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

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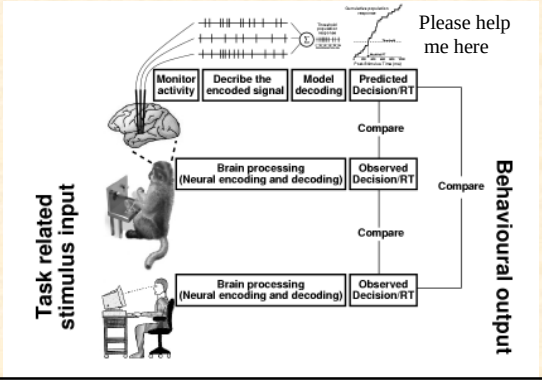
Overview

- 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



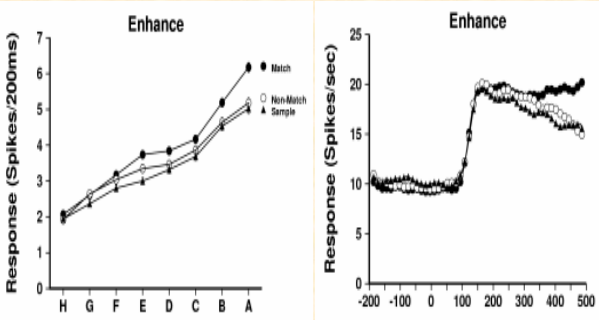
Neural codes and attention

- Fixating monkey doing sequential DMS task

Sample Non-match Non-match Match

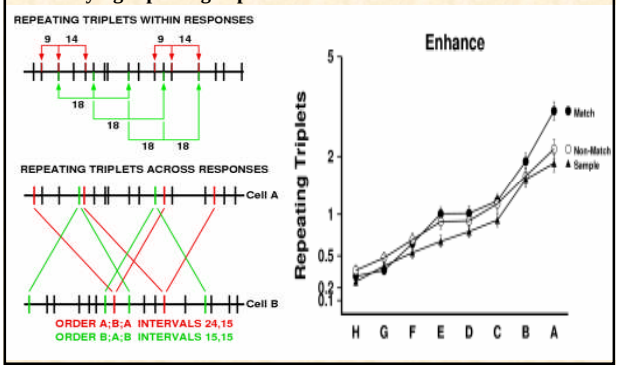
Attention and neuronal codes

Spike count **Time of spike count effect**



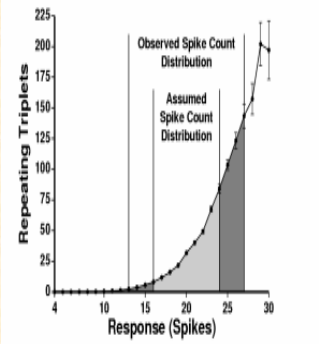
Fine temporal response measures

Identifying repeating triplets **Behavioural relevance**



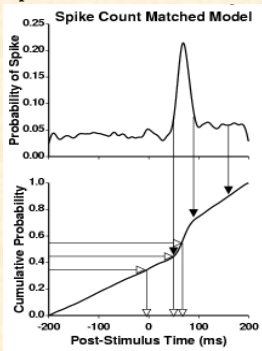
Fine temporal response measures

Spike count distribution



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

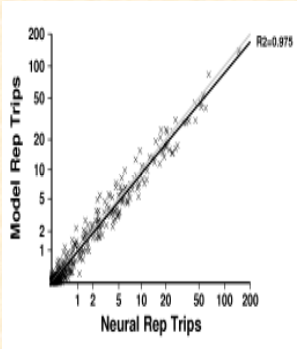
Spike count matched model



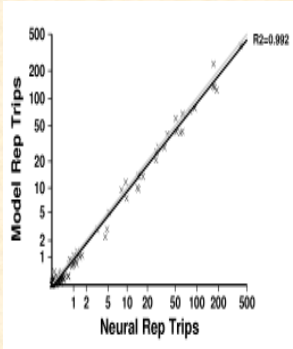
Oram et al. *J Neurophysiol*, 1999

Fine temporal response measures

Within cell repeating triplets



Between cell repeating triplets



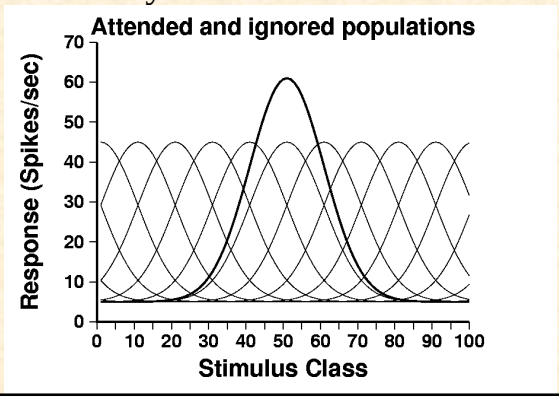
Neural codes in visual system

- 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?

