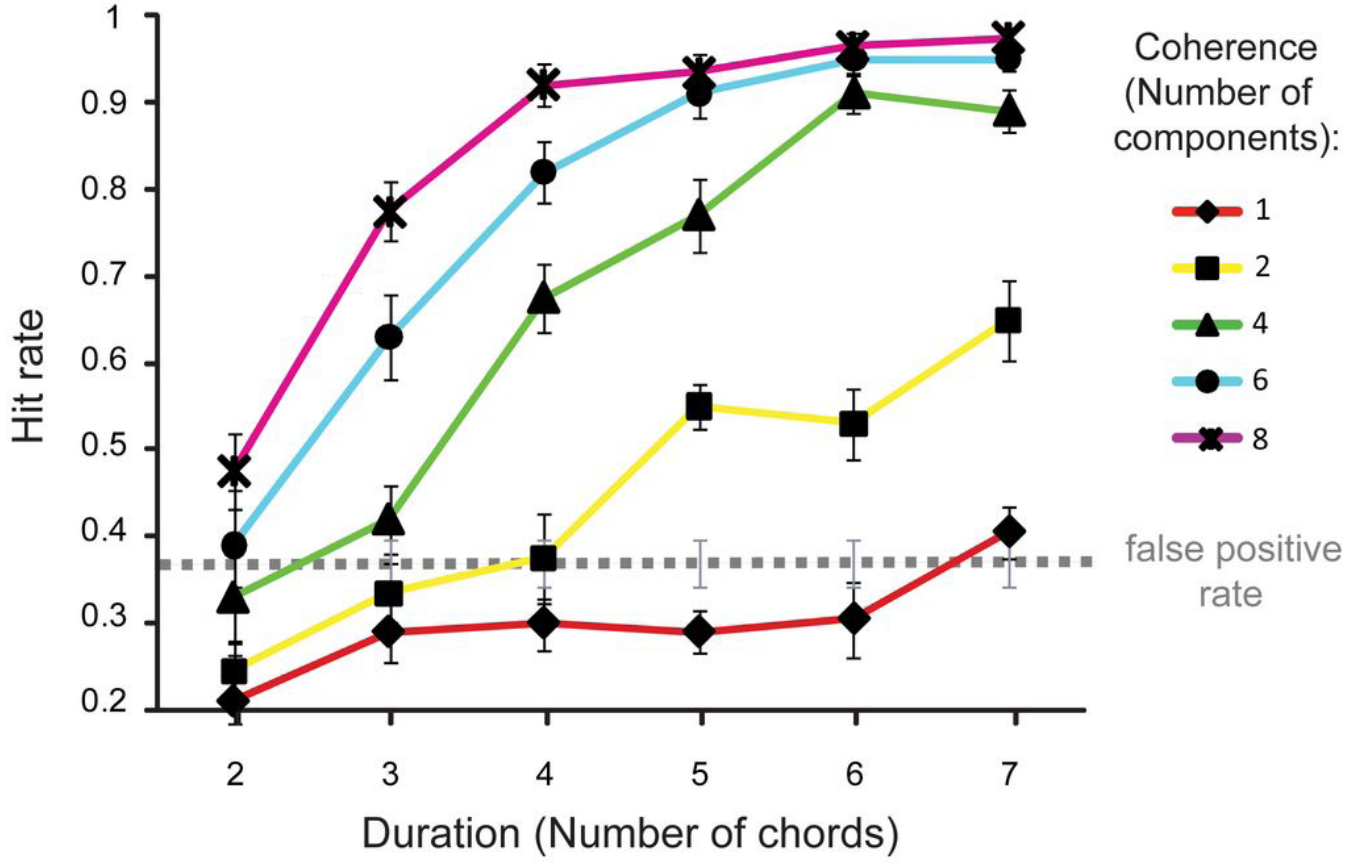
Number of chords over which frequencies repeat : **2-7**

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

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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

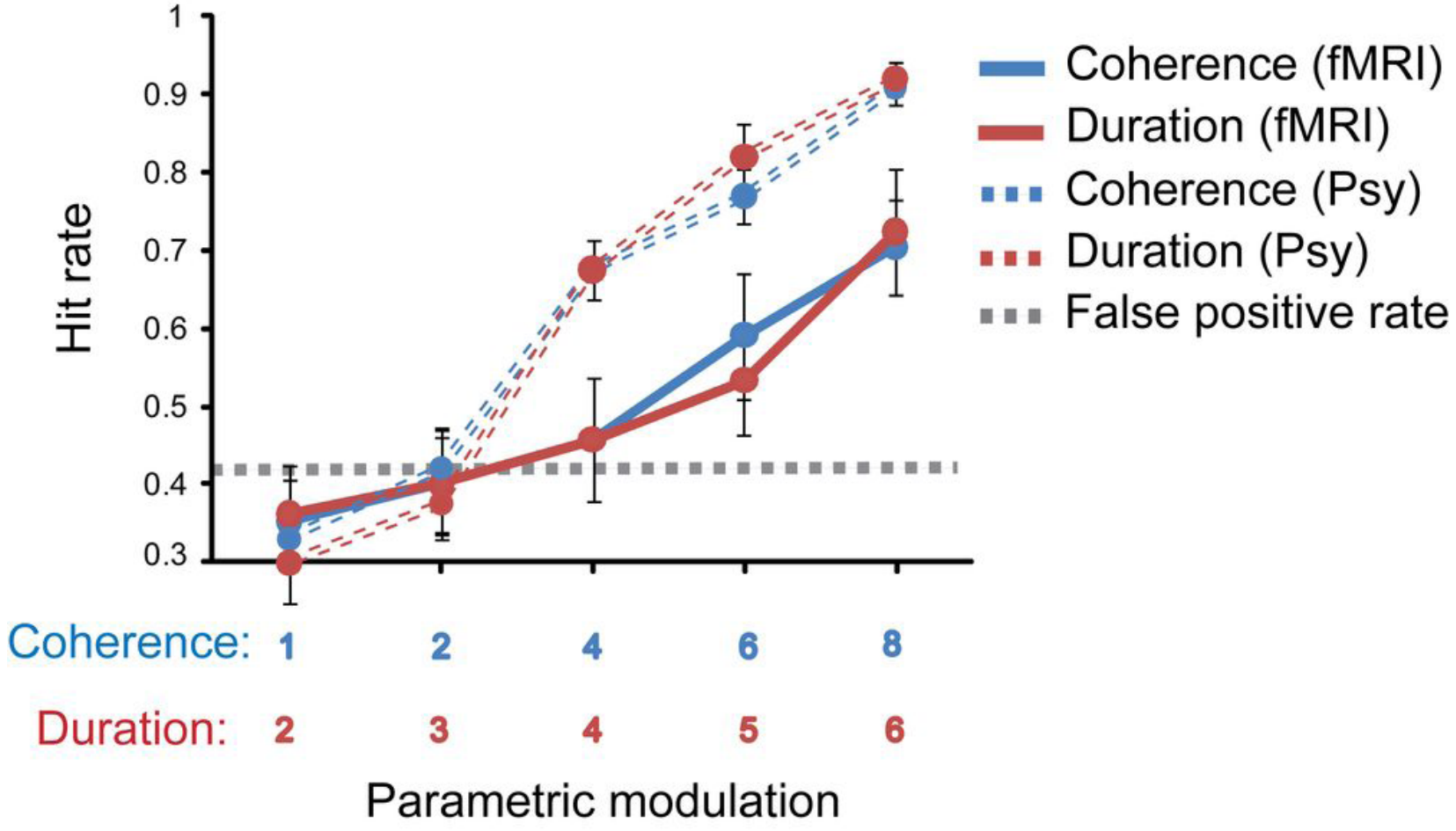
Paradigm:

i. Passive listening

ii. Active detection

- 3 Tesla Siemens Allegra MRI Scanner
- Continuous scanning
- 42 contiguous slices per volume
- TR: 2.52 s; TA: 2.88 s; TE: 30 ms
- Slice thickness: 2 mm with 1mm gap between slices
- In-plane resolution: 3.0 x 3.0 mm^2
- 3 scanning sessions: 510 volumes per subject

Behaviour in scanner



fMRI design

Figure (fixed coherence)

Figure (fixed duration)

Background

Decoy

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

- **Subjects were not actively detecting figures**

fMRI analysis

- 14 subjects (normal hearing, no audiological disorders)
- Standard pre-processing with SPM8
- Whole brain analysis
- Statistical model based on General Linear Model
- Random effects design

Parametric Modulation:

