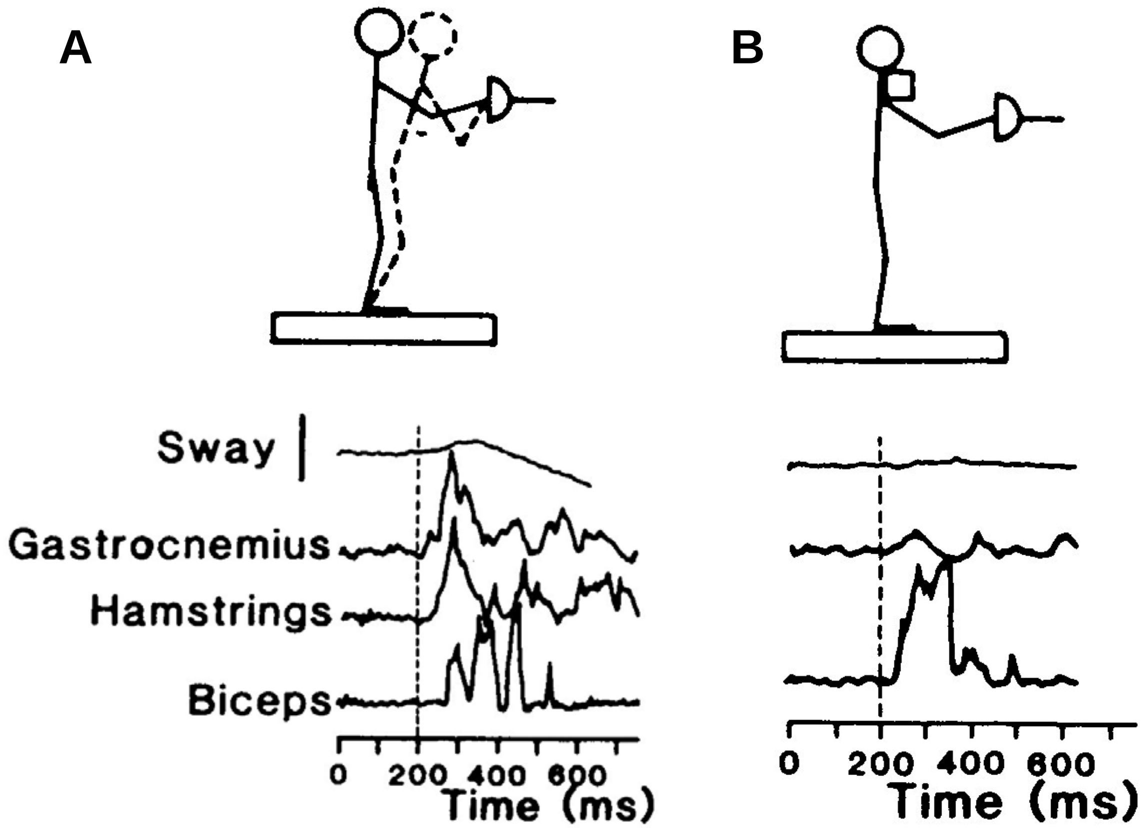
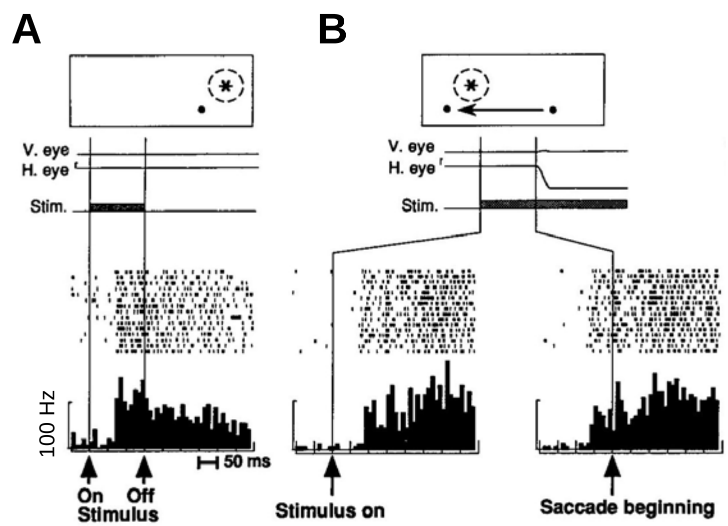
