

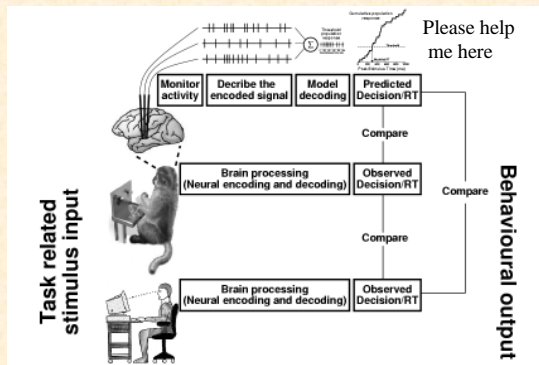
From neural codes to cognitive processes and perception: What we need to model and why

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Overview

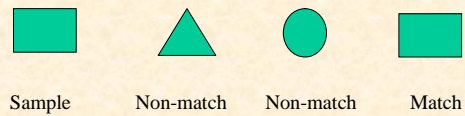
- Why is attention limited?
 - Need to do more “realistic” modelling work
- How does stimulus contrast influence neuronal activity?
 - Need to understand the processing
- Why should we care?
 - Predicting visual search with stimulus inversion
 - Can this be related to “optimal” attention?
 - Predicting visual search with contrast
 - Oh my £U&K*NG G&D – what is going on?

Framework of research

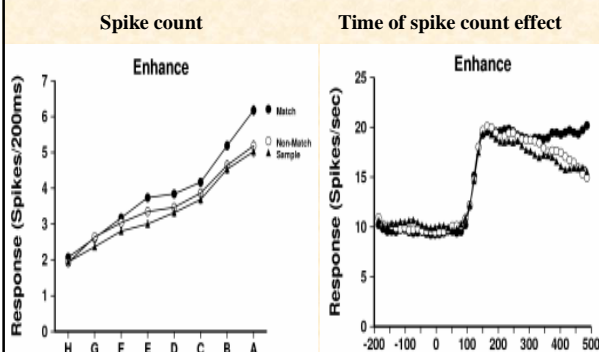


Neural codes and attention

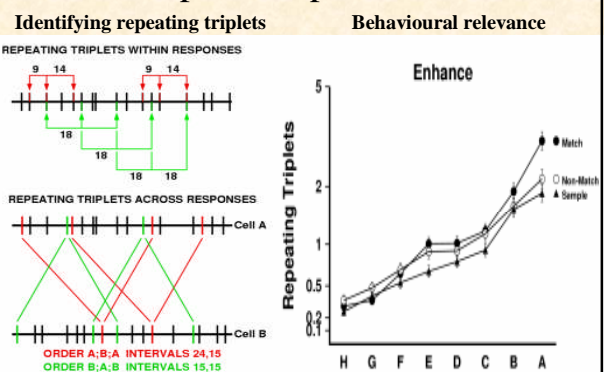
- Fixating monkey doing sequential DMS task