I. Effect of Duration: Fixed coherence (4); varying duration (2-7)

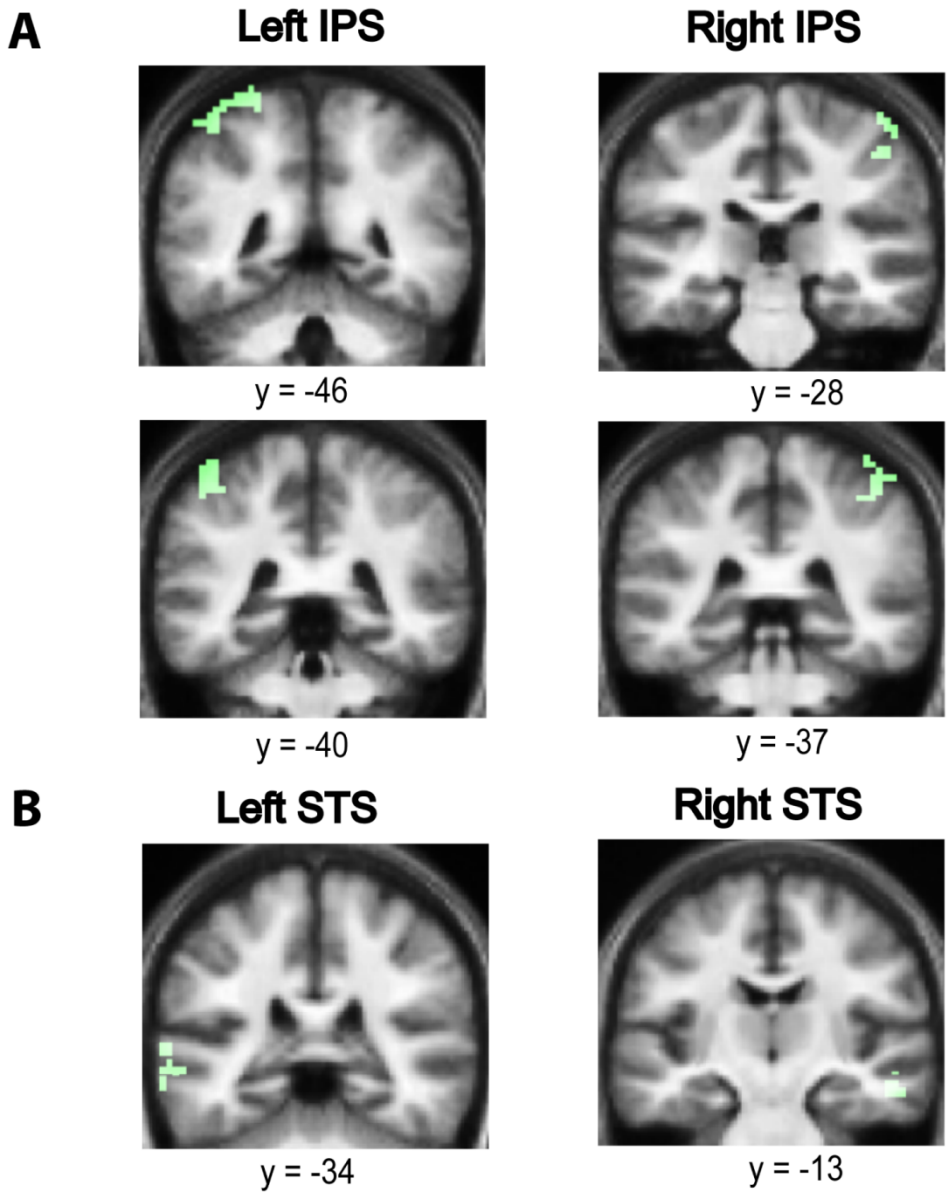
II. Effect of Coherence: Fixed duration (4); varying coherence (1,2,4,6,8)

fMRI Results

I. Effects of Duration:

Intraparietal Sulcus (IPS)	(bilateral; anterior)
Superior Temporal Sulcus (STS)	(bilateral)
Planum Temporale	(R)
Medial Geniculate Body (MGB)	(bilateral)

Effects of Duration



fMRI Results

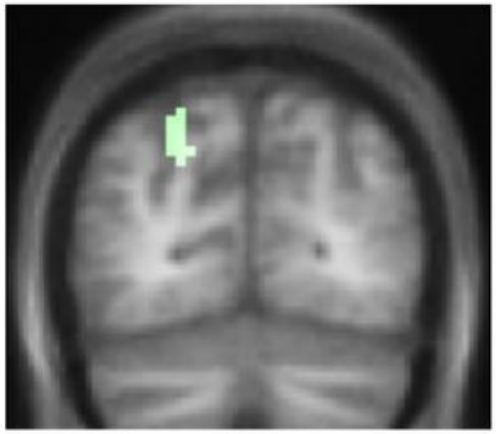
II. Effects of Coherence:

Intraparietal Sulcus	(bilateral; posterior)
Superior Temporal Sulcus	(bilateral)

Effects of Coherence

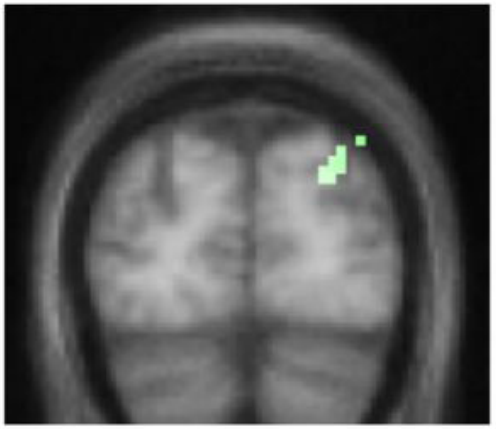
A

Left IPS



y = -73

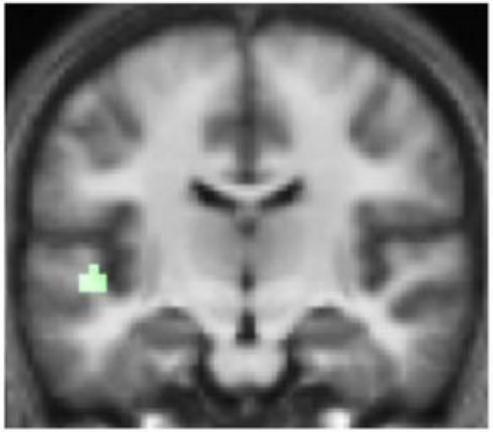
Right IPS



y = -82

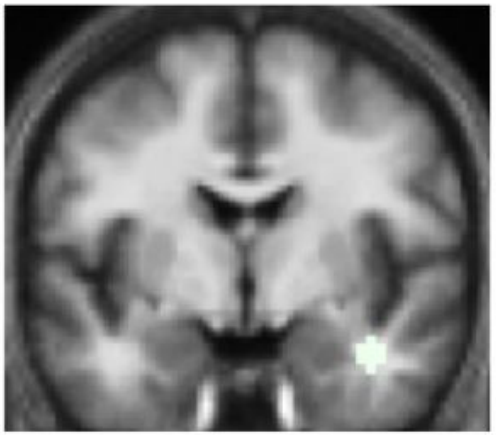
B

Left STS



y = -16

Right STS



y = -4

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 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***

fMRI 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?
- Is IPS causally responsible for segregation?

Teki, Chait et al., J Neurosci (2011)

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Psychophysics

Aims:

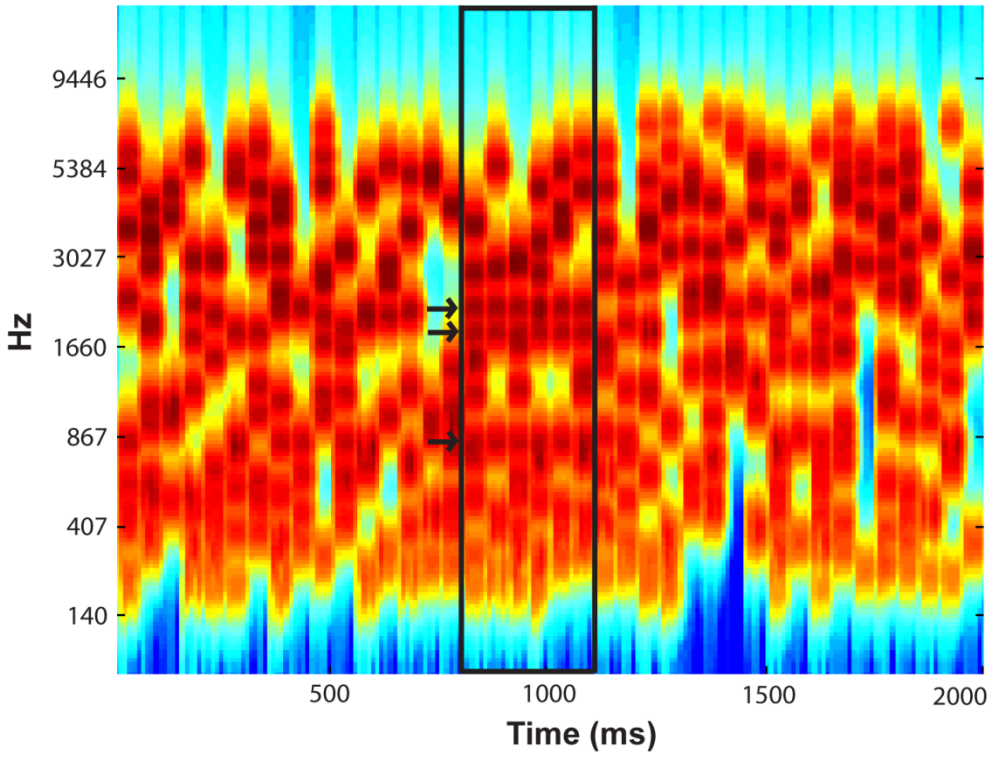
- To characterize the brain mechanisms that underlie complex figure-ground segregation through systematic manipulations of the SFG stimulus

- To examine sensitivity to figures by introducing systematic perturbations

- Test role of adaptation in mediating segregation in our complex stimulus

Expt. 1: ‘Baseline’ (50 ms)