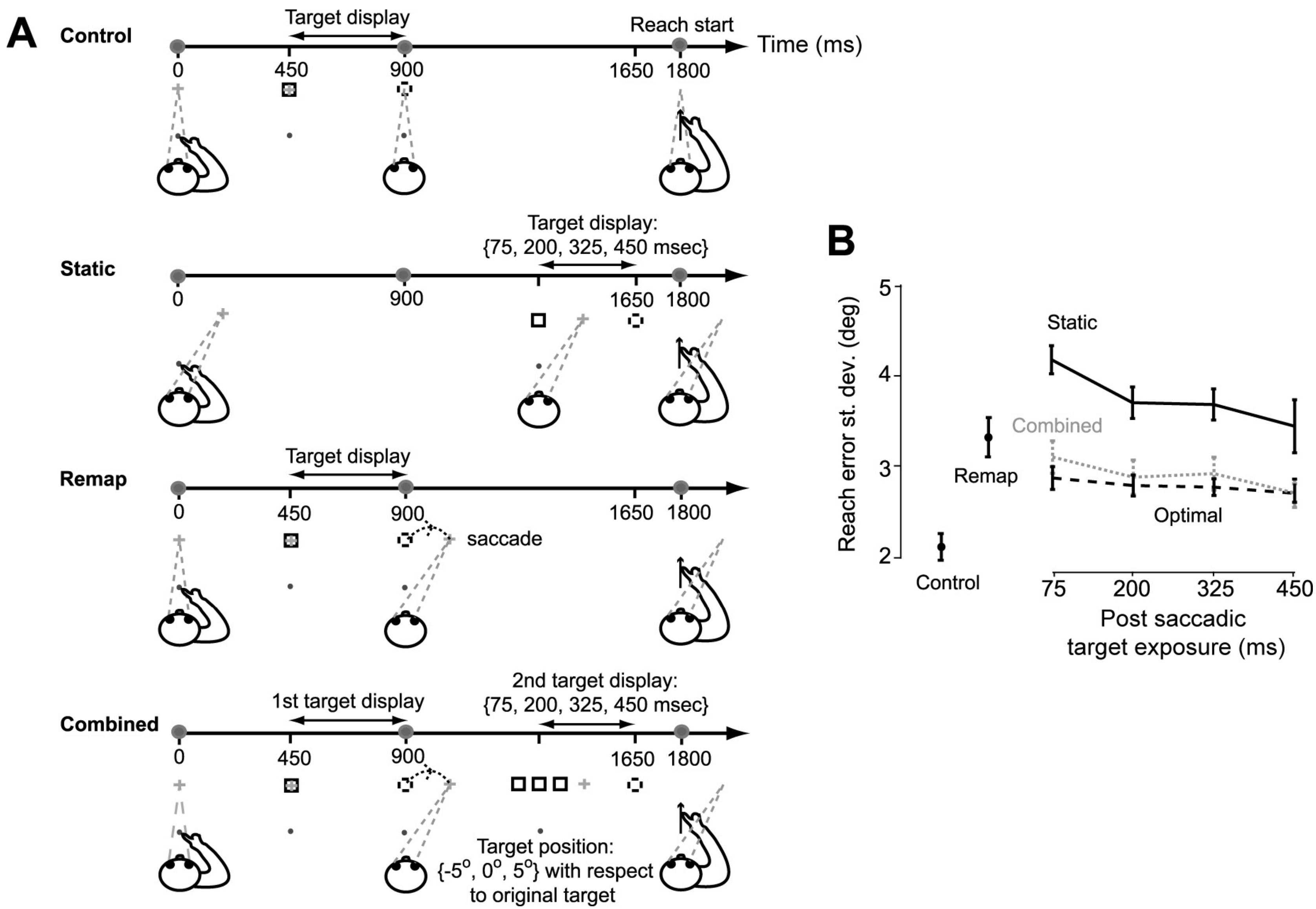
