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Temporal Integration of Olfactory Perceptual Evidence in Human Orbitofrontal Cortex

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Smells Like Teen Spirit

Humans' bad odour discrimination put at use

Loïc Matthey

Tea Talk n°10

13th September 2012

Introduction

- Temporal evidence integration
  - Good strategy under noisy perception
  - Well-studied in animals, e.g. monkeys, visual system
    - Random-dot task
    - Drift Diffusion Model
  - What about other senses, what about humans?
- This paper:
  - Tests olfactory integration
  - Finds fMRI correlates of DDM-like ramping activity in humans

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“Temporal Integration of Olfactory Perceptual Evidence in Human Orbitofrontal Cortex”
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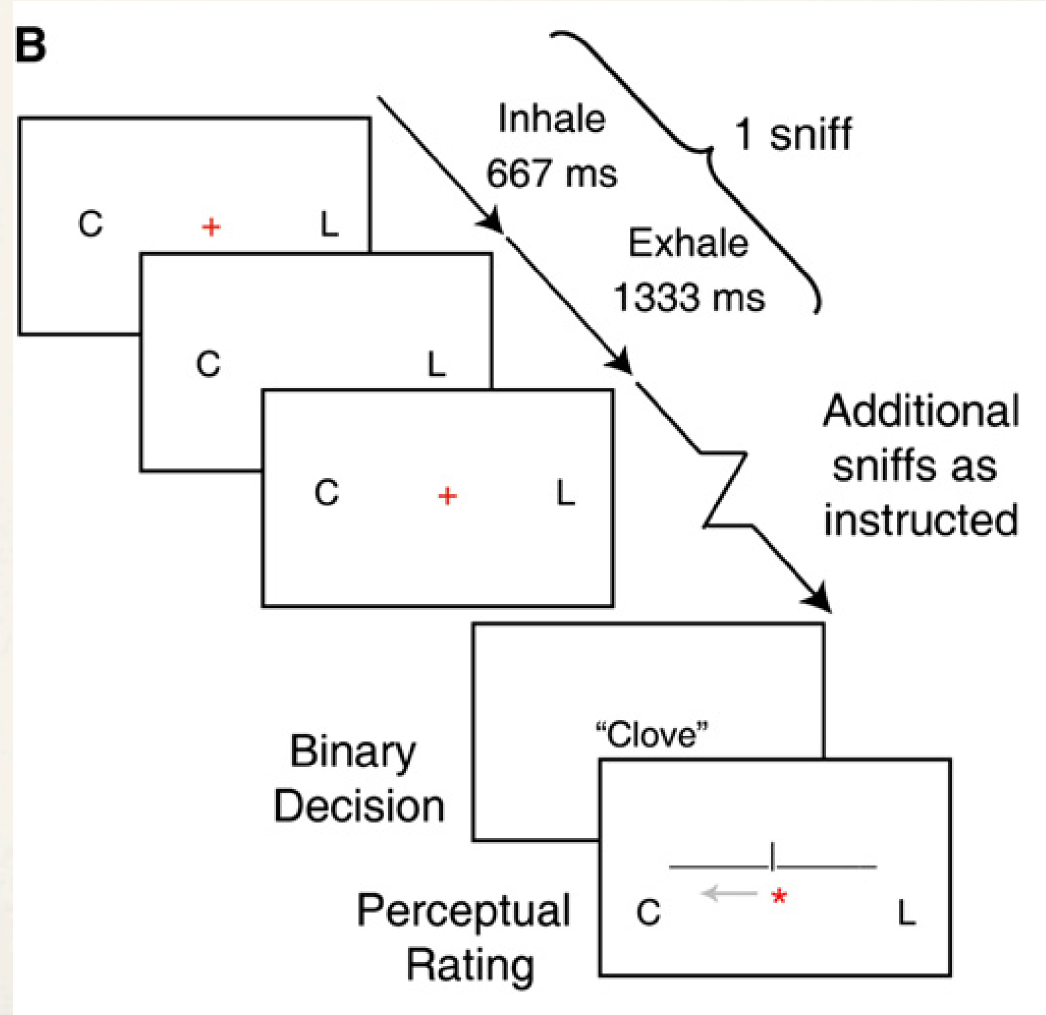
Paper construction

- Verify that odour identification is temporally integrated
- A DDM model is a good fit to observed RTs
- Look for brain regions showing integration-like responses, with fMRI
  - Human olfactory perception slow, especially for mixtures: able to see the signal using fMRI!

Odour discrimination

- Identify dominant odour in mixture
  - Two alternative forced-choice discrimination
  - eugenol (“clove”) vs citral (“lemon”)
    - matched for perceived intensity
    - 8 channels air-dilution olfactometer
    - control proportion each channel contributing to airflow
  - 10 participants
- If integration, more sniffs => better performance

% Lemon	0	12.5	25	37.5	50	62.5	75	87.5	100
% Clove	100	82.5	75	62.5	50	37.5	25	12.5	0



Odour discrimination

- Two blocks of trials
  - "Fixed-sniff"
    - cued, 1-3 sniffs
  - "Open-sniff"
    - As many as needed to make confident decision
  - Binary decision
    - (also ask for perceptual rating but not used in results)
  - 18 s between trials, 144 trials total
  - No feedback