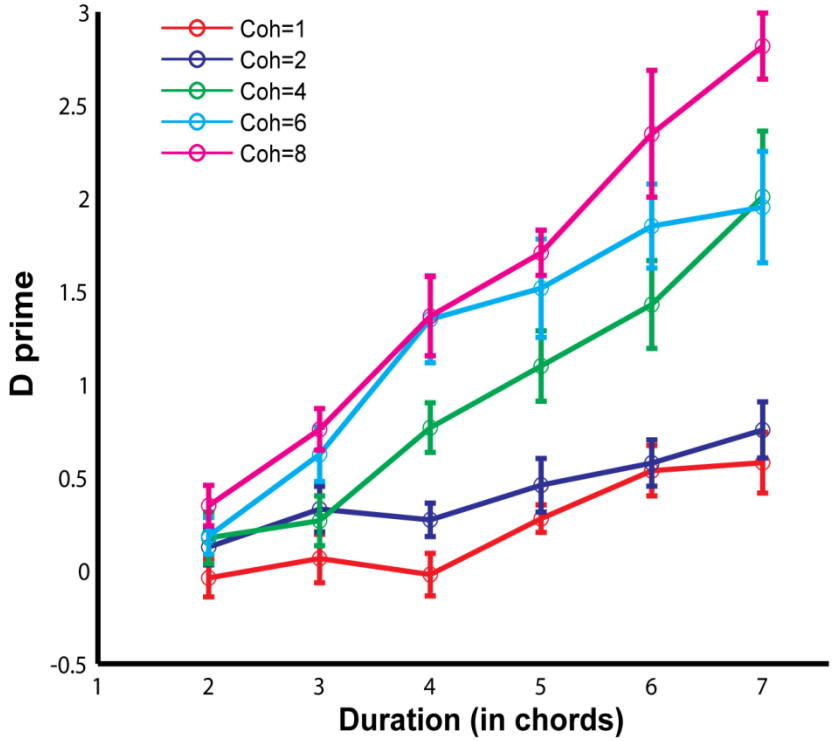
Stimulus consisted of a sequence of 40 x 50ms chords (2 s long)



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

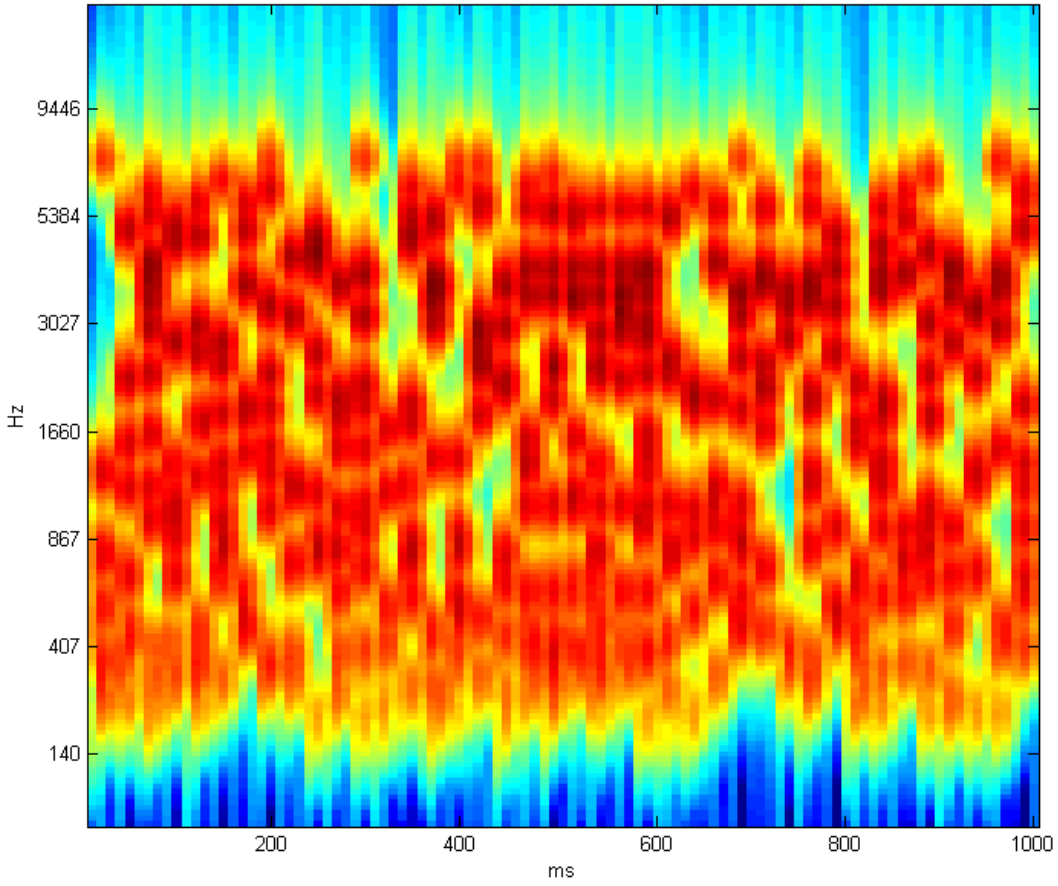
Expt. 1: Results

(n=9)



Expt. 2: ‘Baseline’ (25 ms)

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

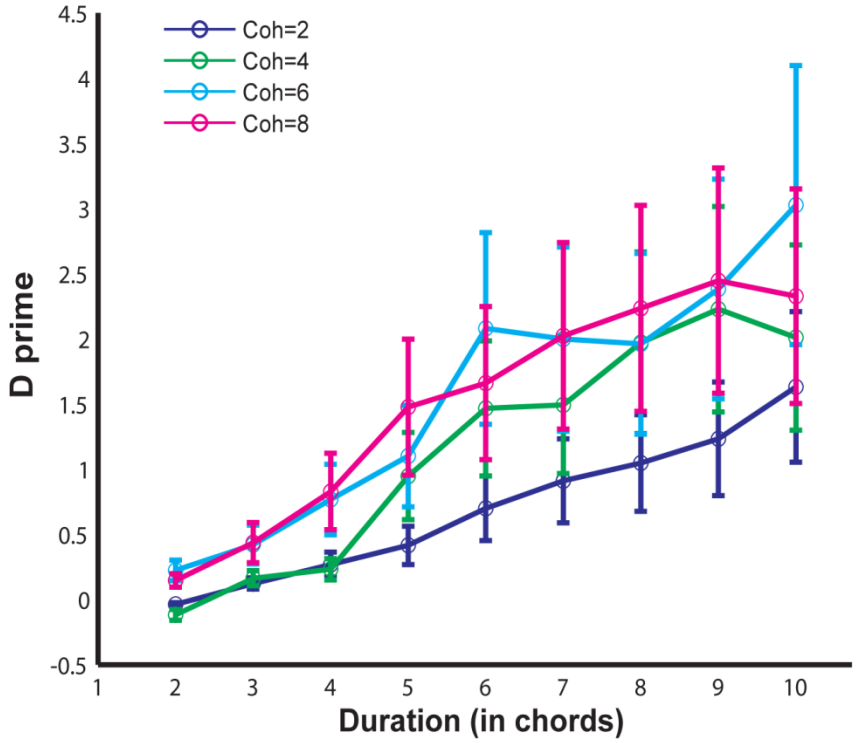


Coherence: [2 4 6 8]

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

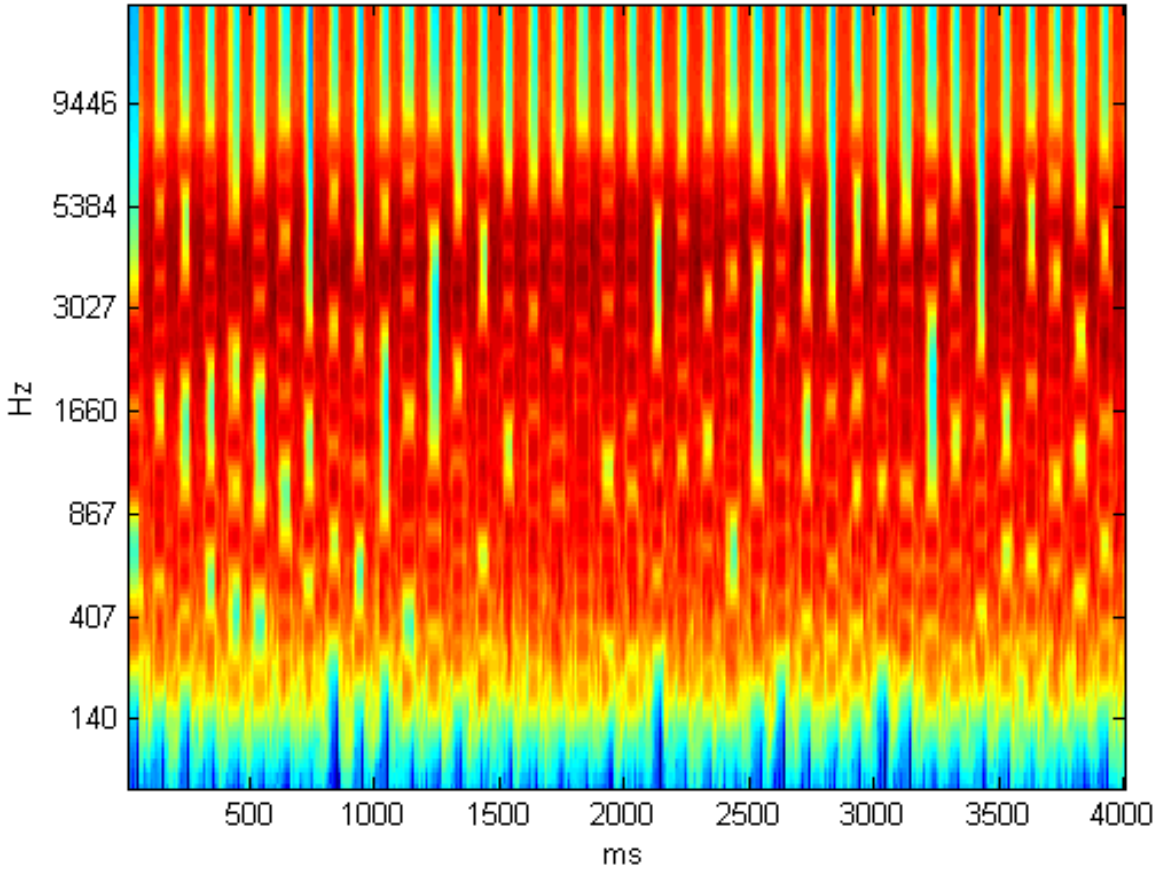
Significant effect of coherence: $F(3, 45) = 77, p < 0.001$