Attention and neuronal codes

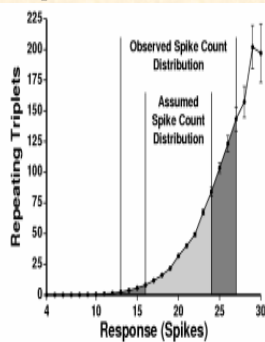


Fine temporal response measures



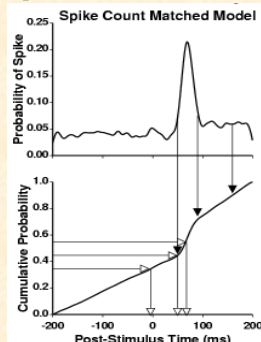
Fine temporal response measures

Spike count distribution



Oram et al. *Phil Trans R. Soc.*, 2002

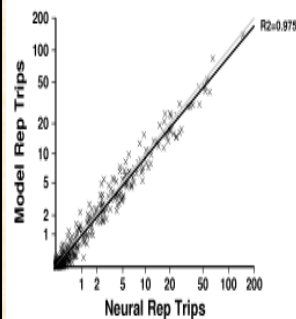
Spike count matched model



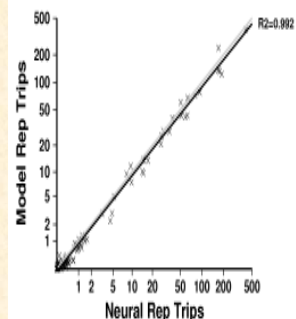
Oram et al. *J Neurophysiol.*, 1999

Fine temporal response measures

Within cell repeating triplets



Between cell repeating triplets



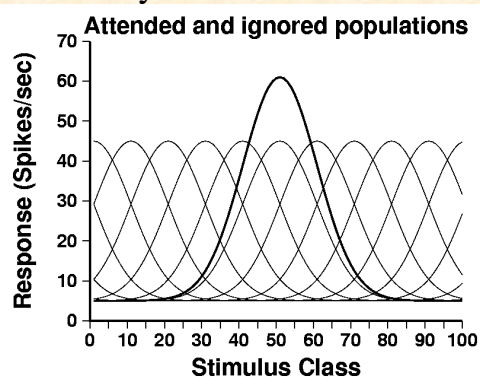
Neural codes in visual system

- Coarse/medium (20-500ms resolution)
 - Plenty of evidence for spike count
 - Evidence of medium (Richmond)
- Fine temporal measures (1-2ms resolution)
 - “Synfire chains” (includes synchrony)
 - We find no evidence (LGN, V1, Motor)
 - Even with behavioural relevance (Oram, Lui, Richmond, in prep)
 - Synchrony
 - No evidence (TE/STS, Rolls et al. 2003, 2004)

Why is attention limited?

- Doesn't seem to be a “I'm attending” signal
- Response magnitude to attended stimuli boosted
 - Inhibitory interactions between neurones biased
- Examine decoding of signals to answer?

Why is attention limited?

