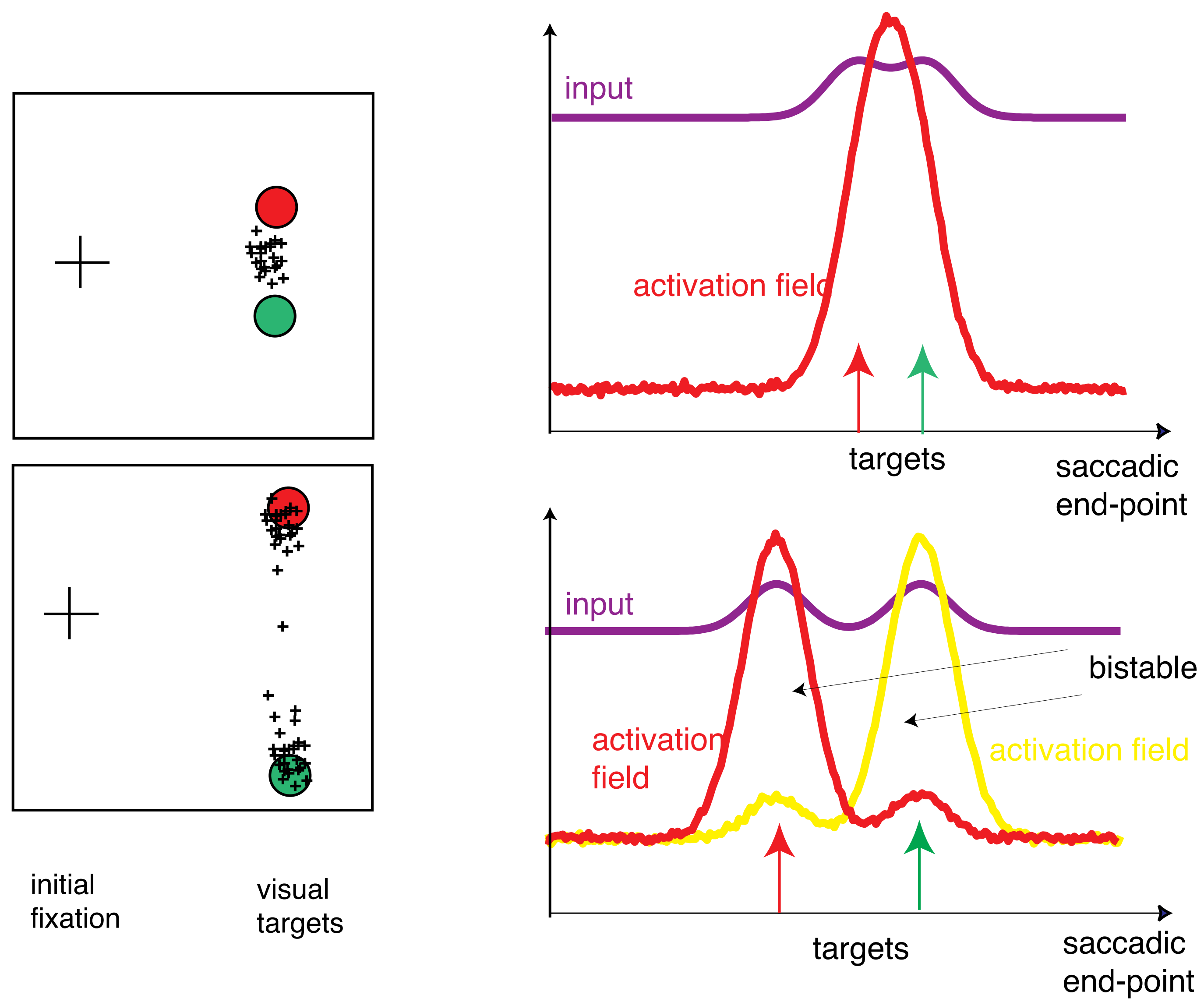
Dynamic Field Theory: Memory

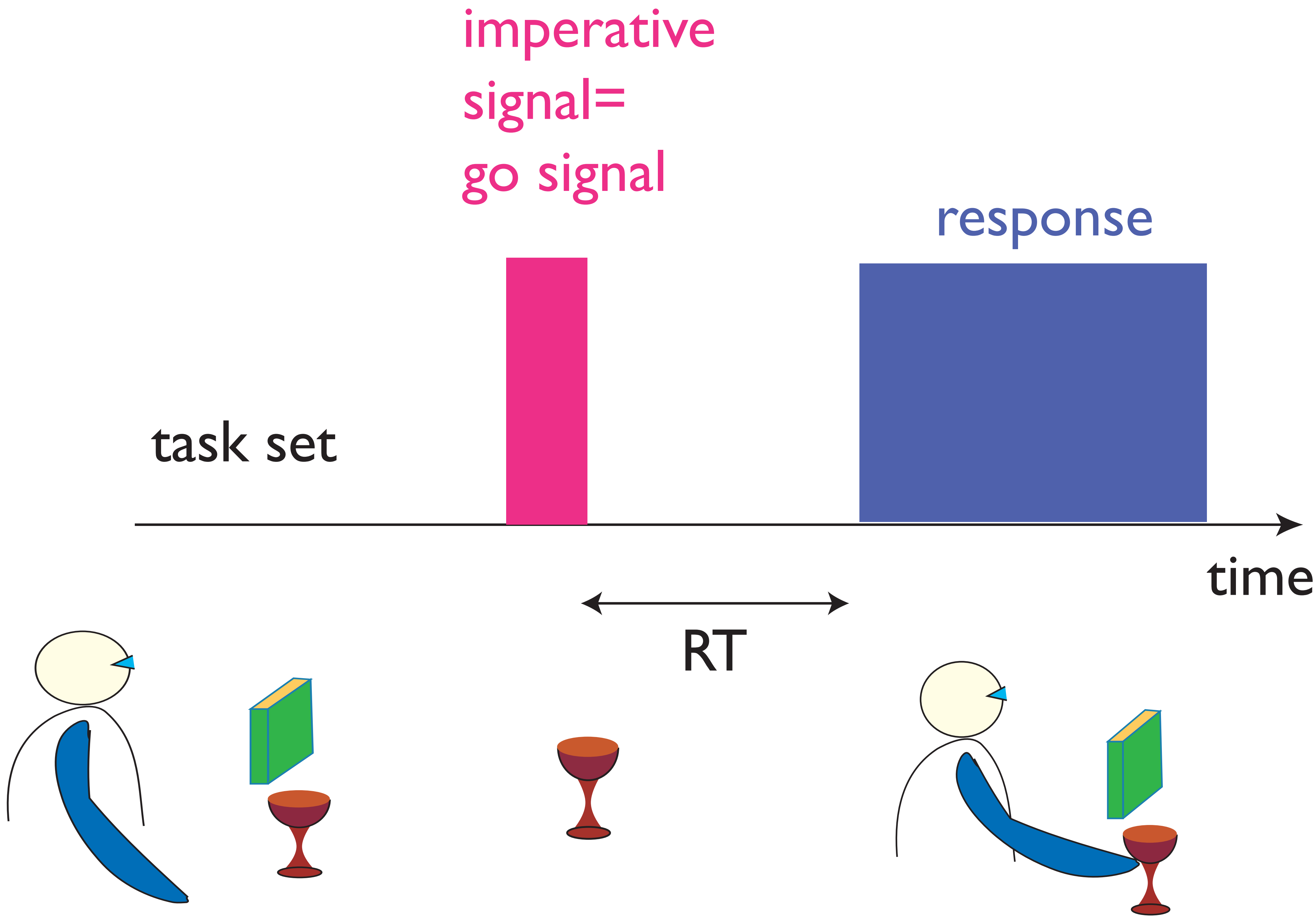
Gregor Schöner
gregor.schoener@ini.rub.de

Recall from last lecture ...

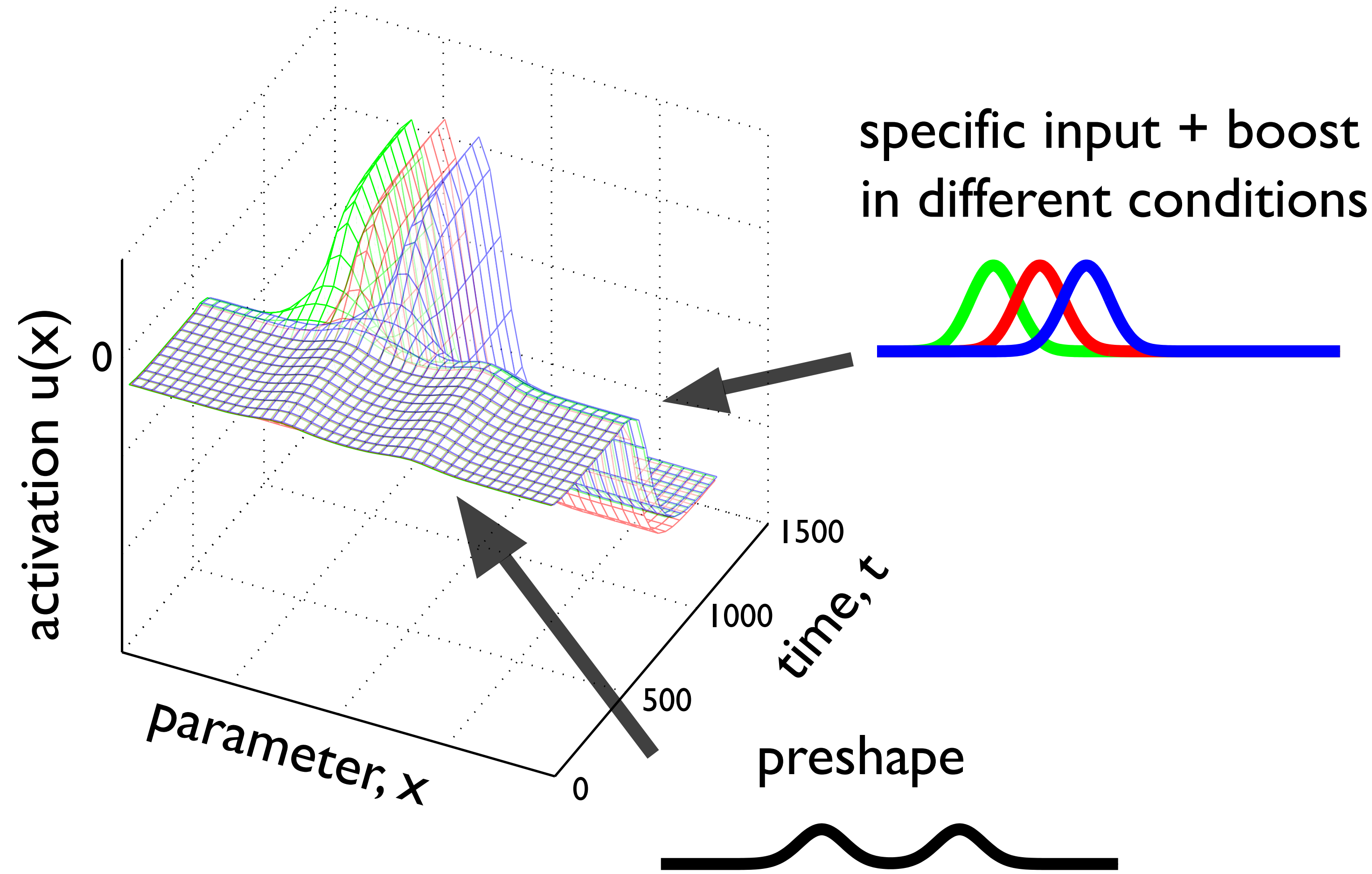


[after: Ottes et al., Vis. Res. 25:825 (85)] [after Kopecz, Schöner: Biol Cybern 73:49 (95)]

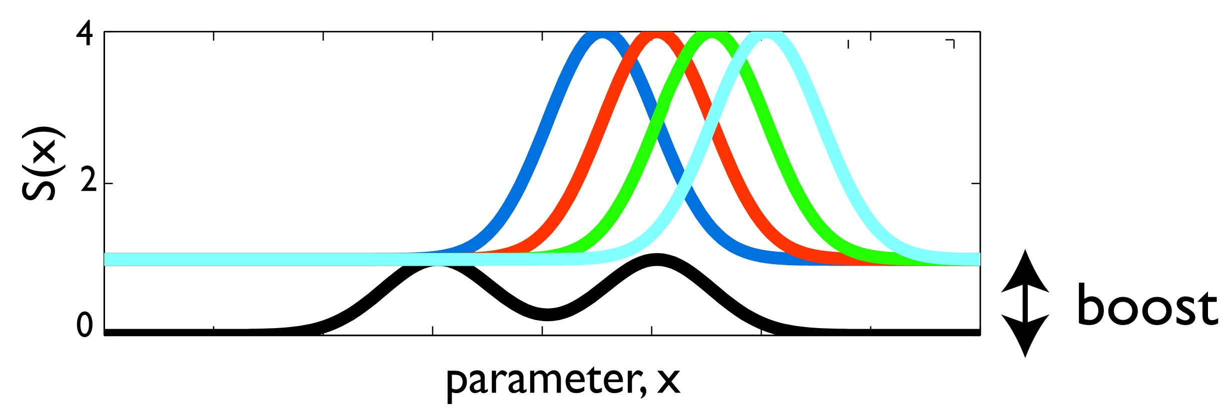
reaction time (RT) paradigm

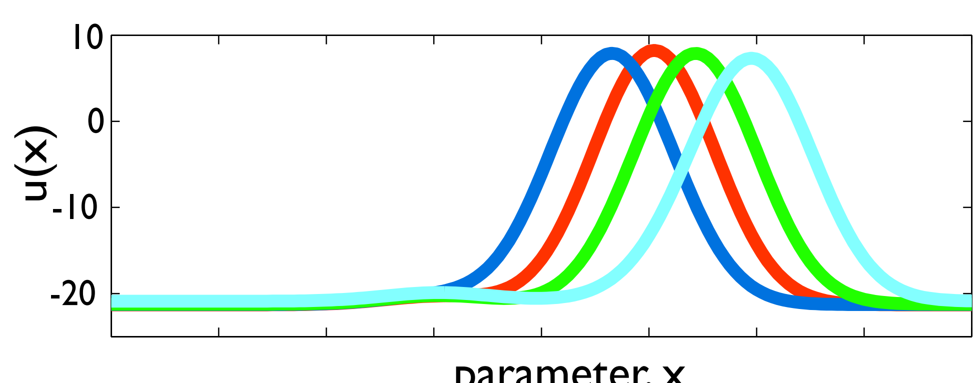


weak preshape in selection



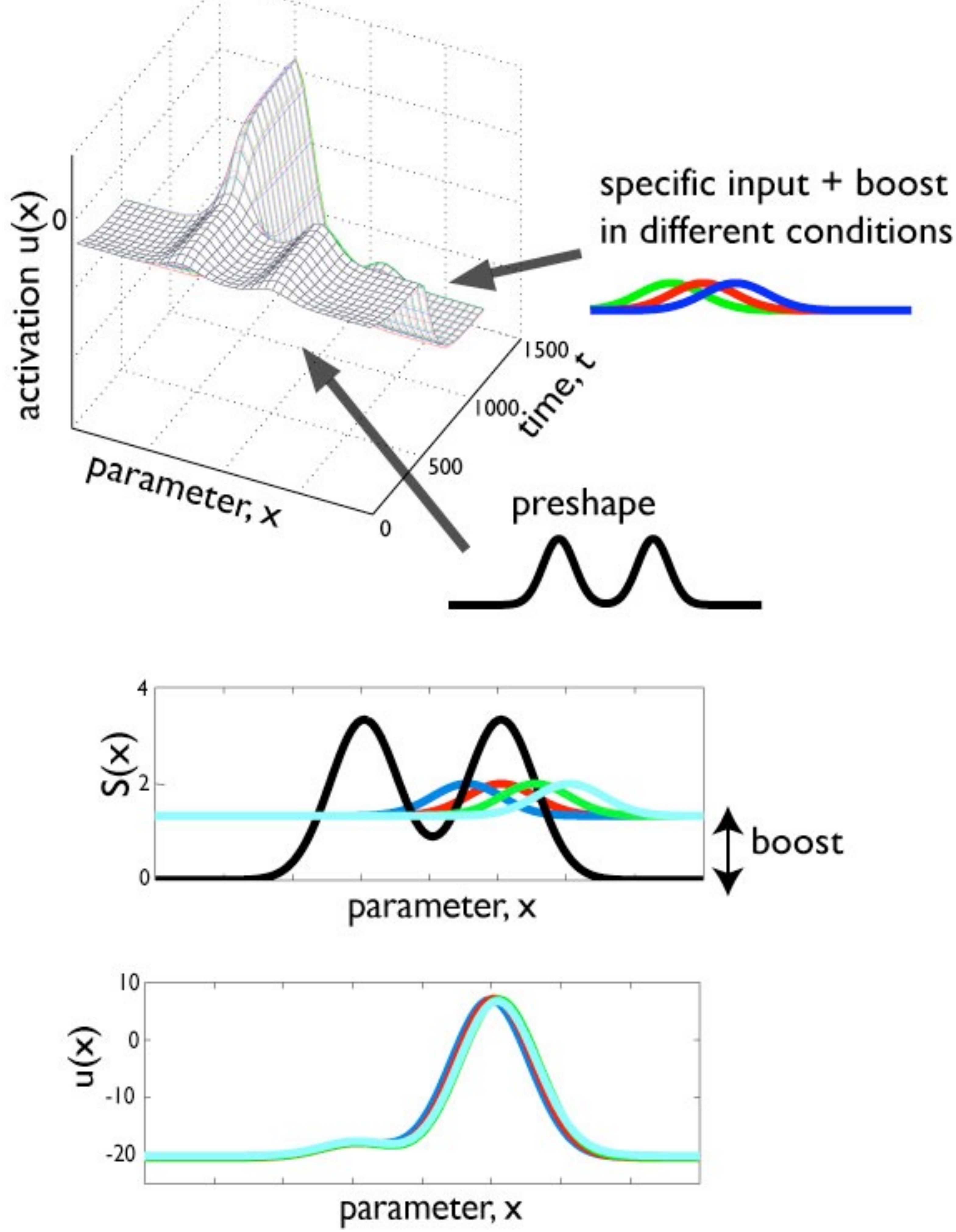
- in which specific (imperative) input dominates and drives detection instability





[Wilimzig, Schöner, 2006]

strong preshape in selection

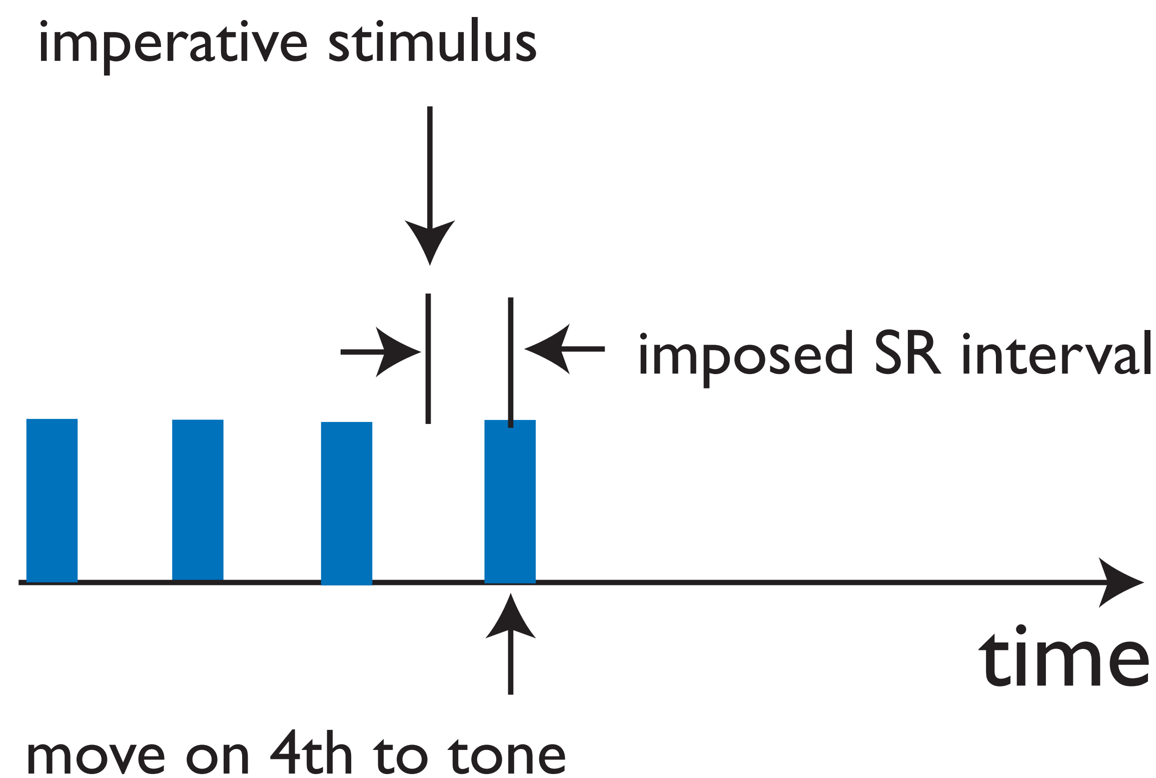


- supports categorical selection decisions

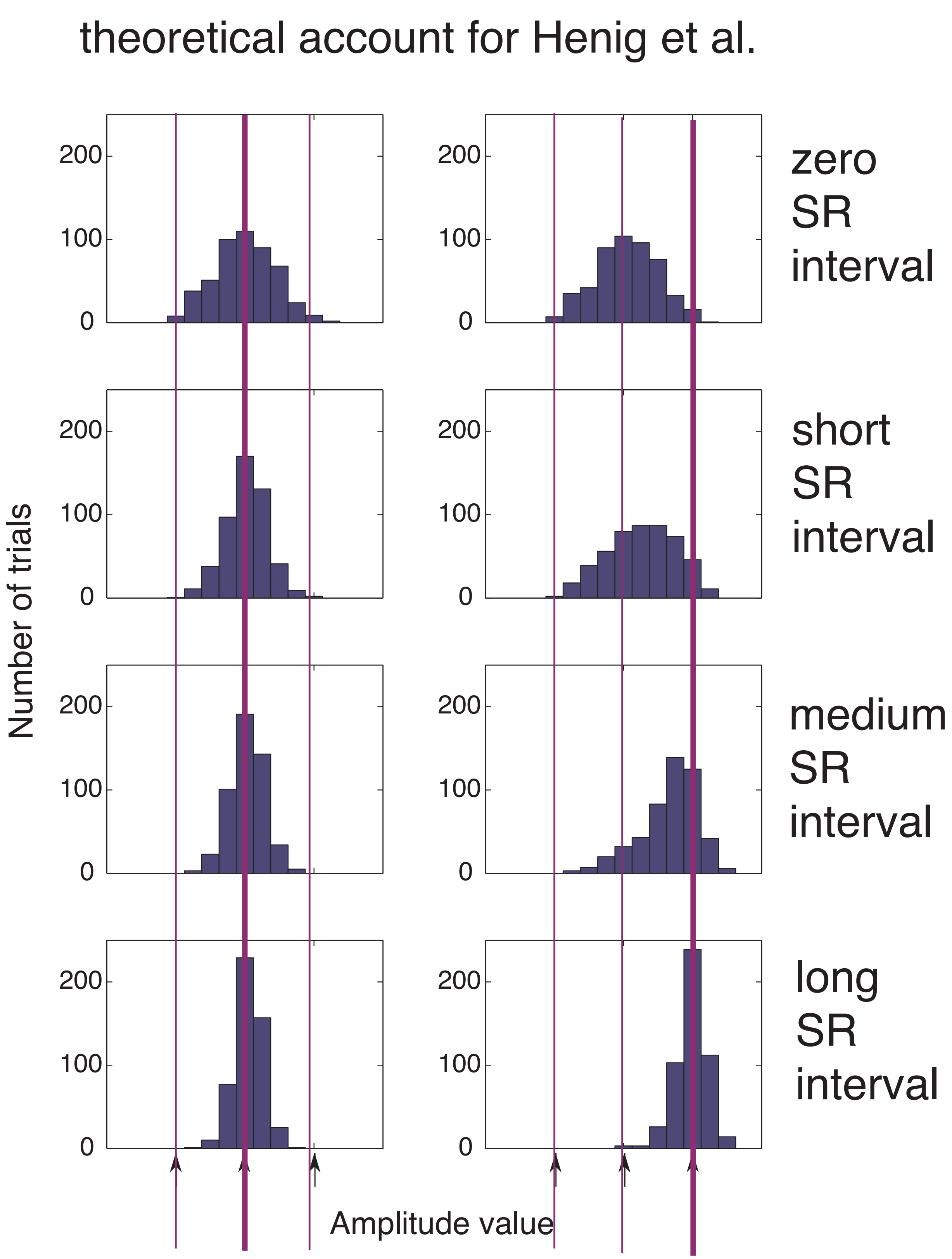
[Wilimzig, Schöner, 2006]