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)

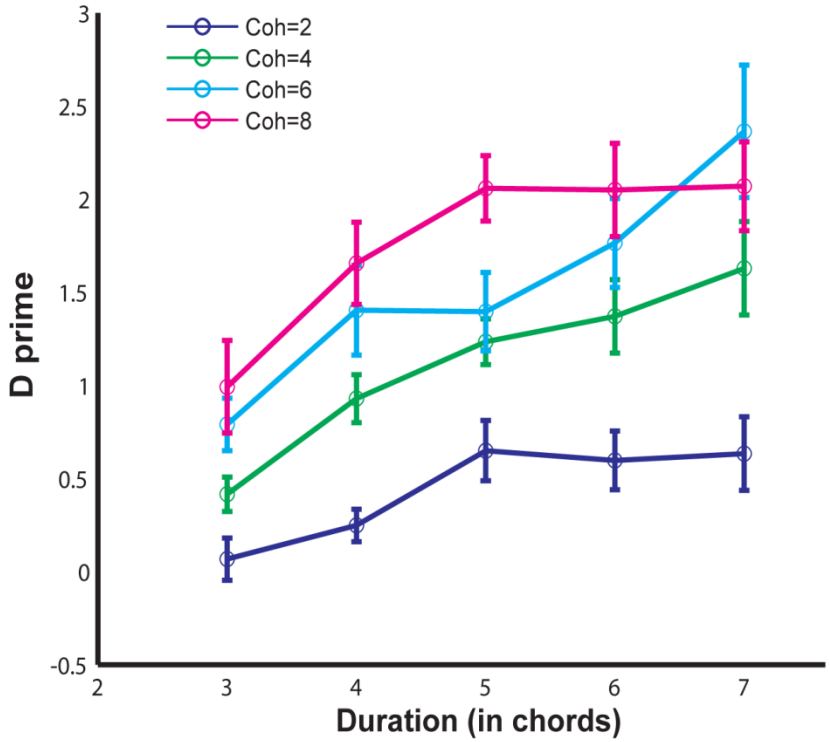


Coherence: [2 4 6 8]

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

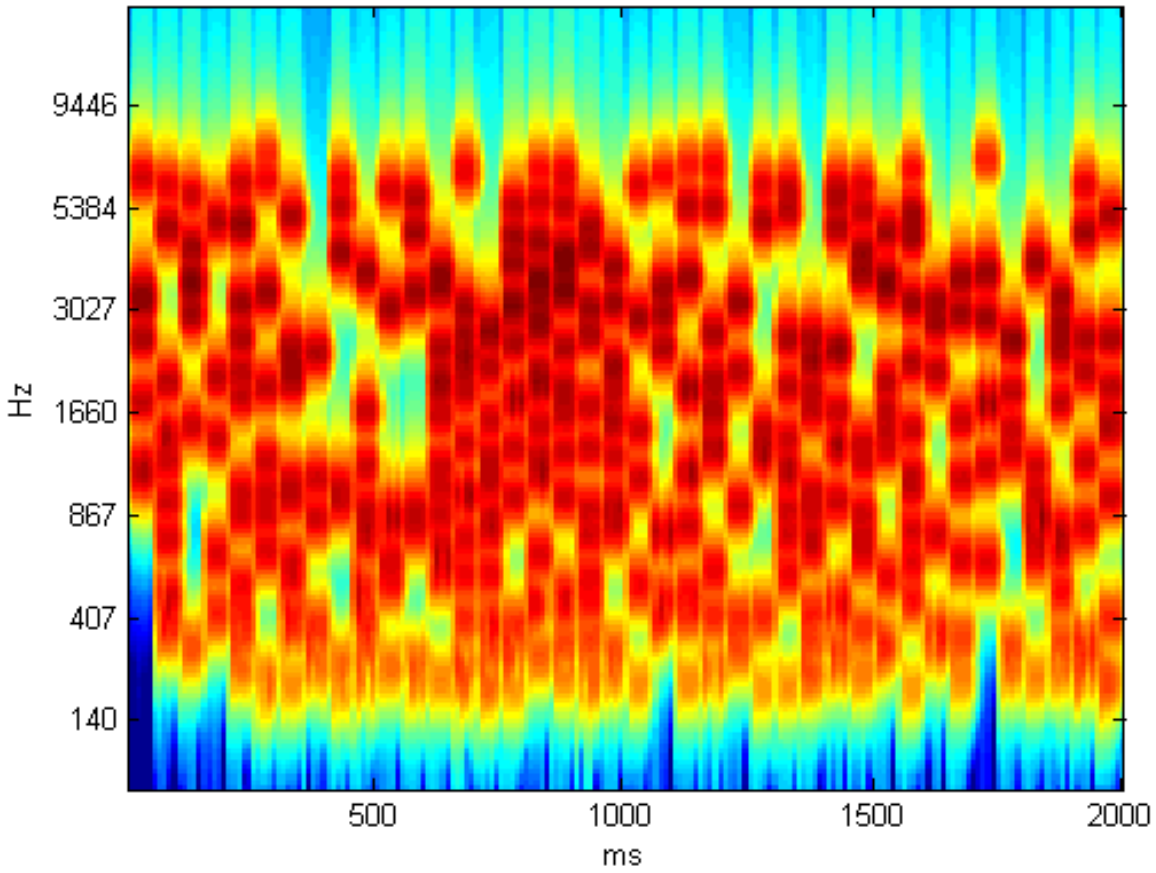
Significant effect of coherence: $F(3, 51) = 23, p < 0.001$

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’

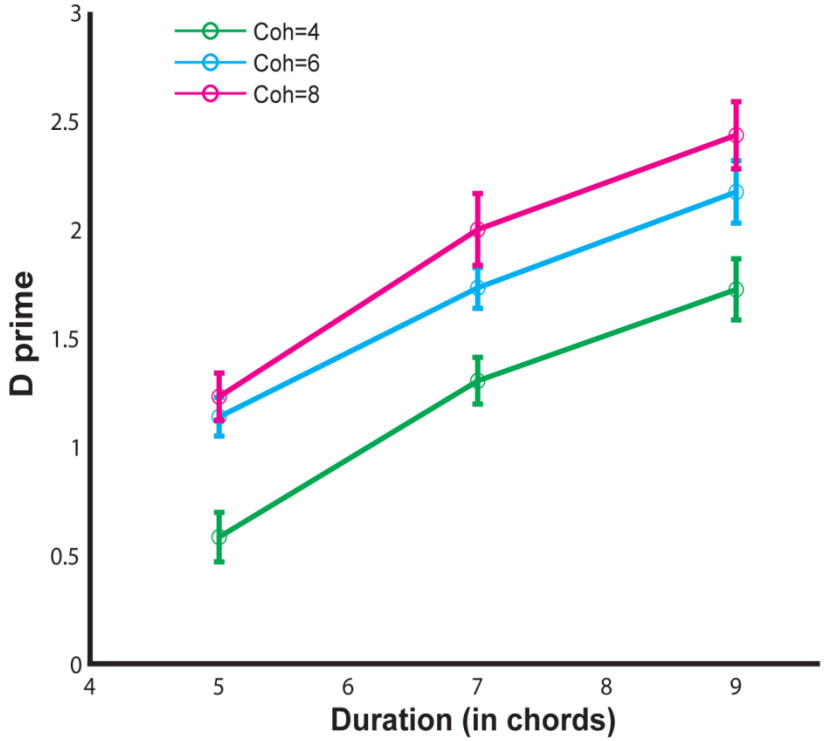
Stimulus: Figures were ramped (successive figure components were not repeating but increasing in frequency in steps of 2*l* or 5*l*, where *l* = 1/24 of an octave is the resolution of our frequency pool; ramps within critical band)