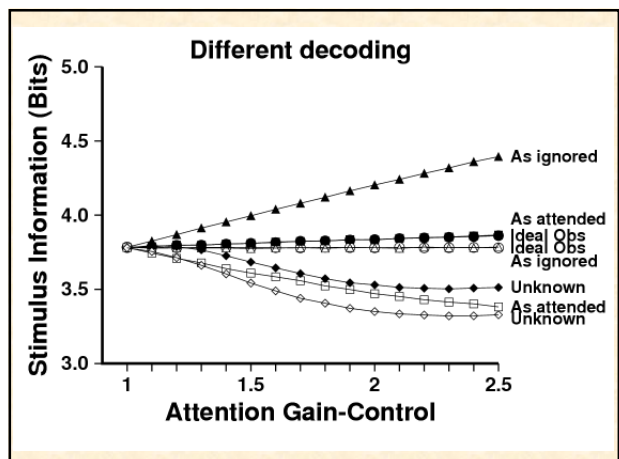
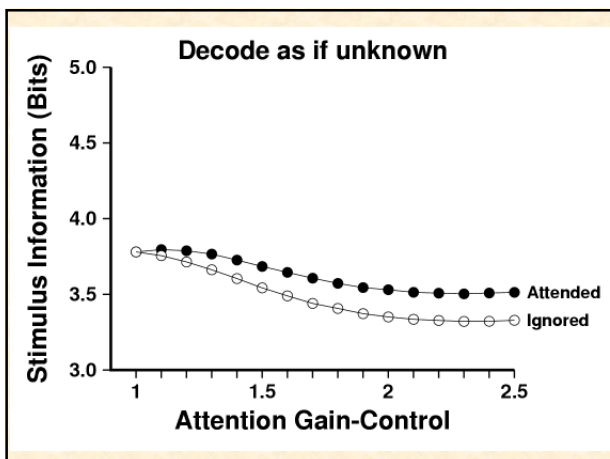
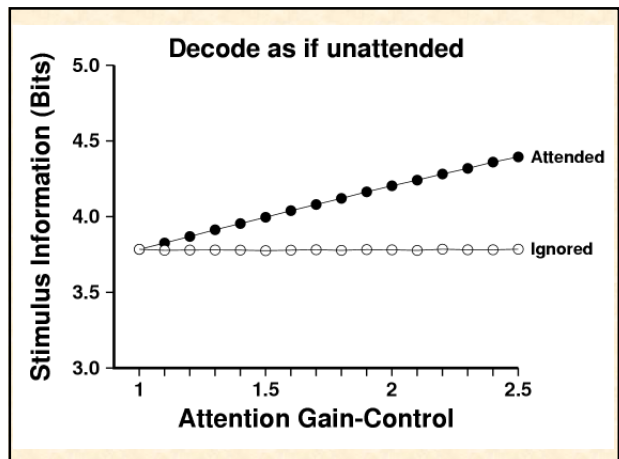
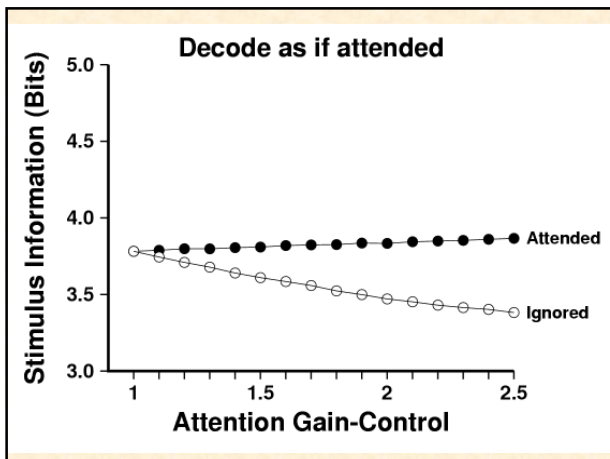
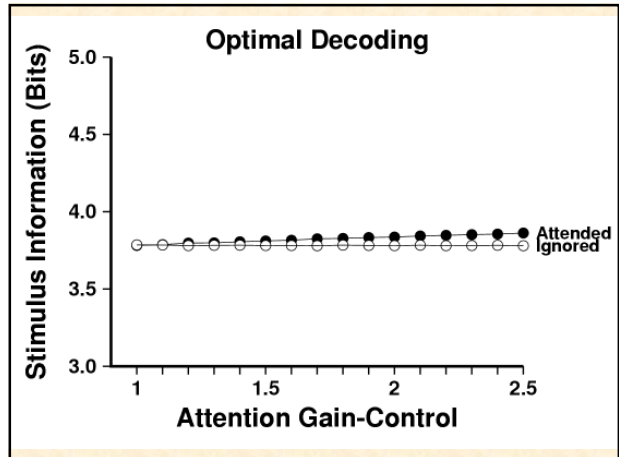


Decoding

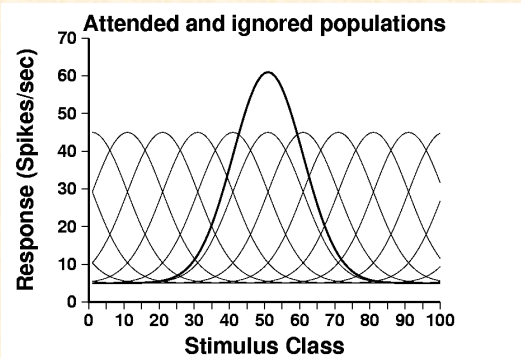
- Model response distributions
 - Mean ~ Variance relationship
 - Non-Gaussian, Non-Poissonian spike count distributions
 - Use Fano factor (Variance/mean) 1.5
 - Truncate the Gaussian
- Apply Bayesian decoding
 - Get $p(s)$ for each stimulus: Use MAP = ML in these simulations
 - Estimate error & information

Model different decoding

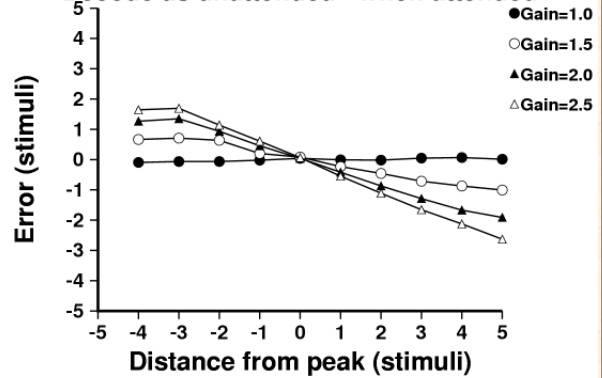
- “Ideal observer” decoding
 - Assumes that system “knows” which response distribution the signal came from (stimulus ignored or stimulus attended)
- Constant decoding
 - Decode assuming responses generated from distributions when stimuli attended
 - Decode assuming responses generated from distributions when stimuli ignored
 - Decode assuming responses generated from mixture of distributions (ignored/attended)