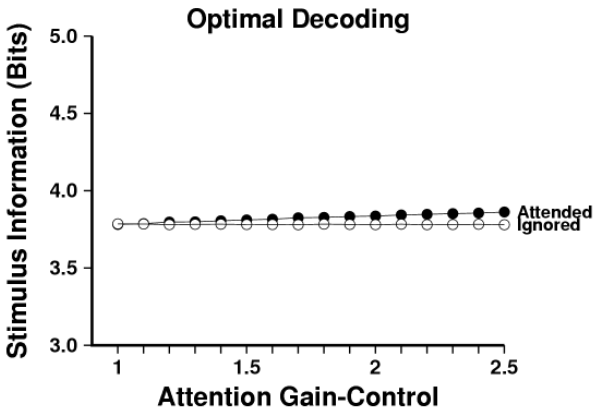


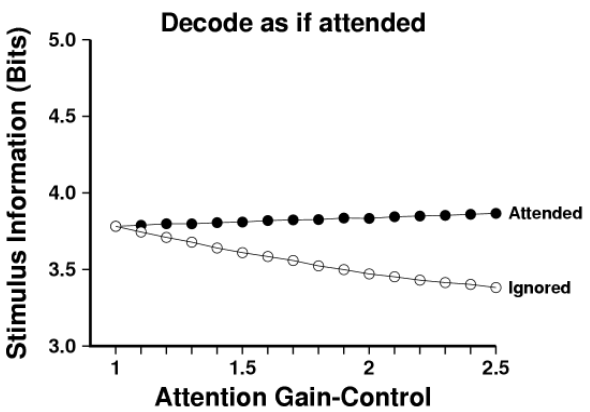
Decoding

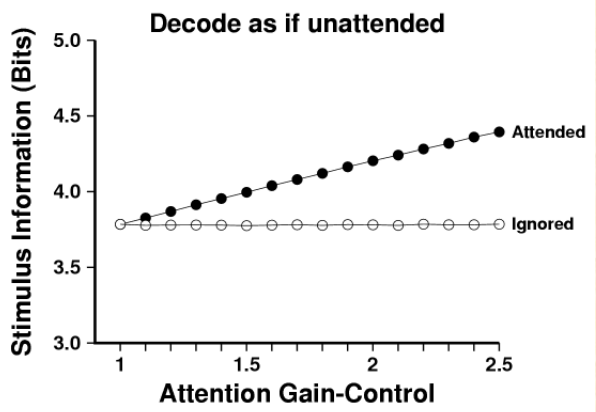
- Model response distributions
  - Mean ~ Variance relationship
  - Non-Gaussian, Non-Poisonian spike count distributions
  - Use Fano factor (Variance/mean) 1.5
  - Truncate the Gaussian
- Apply Bayesian decoding
  - Get p(s) for each stimulus: Use MAP = ML in these simulations
  - Estimate error &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