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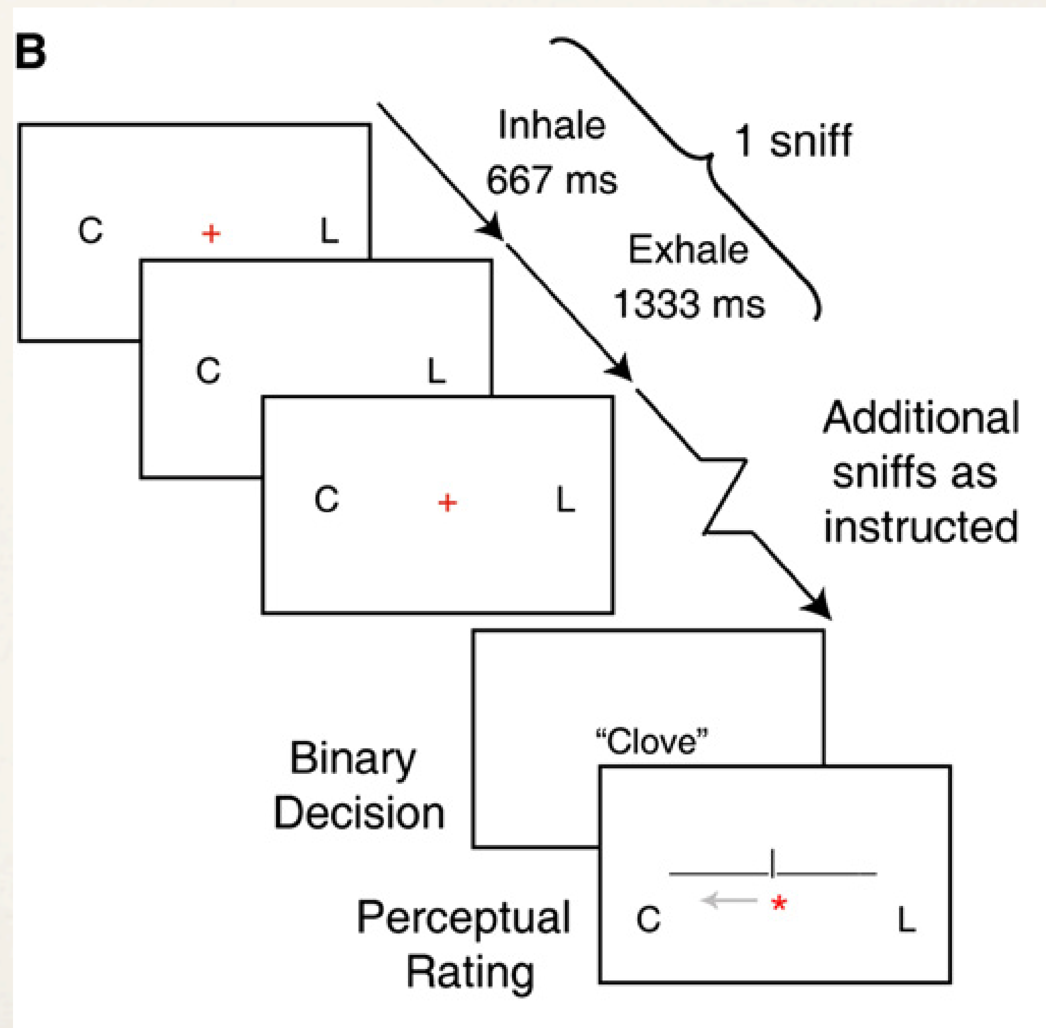
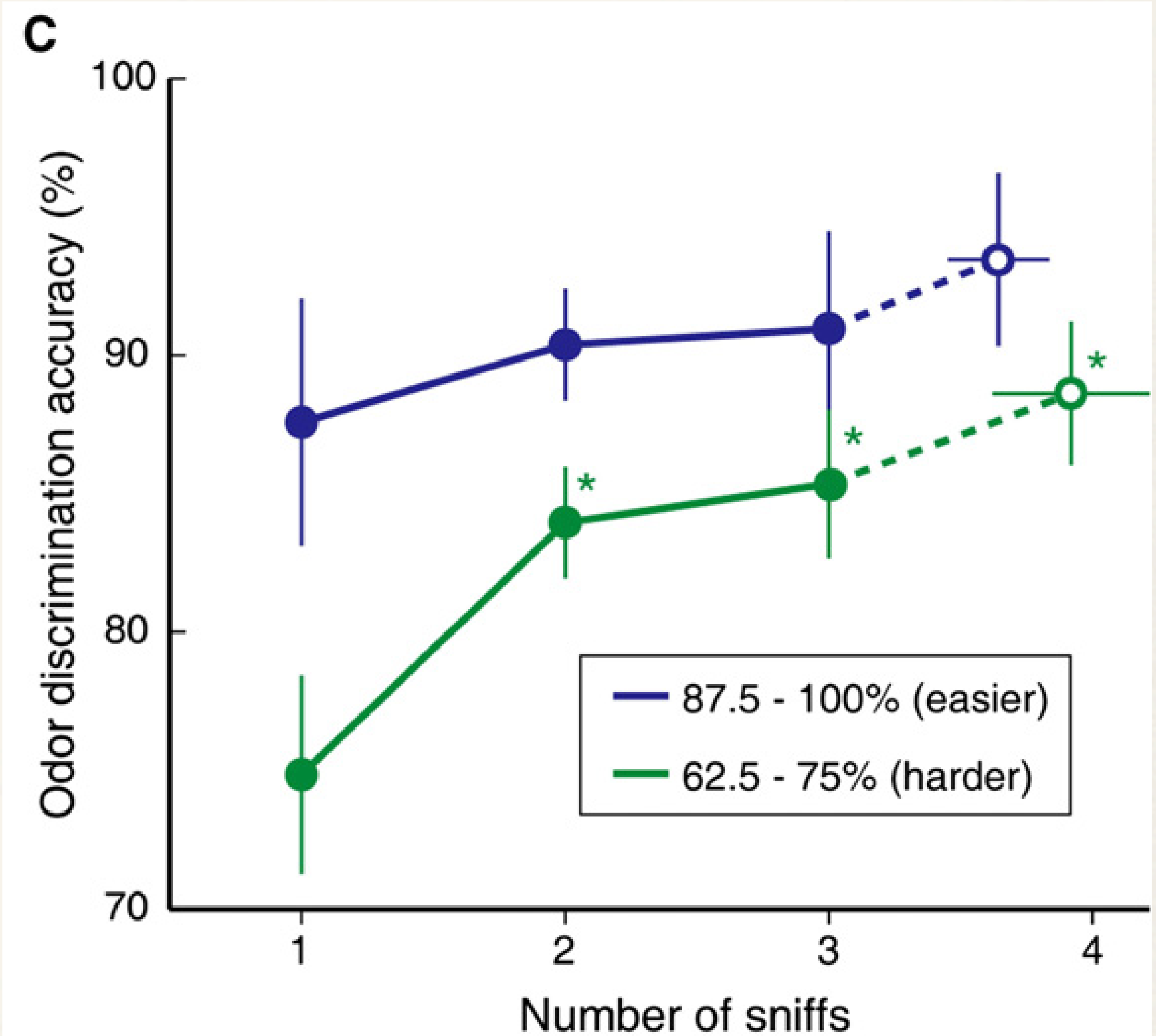