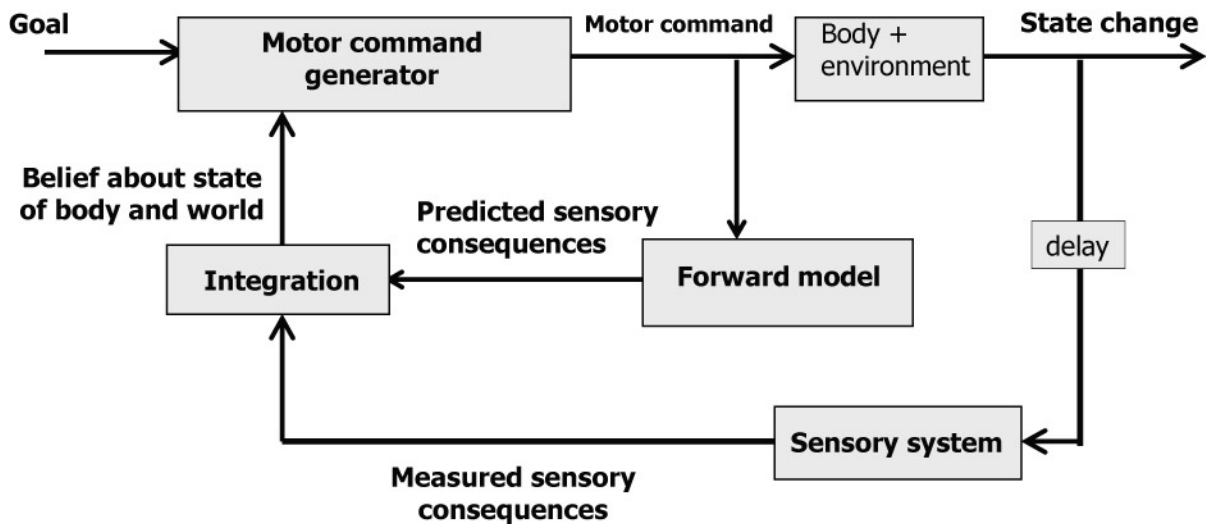
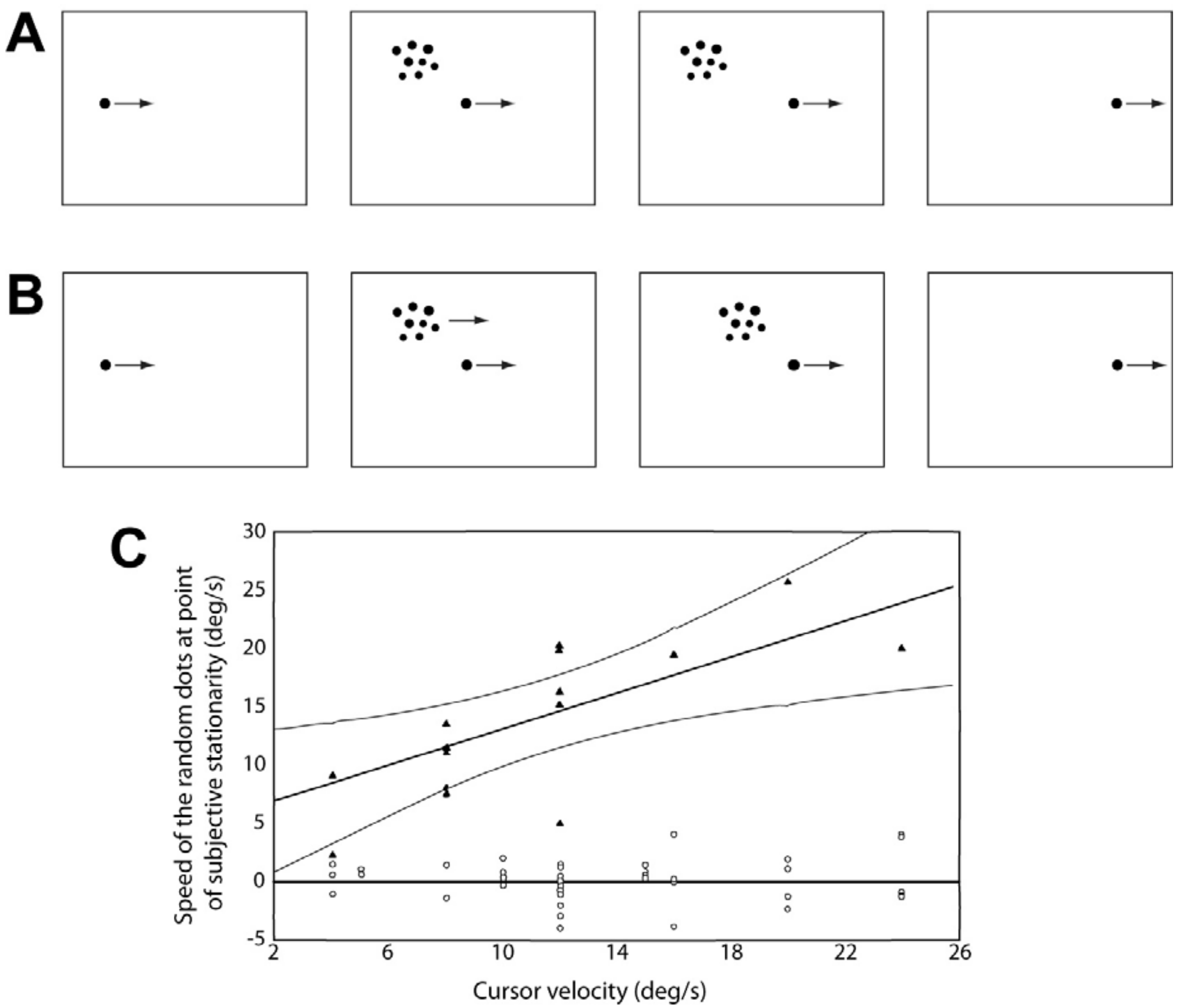