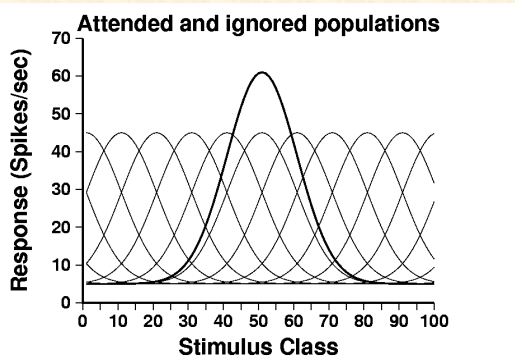
Decode as unattended when the stimulus is attended?



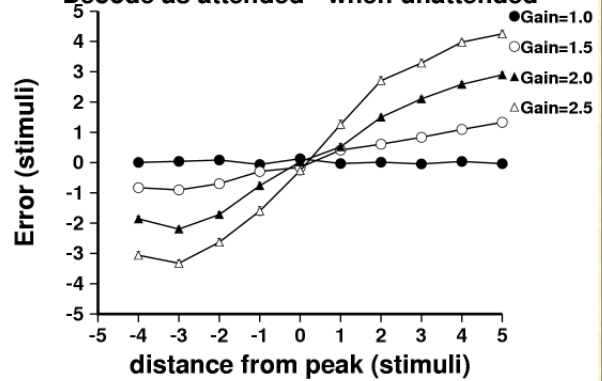
Decode as unattended - when attended



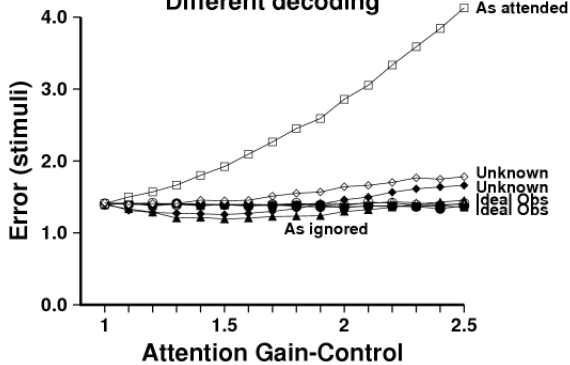
Decode as attended when the stimulus is unattended?



Decode as attended - when unattended



Different decoding



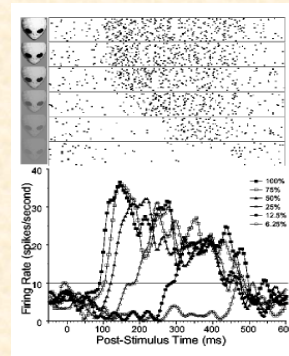
Why is attention limited?

- Simulations
 - Optimal decoding does not give highest information!!!!
 - Does about stimulus/attention combination
 - Decoding assuming ignored “better”
 - Information to attended stimuli rises faster than ideal observer
 - Error has local minimum
- **Anyone want to find out what’s going on?**
 - Do we still see this with more “accurate” model of attention (biases in inhibitory interactions)?
 - How does this local minimum vary?

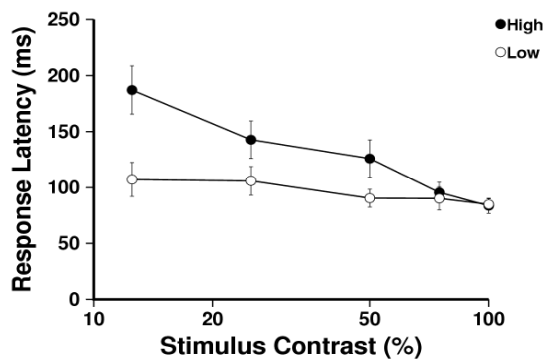
Stimulus contrast and neuronal response latency