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

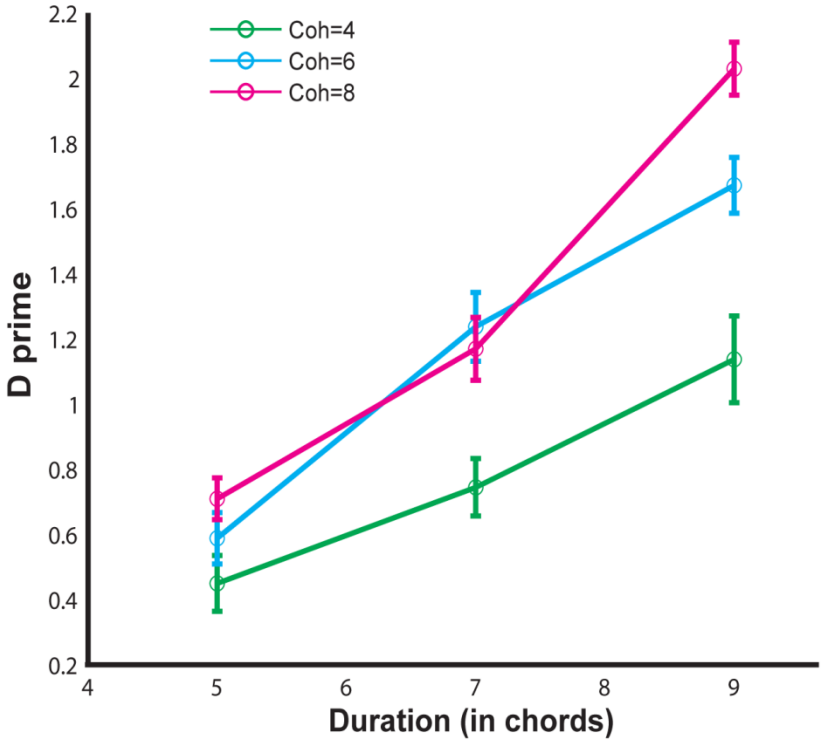
Results: Ramps 2

(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

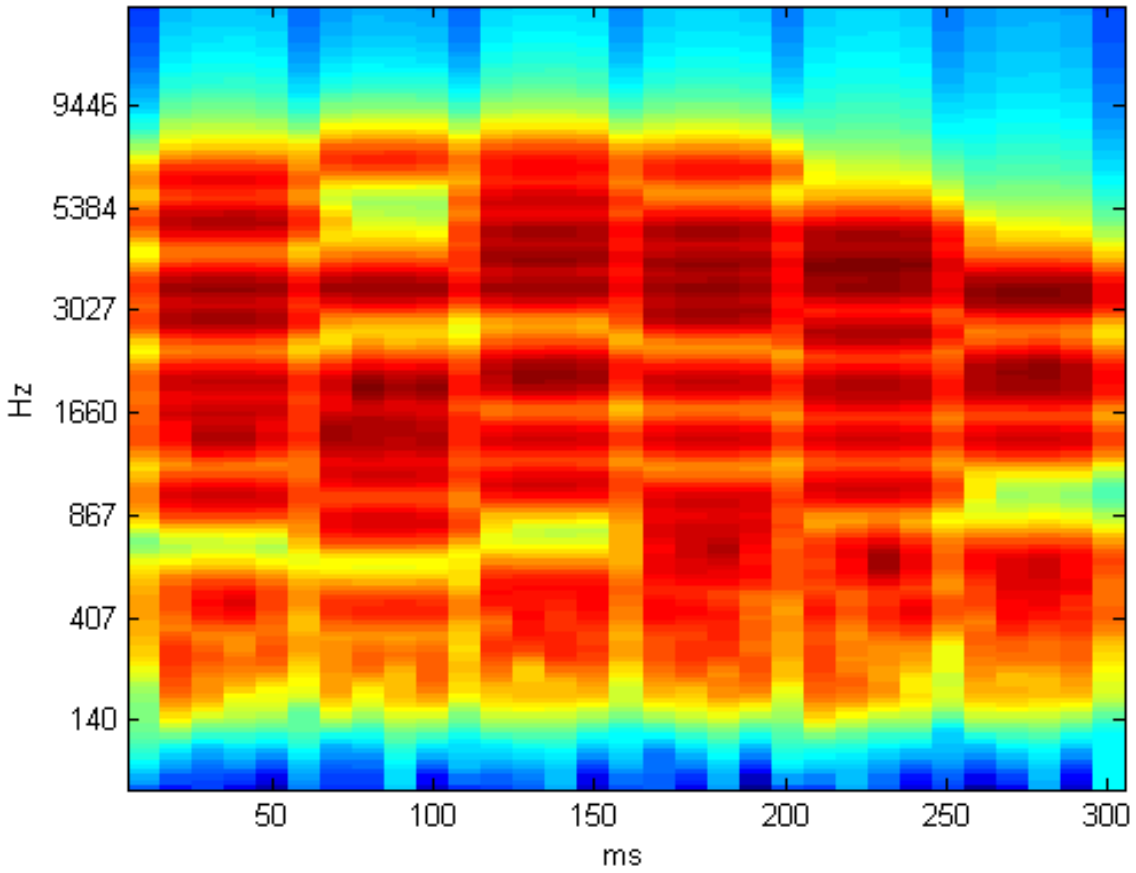


Figure:

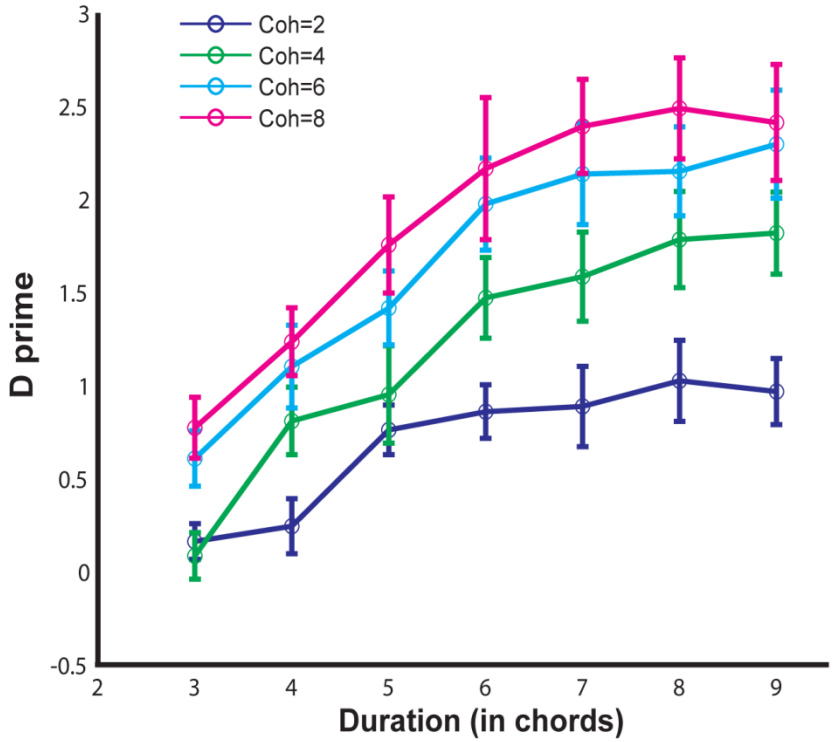
Ground:

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: $F(1,16) = 0.033, p = 0.859$

Psychophysics summary

Figure-detection performance in complex SFG stimulus 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)

And Shihab was cruelly denied his coffee...!