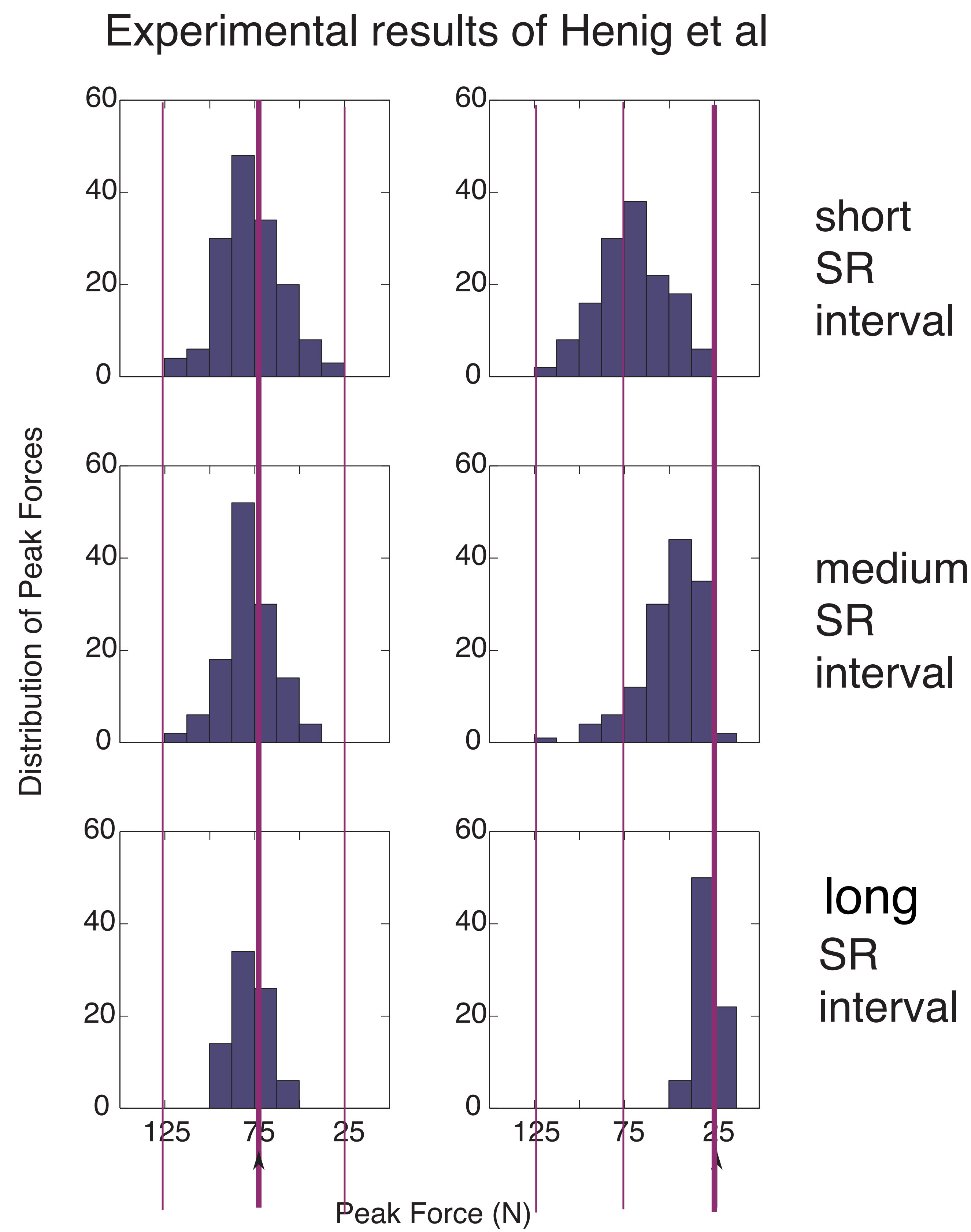
Behavioral evidence for the graded and continuous evolution of decision

timed movement
initiation paradigm



[Ghez and colleagues, 1988 to 1990's]

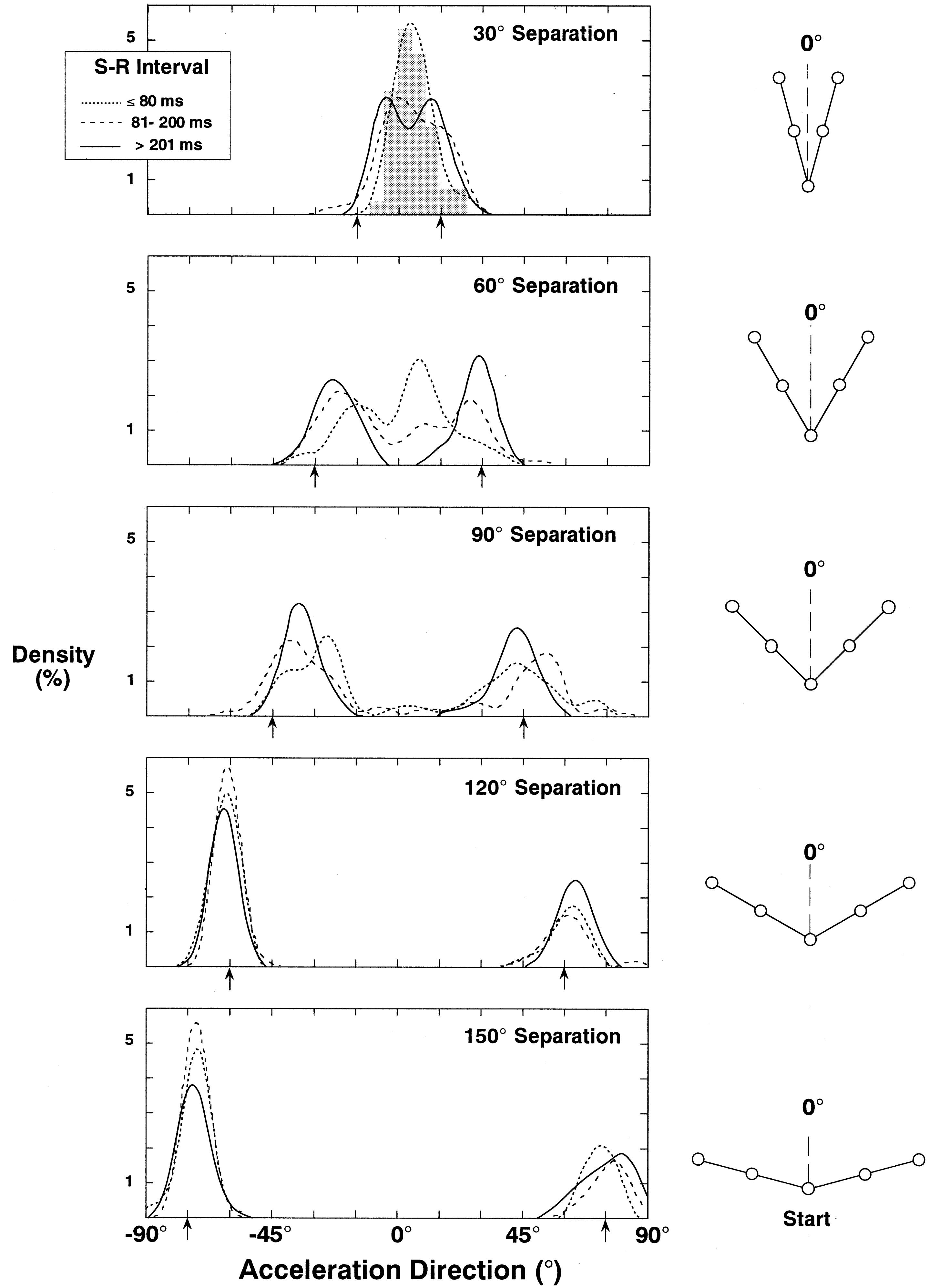




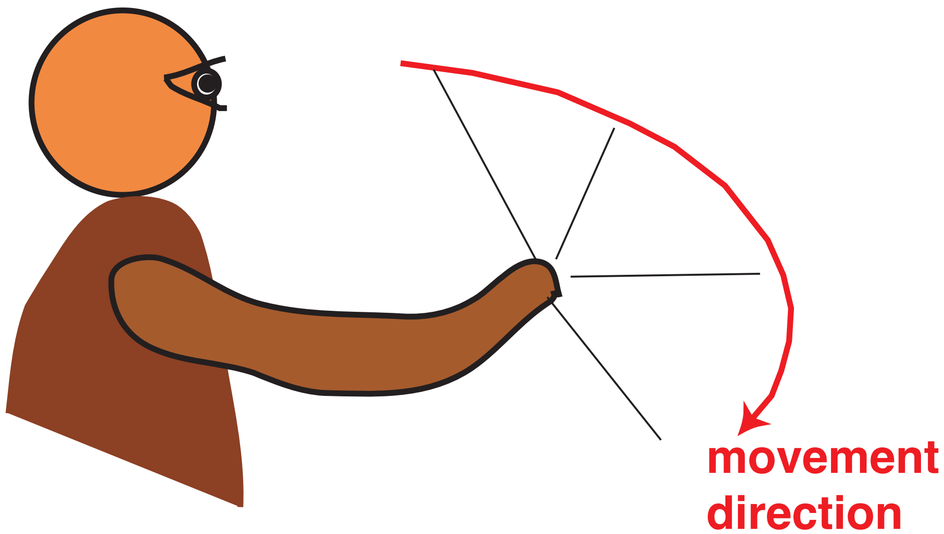
[Erlhagen, Schöner. 2002, Psychological Review 109, 545–572 (2002)]

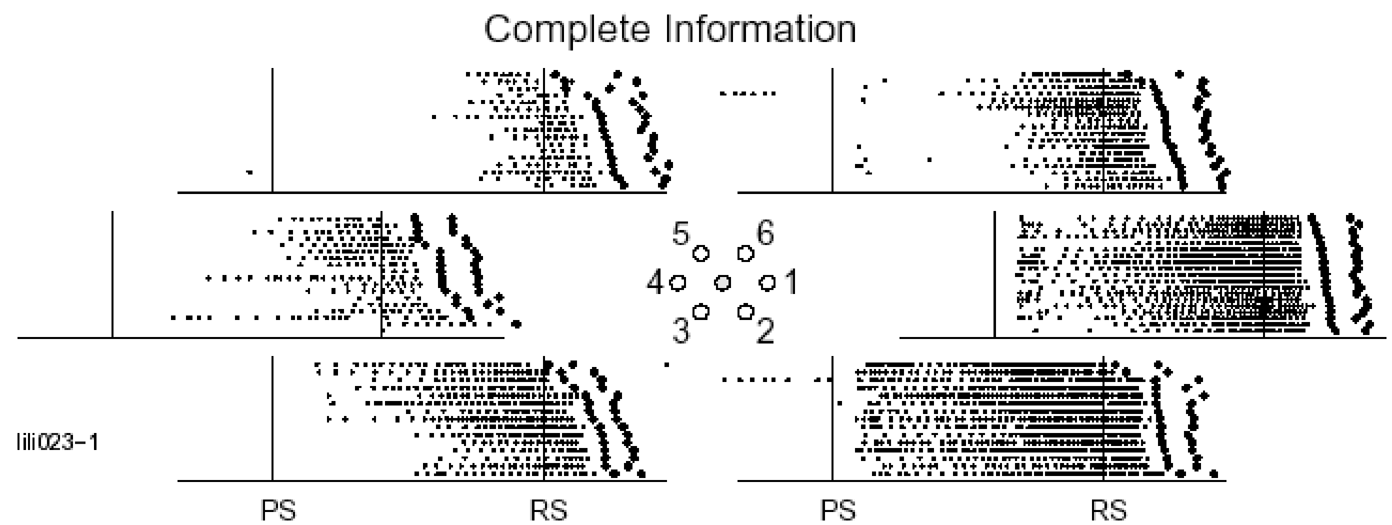
- infer width of preshape peaks in field

[Ghez et al 1997]

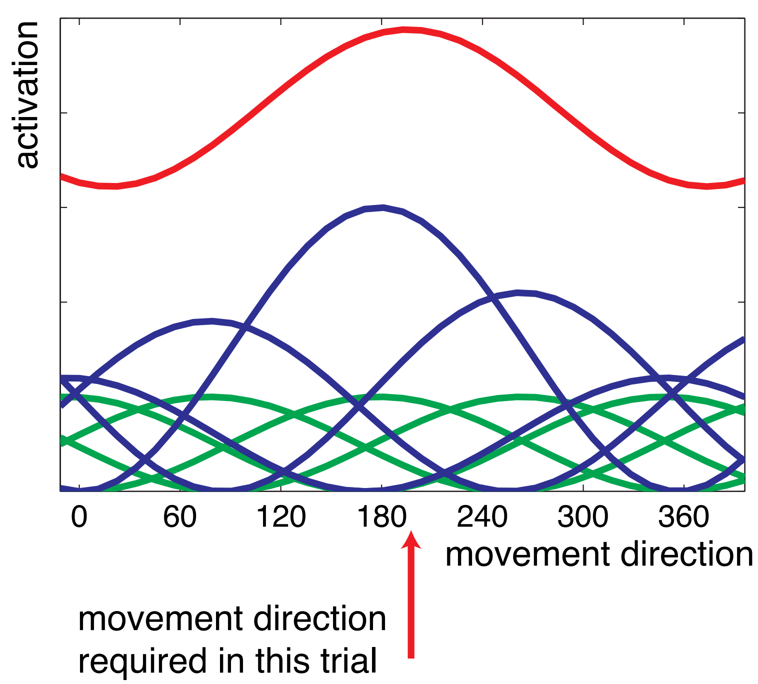


Neural evidence for preshape

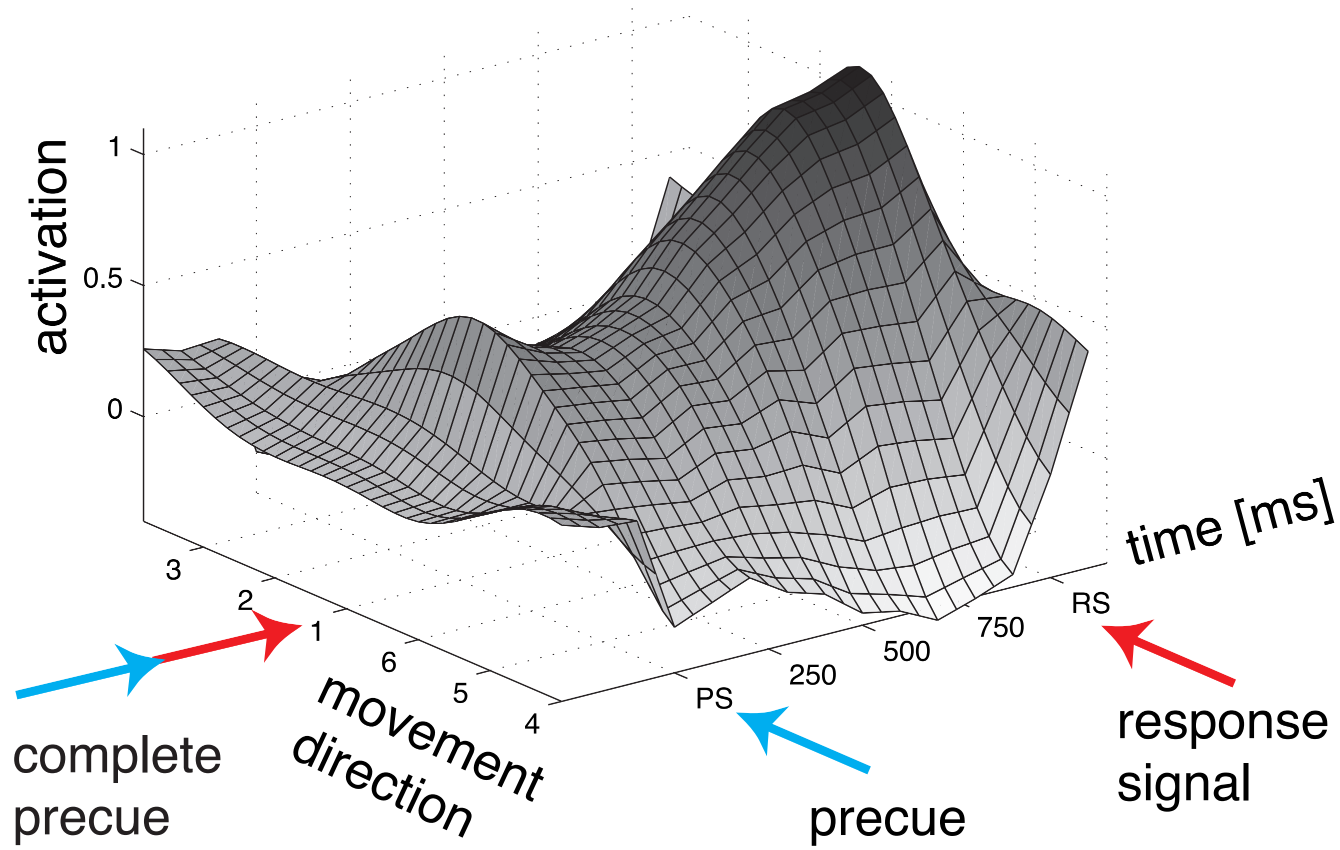




Distribution of population activation =
$\sum_{\text{neurons}}$ tuning curve * current firing rate

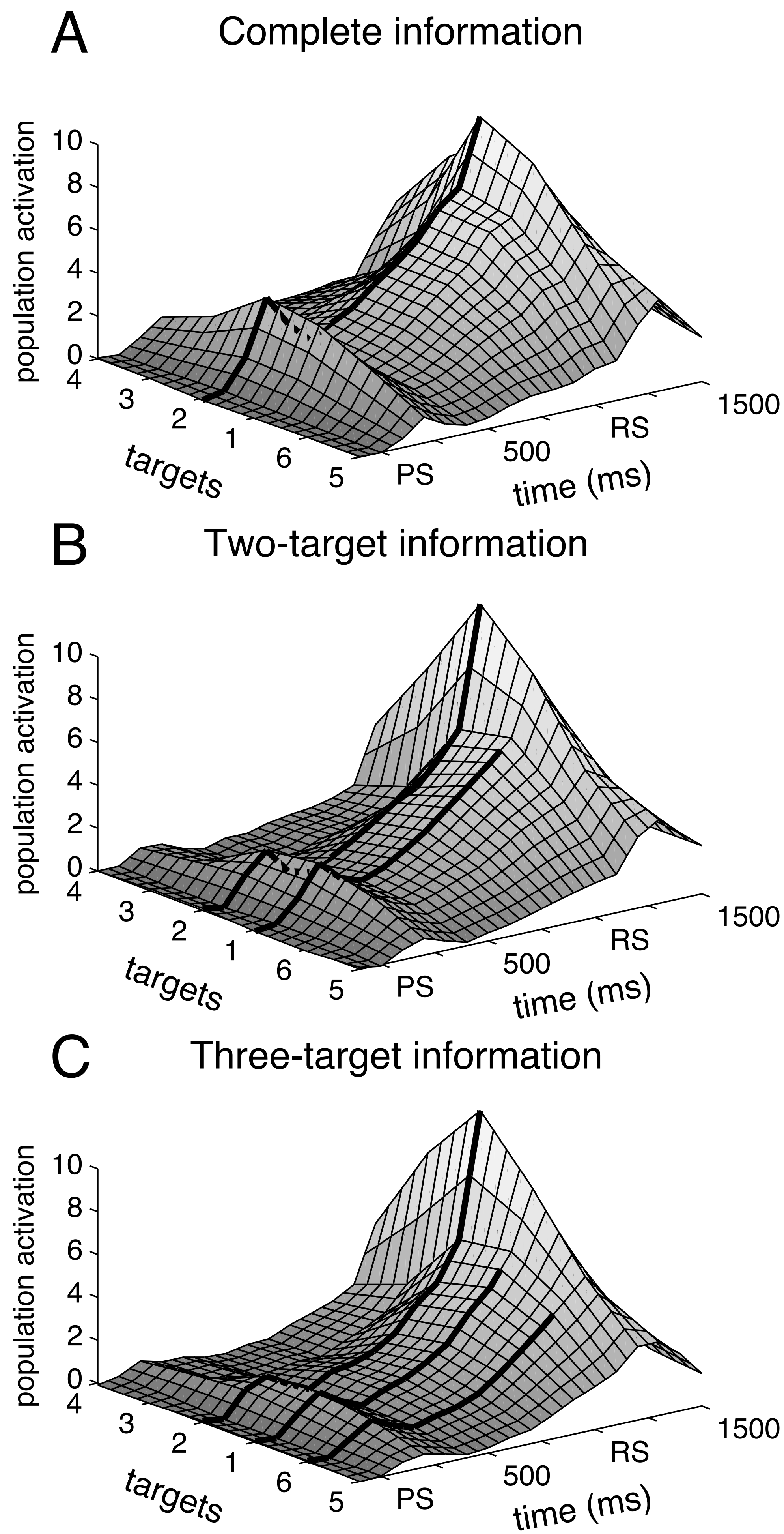


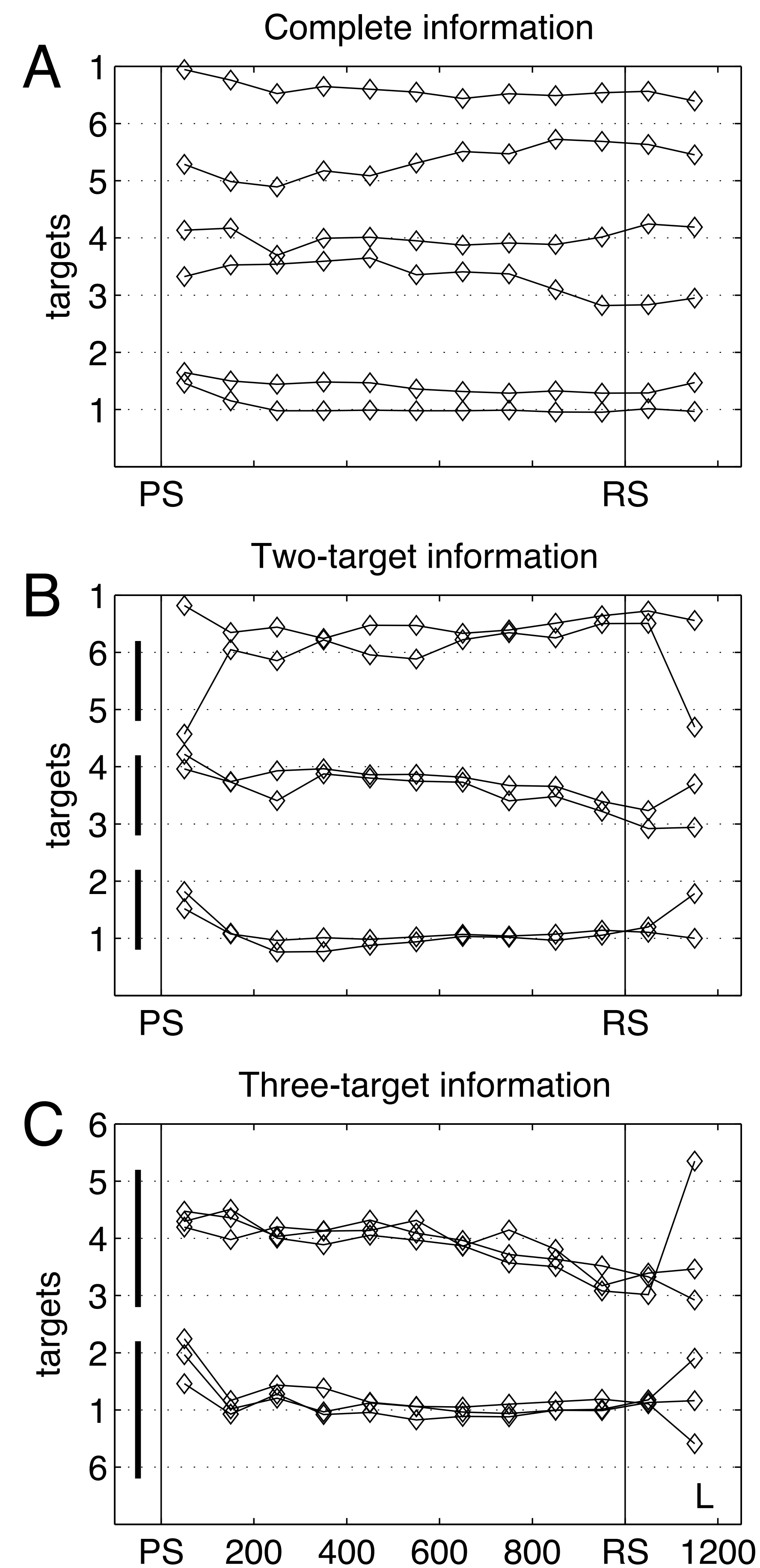
[after Bastian, Riehle, Schöner, submitted]