A
B
Sway
Gastrocnemius
Hamstrings
Biceps
0
200
400
600
Time (ms)
0
200
400
600
Time (ms)

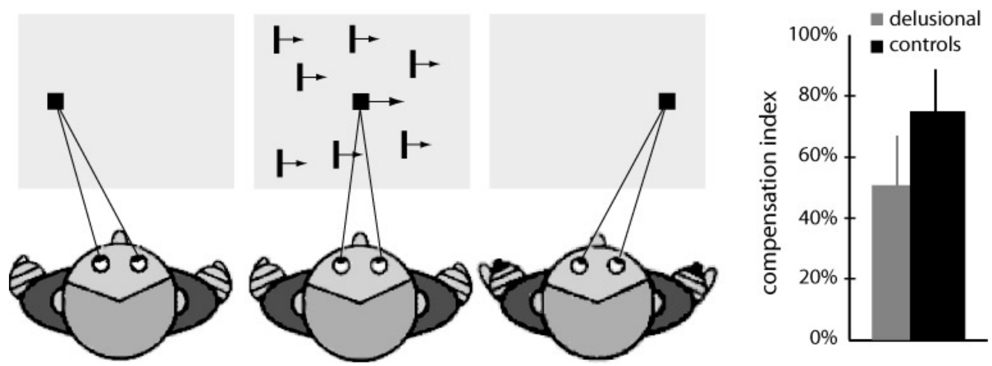

A
B
V. eye
H. eye
Stim.
V. eye
H. eye
Stim.
100 Hz
50 ms
On
Off
Stimulus
Stimulus on
Saccade beginning

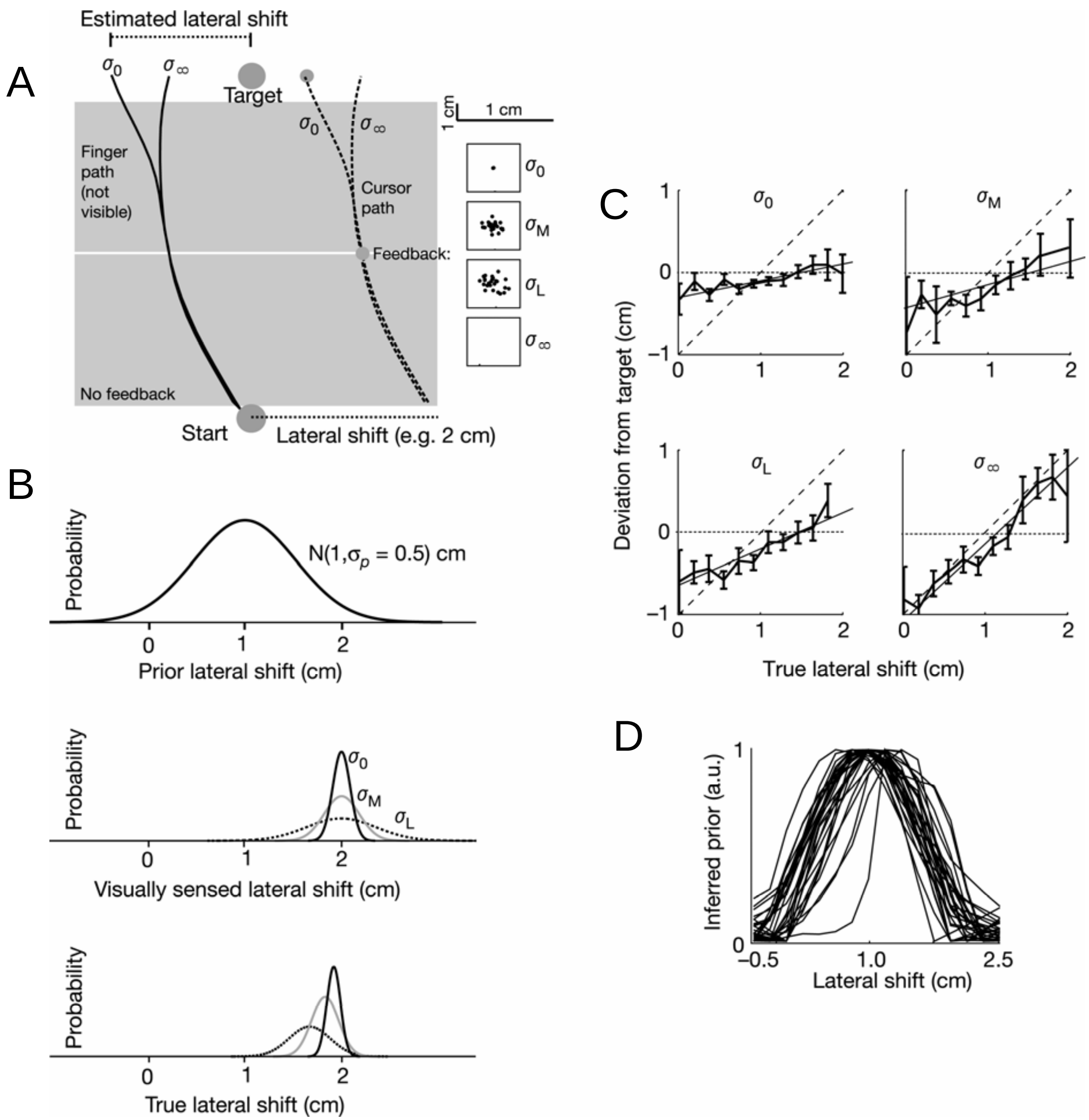

A
Control
Target display
Reach start
Time (ms)
0
450
900
1650
1800
Static
Target display:
{75, 200, 325, 450 msec}
Remap
saccade
Combined
1st target display
2nd target display:
{75, 200, 325, 450 msec}
Target position:
{-5°, 0°, 5°} with respect
to original target
B
Reach error st. dev. (deg)
Static
Combined
Remap
Optimal
Control
75
200
325
450
Post saccadic
target exposure (ms)