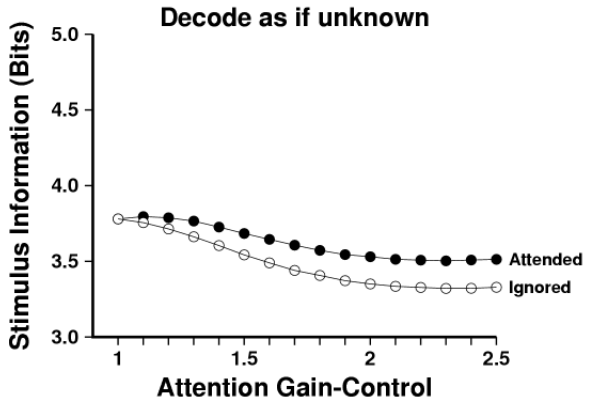
Model different decoding

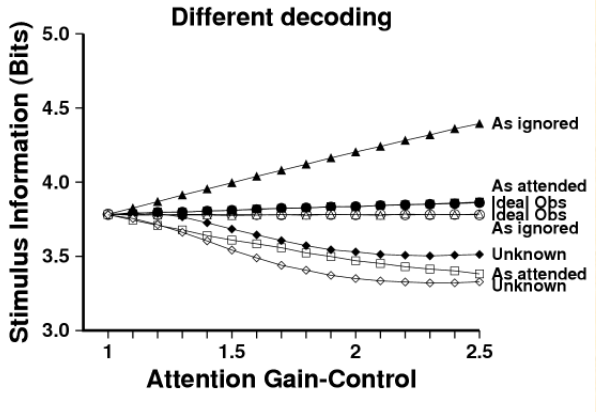
- "Ideal observer" decoding
  - Assumes that system "knows" which response distribution the signal came from (stimulus ignored or stimulus attended)
- Constant decoding
  - Decode assuming responses generated from distributions when stimuli attended
  - Decode assuming responses generated from distributions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



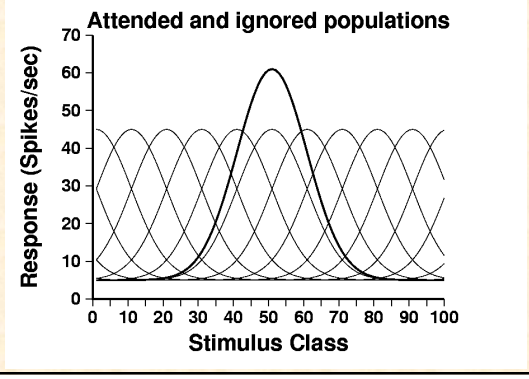


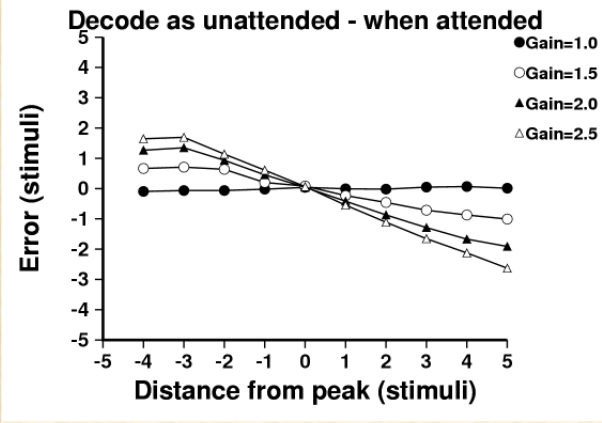




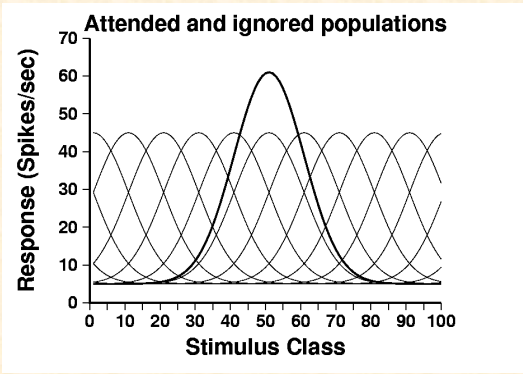


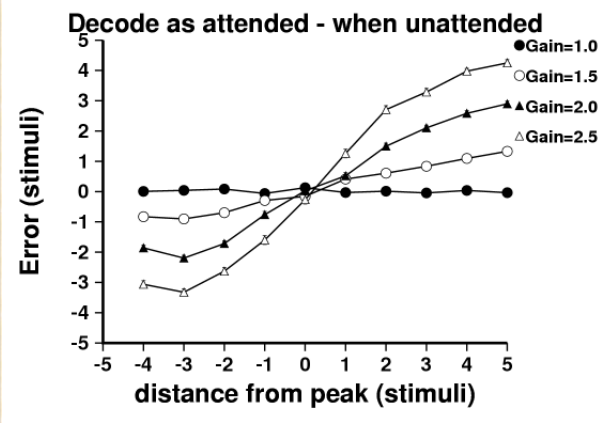
Decode as unattended when the stimulus is attended?