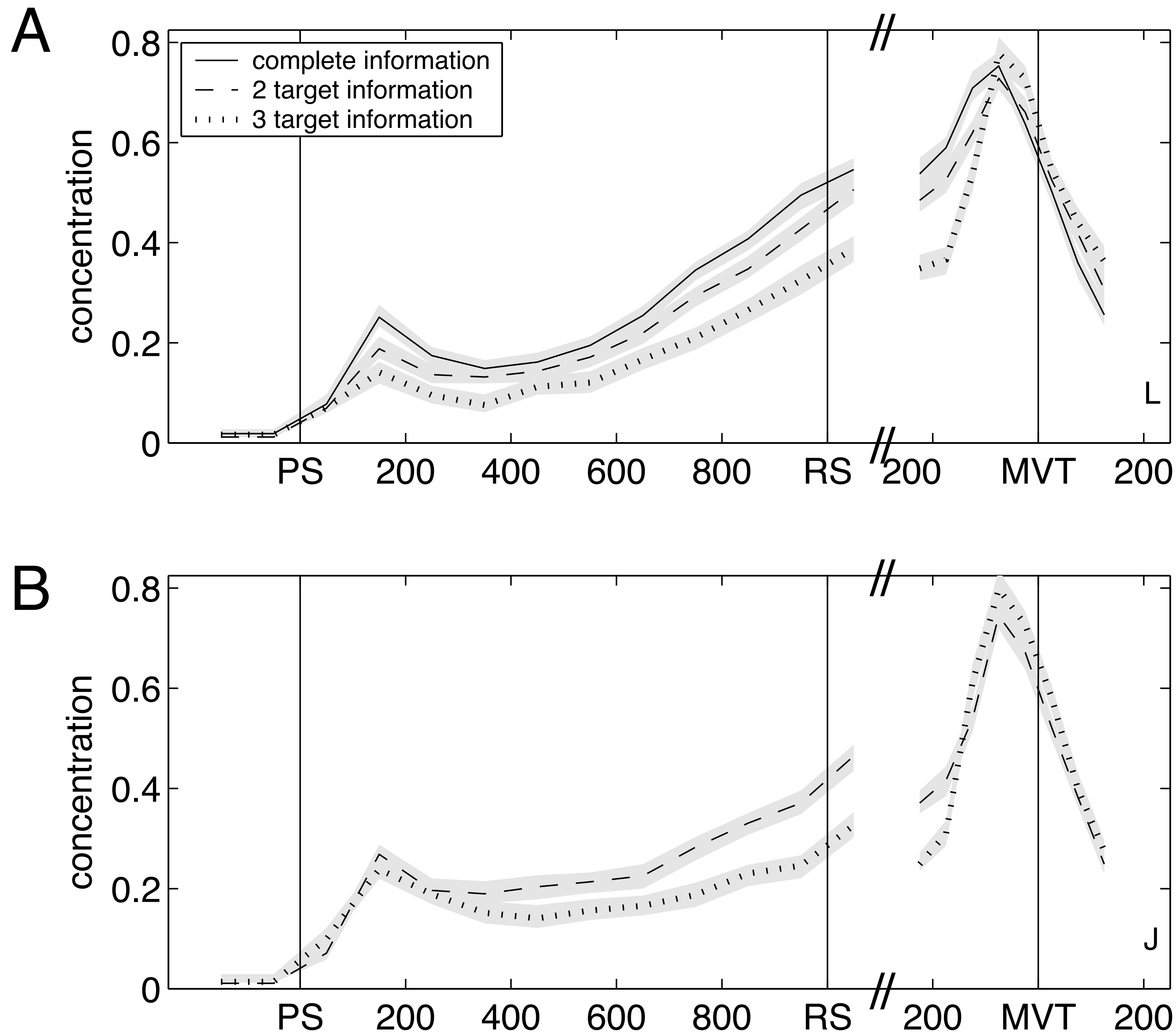
[Bastian, Riehle, Schöner: Europ J Neurosci 18: 2047 (2003)]

- DPA reflects prior information





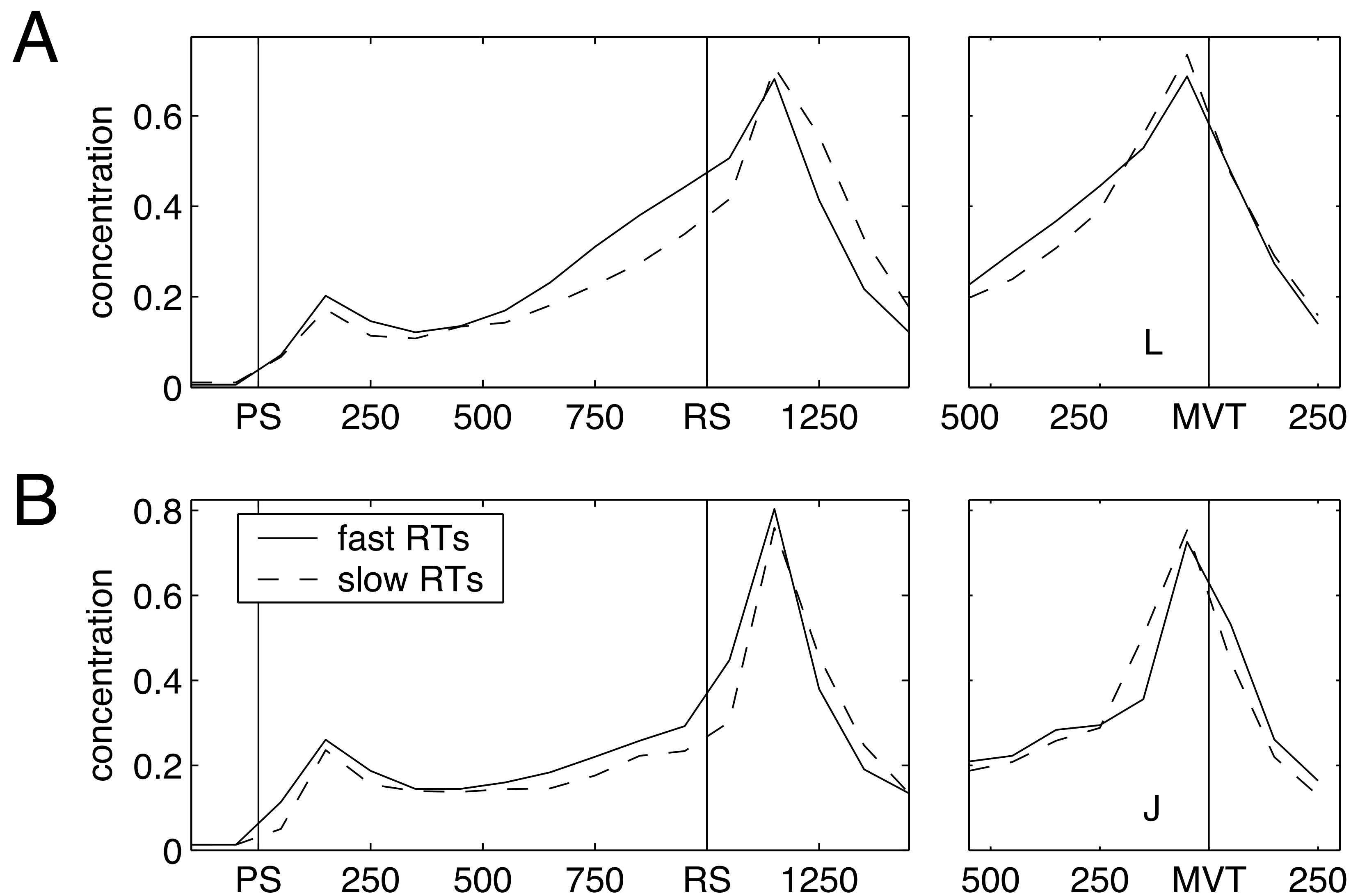
[Bastian, Schöner, Riehle 2003]



- DPA reflects prior information

[Bastian, Schöner, Riehle 2003]

- preshape correlates with RT



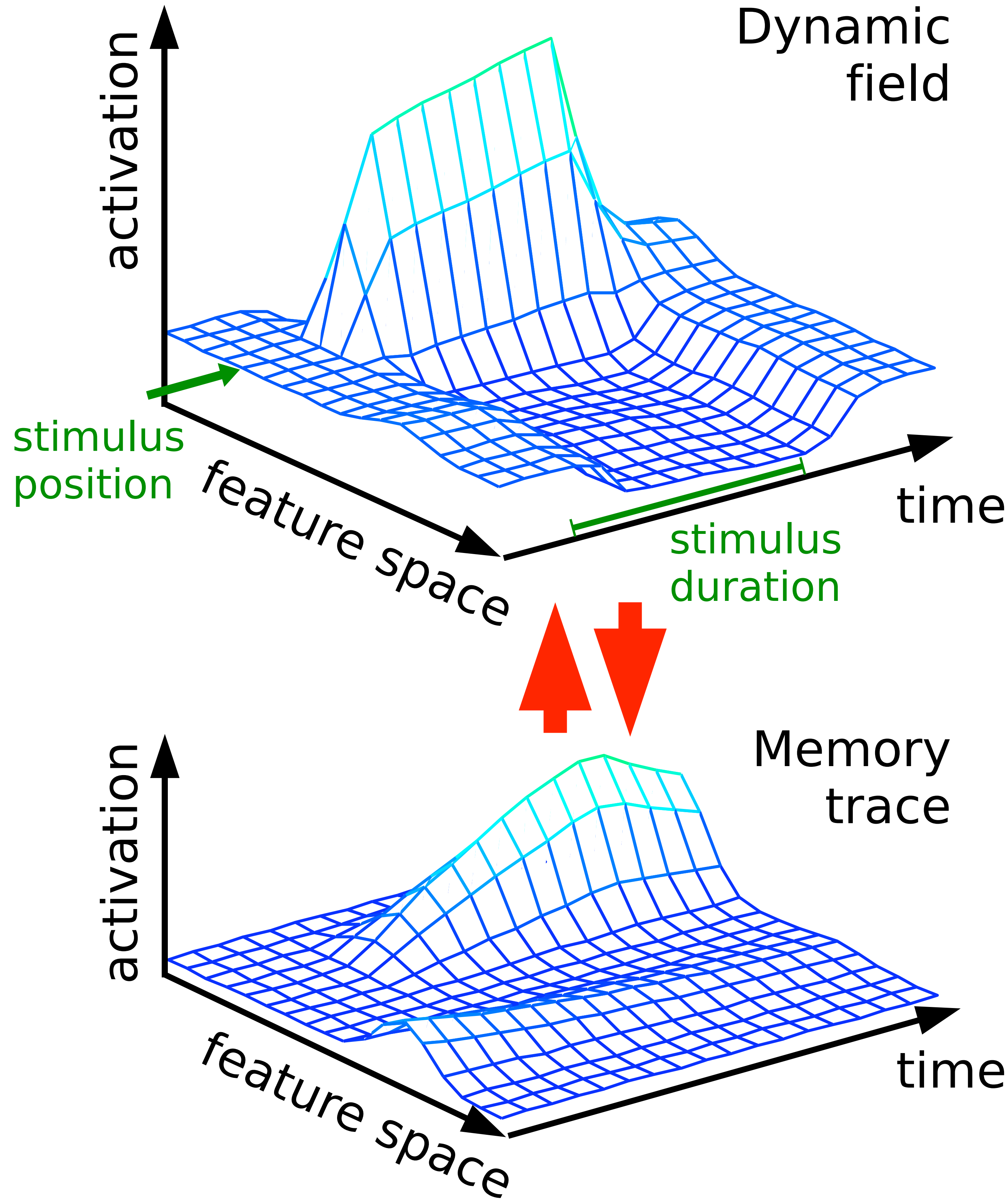
[Bastian, Schöner, Riehle 2003]

Pre-shape and memory trace

- how does pre-structuring of representations arise?
  - in some cases, from the perceptual layout, the environment…
  - but in other cases, from experience…. memory trace

the memory trace

- inhomogeneities from simplest from the memory trace
- ~ habit formation (?) William James: habit formation as the simplest form of learning
- habituation: the memory trace for inhibition..



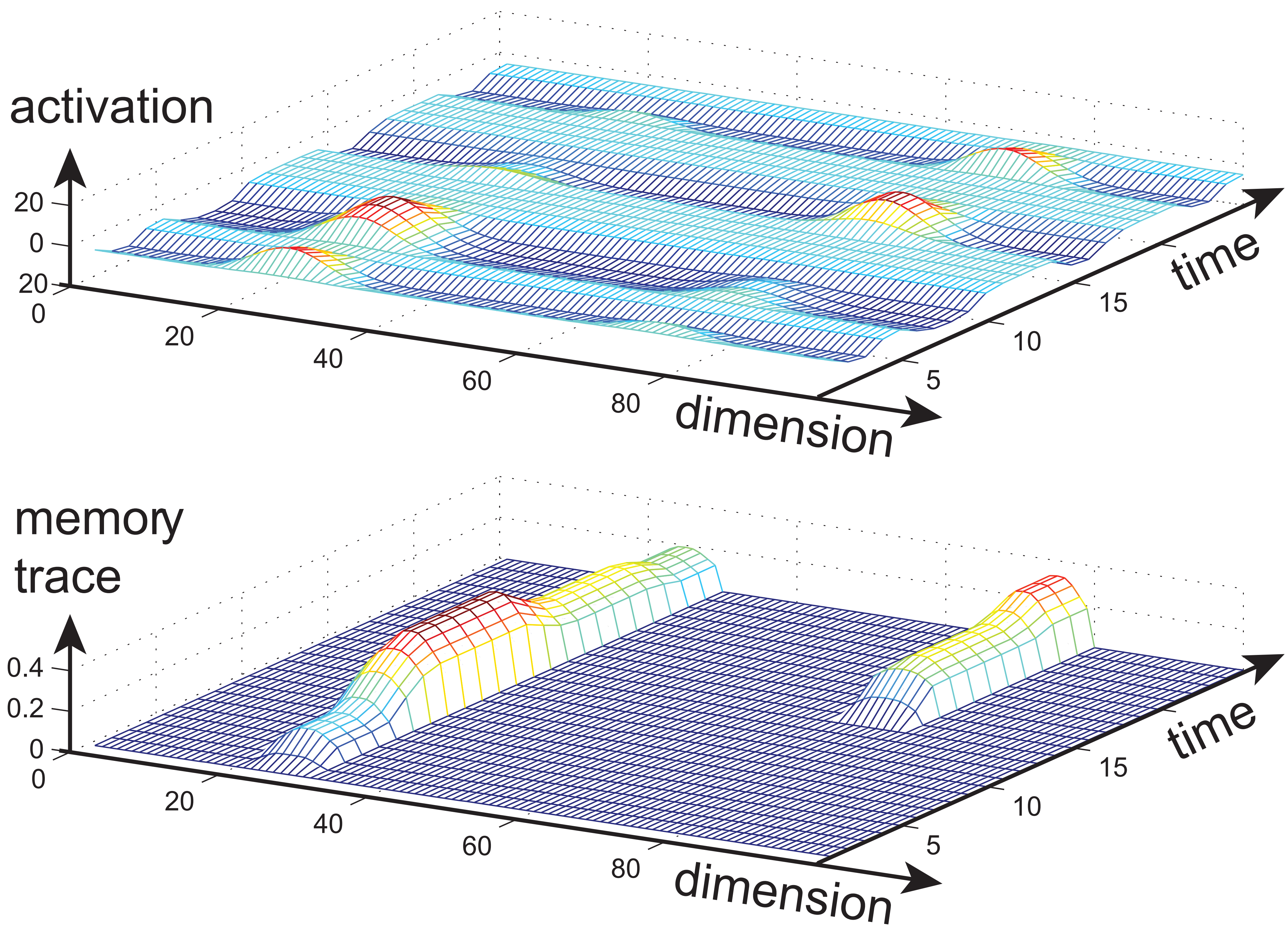
mathematics of the memory trace

$$\begin{aligned}\tau \dot{u}(x,t) &= -u(x,t) + h + S(x,t) + u_{\text{mem}}(x,t) \\ &+ \int dx' \; w(x-x') \; \sigma(u(x'))\end{aligned}$$

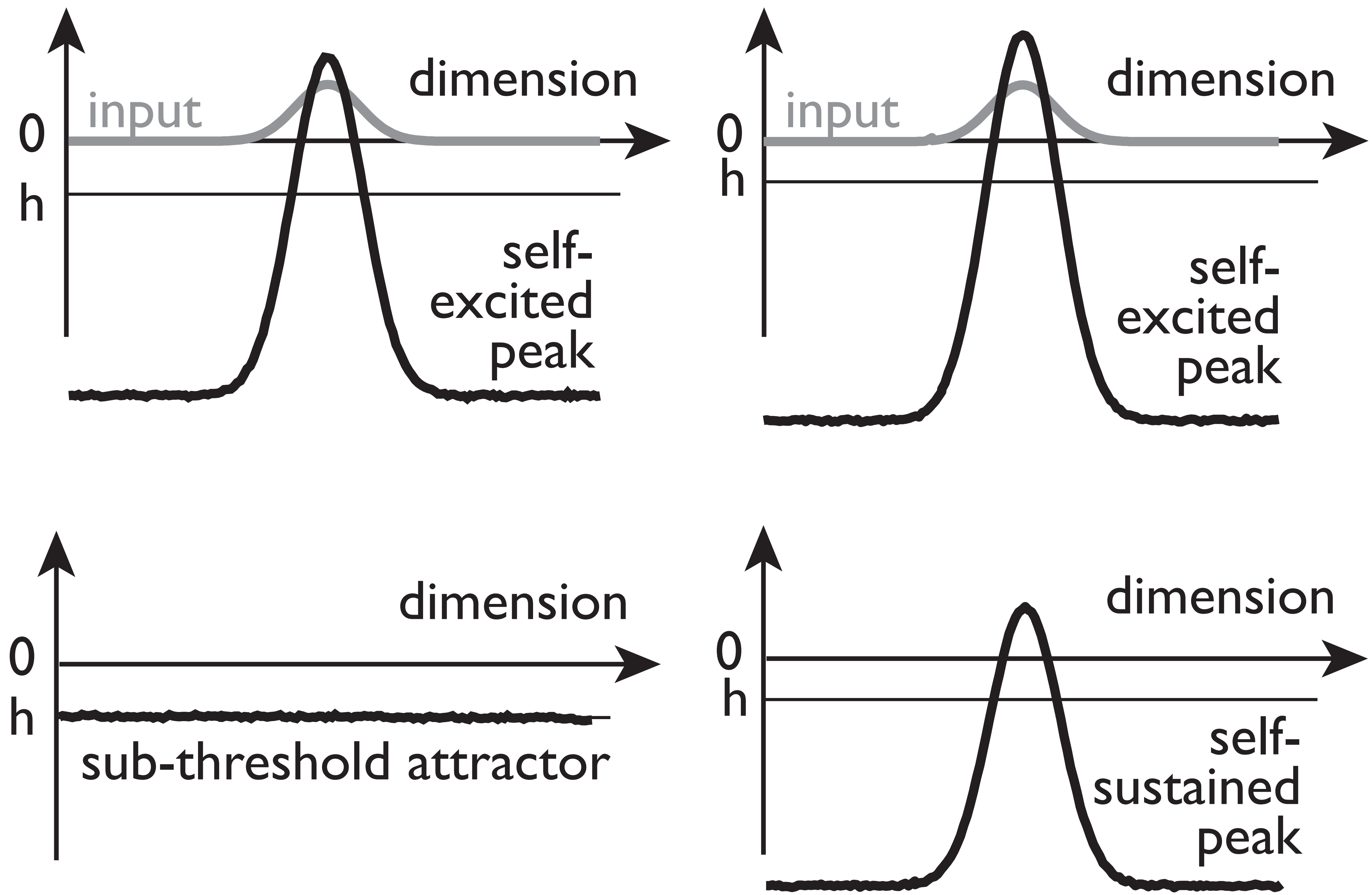
$$\begin{aligned}\tau_{\text{mem}} \; \dot{u}_{\text{mem}}(x,t) &= -u_{\text{mem}}(x,t) \\ &+ \int dx' \; w_{\text{mem}}(x-x')\sigma(u(x',t))\end{aligned}$$