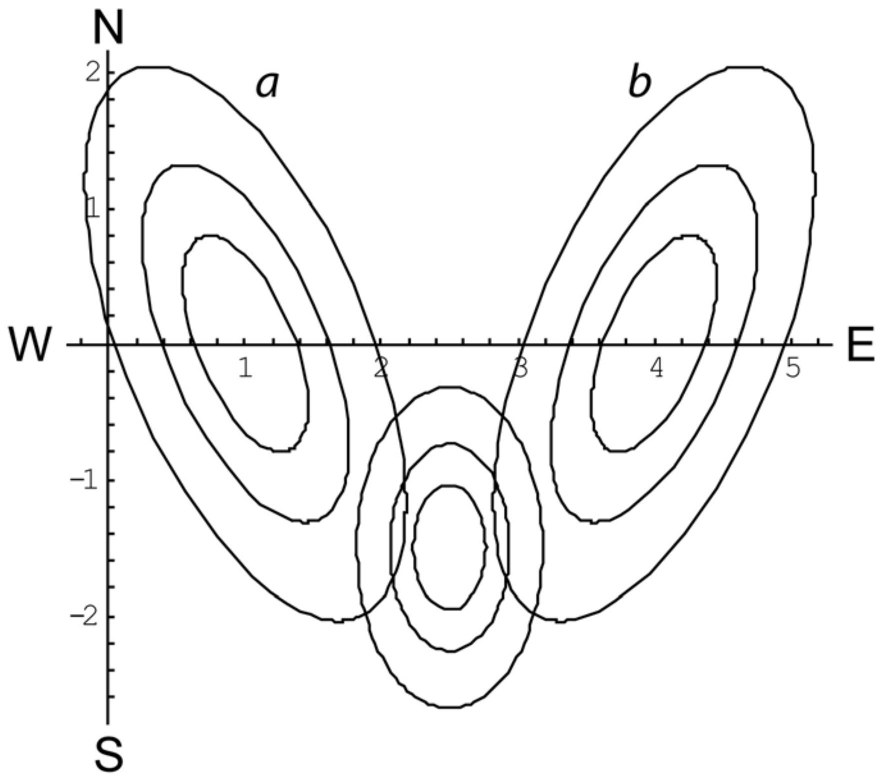


Goal
Motor command generator
Motor command
Body + environment
State change
Belief about state of body and world
Predicted sensory consequences
Integration
Forward model
delay
Sensory system
Measured sensory consequences