Odour discrimination

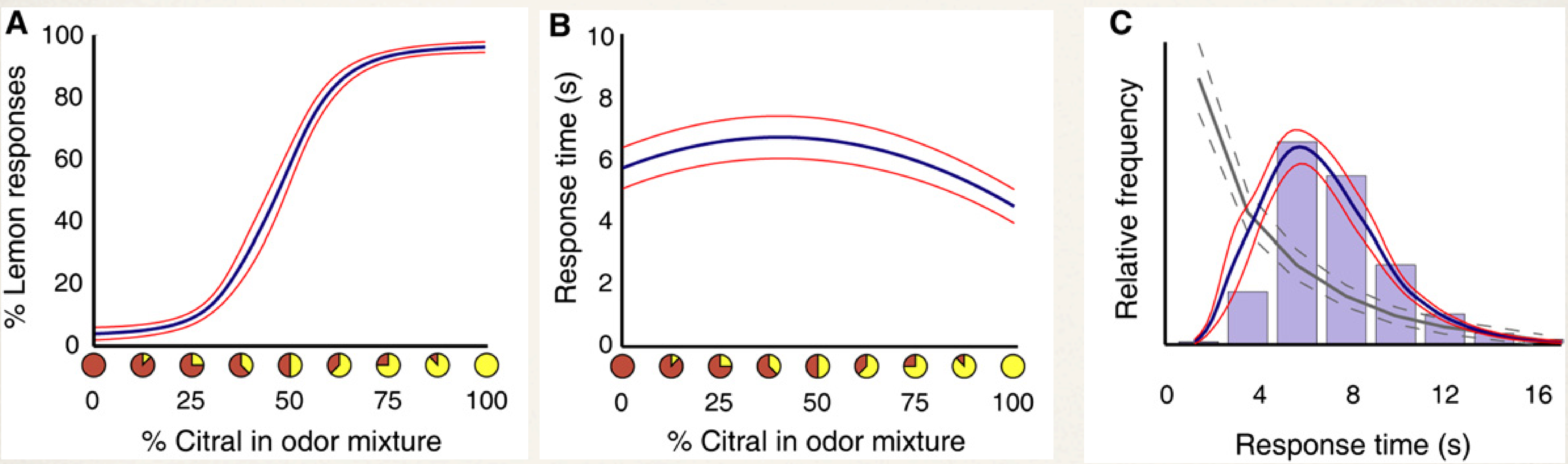
- Results
  - Accuracy improvement with number of sniffs
  - Depends on mixture difficulty



*p < 0.05

Odour discrimination

- Results
  - Psychophysical data
  - Consistent with Drift-Diffusion Model



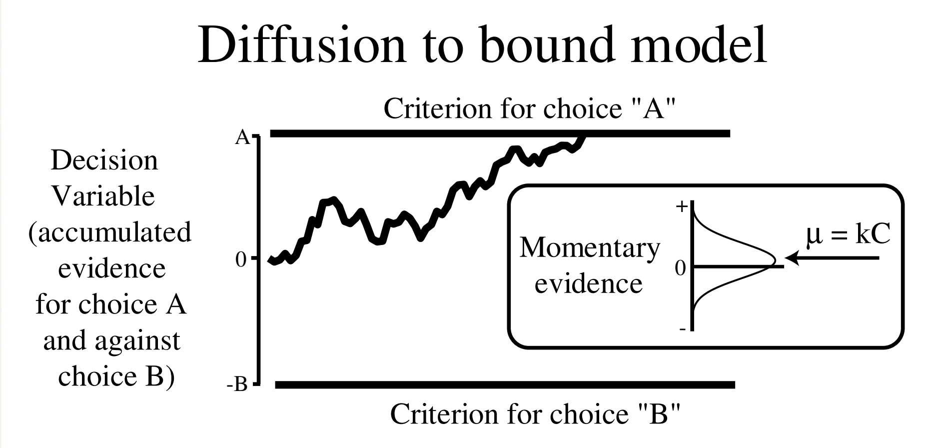
DDM

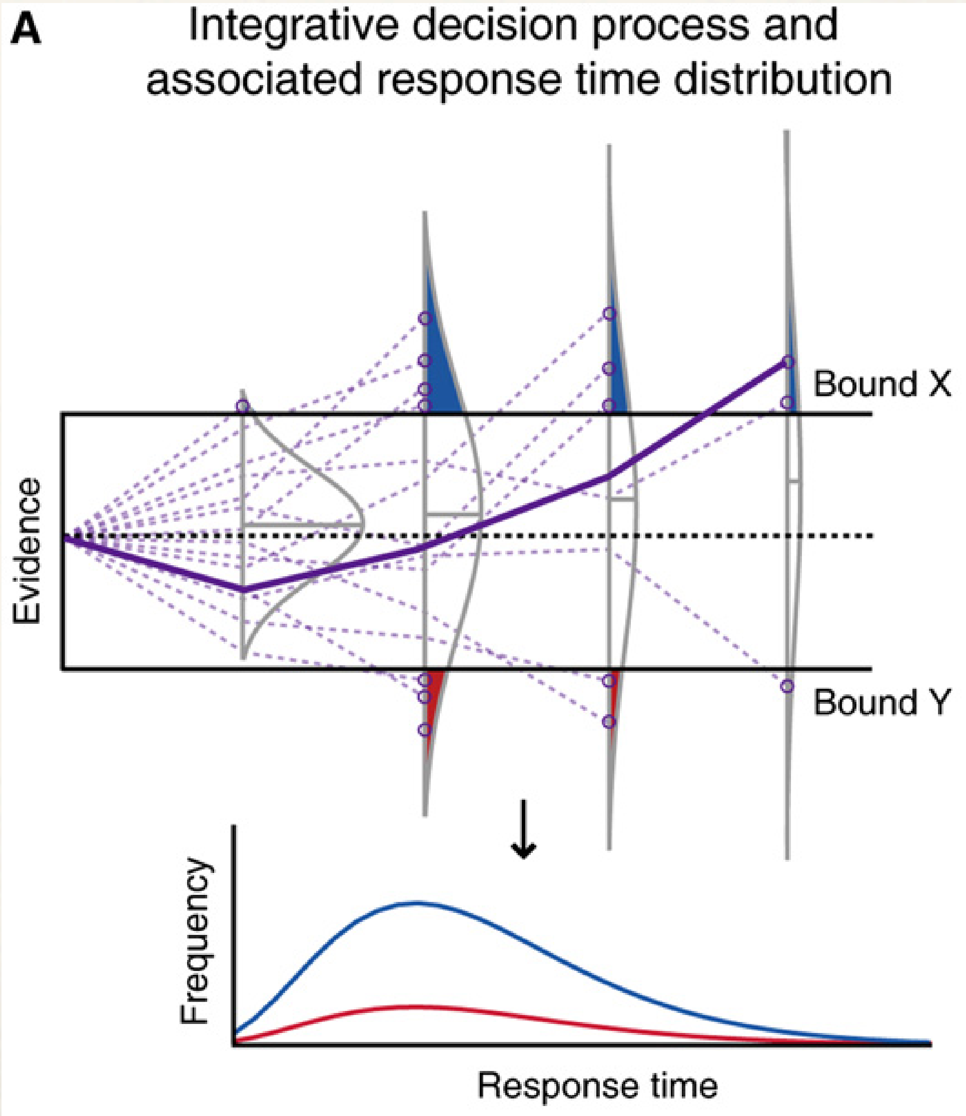
- Drift-diffusion model
  - Simple 1D model of evidence integration

$$dx = Adt + cdW, \quad x(0) = 0$$

  - x: accumulated evidence.
    - Positive: towards choice A
    - Negative: towards choice B
  - A: drift term, "momentary evidence" biased towards A or B for a given trial.
  - Noise: $dW \sim N(0, c^2\, dt)$
  - Easy to solve for distribution, error rates and response times