- memory trace only evolves while activation is excited
- potentially different growth and decay rates

memory trace reflects history of decisions formation



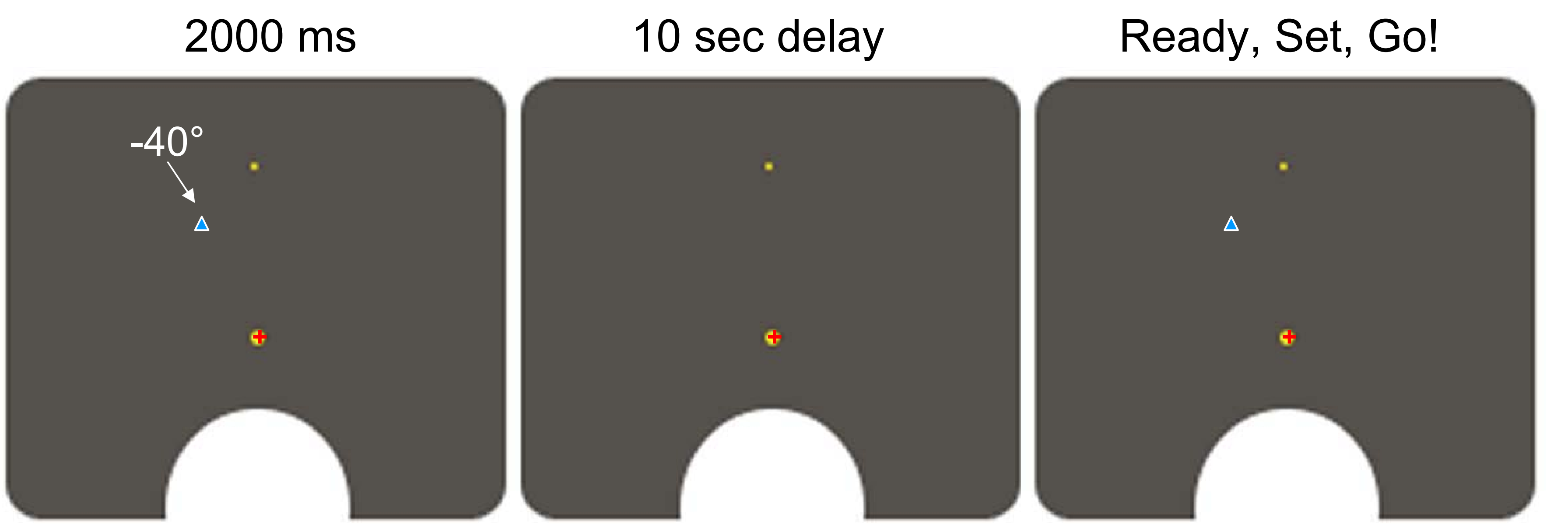
(Working) memory instability

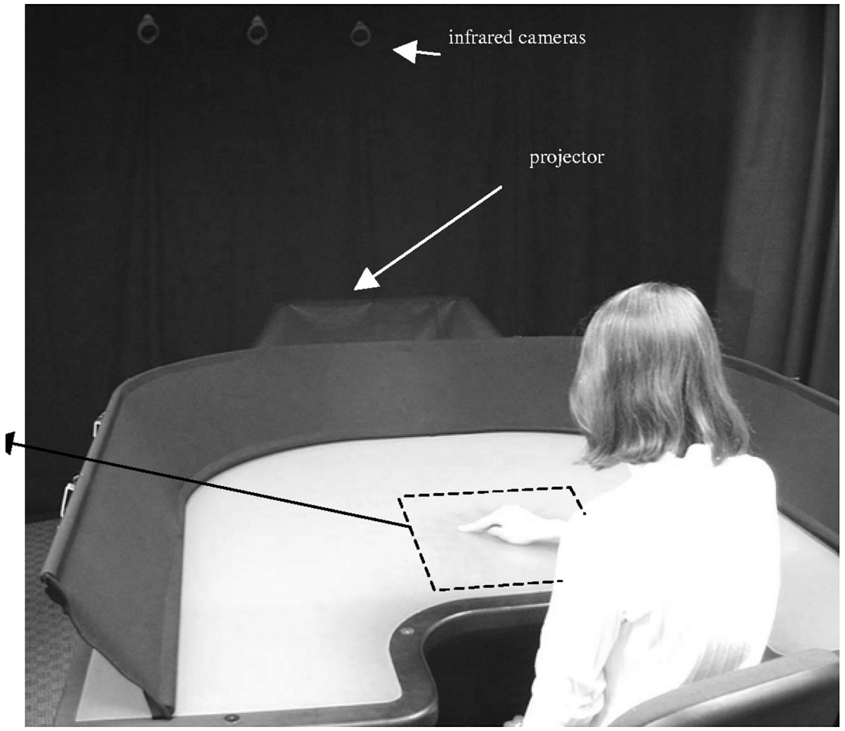


Working memory as sustained peaks

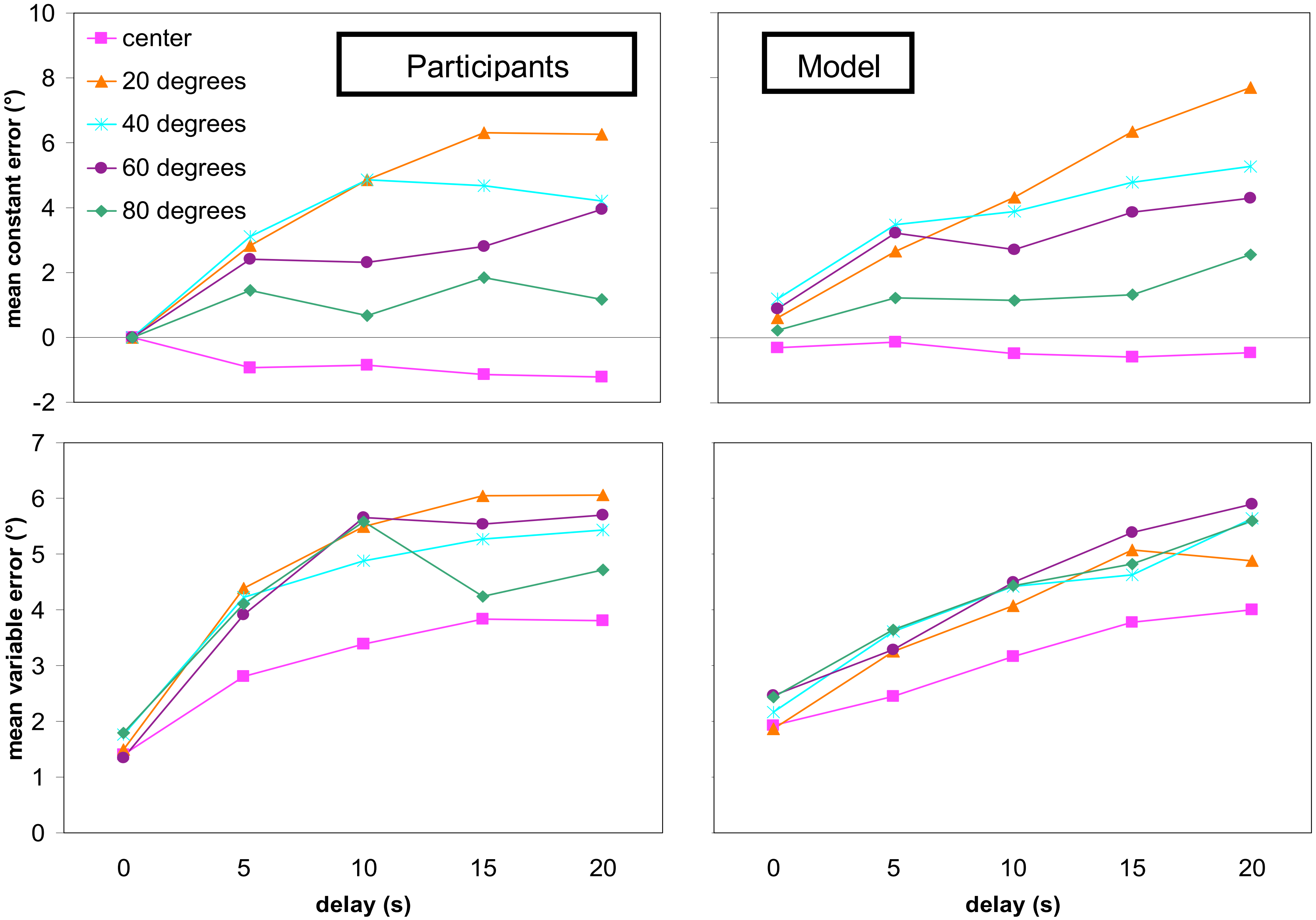
- WM is marginally stable state: it is not asymptotically stable against drift within the low-dimensional space
- => empirically real.. ?

"space ship" task probing spatial working memory

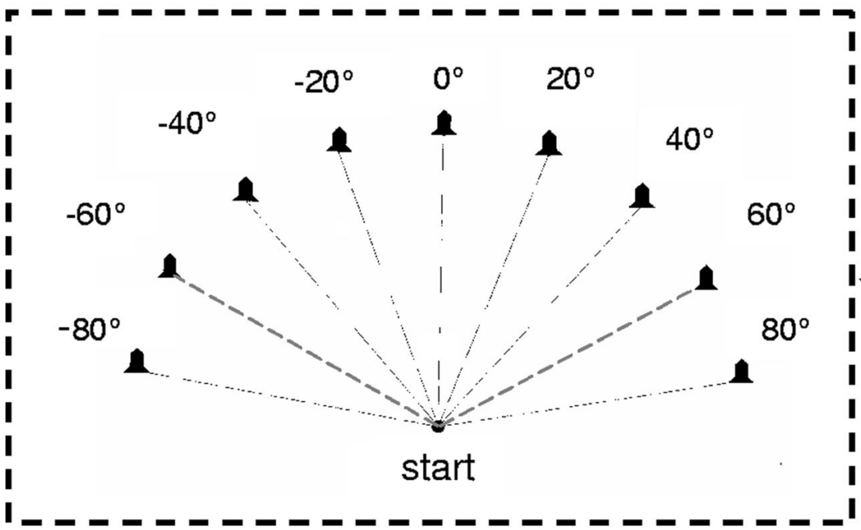


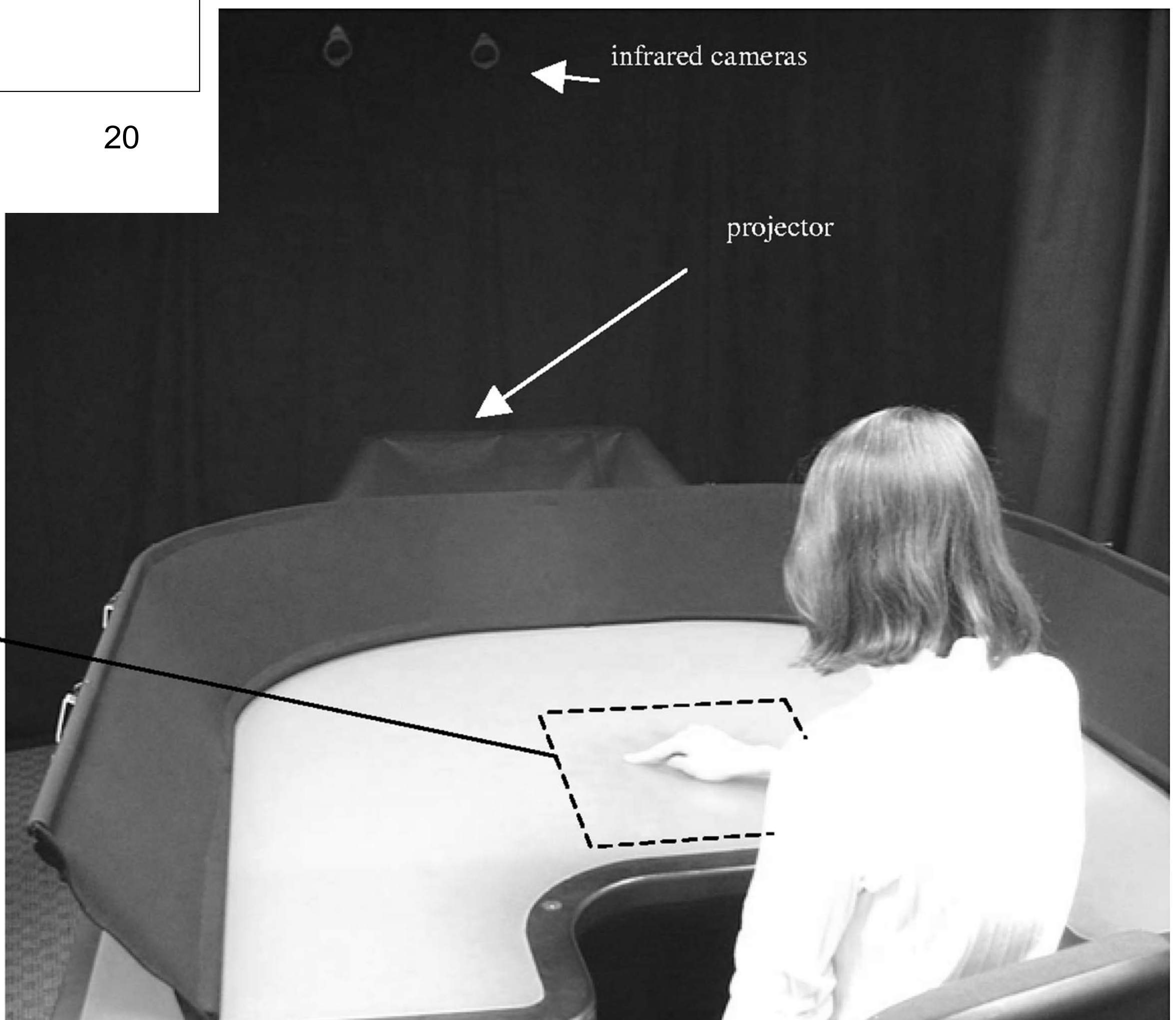


[Schutte, Spencer, JEP:HPP 2009]



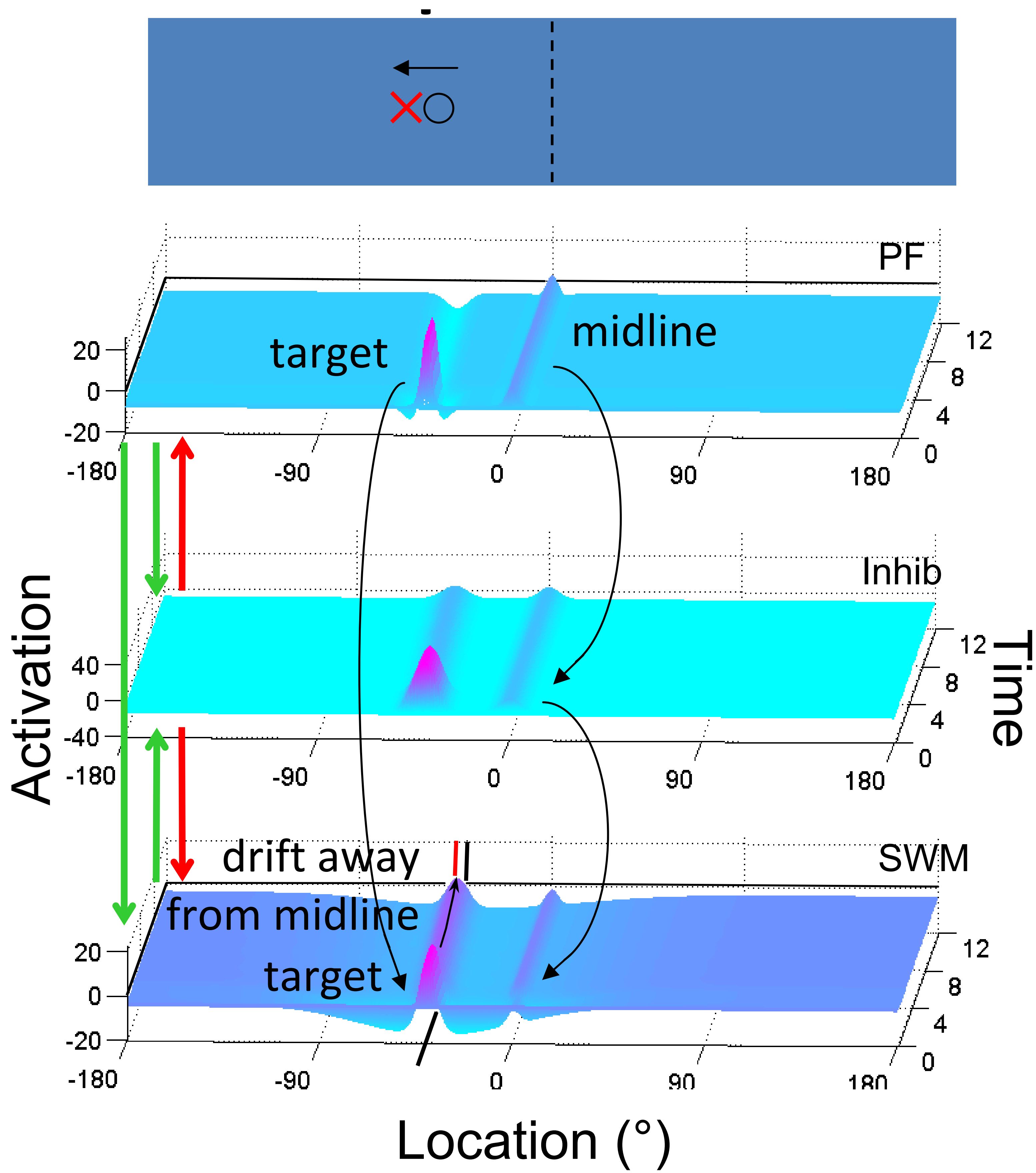
repulsion from mid-line





[Spencer, Schöner, 2006]

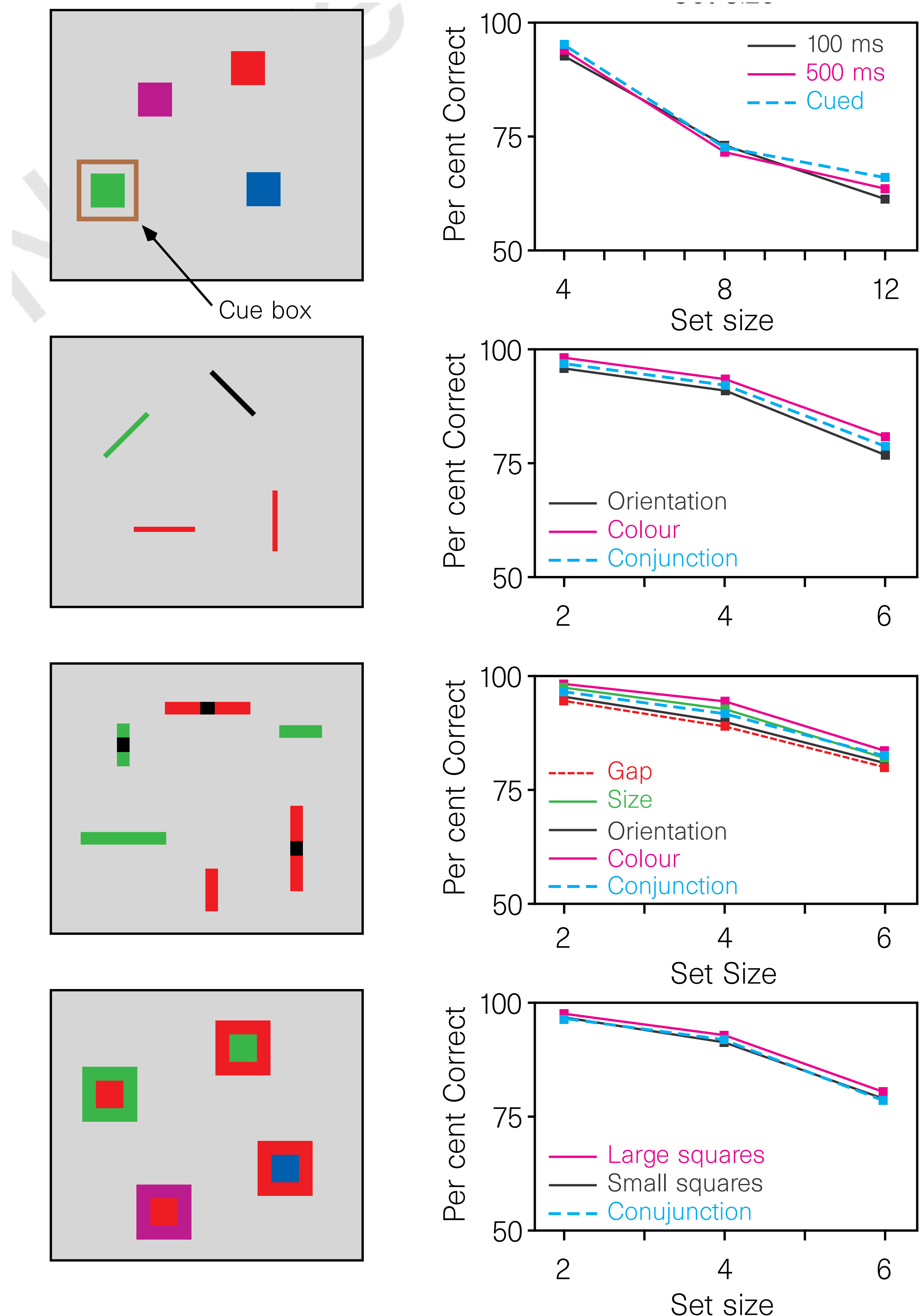
- DFT account of repulsion: inhibitory interaction with peak representing landmark



[Simmering, Schutte, Spencer: Brain Research, 2007]

visual working memory

- has limited capacity
  - based on the number of objects…
  - about 4
- probed by change detection, free recall



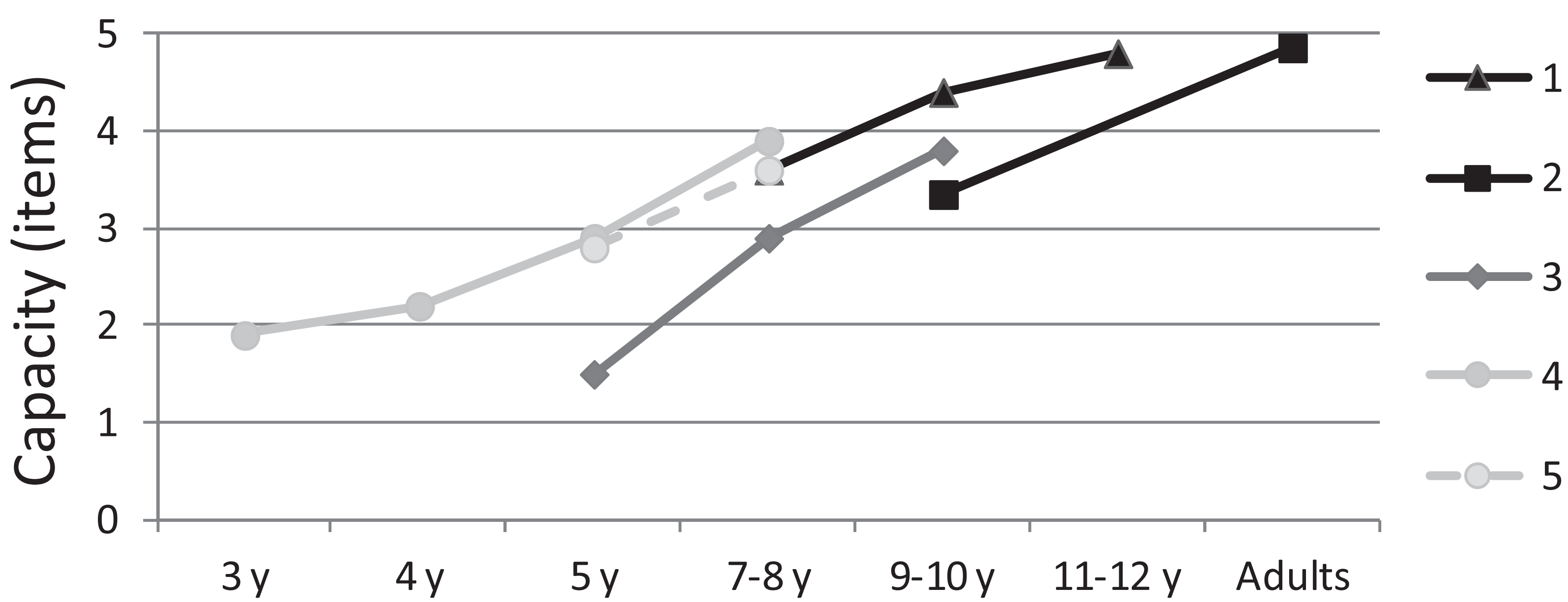
[Luck, Vogel, 1997]