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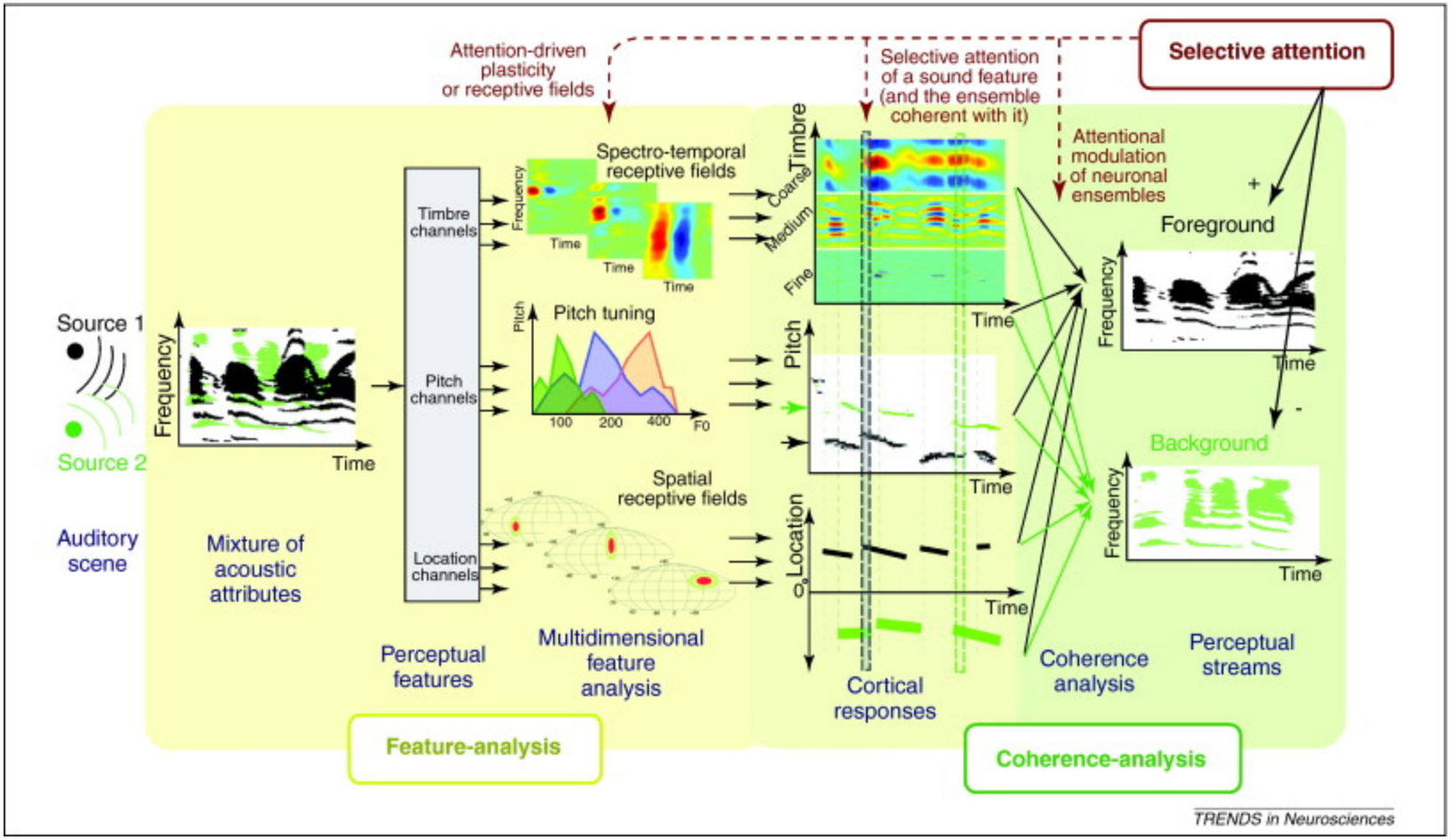
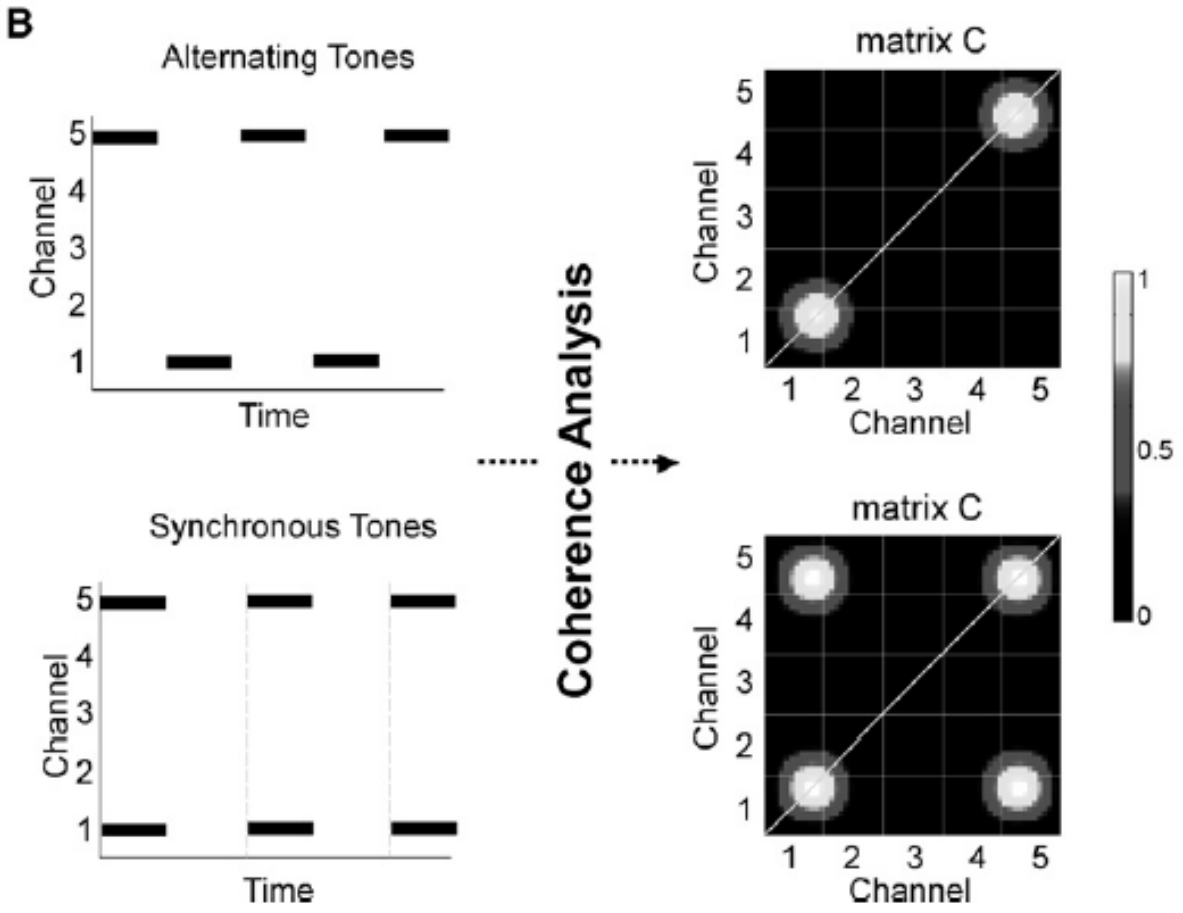
- Psychophysics
- **Temporal coherence model**
- **Summary**

Temporal coherence model



(Chi et al., 2005; Elhilali et al., 2009; Shamma et al., 2011)

Temporal coherence model



(Elhilali et al., 2009)

Temporal coherence model

The temporal coherence model incorporates two different stages:

i. Feature analysis: -> multi-rate, multi-scale spectrotemporal receptive fields

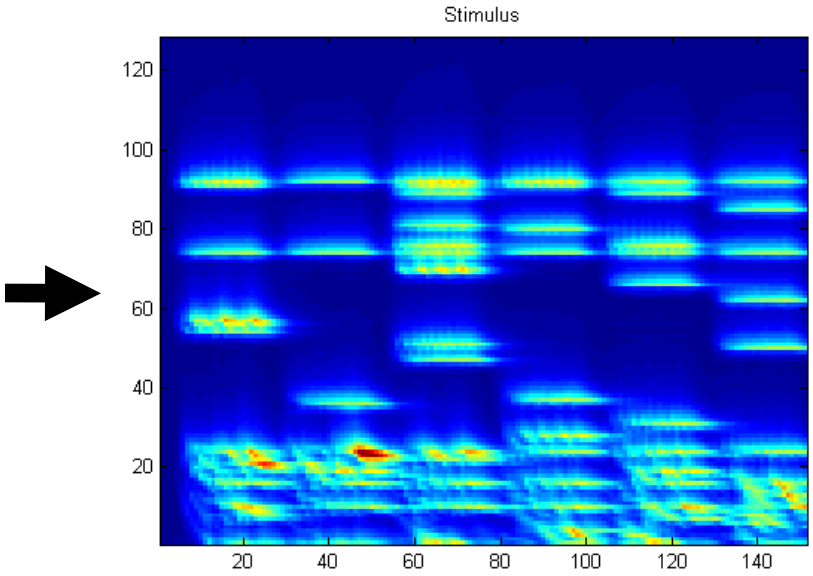
ii. Coherence analysis: -> dynamic coherence matrix

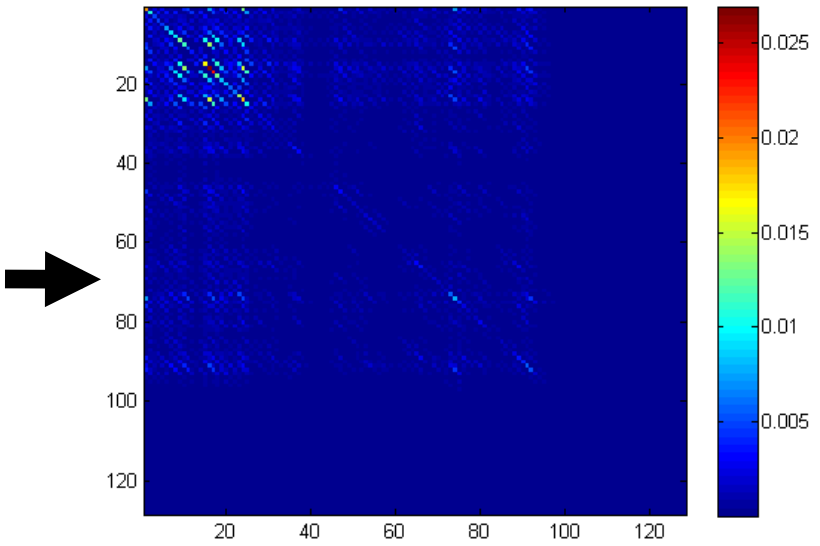
Analysis:

- **Parameters:** temporal modulation rate of 20 Hz, and bandwidth of 24 ch/octave
- **Input:** 1000 different examples of figure and ground stimuli for each (coh, dur)
- **Measure:** Average of maximum cross-correlation value for each stimulus
- **Output:** Average cross-correlation (figure) - Average cross-correlation (ground)