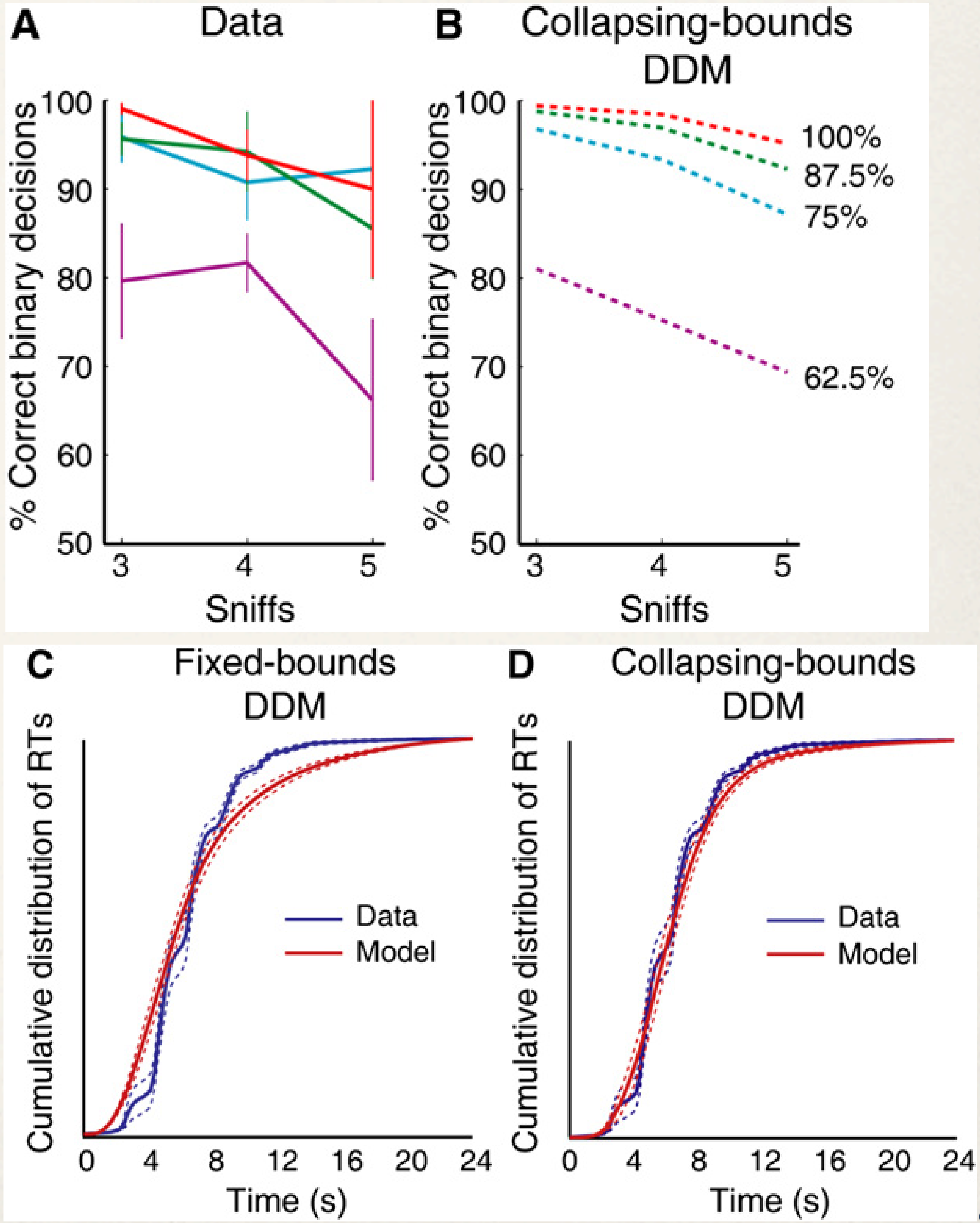
$$p(x,t) = N(At, c\sqrt{t})$$

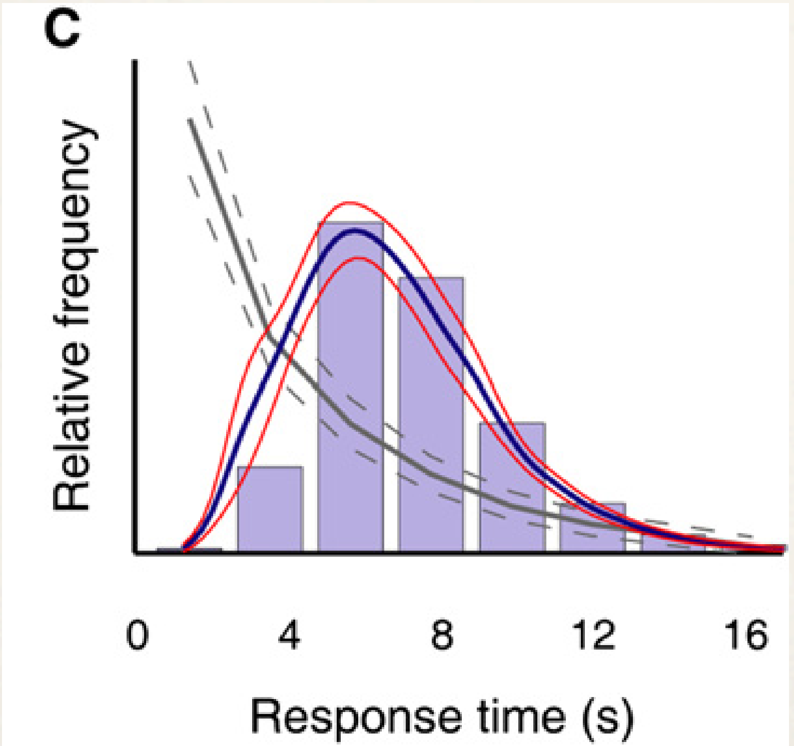




Match with DDM

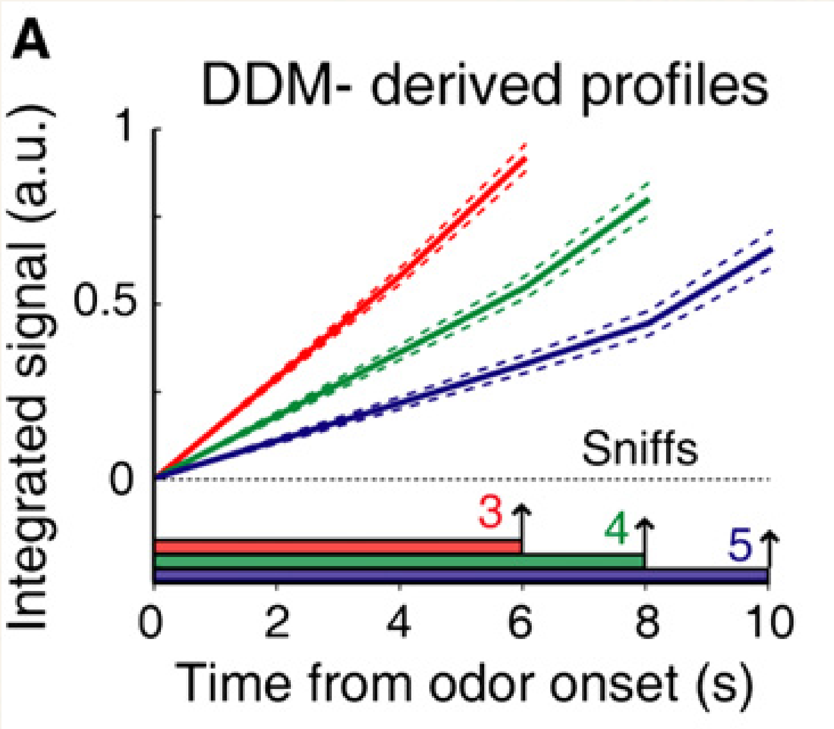
- RTs correspond to DDM
- Collapsing-bounds DDM actually better fit.





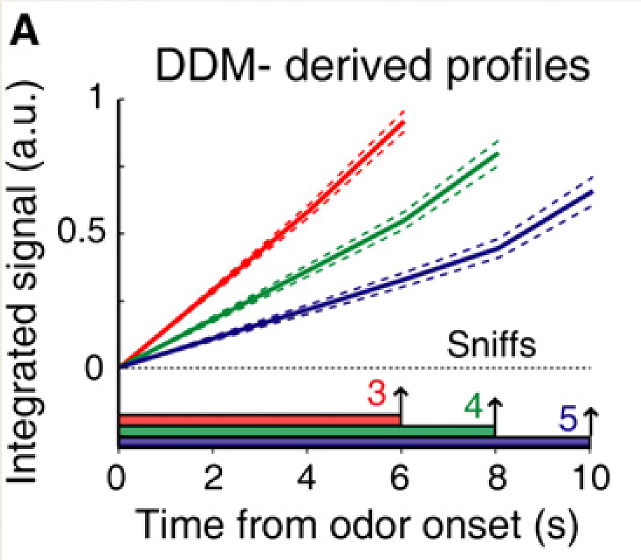