DFT account of WM capacity

- fundamentally caused by accumulation of inhibitory interaction across peaks
- => generic to DFT

WM capacity depends on interaction

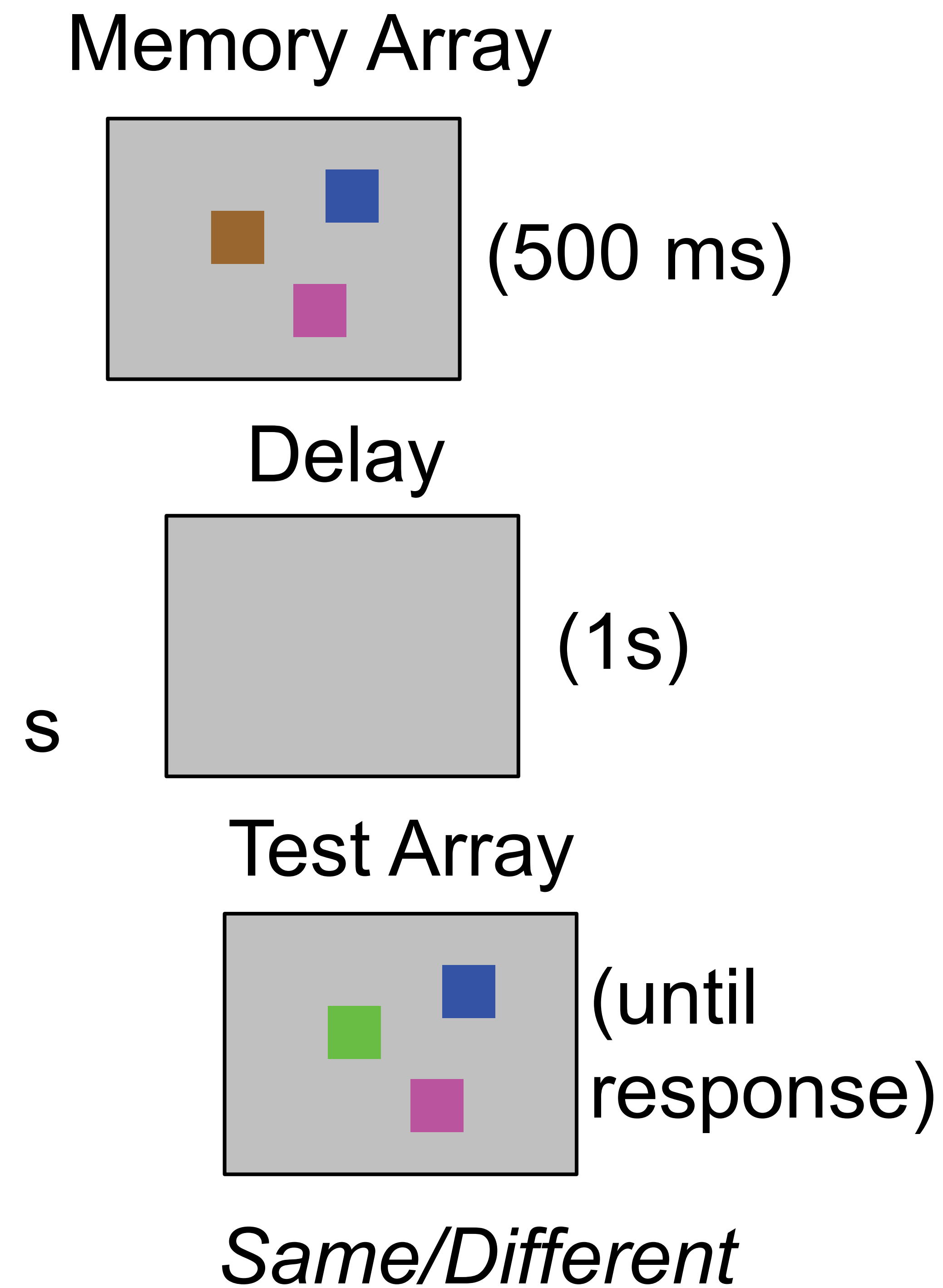
- capacity increases across development
- consistent with "spatial precision hypothesis"… interaction becomes more excitatory/local over development



[Simmering 2010]

Change detection

- the standard probe of working memory

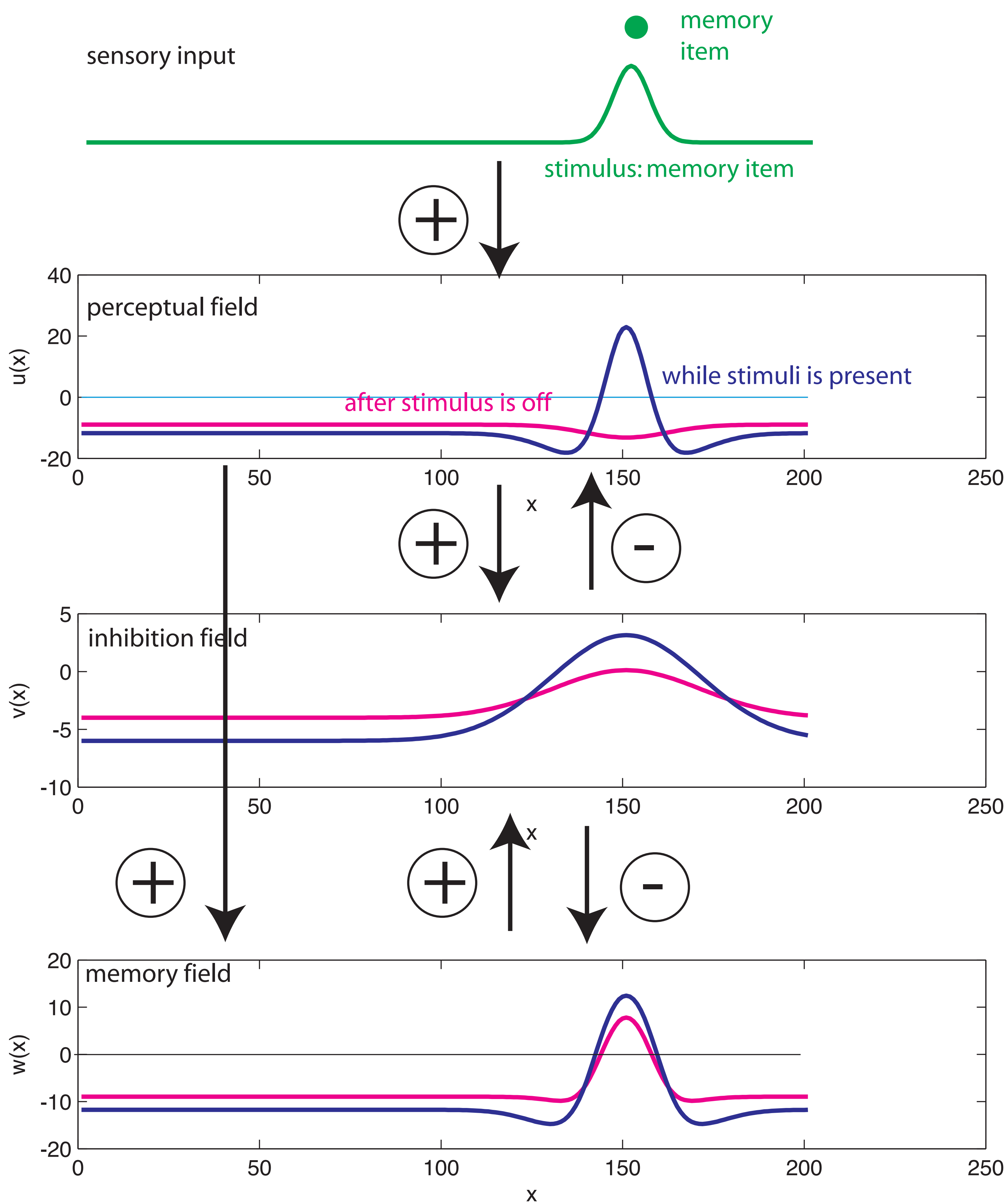


[Johnson, et al. 2009]

DFT account for change detection

- separation between perceptual and memory function

3 layer model



3 layer model

$$
\begin{aligned}
\tau \dot{u}(x,t) &= -u(x,t) + h_u + S(x,t) + \int dx'\; c_{\mathrm{uu}}(x-x')\;\sigma(u(x',t)) \\
&- \int dx'\; c_{\mathrm{uv}}(x-x')\;\sigma(v(x',t)) + \int dx'\; c_{\mathrm{uw}}(x-x')\;\sigma(w(x',t)) \\
\tau \dot{v}(x,t) &= -v(x,t) + h_v \\
&+ \int dx'\; c_{\mathrm{vu}}(x-x')\;\sigma(u(x',t)) + \int dx'\; c_{\mathrm{vw}}(x-x')\;\sigma(w(x',t)) \\
\tau \dot{w}(x,t) &= -w(x,t) + h_w + \int dx'\; c_{\mathrm{ww}}(x-x')\;\sigma(w(x',t)) \\
&- \int dx'\; c_{\mathrm{wv}}(x-x')\;\sigma(v(x',t)) + \int dx'\; c_{\mathrm{wu}}(x-x')\;\sigma(u(x',t))
\end{aligned}
$$

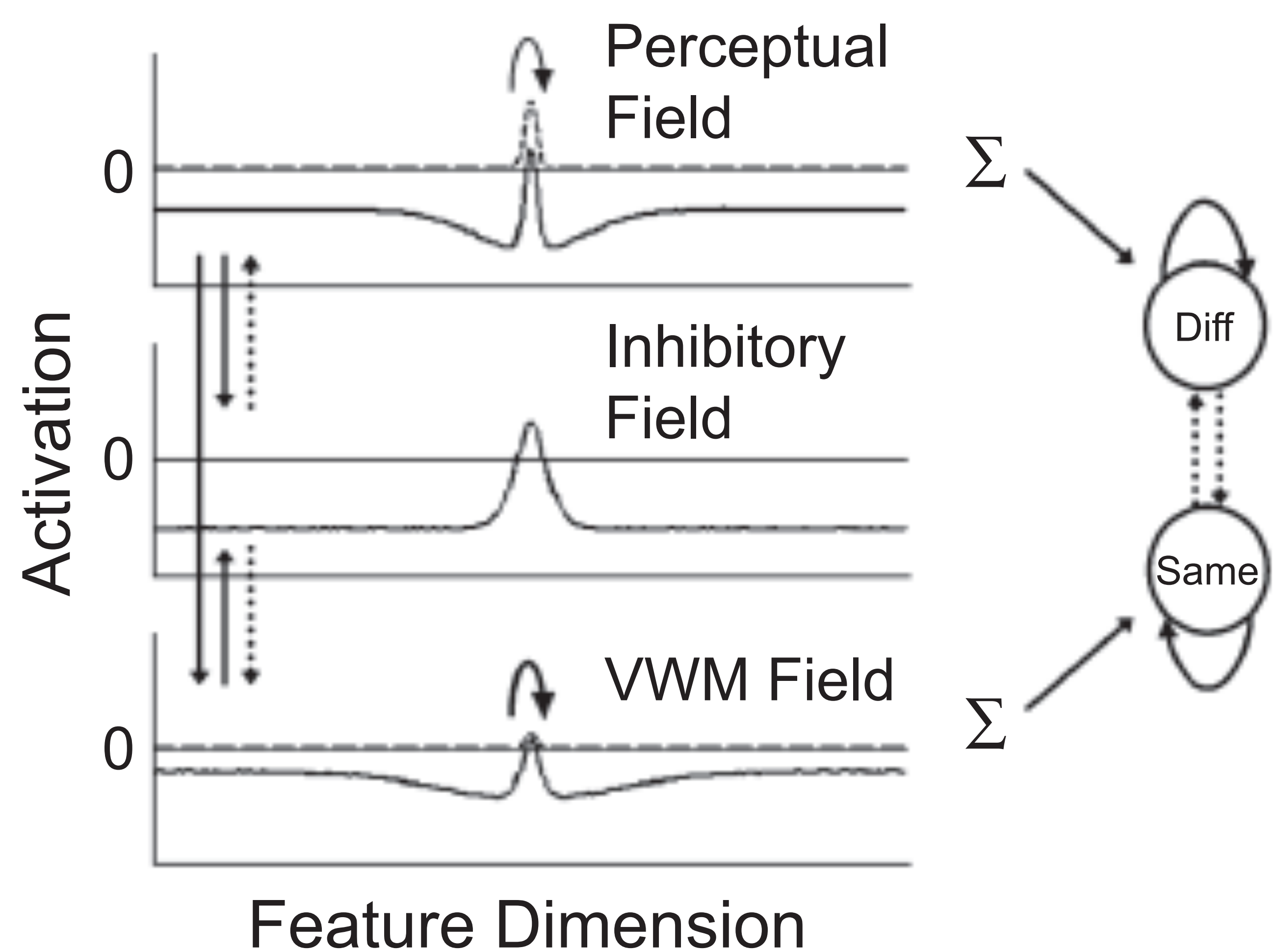
=> simulations

DFT account for change detection

- => account for how working memories arise from percepts, how percepts may detect change and update memories…

DFT account for change detection

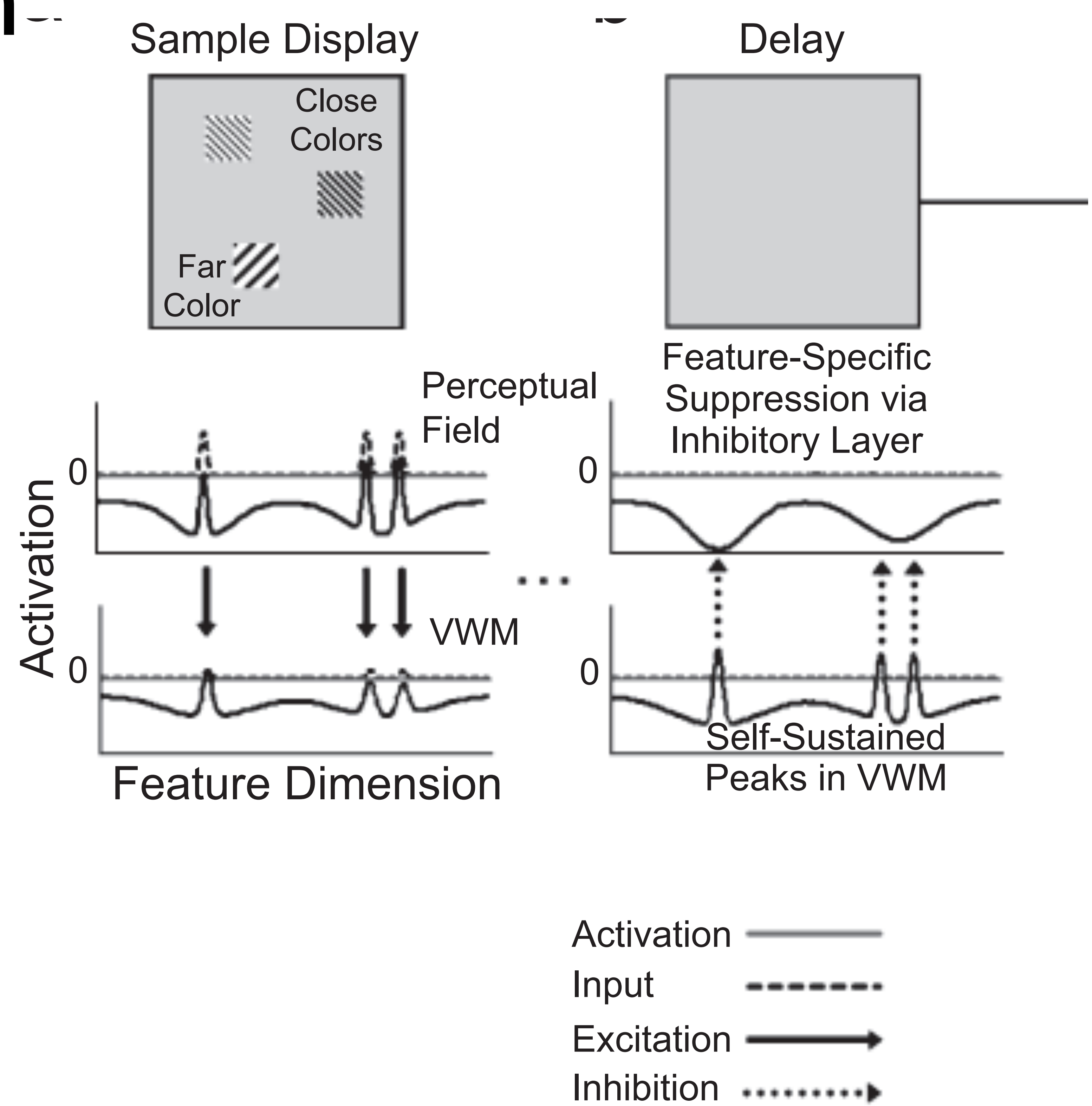
- generate the categorical "answer" by two competing nodes
- based on the "hidden" go-signal in the task



[Johnson, et al. 2009]

DFT account for change detection

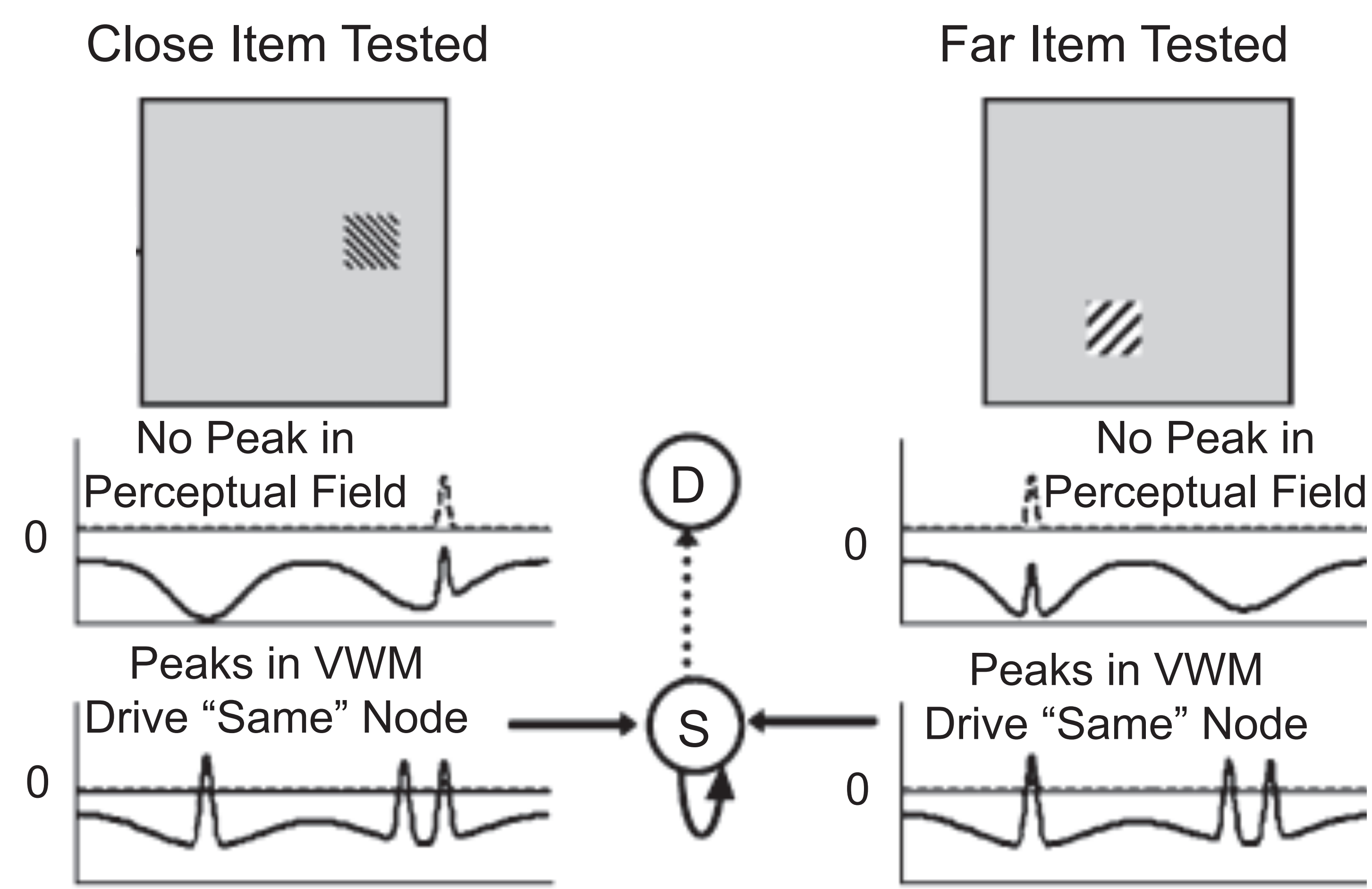
- 1) working memory is created



[Johnson, et al. 2009]