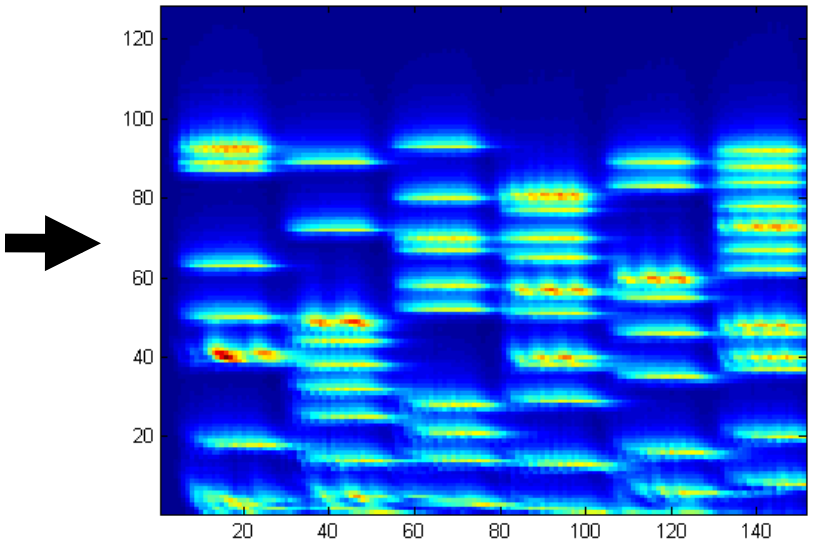
Isolated: expt. 5

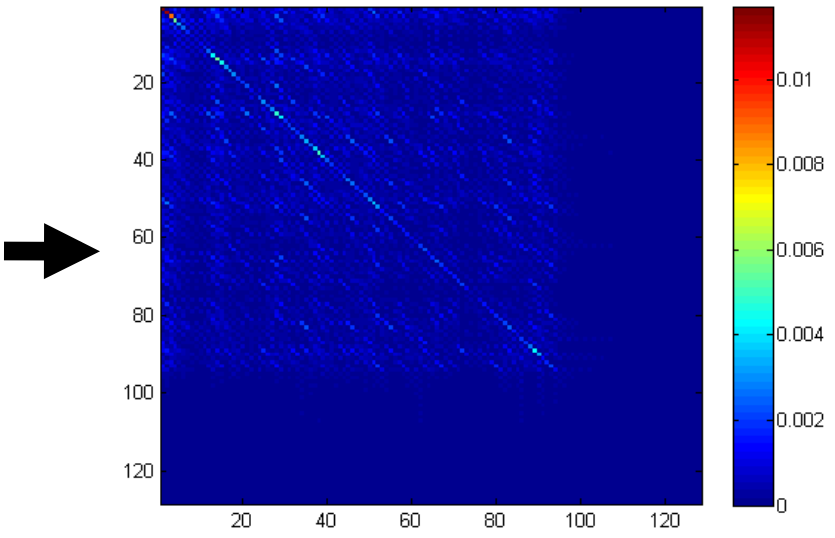
FIGURE





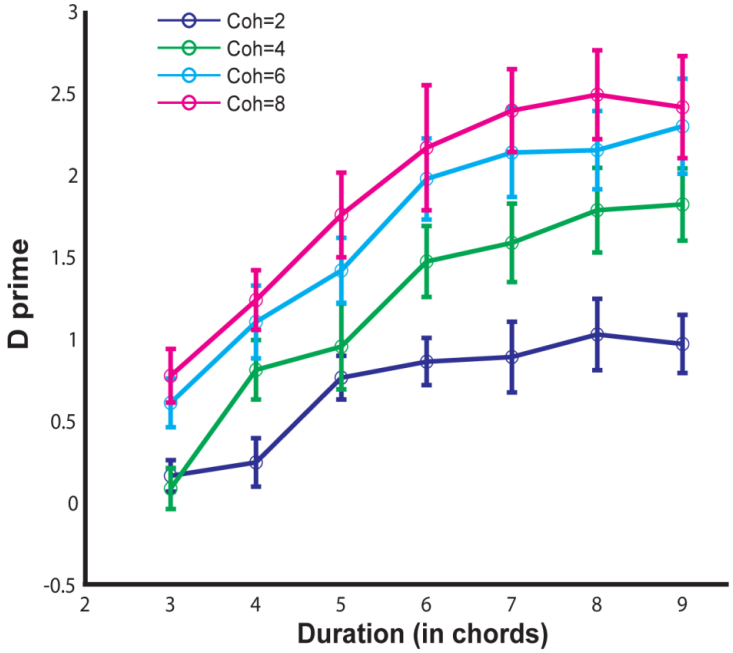
GROUND

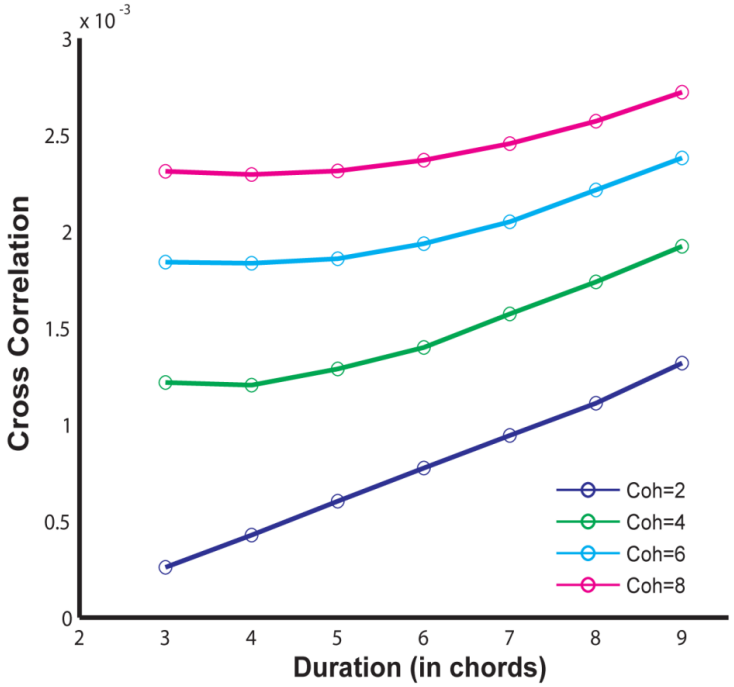




Expt. 5: Isolated

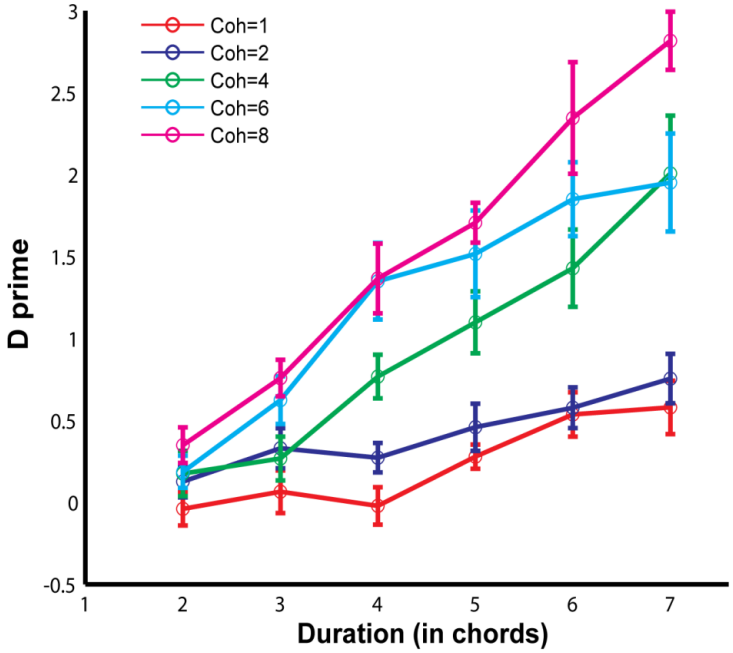
sv=24 Hz, rv=20 Hz

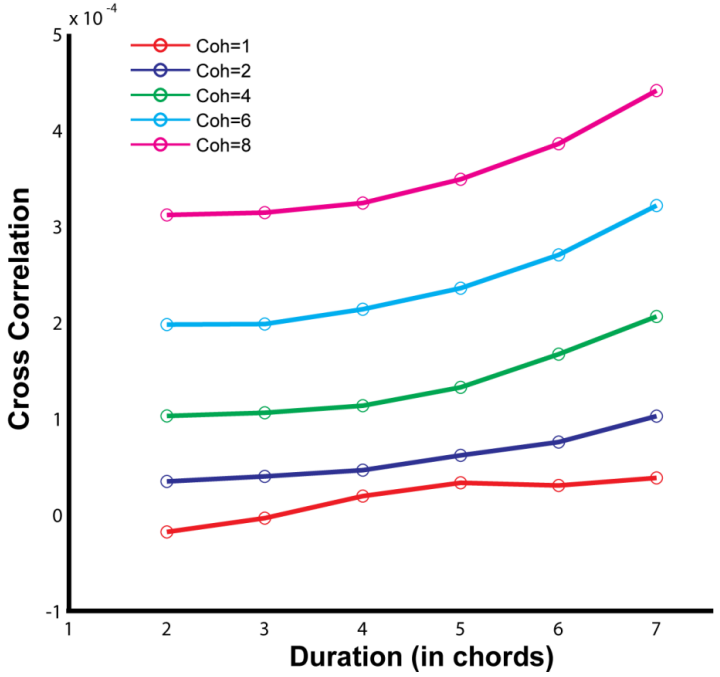




Expt. 1: Baseline (50 ms)