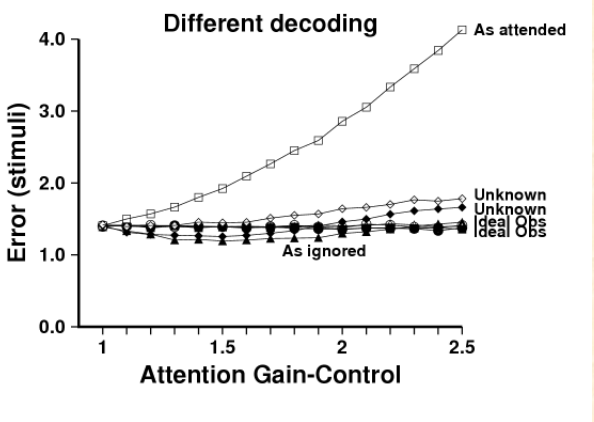




Decode as attended when the stimulus is unattended?







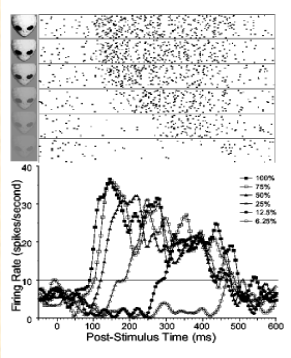
Why is attention limited?

- 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?

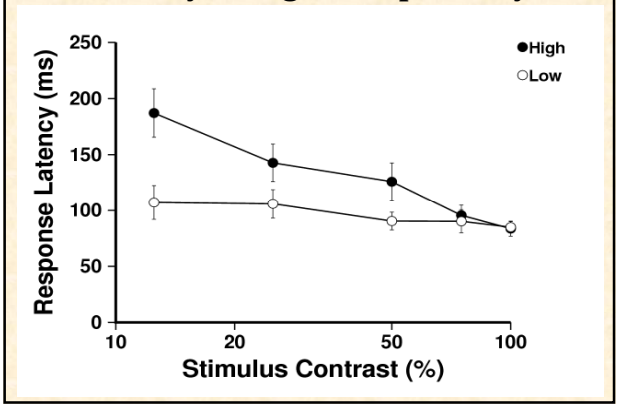
Stimulus contrast and neuronal response latency

- 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

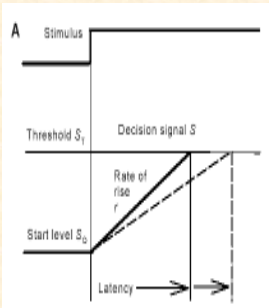
- Why should effect of contrast vary with degree of response selectivity?
  - Latency to high contrast stimuli the same
    - Suggests same number of "synapses"
  - Increase in latency with decreasing contrast higher for neurones showing higher response selectivity
    - Not effect of changes in response 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