DFT account for change detection

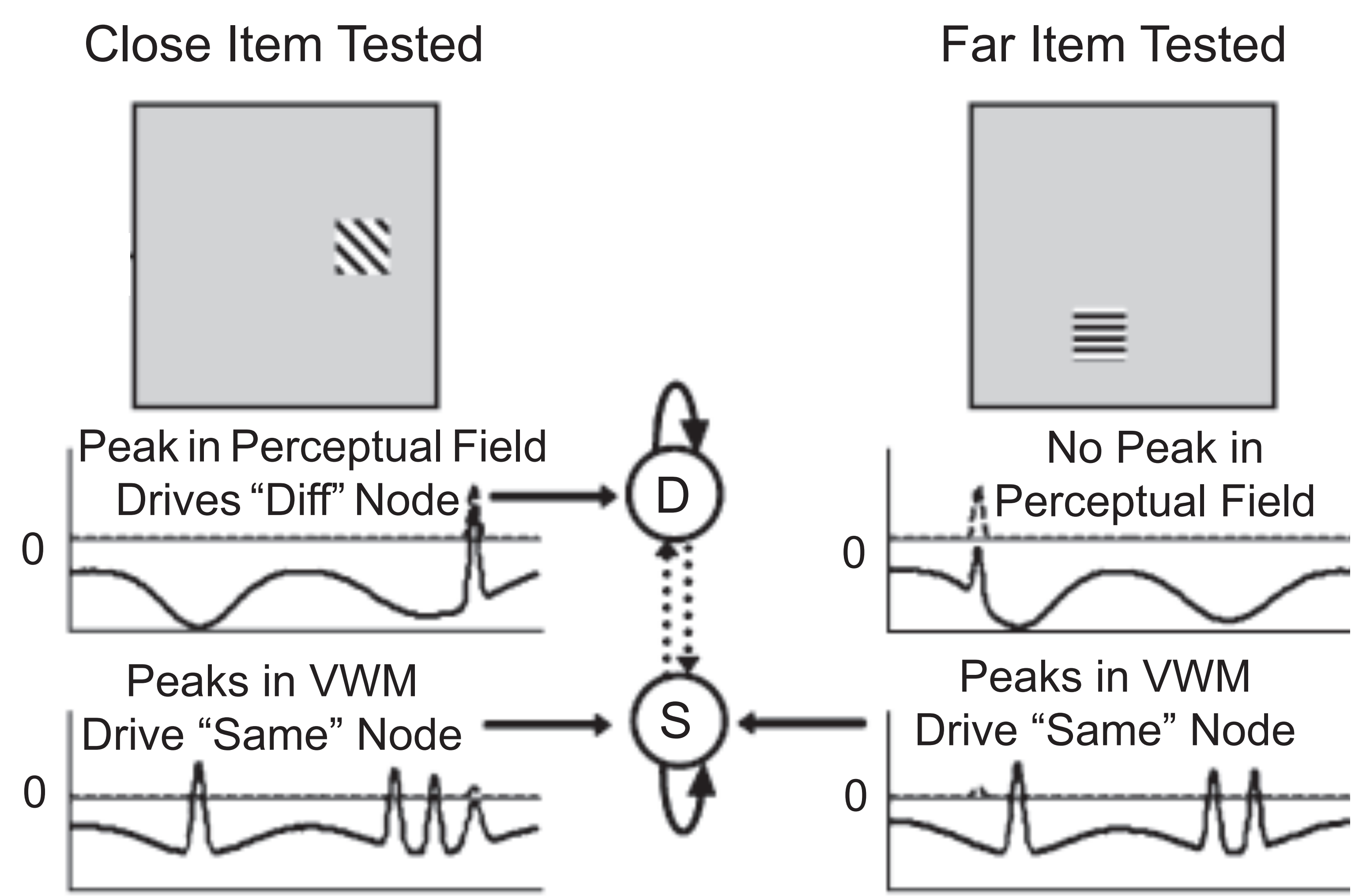
- 2) change detection in “same” trial



[Johnson, et al. 2009]

DFT account for change detection

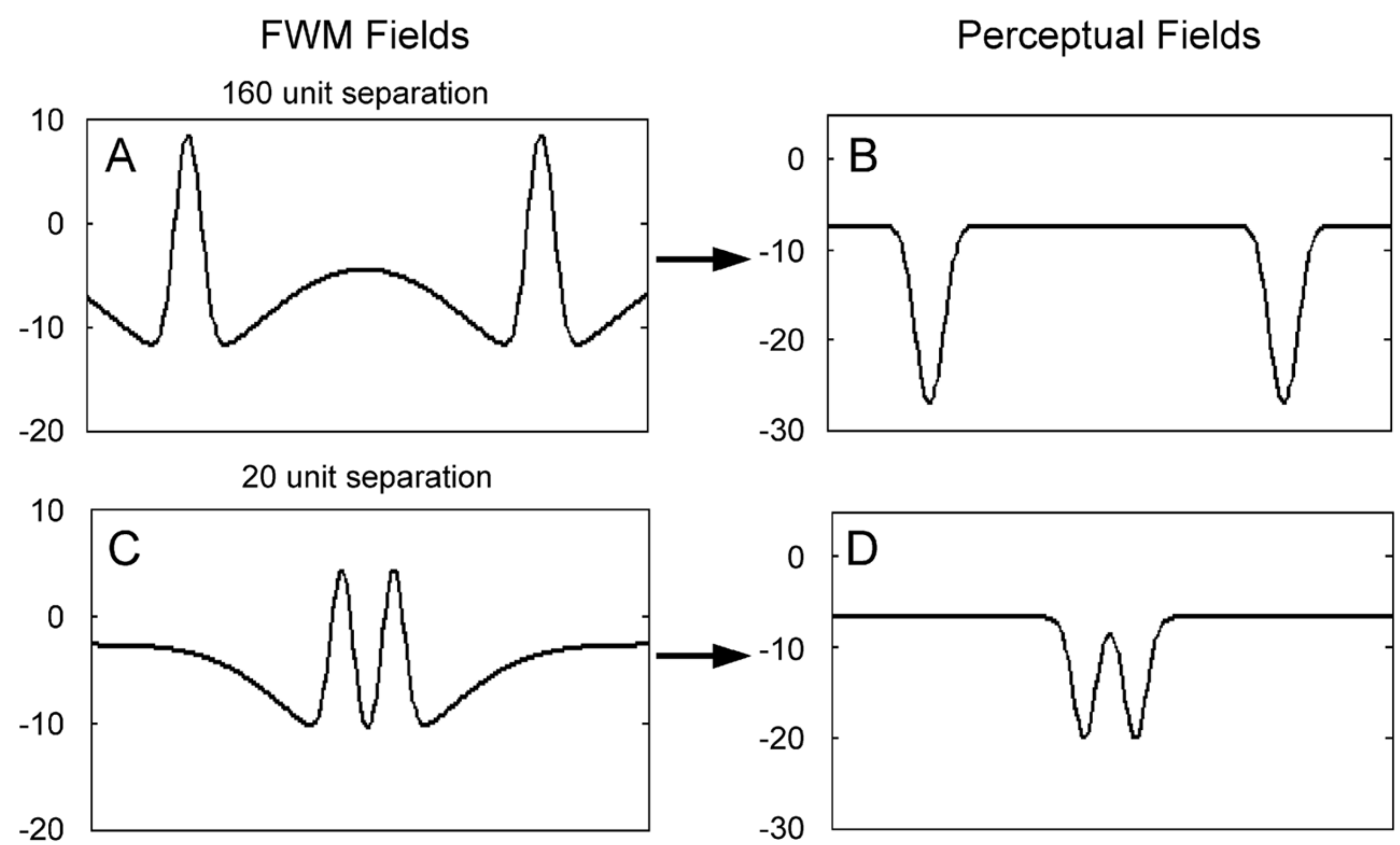
- 2) change detection in "different" trial



[Johnson, et al. 2009]

DFT account for change detection

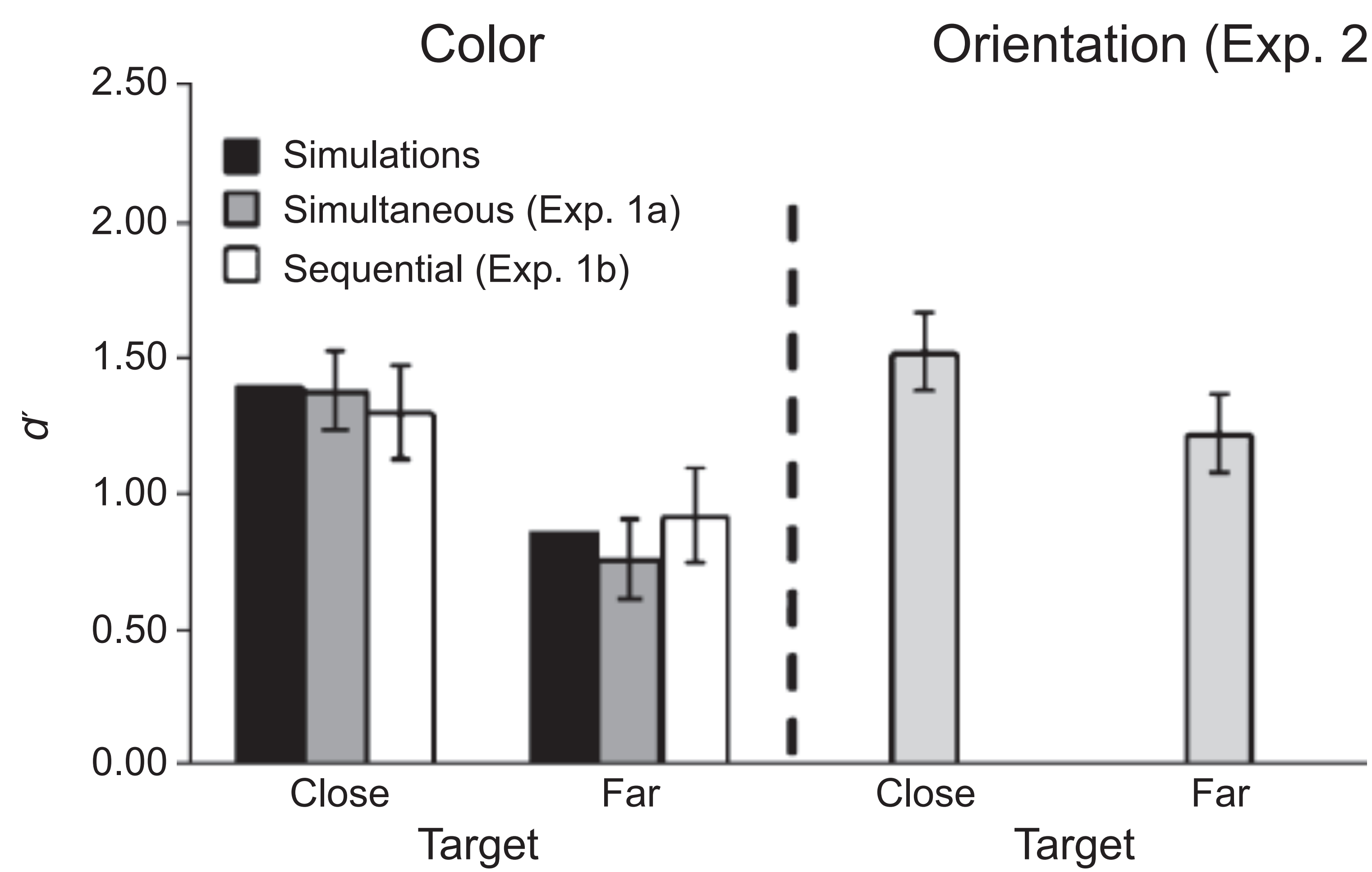
- predict better change detection when items are metrically closer !



[Johnson, et al. 2009]

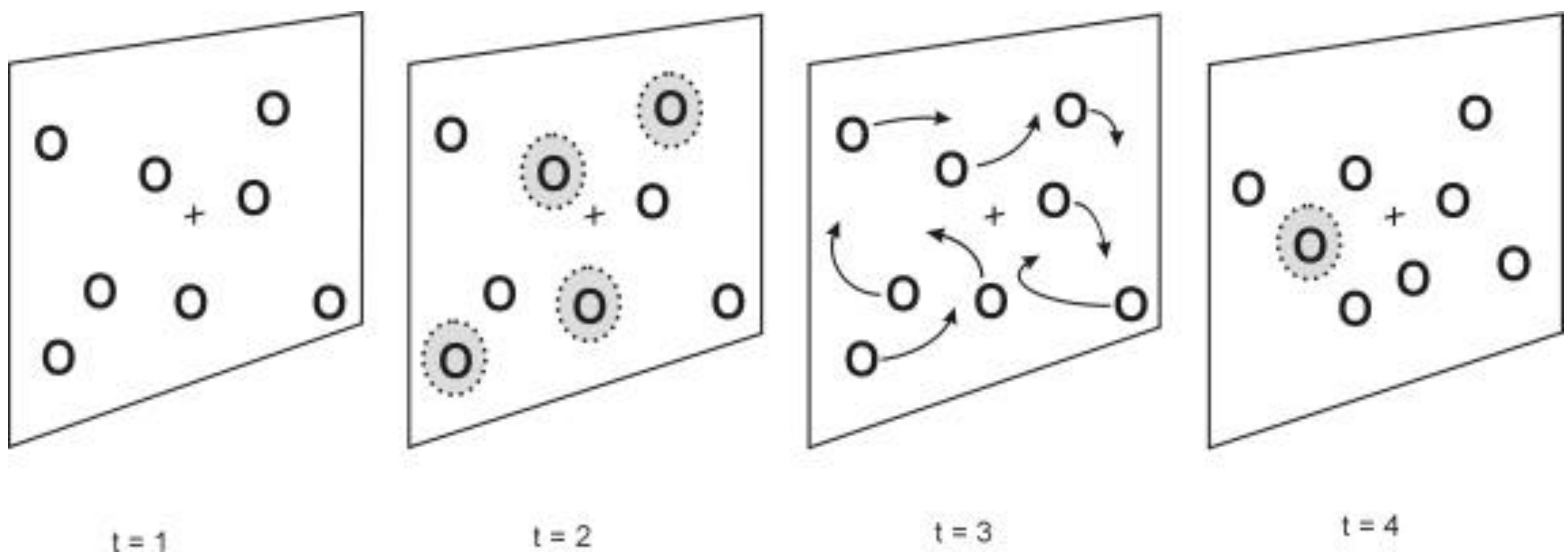
DFT account for change detection

- predict better change detection when items are metrically closer !



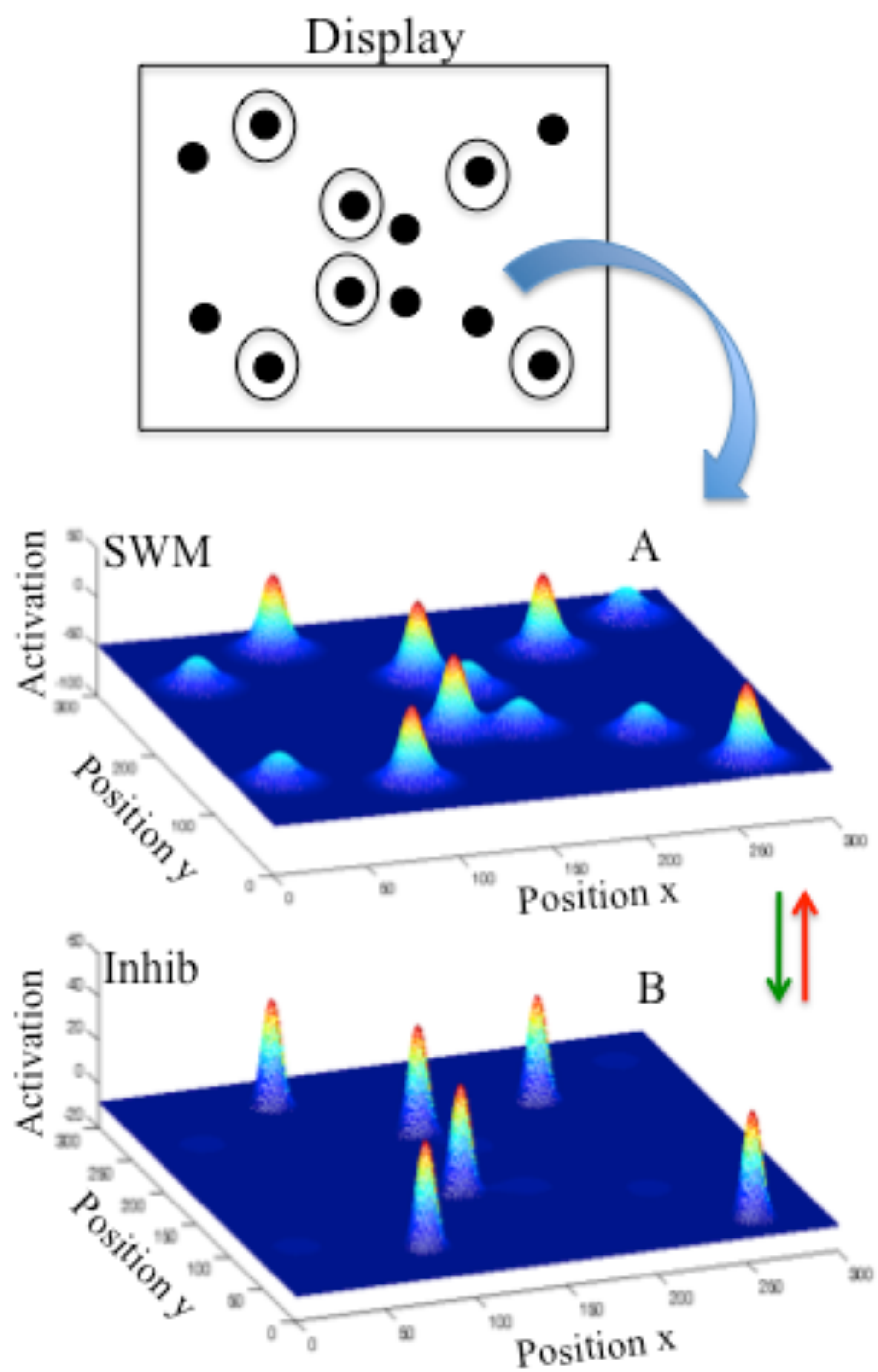
[Johnson, et al. 2009]

Multi-object tracking



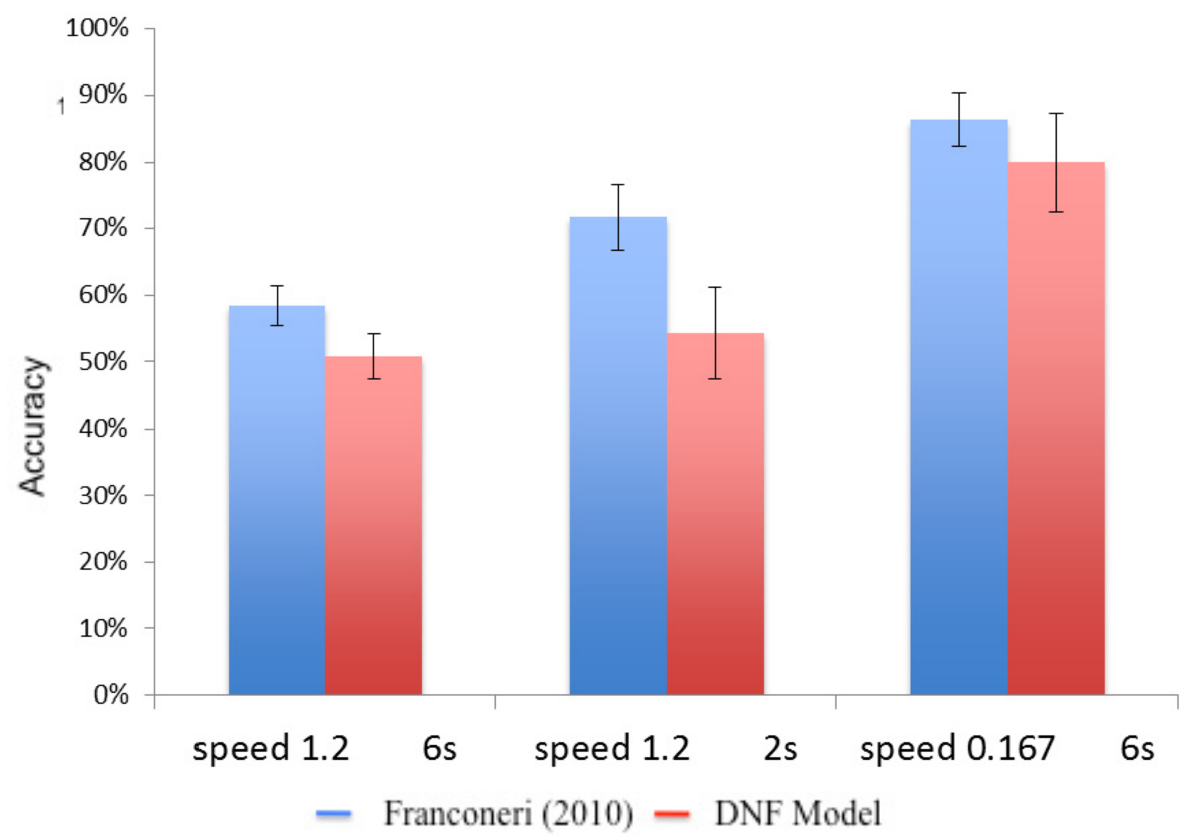
[Pylyshyn]

Multi-object tracking



[Spencer et al]