fMRI correlates

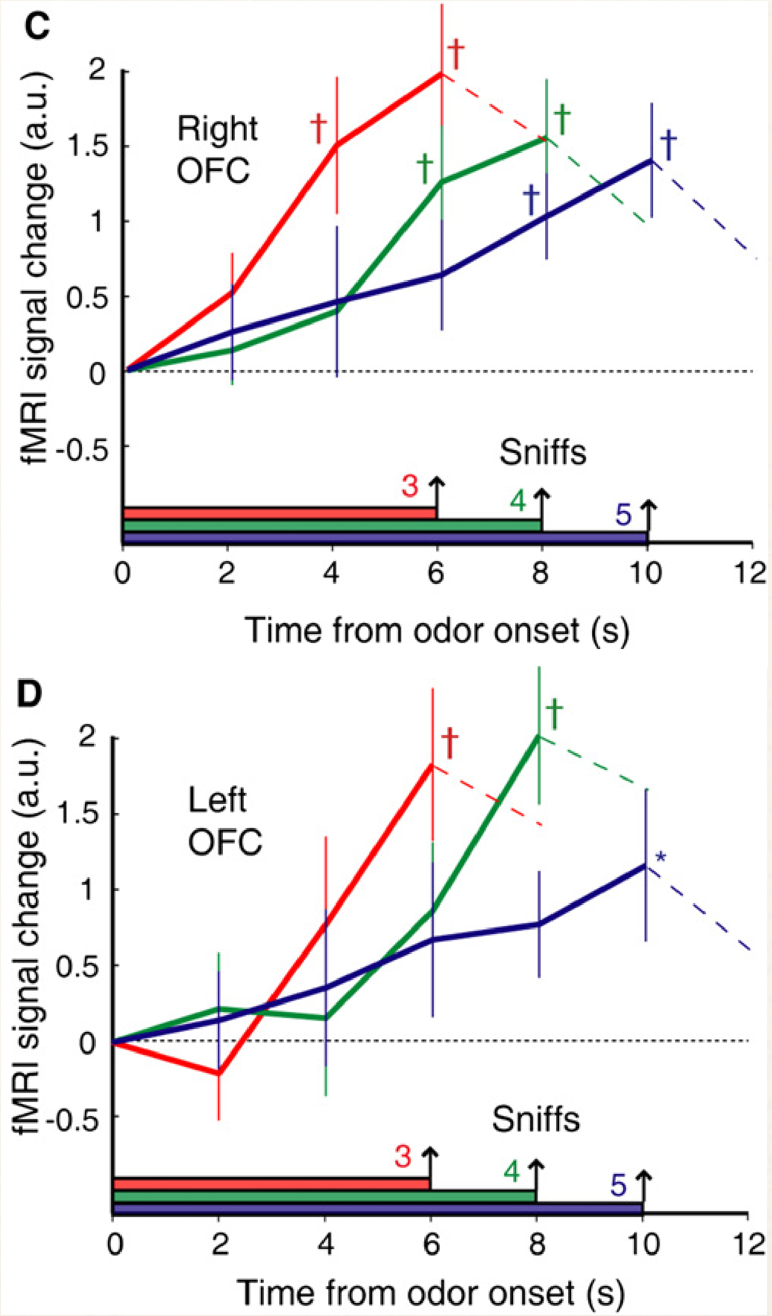
- Open-sniff experiment
- 2s repetition time, 128x120 voxels
  - 1 sniff = 2s as well
- Look for voxels correlating with DDM-derived integrated signal responses
  - Per subject fit, DDM profiles, voxel selection.
  - 14 time bins of 2s duration