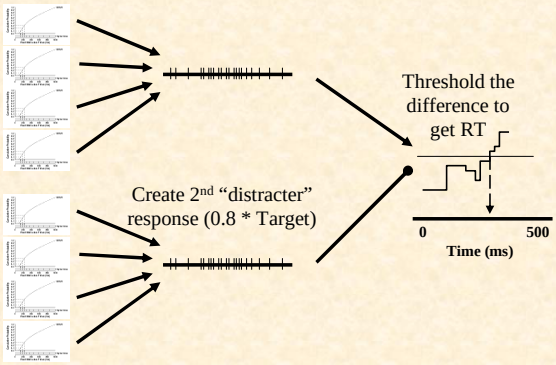
Models of decisions

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



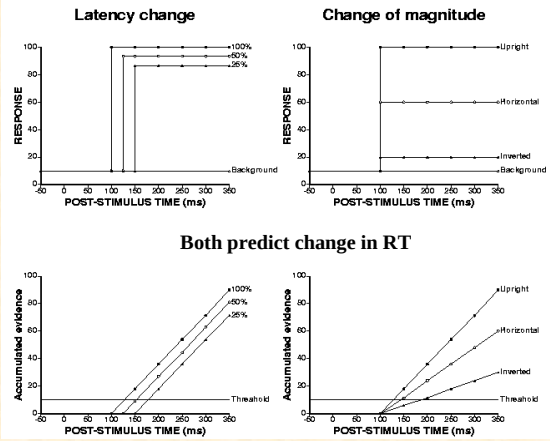
Carpenter & Williams, *Nature*, 1995

Modeling a decision



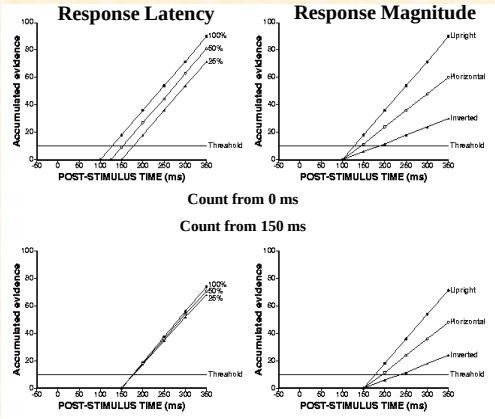
Modeling a decision

- 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)?