Multi-object tracking

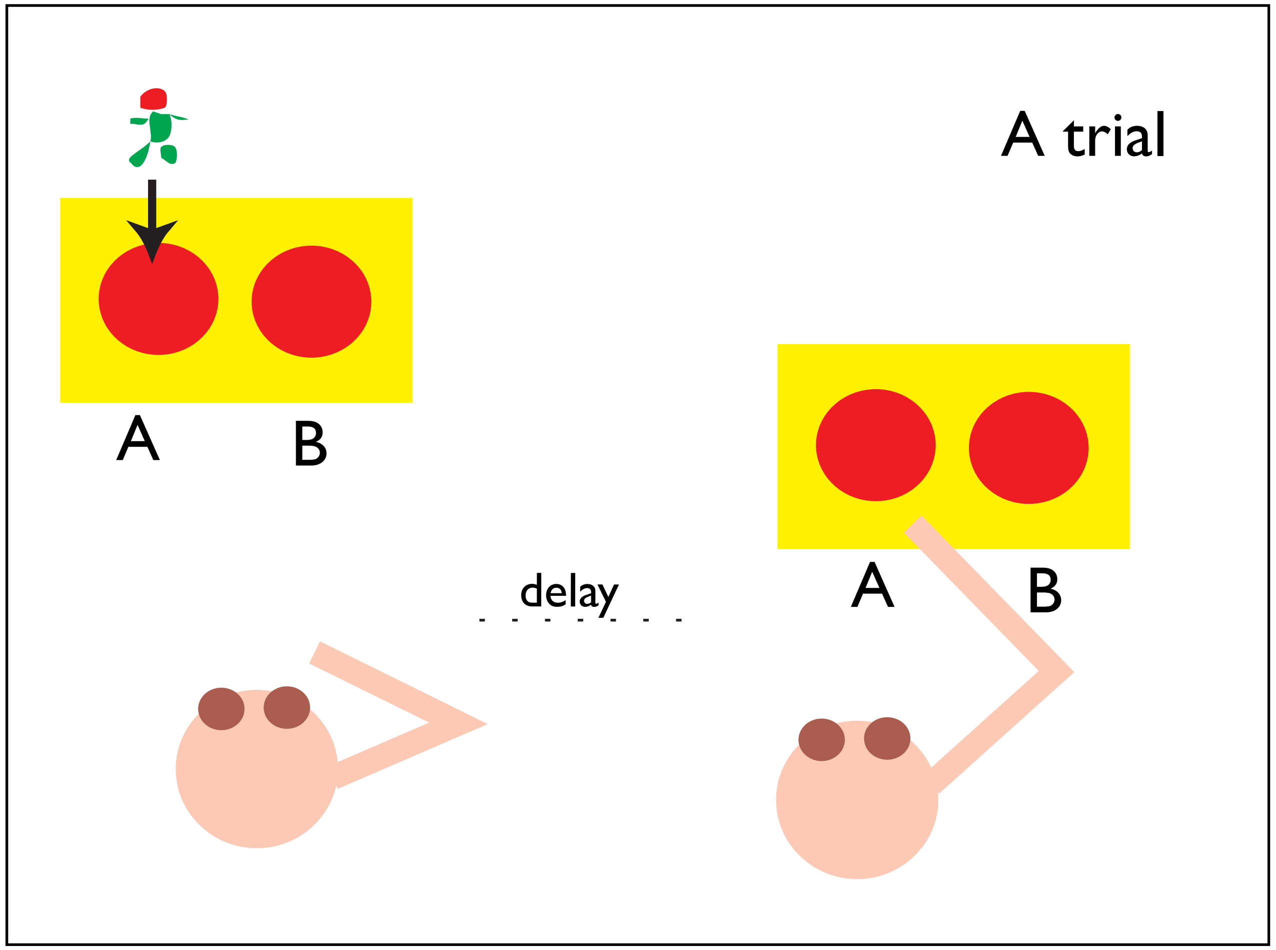


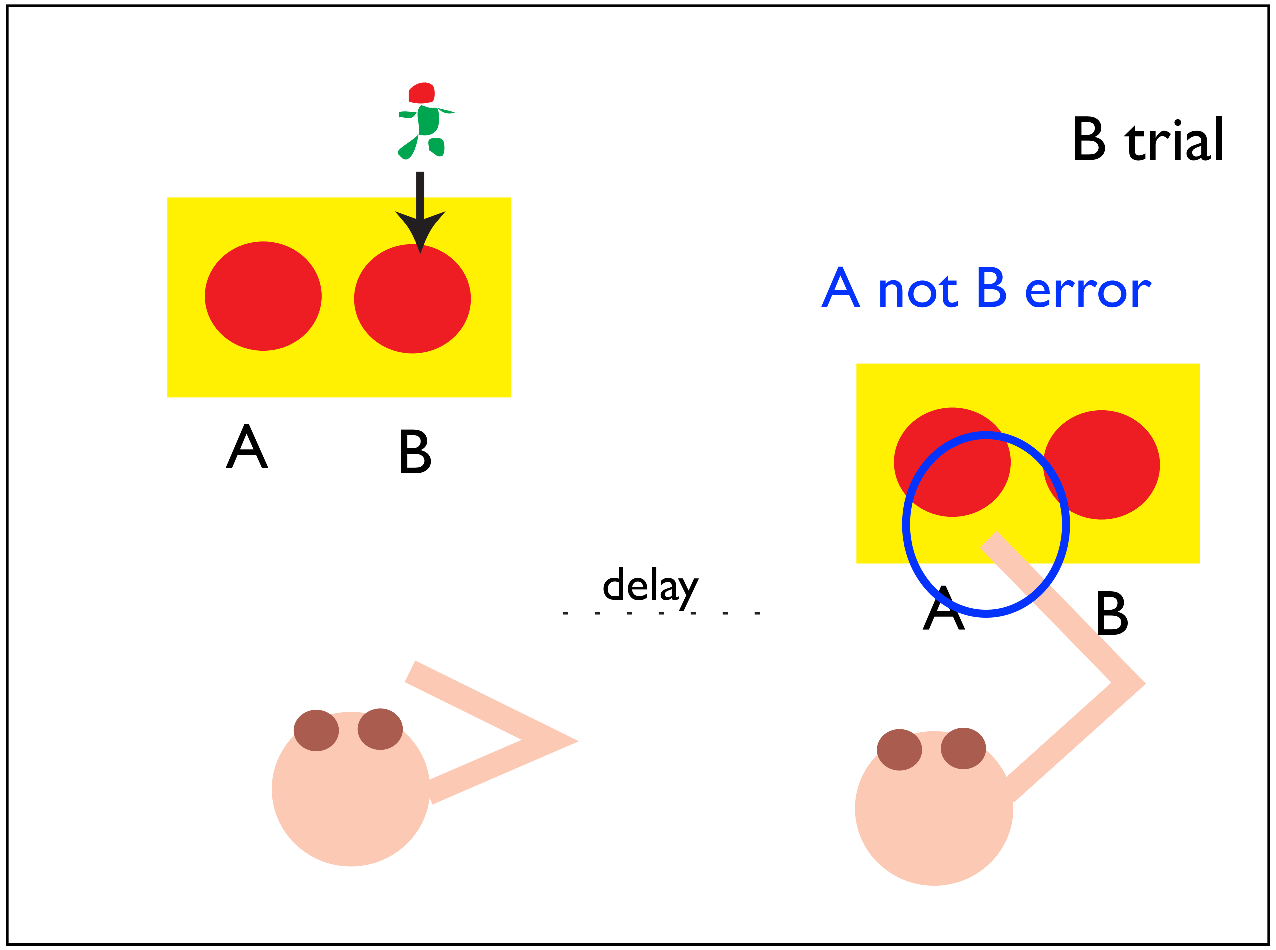
[Spencer et al]

Combining working memory and the memory trace

- in a case study that invokes all dynamic instabilities of DFT as well…

Piaget's A not B paradigm: "out-of-sight -- out of mind"

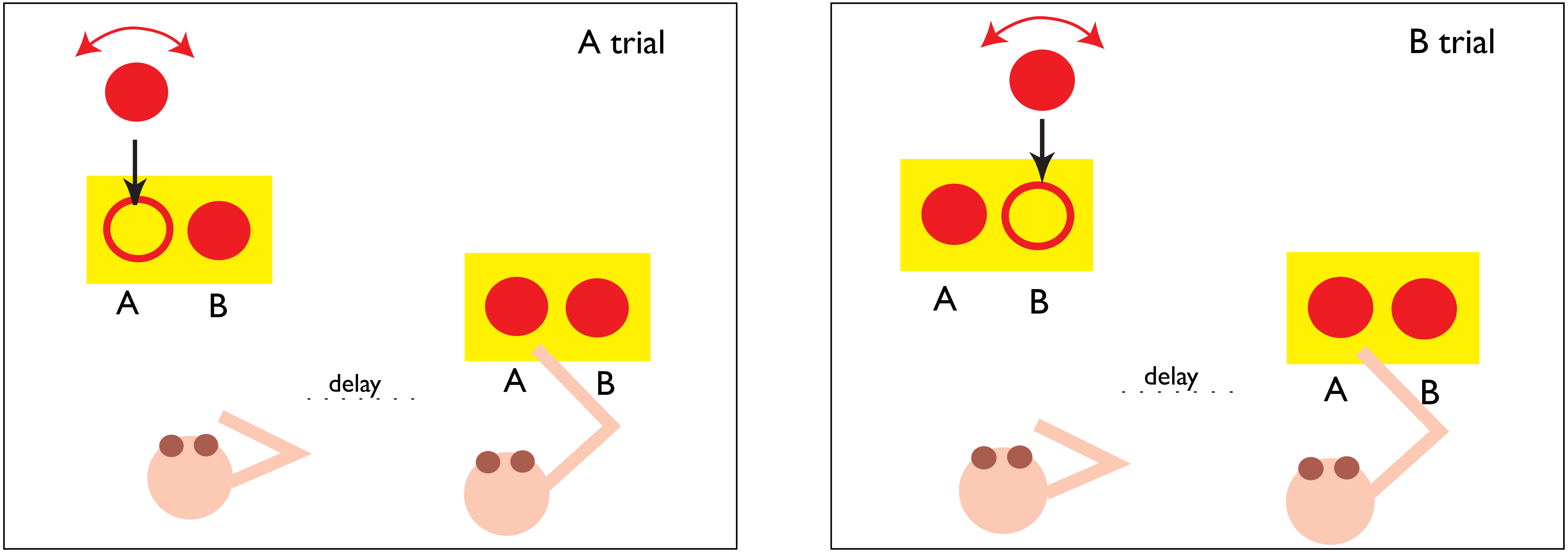




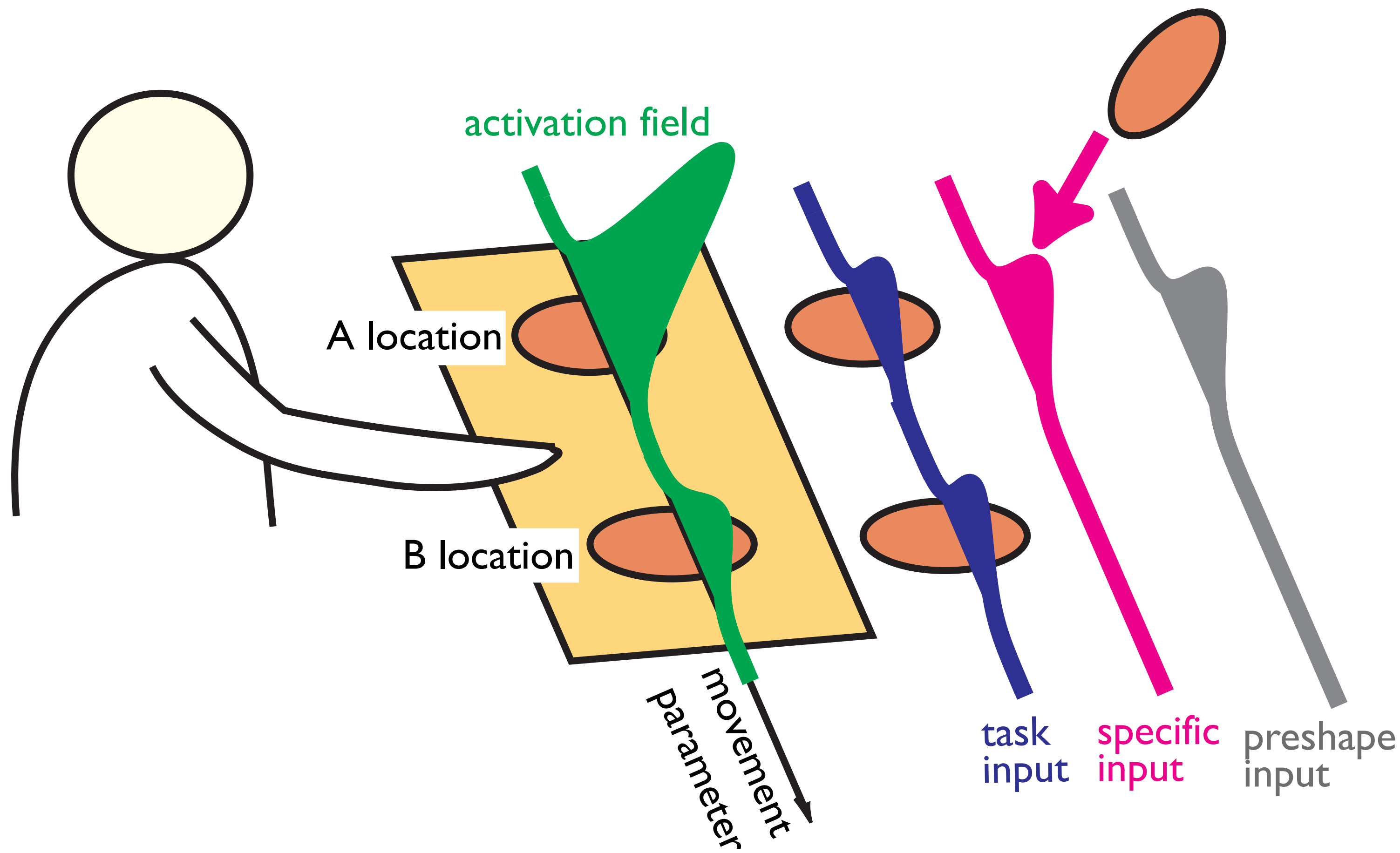
Toyless variant of A not B task

[Smith, Thelen et al.: Psychological Review (1999)]

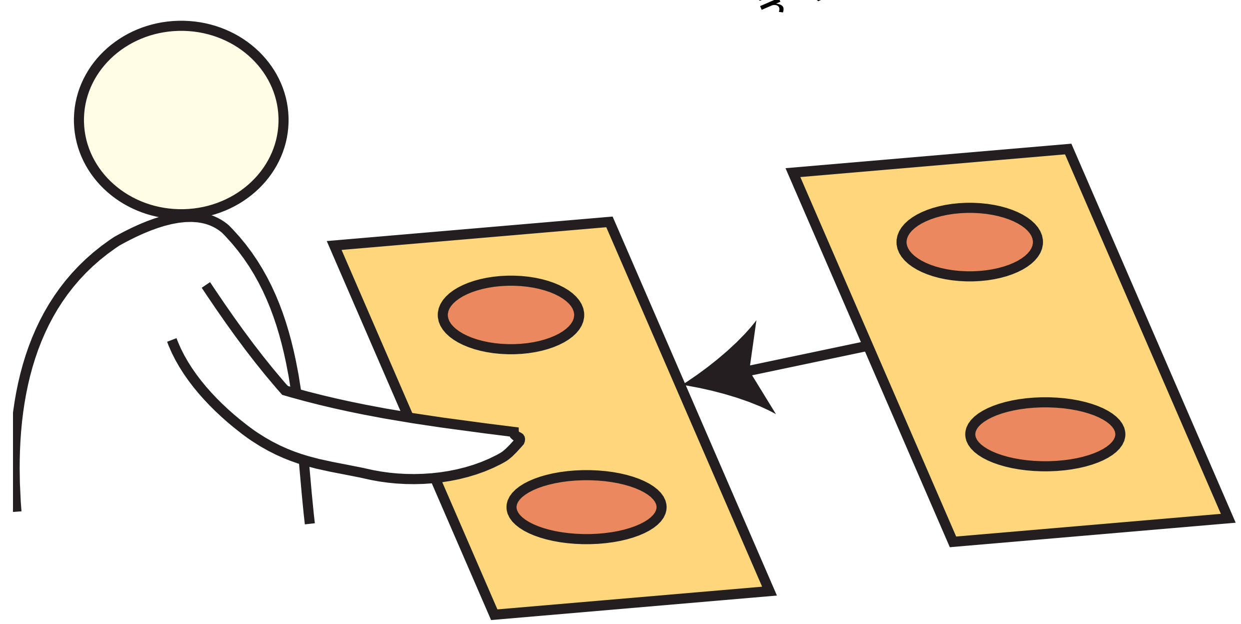
Toyless variant of A not B task reveals that A not B is essentially a decision task!



[Smith, Thelen et al.: Psychological Review (1999)]



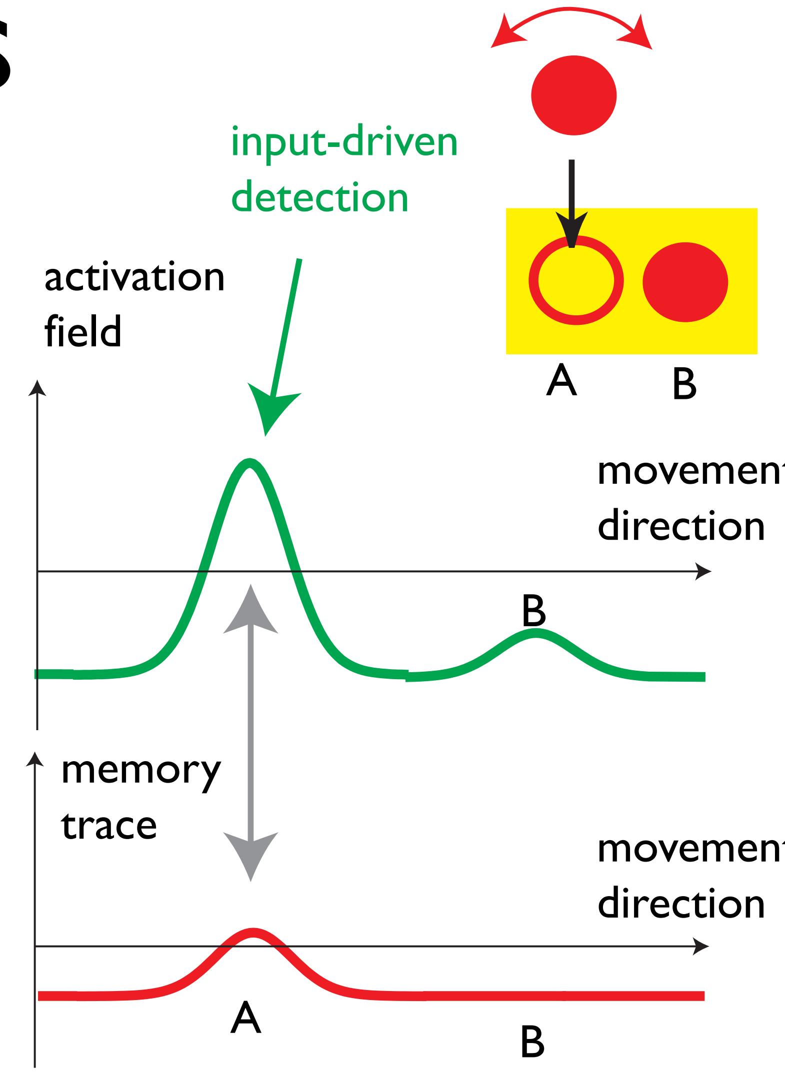
[Thelen, et al., BBS (2001)]



[Dineva, Schöner, Dev. Science 2007]

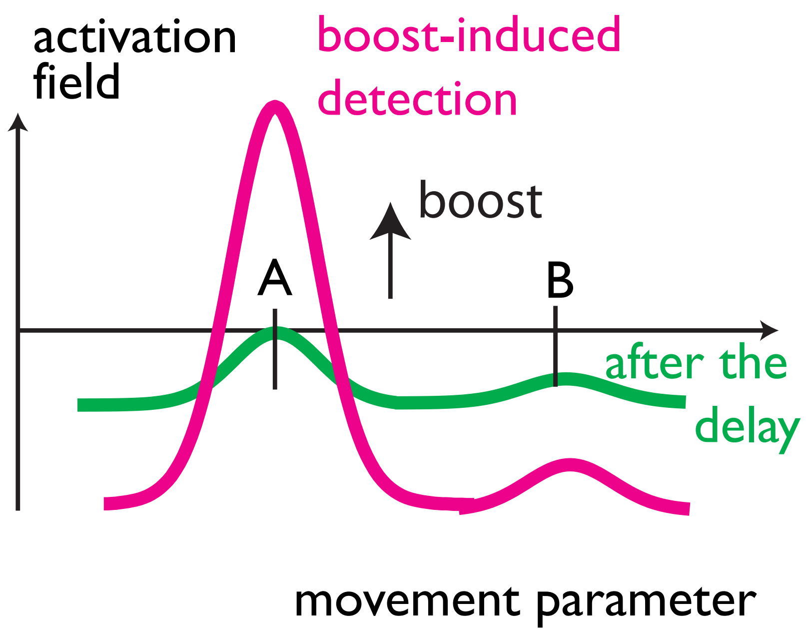
Instabilities

- detection: forming and initiating a movement goal
- selection: making sensori-motor decisions
- (learning: memory trace)
- boost-driven detection: initiating the action
- memory instability: old infants sustain during the delay, young infants do not



Instabilities

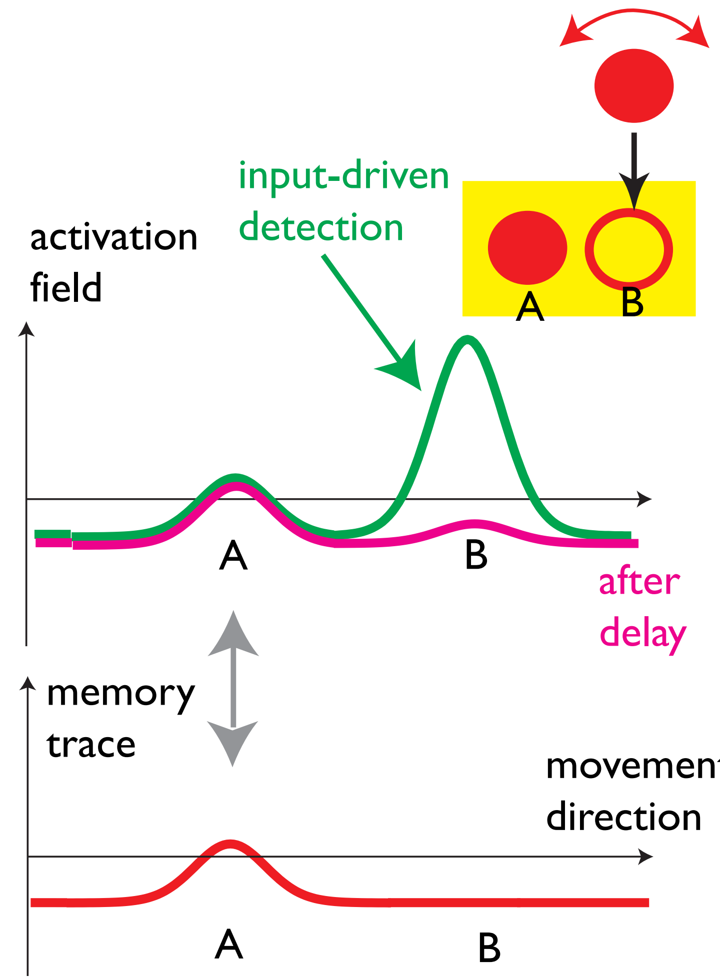
- detection: forming and initiating a movement goal
- selection: making sensori-motor decisions
- (learning: memory trace)
- boost-driven detection: initiating the action
- memory instability: old infants sustain during the delay, young infants do not



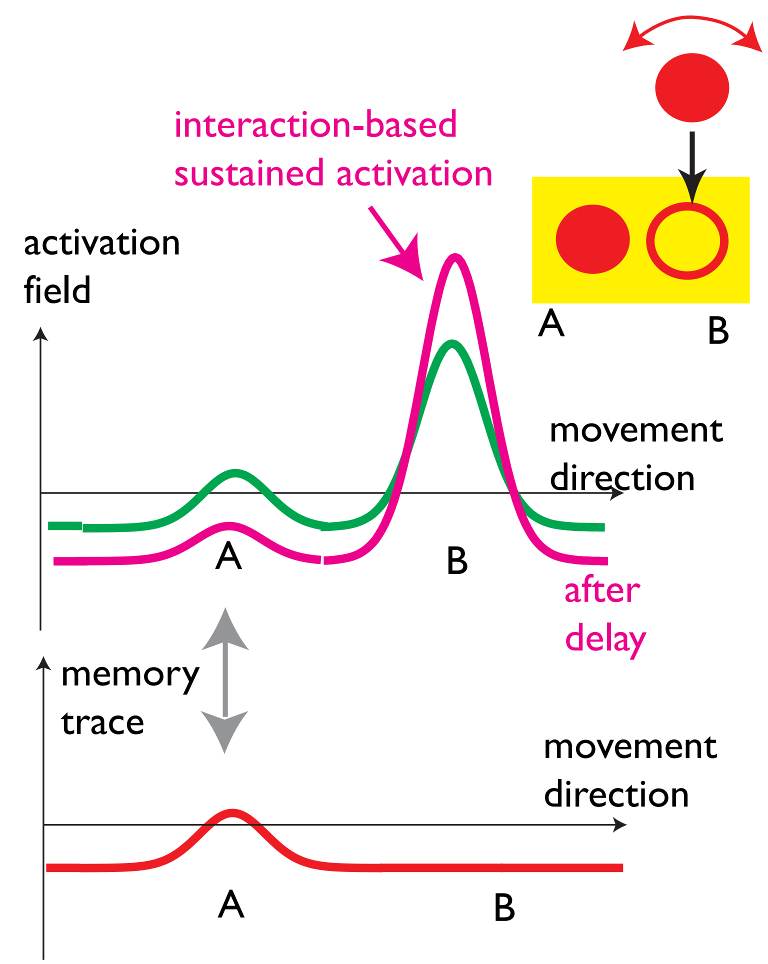
Instabilities

- detection: forming and initiating a movement goal
- selection: making sensori-motor decisions
- (learning: memory trace)
- boost-driven detection: initiating the action
- memory instability: old infants sustain during the delay, young infants do not