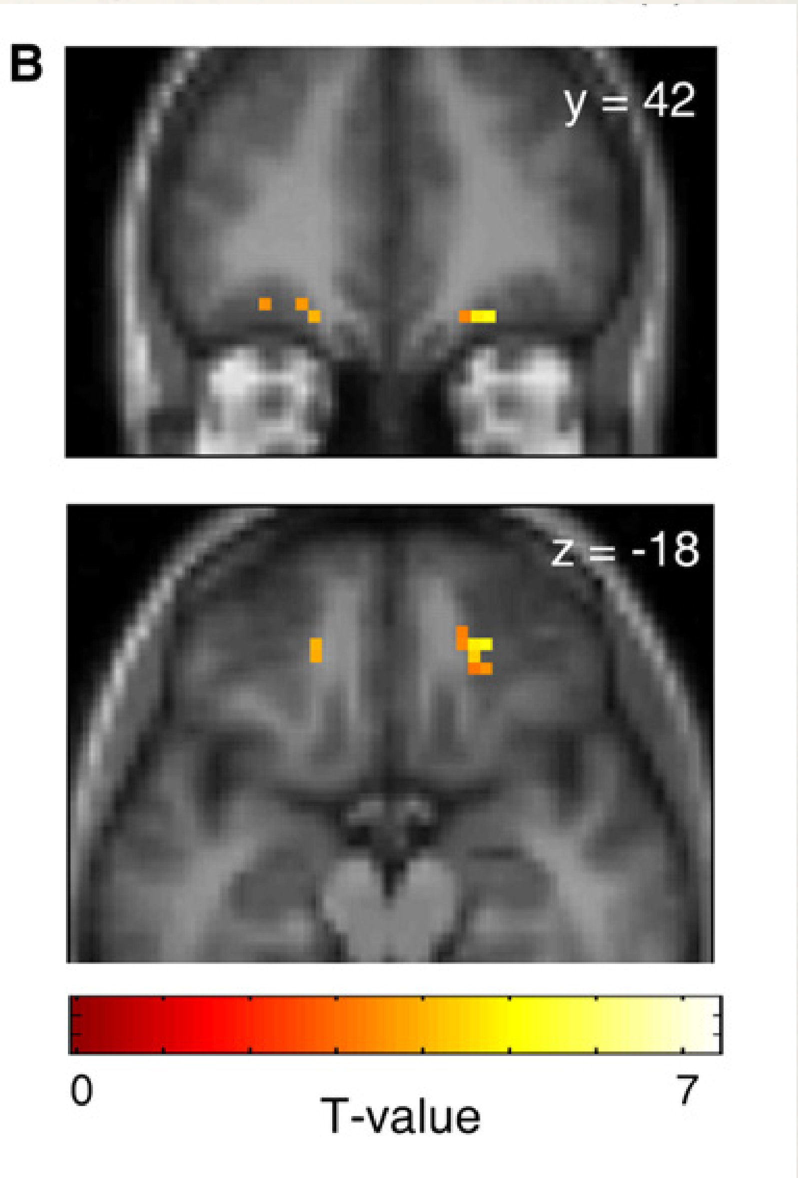
fMRI correlates

- Results
  - Found region showing integration-like profiles:
    - Medial Orbitofrontal Cortex (OFC)