- Latency increases and response magnitude decreases as stimulus contrast is decreased
- Carrandini & Heeger model “explains” this
 - Pooled activity across neurones gives shunting (divisive) inhibitory input
 - Changes the membrane time constant (RC circuit)
 - Gives results from V1
 - But NOT STS

Stimulus contrast and response latency in TE/STS



Latency change and specificity



Stimulus contrast, neuronal response latency and magnitude

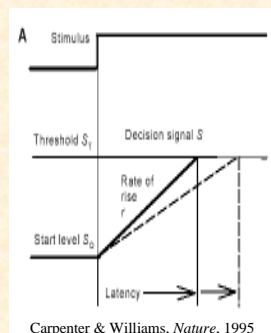
- Why should effect of contrast vary with degree of response selectivity?
 - Latency to high contrast stimuli the same
 - Suggests same number of “synapses”
 - Increase in latency with decreasing contrast higher for neurones showing higher response selectivity
 - Not effect of changes in response magnitude
 - Not effect of “type” of effective stimulus
 - Possible effect of “contrast” (difference) in inputs
- **Anyone want to help?**

Neural codes in late visual system

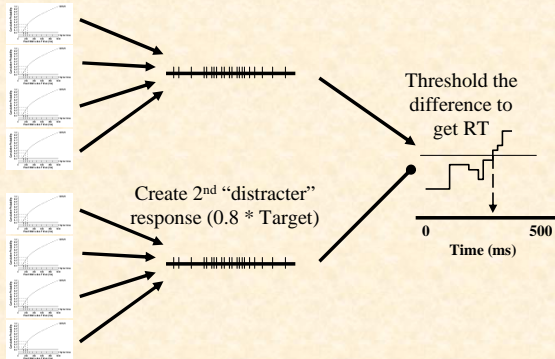
- **Evidence for spike count and response latency**
 - Information encoded by spike count, latency when
- **Do these codes “mean” anything?**
 - Spike counts
 - Micro-stimulation studies (e.g. Newsome, Parker)
 - Latency
 - How to test?
 - Can’t stimulate to change latency
 - Want to relate to behaviour

Models of decisions

- Information acquisition hypothesis
 - Decisions when information reaches threshold
 - Ratcliff 1978
 - McClelland 1979
 - Carpenter & Williams, *Nature* 1995
 - Gold & Shadlen, *TICS*, 2001



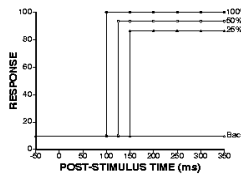
Modeling a decision



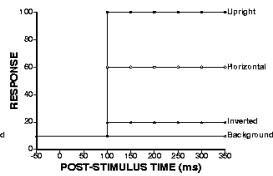
Modeling a decision

- What do neural codes predict for RT?
 - Latency (change contrast)
 - Magnitude (change orientation)
- What happens experimentally?
 - Are the codes reflected in behaviour (i.e. “mean” anything)?

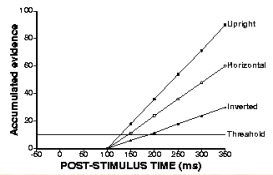
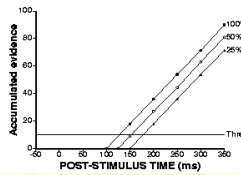
Latency change