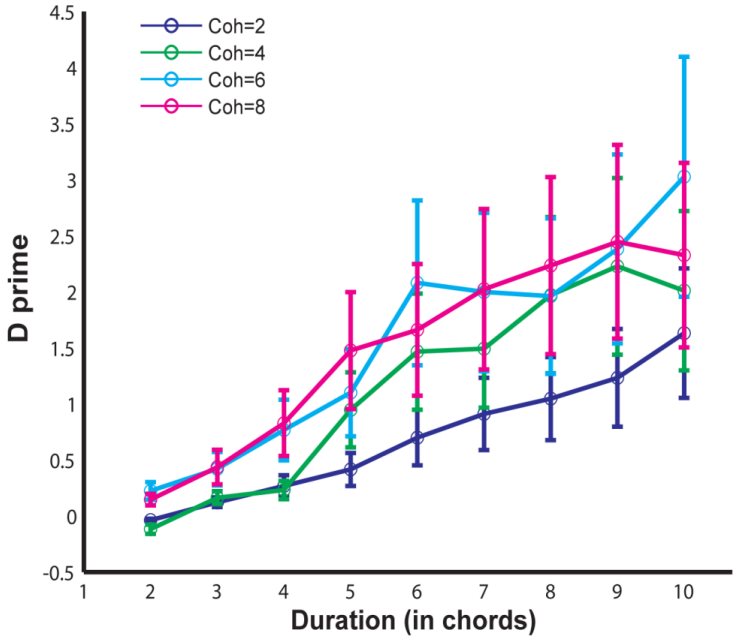
sv=24 Hz, rv=20 Hz

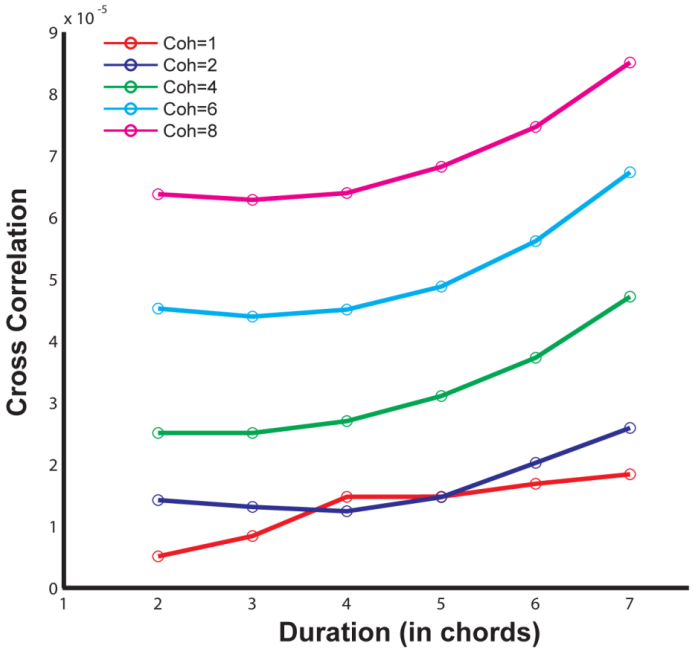




Expt. 2: Baseline (25 ms)

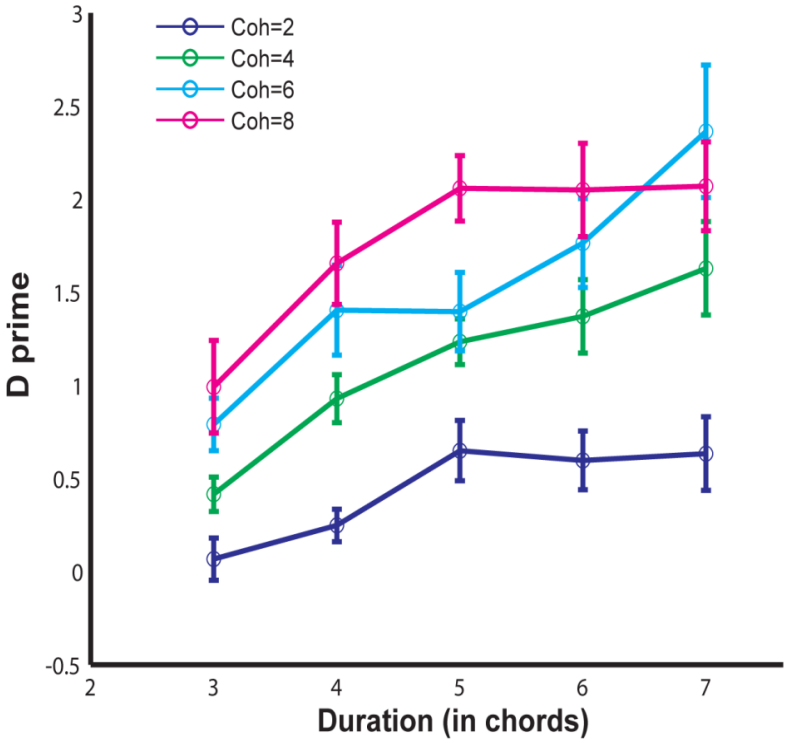
sv=24 Hz, rv=40 Hz

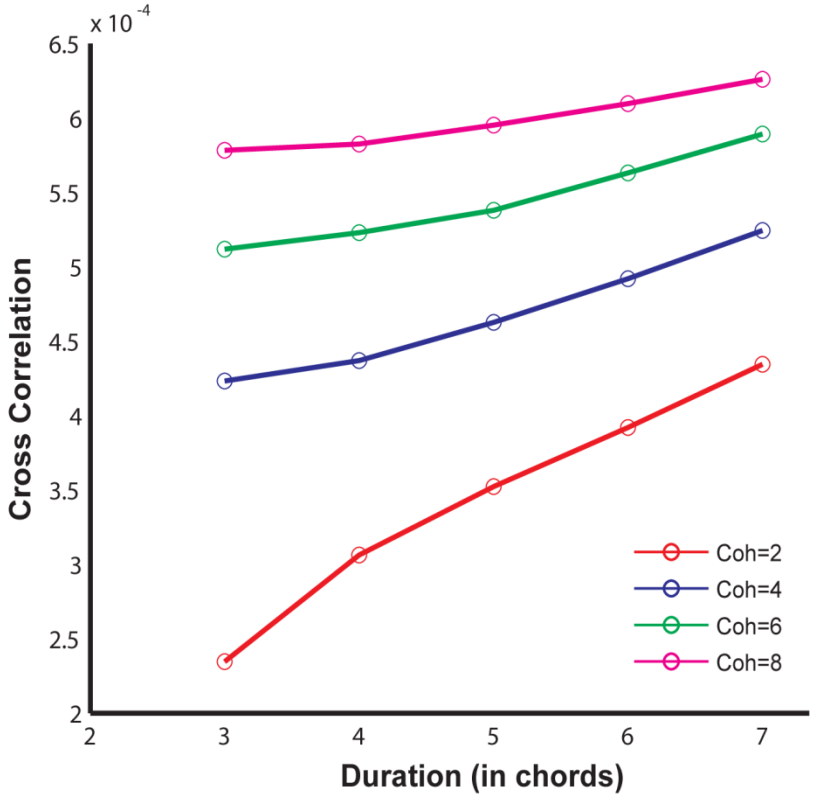




Expt. 3: SFG/Noise

sv=24 Hz, rv=20 Hz





Modelling summary

- Temporal coherence model can explain figure-detection in complex SFG stimulus for each psychophysics experiment.

- Model performs better than humans even at very short durations of the figure

- Auditory segregation in complex acoustic scenes may be based on computation of cross-channel coherence.

Outline

- Introduction
- Figure-ground stimulus
- fMRI study
- Psychophysics
- Temporal coherence model
- **Summary**

General summary

- **SFG stimulus:**
  Listeners can segregate figure from ongoing background very well.

- **fMRI:**
  Areas outside the auditory system, such as IPS are involved in segregation in complex acoustic scenes

- **Psychophysics:**
  Adaptation is not critical for complex auditory segregation.

- **Temporal coherence model:**
  Can explain figure-ground segregation in complex acoustic scenes.

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wellcome trust


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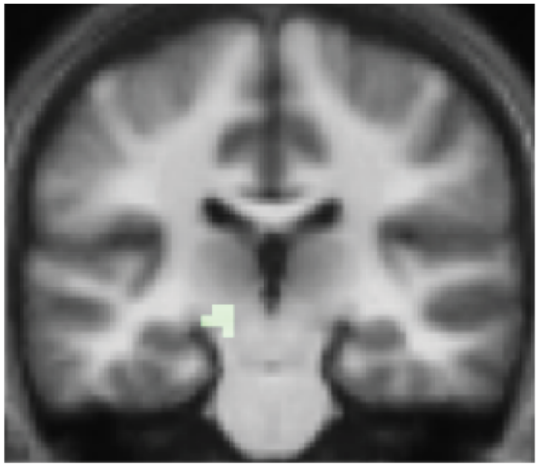
Questions ?

Table 1. Stereotactic MNI-coordinates

Contrast	Area	x	y	z	t	z
Effects of duration	Left IPS	-42	-46	64	5.14	3.67
		-48	-40	61	4.89	3.56
	Right IPS	51	-28	61	5.17	3.68
		45	-37	64	4.24	3.25
	Left STS	-57	-34	-2	4.42	3.34
	Right STS	60	-13	-11	4.06	3.16
	Right PT	60	-13	10	4.96	3.59
	Left MGB	-15	-25	-8	4.85	3.54
	Right MGB	18	-25	-8	4.92	3.57
Effects of coherence	Left IPS	-21	-73	46	4.99	3.60
		-24	-73	37	4.36	3.31
	Right IPS	27	-82	31	3.69	2.96
	Left STS	-48	-16	-5	3.43	2.81
	Right STS	39	-4	-26	3.77	3.00

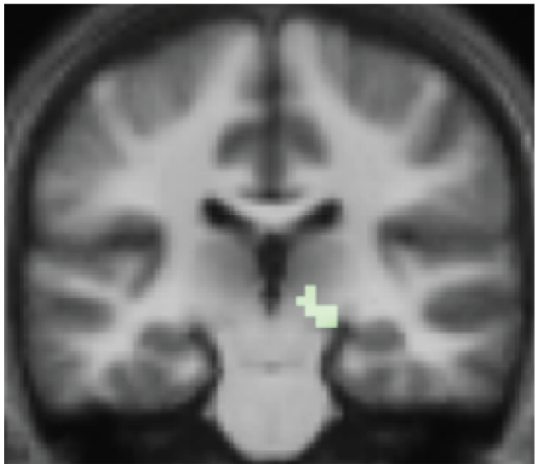
Local maxima for effects of duration, coherence as well as combined effects of duration and coherence are shown. Results are thresholded at $p<0.001$ (uncorrected)

Left MGB



y = -40

Right MGB



y = -37