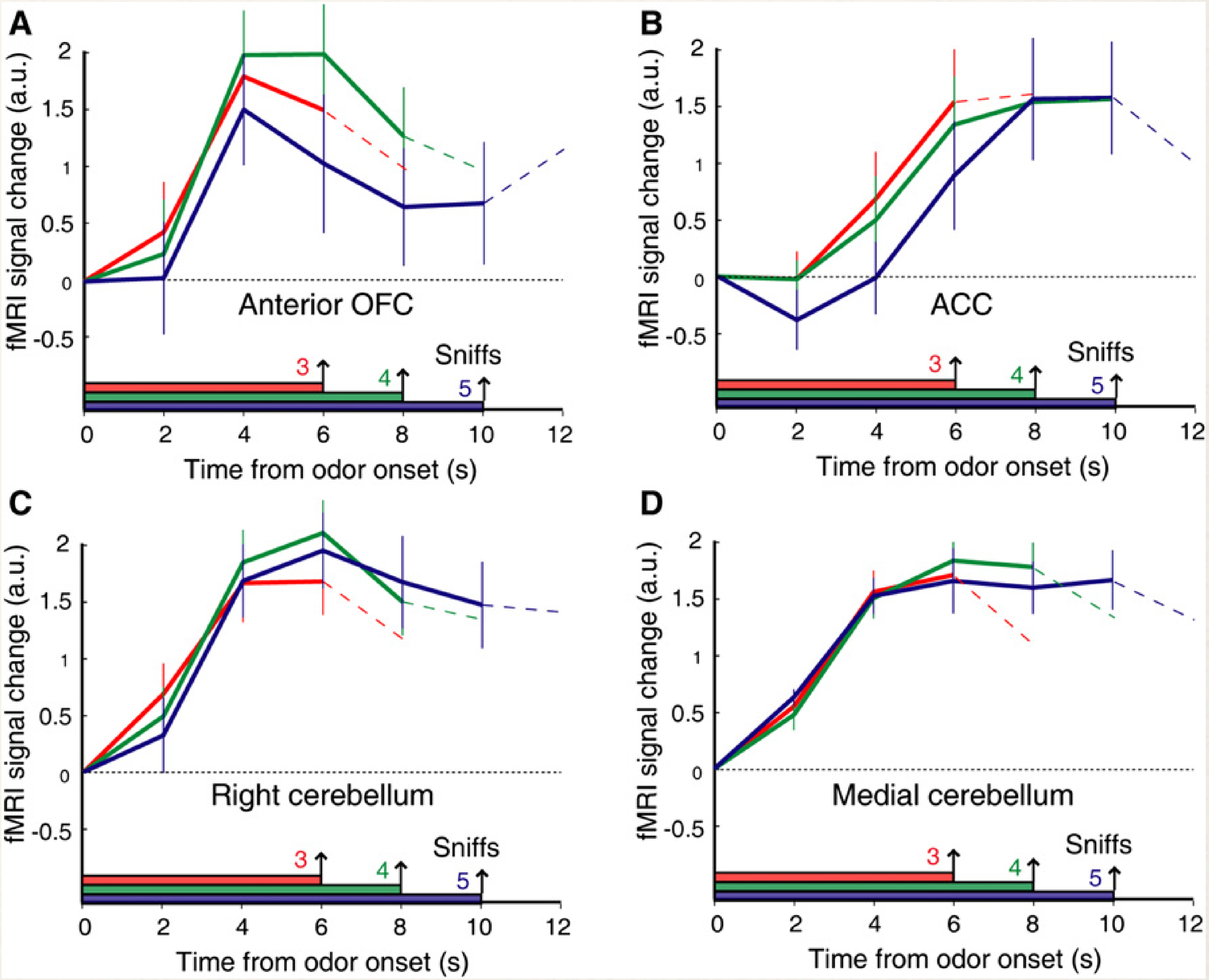


*p < 0.05; †, p < 0.01



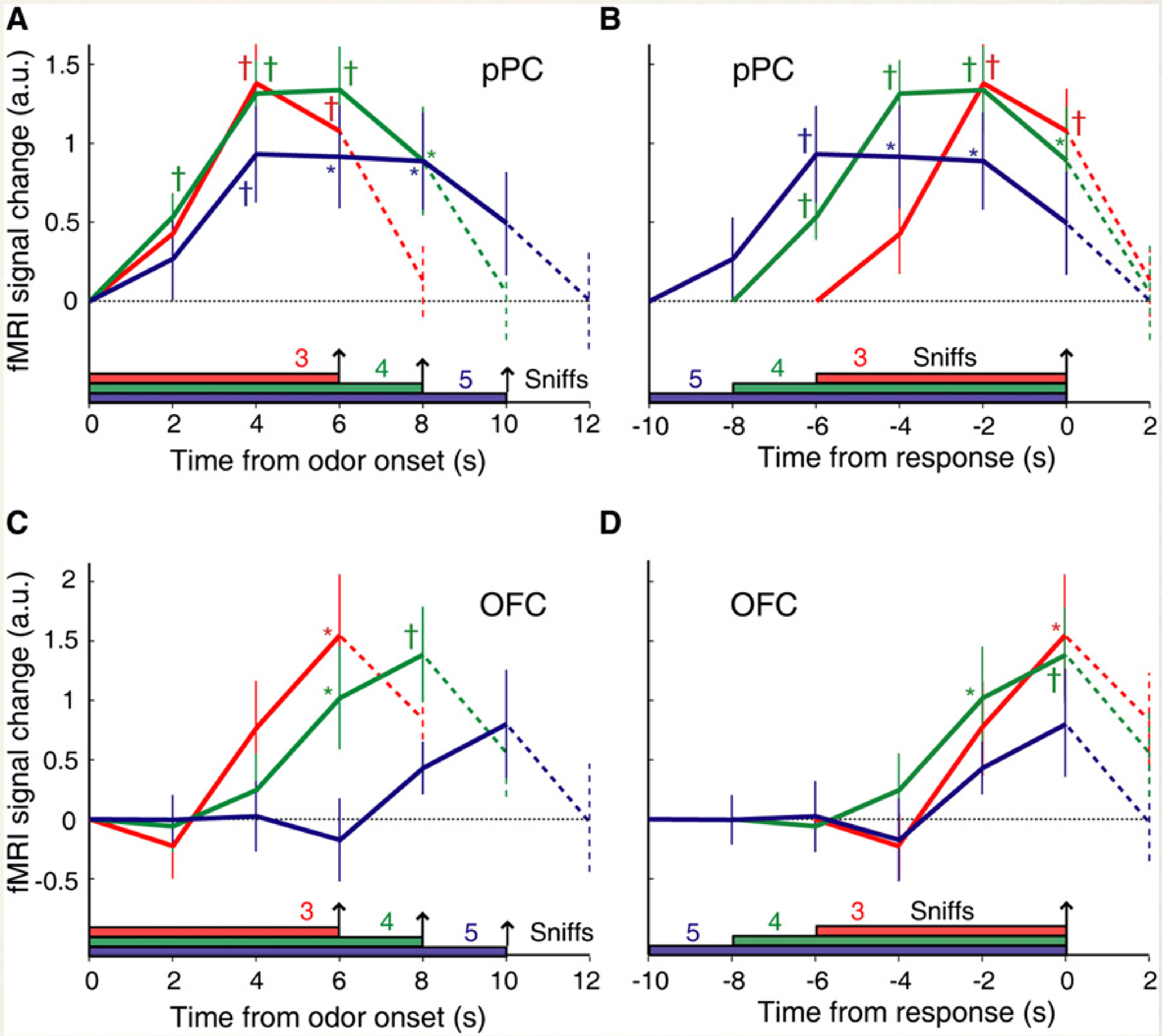
fMRI correlates

- Other activations
  - Anterior Cingulate Coretex (ACC), Cerebellum
  - Do not show significant interaction of condition and time



fMRI correlates

- Hypothesis:
  pPC generates momentary olfactory evidence, to be integrated by OFC
- fMRI signal somehow consistent.



Conclusion

- Found temporal integration of olfactory evidence (though weak)
- Make use of slow poor human performance to their advantage
- Found OFC correlates with DDM-like integration profiles
  - Identified region corresponds to putative olfactory projection site in human OFC
  - Rodent single-unit recording study on OFC:
    OFC report decision confidence during postchoice period
- pPC - OFC similar to MT - LIP in visual perceptual evidence integration in monkeys.

The End

- Questions?