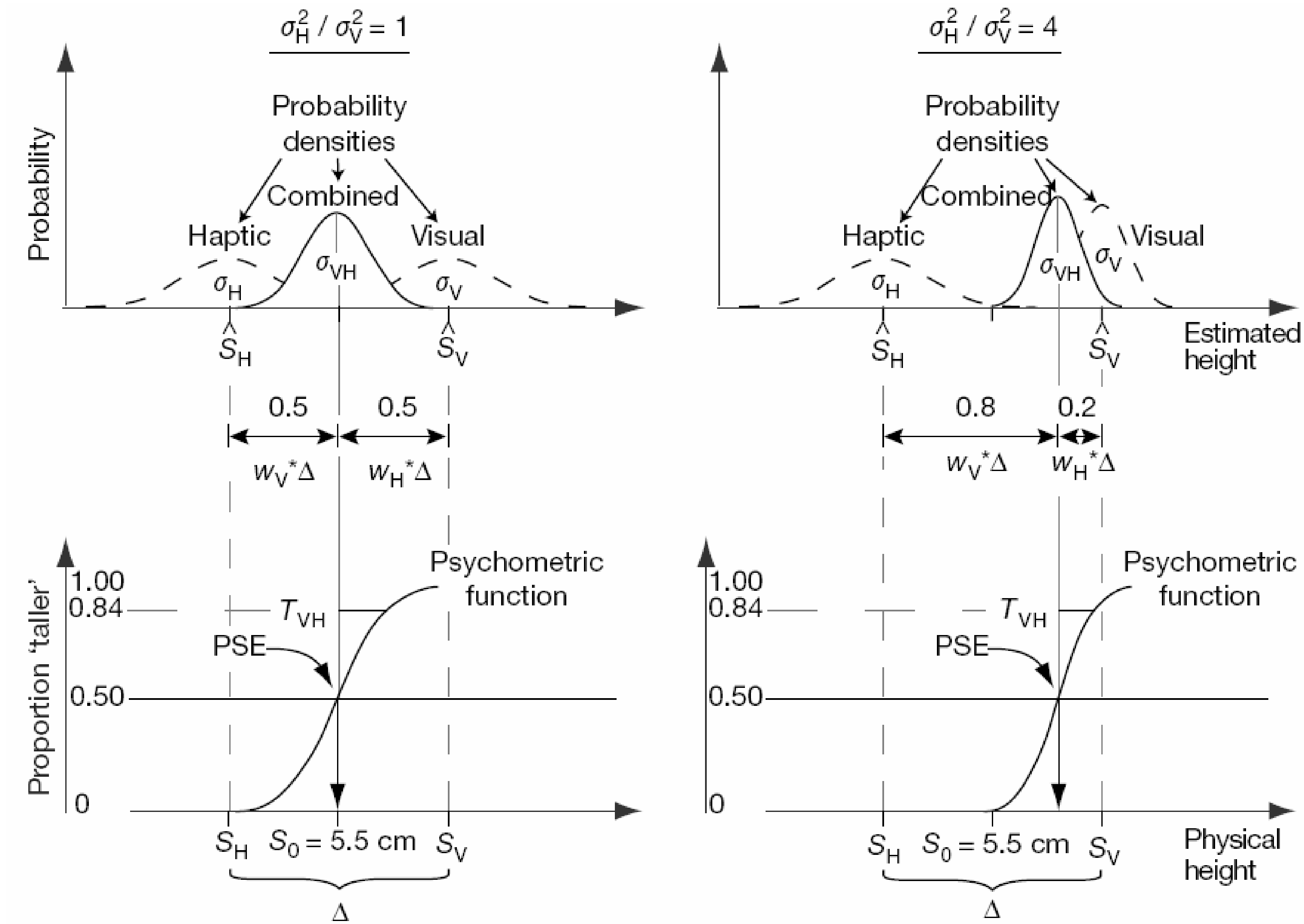

A
B
C
Speed of the random dots at point of subjective stationarity (deg/s)
30
25
20
15
10
5
0
-5
2
6
10
14
18
22
26
Cursor velocity (deg/s)