Change of magnitude

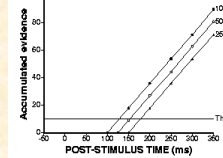


Both predict change in RT

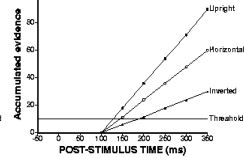


Both give RT changes

Response Latency

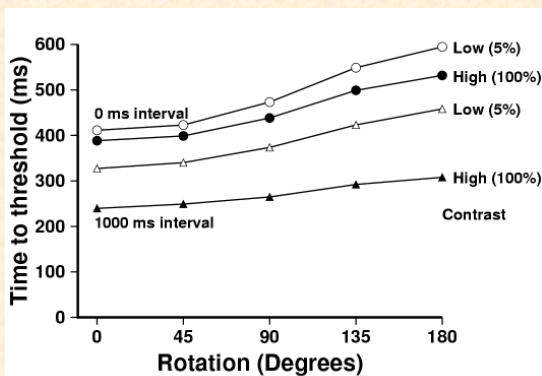


Response Magnitude

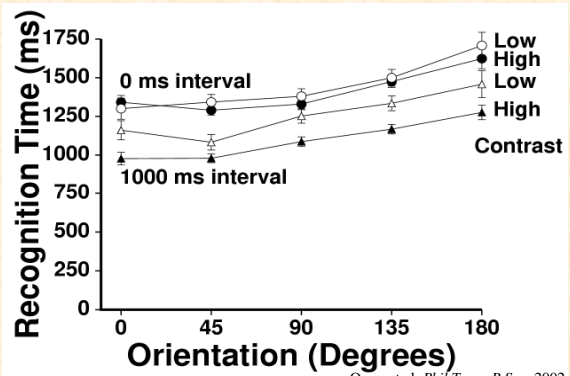


Unless can delay the start of counting

Predicting mean RT

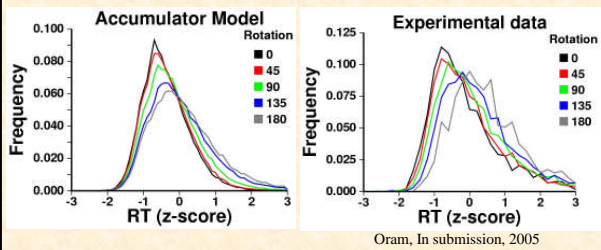


Testing mean RT predictions

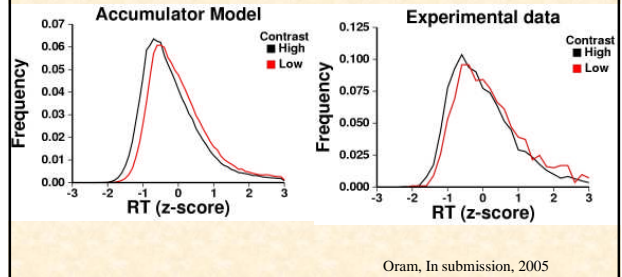


Oram et al. *Phil Trans R Soc*, 2002

Change of response magnitude causes skewing of RT distribution



Change of response latency causes shifting of RT distribution



Latency and RT

- Model the latency shifts:
 - Mutually inhibitory populations
 - Integrate & fire neurones in simple network (Mark van Rossum: How's it going?)
- Model predicted RT distributions:
 - Model RT distributions from
 - diffusion models,
 - accumulator models,
 - leaky accumulator models
 - Compare with experimental data

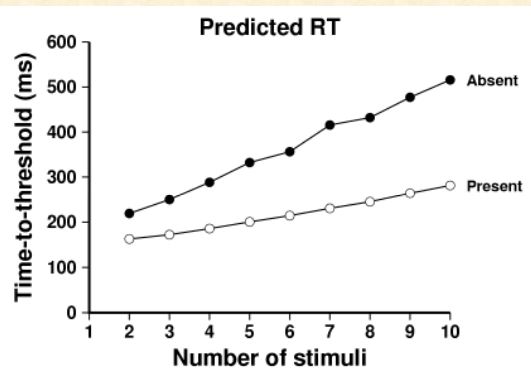
Visual search as signal processing

- Use the same model and apply to visual search
- Target is attended (looked for)
 - Gives a neural response “gain” of about 1.2 to 1.5
- Inhibitory interactions between neurones
 - Attention biases the interactions (see Reynolds)

Visual search as signal processing

- As the number of stimuli increase, firing rate decreases ($1/\sqrt{N}$) - Ward & McClelland 1986
- Attention biases the competition
 - Firing rate of neurones selective for the attended stimulus act as if gain control
- Take the modelled activity levels
 - Use in the accumulator model
 - Do pair-wise comparisons in **parallel**