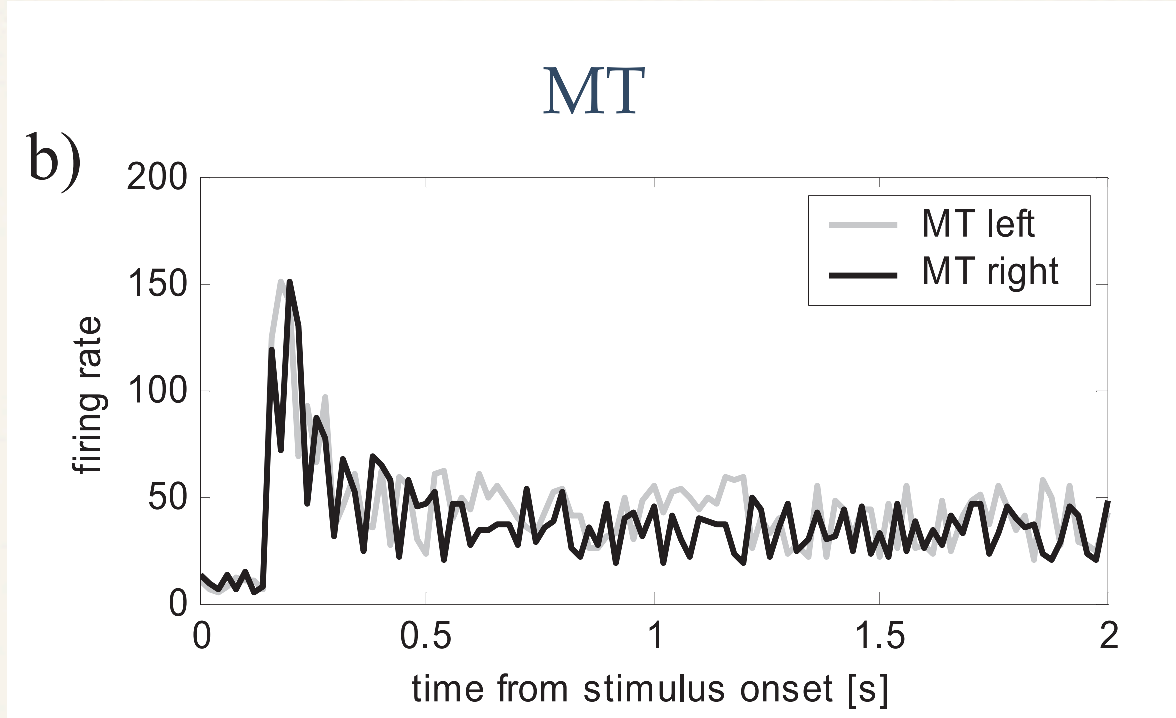
- References:

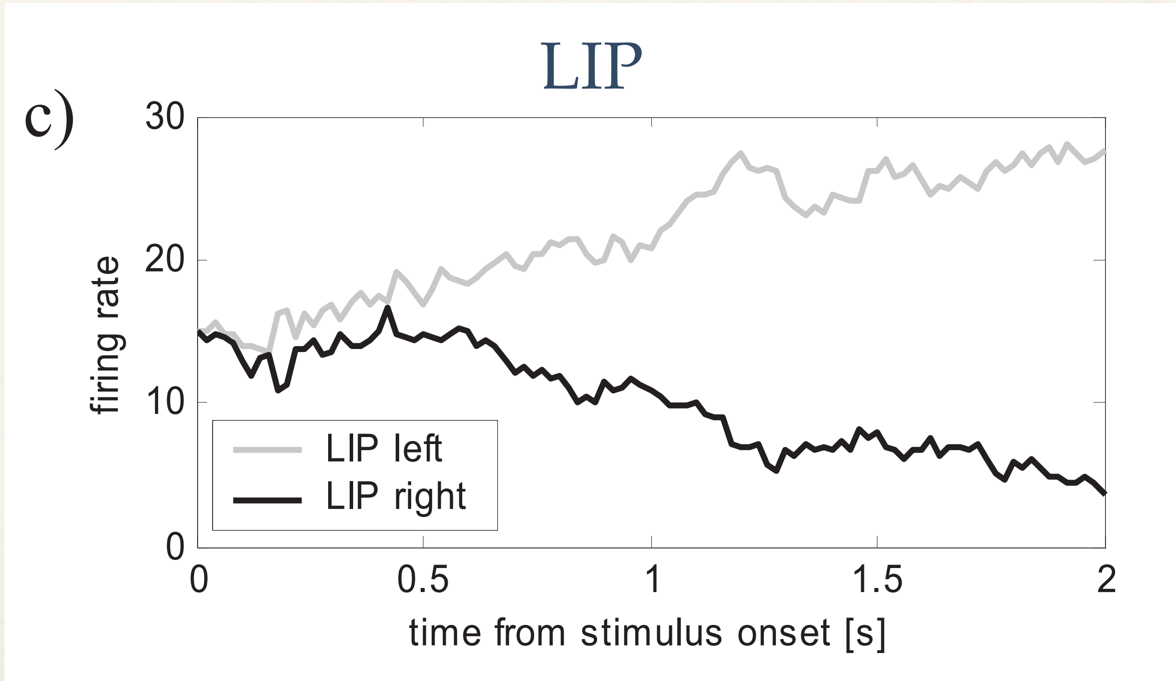
  - M. B. Ahrens, J. M. Li, M. B. Orger, D. N. Robson, A.F. Schier, F. Engert, R. Portugues, “Brain-wide neuronal dynamics during motor adaptation in zebrafish”, Nature, published online May 2012

- Supplementary slides

Experimental data

- Behavioral data
  - Performance as function of coherence (~difficulty of task)
  - Distribution of response times.
- Neuronal recordings:
  - Middle Temporal Area (MT)
    - ~ momentary evidence
  - Lateral Intraparietal Area (LIP)
    - ~ accumulated evidence





Sequential Probability Ratio Test

- Assume two populations reporting evidence for two alternatives (left/right): I_1 and I_2
- Let $Y = I_1 - I_2$.
  - If "right" hypothesis is true: $Y \sim p_1(y)$, with mean $\mu_1 > 0$
  - If "left": $Y \sim p_2(y)$, with mean $\mu_2 < 0$
- Get iid samples from $p_i(y)$.
- Goal: Decide as soon as possible which hypothesis is true.
- Optimal solution: Likelihood-ratio test: $$Z_2 < \frac{p_1(y_1)p_1(y_2)\ldots p_1(y_n)}{p_2(y_1)p_2(y_2)\ldots p_2(y_n)} < Z_1$$
- Taking *log*, equivalent to random walk

$$\log Z_2 < \log \frac{p_1(y_1)}{p_2(y_1)} + \ldots + \log \frac{p_1(y_n)}{p_2(y_n)} < \log Z_1$$

$$\Rightarrow I^n = I^{n-1} + \log \frac{p_1(y_n)}{p_2(y_n)}$$

Drift Decision Model

- Simple:
  Analytical formulas for the Error rate and Response time.

z: bound

Fixed time

$$ER = \Phi\left(-\frac{A}{c}\sqrt{T}\right)$$

Free-response

$$ER = \frac{1}{1+e^{\frac{2Az}{c^2}}} \qquad DT = \frac{z}{A}\tanh\left(\frac{Az}{c^2}\right)$$

- Optimal model, as implements the Neyman-Pearson test.

- Extensions:
  - Drift variability:
    $A \sim N(m_A, s_A)$
  - Initial position variability:
    $x_0 \sim U[-s_x, s_x]$