delusional
controls
100%
80%
60%
40%
20%
0%
compensation index

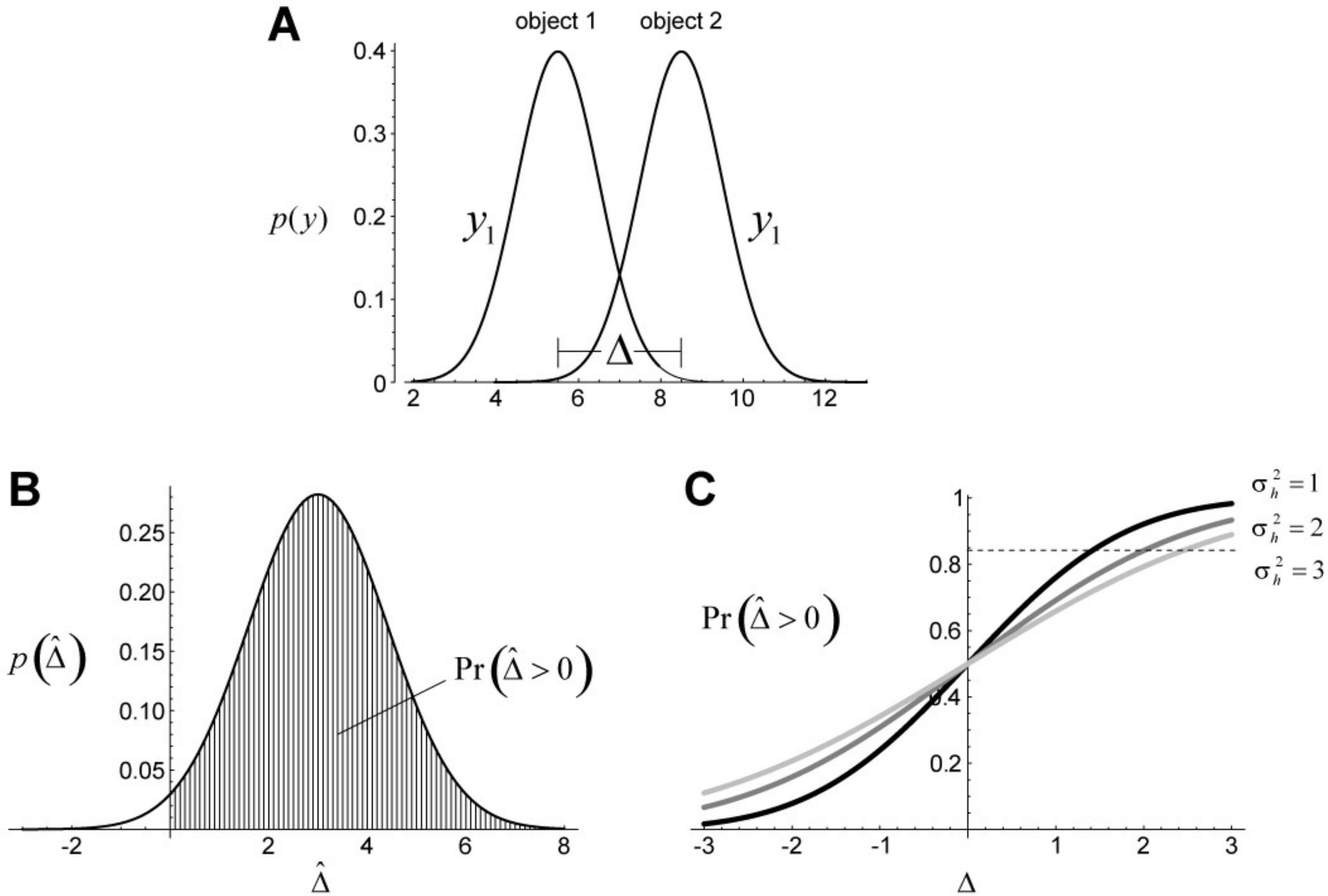

A
Estimated lateral shift
σ_0
σ_∞
Target
1 cm
1 cm
Finger path (not visible)
Cursor path
Feedback:
σ_M
σ_L
No feedback
Start
Lateral shift (e.g. 2 cm)
B
Probability
N(1,σ_p = 0.5) cm
Prior lateral shift (cm)
Visually sensed lateral shift (cm)
True lateral shift (cm)
C
Deviation from target (cm)
True lateral shift (cm)
D
Inferred prior (a.u.)
Lateral shift (cm)