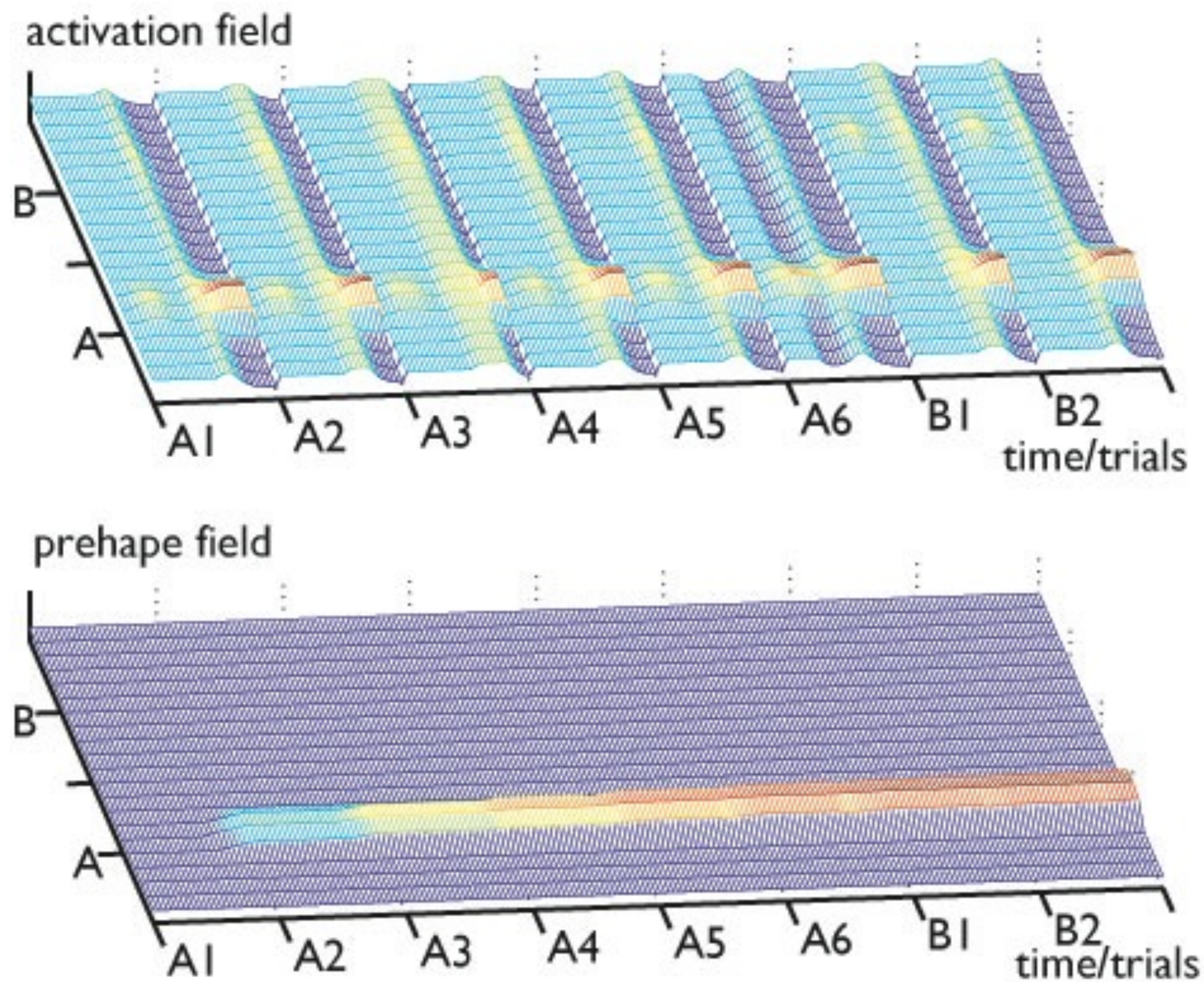
young



old

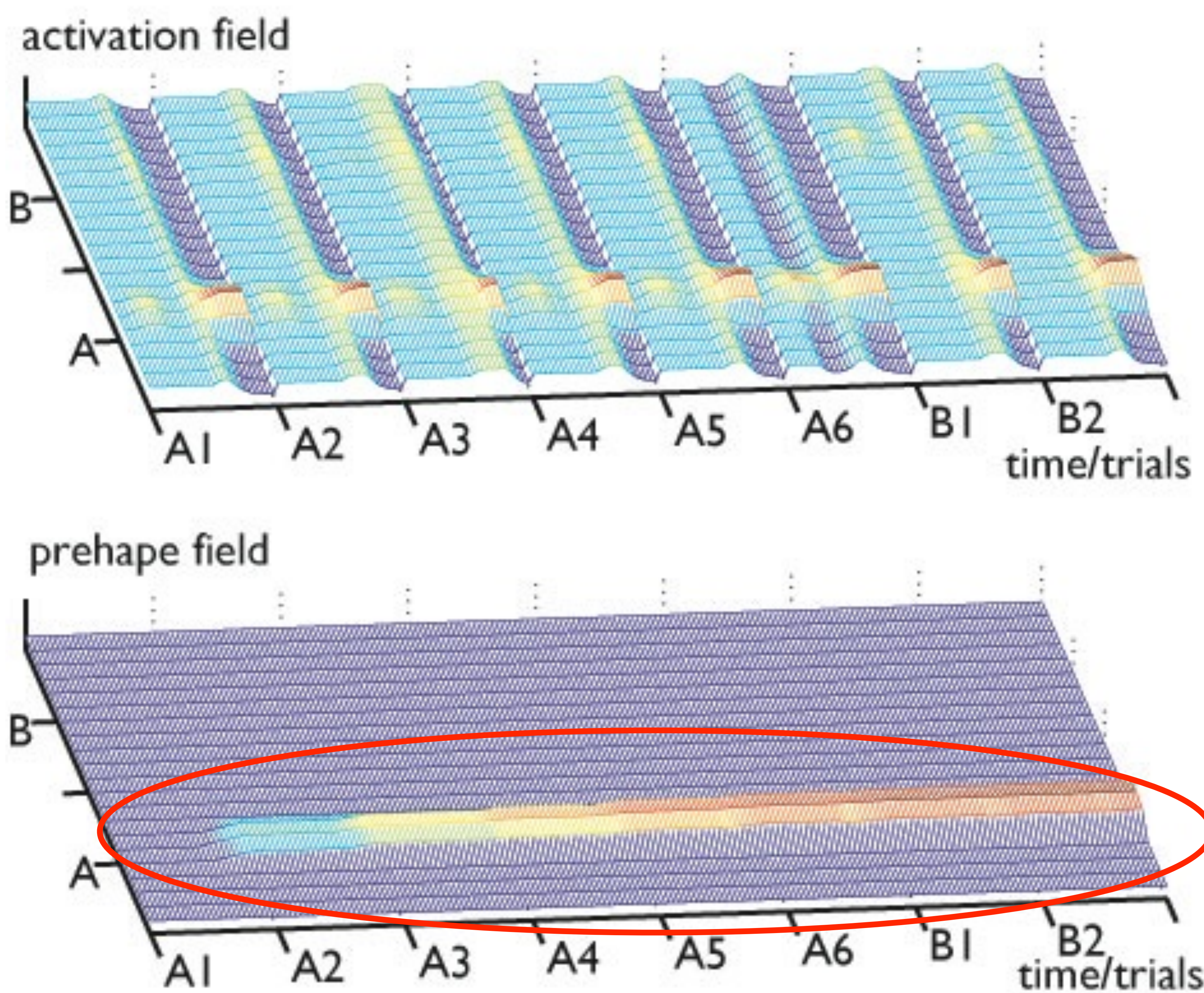


DFT of infant perseverative reaching



[Dinveva, Schöner, Dev. Science 2007]

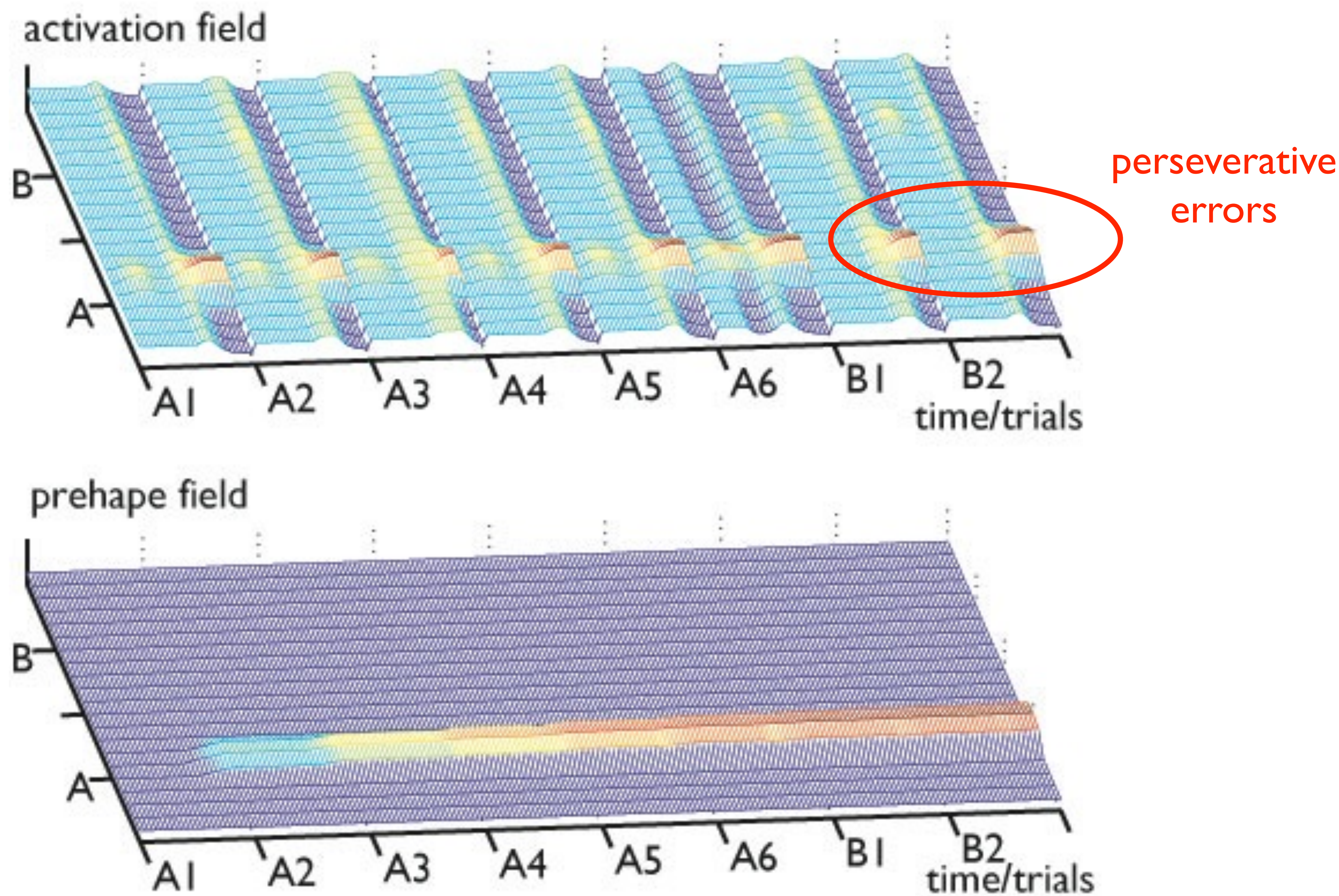
DFT of infant perseverative reaching



memory trace

[Dinveva, Schöner, Dev. Science 2007]

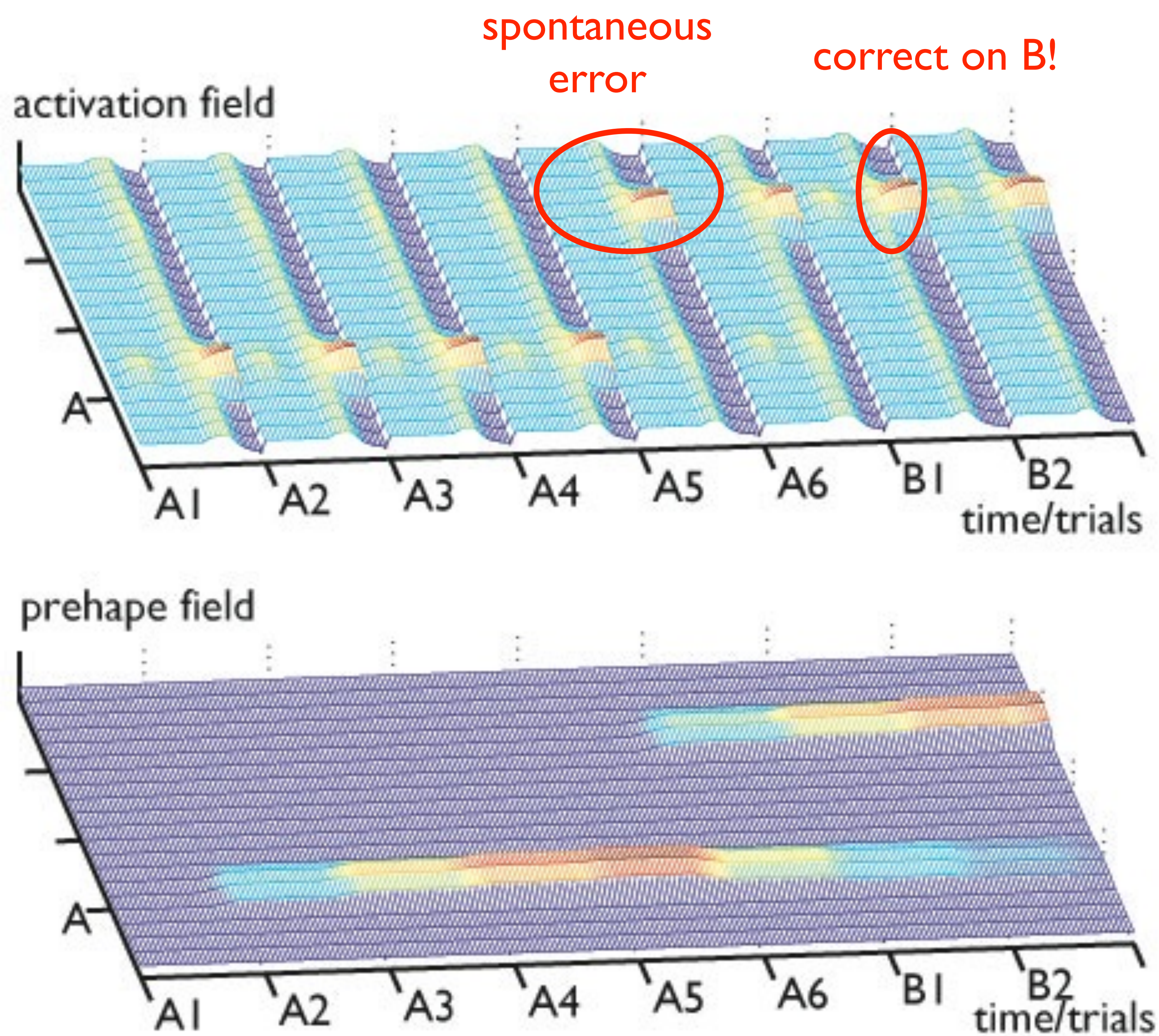
DFT of infant perseverative reaching



[Dinveva, Schöner, Dev. Science 2007]

DFT of infant perseverative reaching

- in spontaneous errors, activation arises at B on an A trial
- which leads to correct reaching on B trial
- because reaches to B on A trials leave memory trace at B

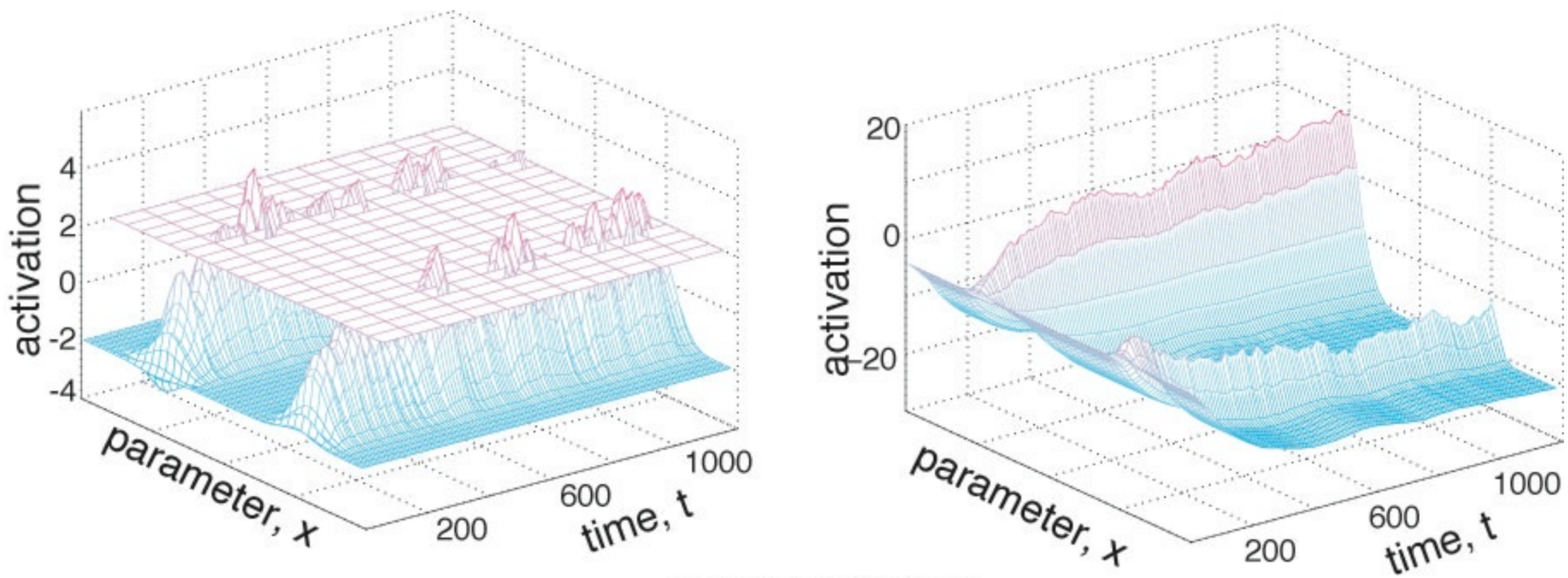


[Dinveva, Schöner, Dev. Science 2007]

=> DFT is a neural process model

- that makes the decisions in each individual trial, by amplifying small differences into a macroscopic stable state

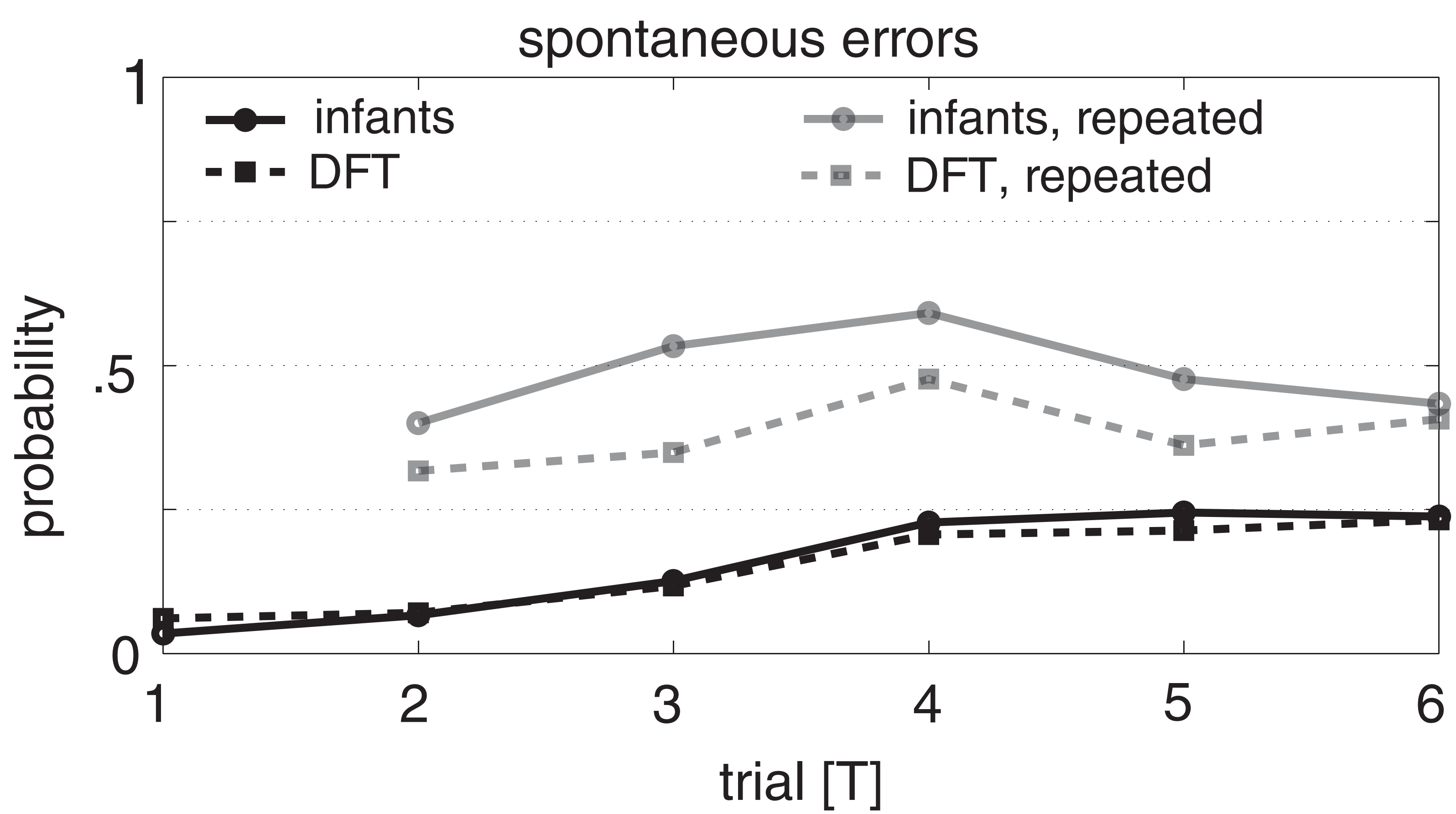
- and that's how decisions leave traces, have consequences



[Wilimzig, Schöner, 2006]

Decisions have consequences

- a spontaneous error doubles probability to make the spontaneous error again



[Dineva, Schöner: Connection Science 2018]

Conclusions

- action, perception, and embodied cognition takes place in continuous spaces. peaks = units of representation are attractors of the neural dynamics
- neural fields link neural representations to these continua
- stable activation peaks are the units of neural representation
- peaks arise and disappear through instabilities through which elementary cognitive functions (e.g. detection, selection, memory) emerge