Modelling visual search



Visual search: Accumulator model

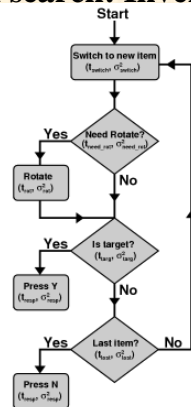
- **RT(Y) determined by orientation of target**
 - Last time-to-threshold when target identified
 - With all upright:
 - Target upright vs distracter upright
 - With all inverted:
 - Target inverted vs distracter inverted
 - With half upright, half inverted:
 - **Target upright:** Target upright vs distracter upright
 - **Target inverted:** Target inverted vs distracter inverted
- **All upright=Mix upright < All inverted=inverted**

Visual search: Accumulator model

- **RT(N) determined by distracter inversion**
 - Last time-to-threshold when identified as non-target
 - With all upright:
 - Non-target upright vs distracter upright
 - With all inverted:
 - Non-target inverted vs distracter inverted
 - With half upright half inverted:
 - **Non-target upright:** some non-target inverted vs distracter inverted (same as all inverted)
 - **Non-target inverted:** Non-target inverted vs distracter inverted (same as all inverted)
- **RT(N) mix inversion = all inverted**

Modelling visual search: Inversion

- Inversion: STSS like visual search



Visual search: STSS model

- **RT(Y) 1/2 way between all upright and all inverted**

$$- RT(Y_{mix}) = 0.5 * N_{items} * (t_{switch} + t_{need_rot} + 0.5 * t_{rotate} + t_{decision} + t_{last}) + t_{resp}$$

$$- RT(Y_{inv}) = 0.5 * N_{items} * (t_{switch} + t_{need_rot} + t_{rotate} + t_{decision} + t_{last}) + t_{resp}$$

$$- RT(Y_{up}) = 0.5 * N_{items} * (t_{switch} + t_{need_rot} + t_{decision} + t_{last}) + t_{resp}$$

– **Target orientation does not matter**

- **Guided search (Wolfe):**

$$- RT(Y_{mix-up}) < RT(Y_{up})$$

$$- RT(Y_{mix-inv}) > RT(Y_{inv})$$

Visual search: STSS model

- **RT(N) 1/2 way between all upright and all inverted**

$$- RT(N_{mix}) = N_{items} * (t_{switch} + t_{need_rot} + 0.5 * t_{rotate} + t_{decision} + t_{last}) + t_{resp}$$

$$- RT(N_{inv}) = N_{items} * (t_{switch} + t_{need_rot} + t_{rotate} + t_{decision} + t_{last}) + t_{resp}$$

$$- RT(N_{up}) = N_{items} * (t_{switch} + t_{need_rot} + t_{decision} + t_{last}) + t_{resp}$$

– **Target orientation does not matter**

- **Guided search:**

$$- RT(N_{up}) < RT(N_{mix-up}) = RT(N_{mix-inv}) < RT(N_{inv})$$

Visual search with mixed inversion

- **Self-terminating serial search model**

• RT(Y) 1/2 way between all upright and all inverted

• RT(N) 1/2 way between all upright and all inverted

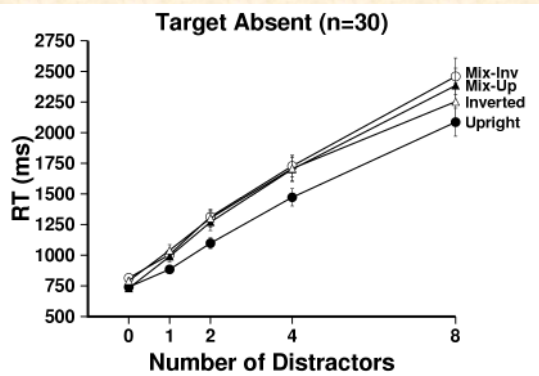
• Target orientation does not matter

- **Accumulator model:**

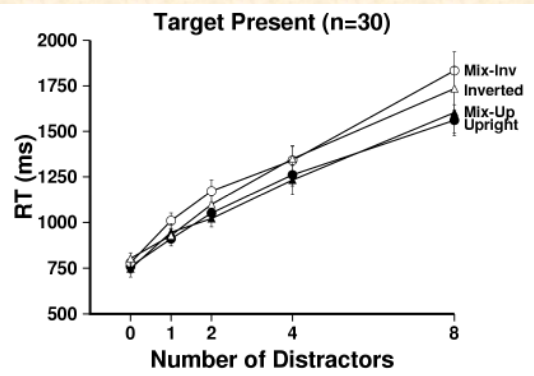
• **RT (Y):** All upright=mix upright < All inverted=mix inverted