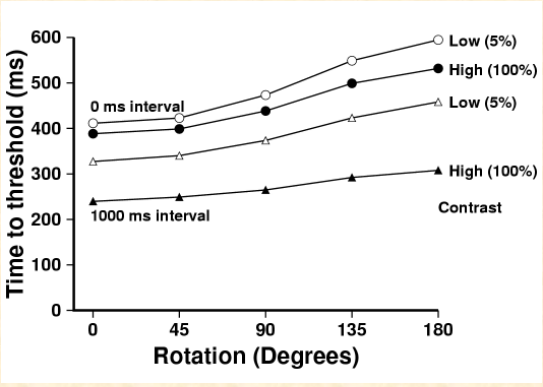


Both give RT changes

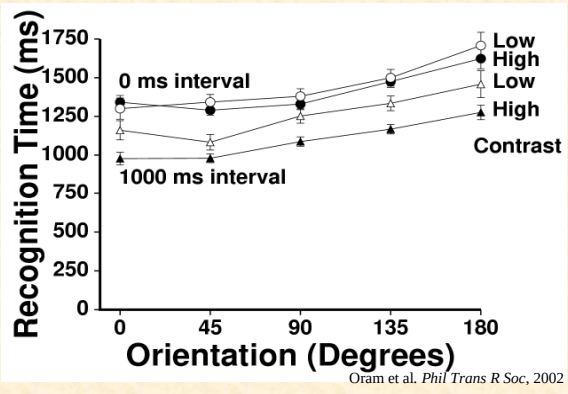
Unless can delay the start of counting



Predicting mean RT

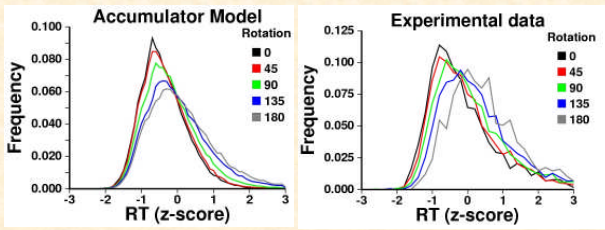


Testing mean RT predictions



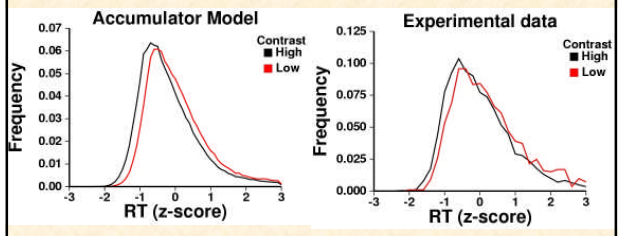
Oram et al. *Phil Trans R Soc*, 2002

Change of response magnitude causes skewing of RT distribution



Oram, In submission, 2005

Change of response latency causes shifting of RT distribution



Oram, In submission, 2005

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

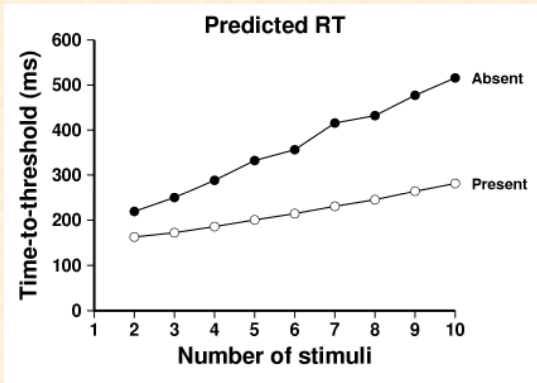
Visual search as signal processing

- 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

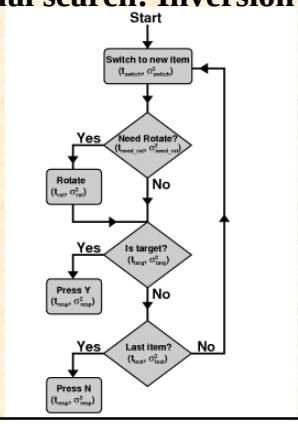
- **RT(Y) determined by orientation of target**
  - Last time-to-threshold when target identified
  - With all upright:
    - Target upright vs distracter upright
  - With all inverted:
    - Target inverted vs distracter inverted
  - With half upright, half inverted:
    - **Target upright:** Target 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) ½ 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):**
  - $RT(Y_{mix\text{-}up}) < RT(Y_{up})$
  - $RT(Y_{mix\text{-}inv}) > RT(Y_{inv})$

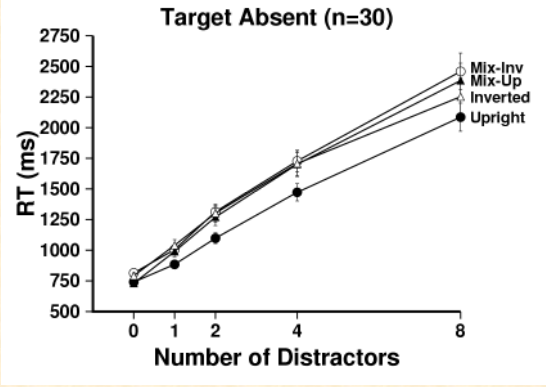
Visual search: STSS model

- **RT(N) ½ 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:**
  - $RT(N_{up}) < RT(N_{mix\text{-}up}) = RT(N_{mix\text{-}inv}) < RT(N_{inv})$

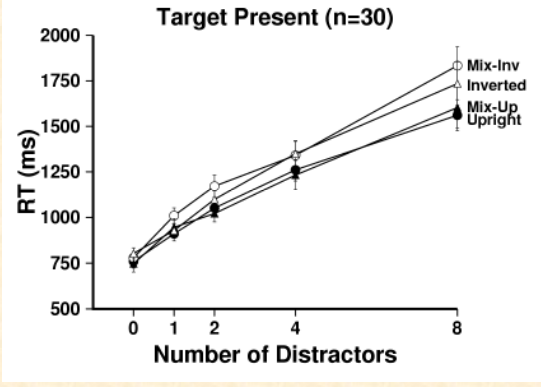
Visual search with mixed inversion

- **Self-terminating serial search model**
  - RT(Y) ½ way between all upright and all inverted
  - RT(N) ½ 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

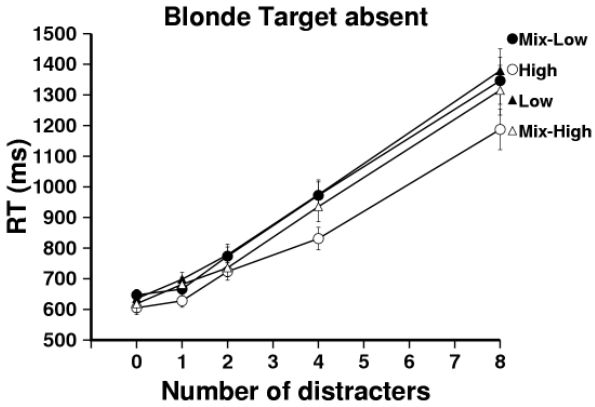


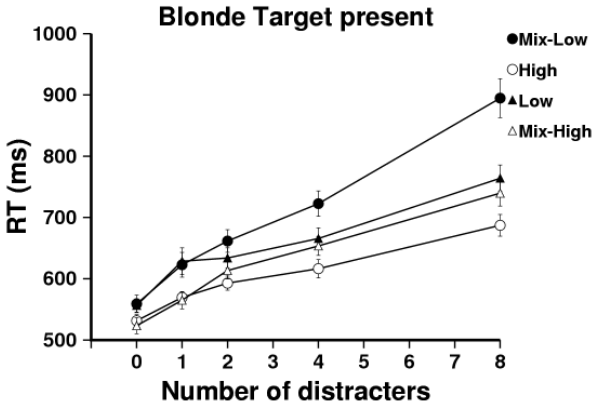
Visual search: Mixed orientation



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?





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?