• **RT (N):** Half-inverted = All inverted

Visual search: Mixed orientation



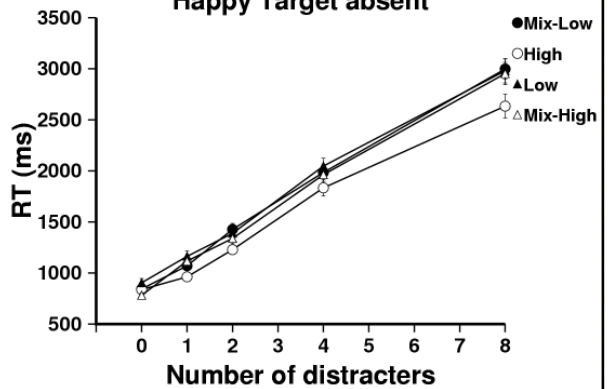
Visual search: Mixed orientation



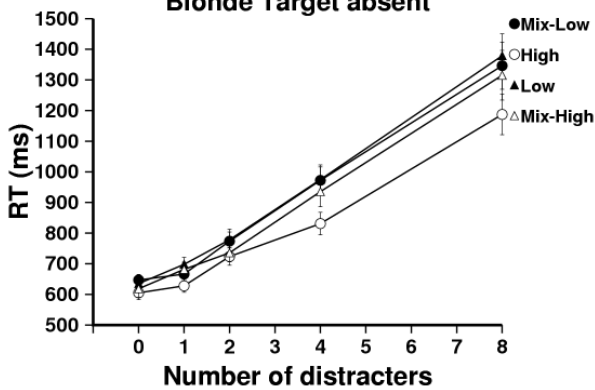
Search & inversion

- Is the pattern of results related to “optimal” attention
 - Use a more complete model of neural populations (e.g. I&F, attention bias of inhibitory interactions)
 - What is “optimal” attention modulation as number of stimuli increases?
 - What happens to modelled activity levels as more and more stimuli are processed?

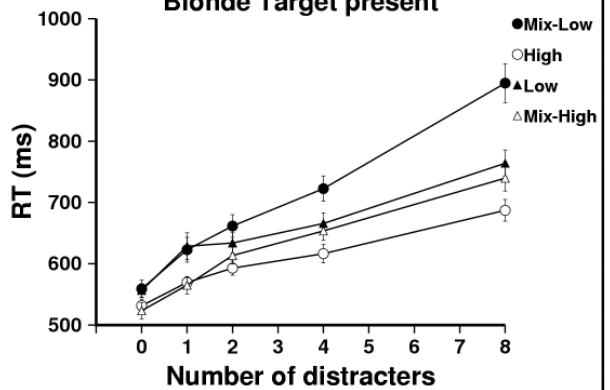
Happy Target absent

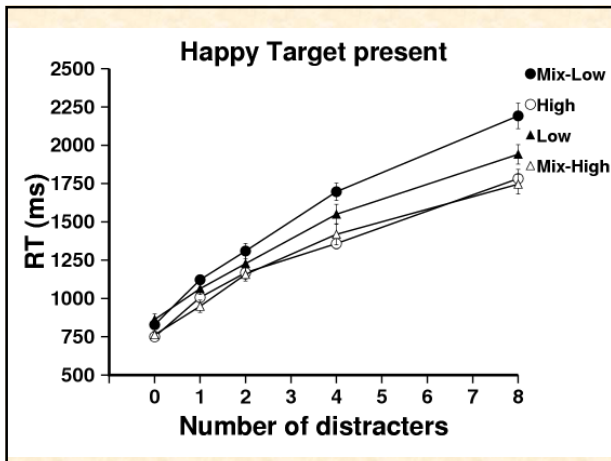


Blonde Target absent



Blonde Target present





Search and contrast

- Results inconsistent with STSS and guided search
- Accumulator model is underspecified
 - What happens to inhibitory interactions when some signals are delayed?
 - What does this predict for RT?
 - Can we reject the simple accumulator model?
 - If so, any ideas as to what is happening?