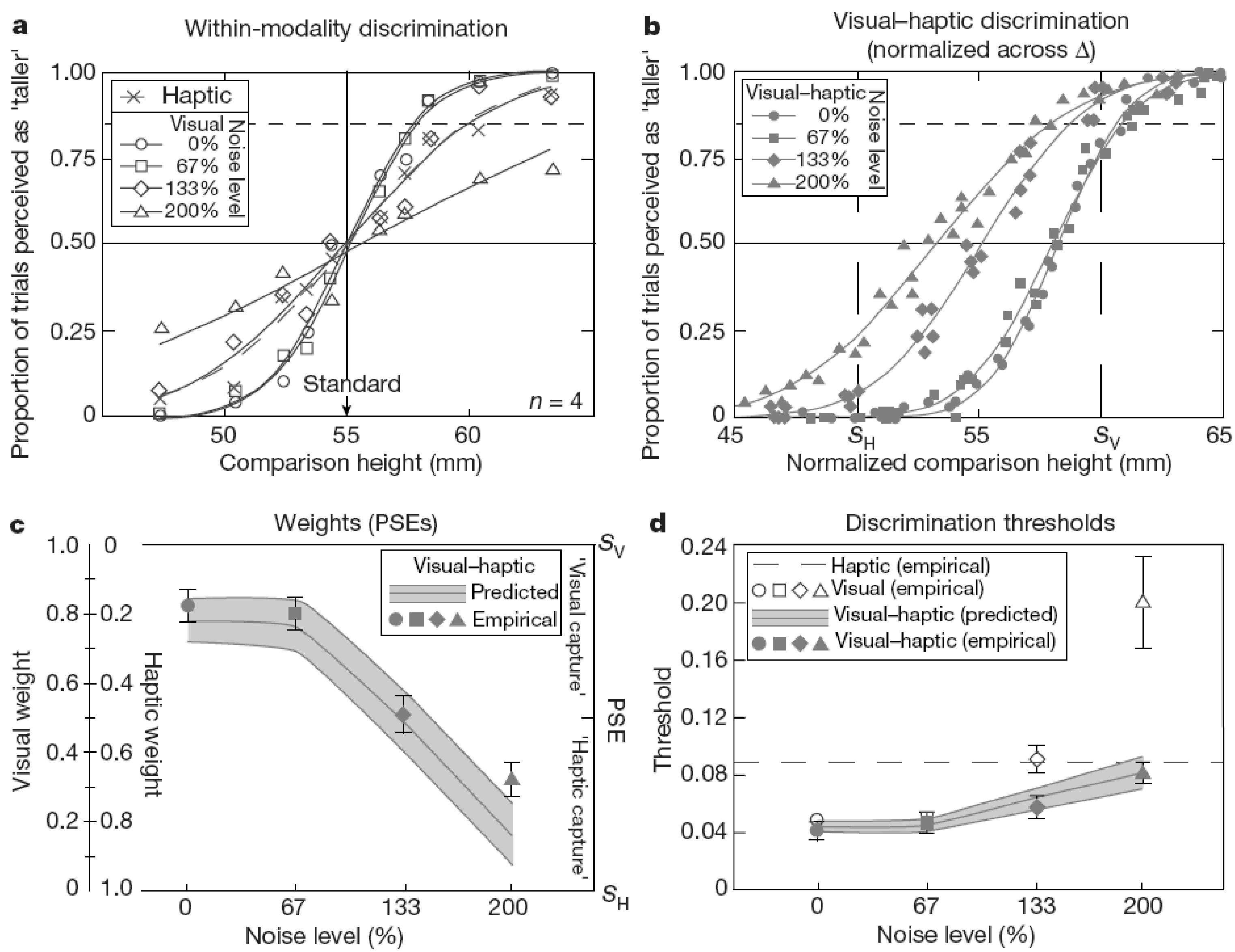


N
a
b
W
E
S
2
1
−1
−2
1
2
3
4
5

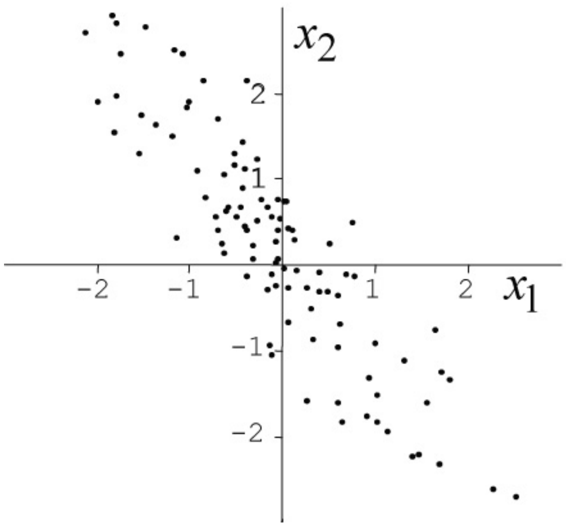


$\sigma_H^2 / \sigma_V^2 = 1$
Probability
Probability densities
Combined
Haptic
Visual
σ_H
σ_{VH}
σ_V
$\hat{S}_H$
$\hat{S}_V$
0.5
0.5
$w_V{}^*\Delta$
$w_H{}^*\Delta$
Proportion 'taller'
1.00
0.84
0.50
0
T_{VH}
PSE
Psychometric function
S_H
$S_0 = 5.5$ cm
S_V
Δ
$\sigma_H^2 / \sigma_V^2 = 4$
Probability densities
Combined
Haptic
Visual
σ_H
σ_{VH}
σ_V
$\hat{S}_H$
$\hat{S}_V$
Estimated height
0.8
0.2
$w_V{}^*\Delta$
$w_H{}^*\Delta$
1.00
0.84
0.50
0
T_{VH}
PSE
Psychometric function
S_H
$S_0 = 5.5$ cm
S_V
Physical height
Δ

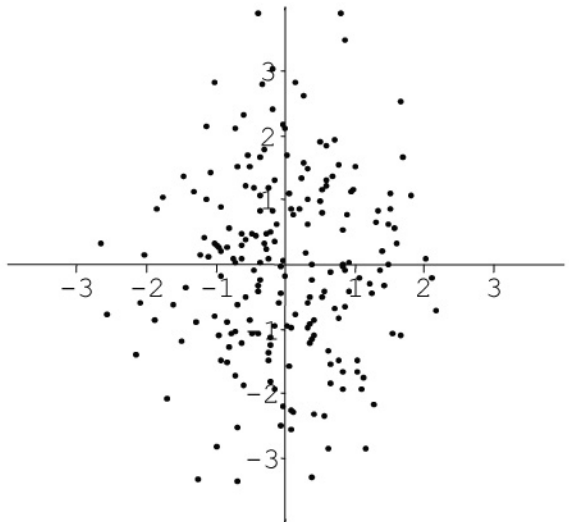

A
object 1
object 2
p(y)
y1
y1
Δ
B
p(Δ̂)
Pr(Δ̂ > 0)
Δ̂
C
Pr(Δ̂ > 0)
σ_h^2 = 1
σ_h^2 = 2
σ_h^2 = 3
Δ


a
Within-modality discrimination
Haptic
Visual
0%
67%
133%
200%
Noise level
Standard
n = 4
Proportion of trials perceived as 'taller'
Comparison height (mm)
b
Visual–haptic discrimination
(normalized across Δ)
Visual–haptic
0%
67%
133%
200%
Noise level
Normalized comparison height (mm)
c
Weights (PSEs)
Visual–haptic
Predicted
Empirical
'Visual capture'
'Haptic capture'
PSE
Visual weight
Haptic weight
Noise level (%)
d
Discrimination thresholds
Haptic (empirical)
Visual (empirical)
Visual–haptic (predicted)
Visual–haptic (empirical)
Threshold
Noise level (%)

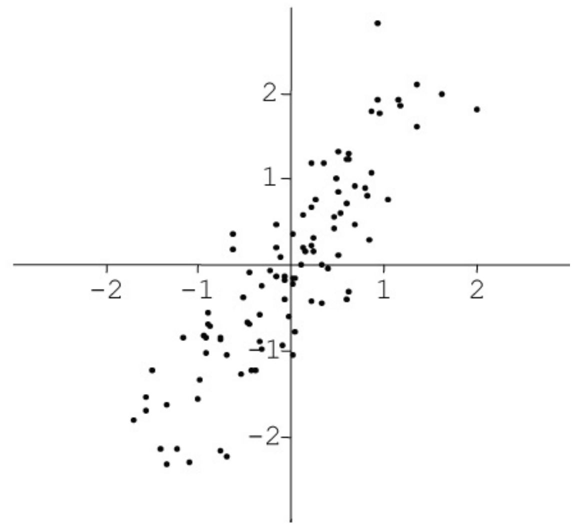
$$\mathbf{x} \sim N\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}1 & -0.9\sqrt{2}\\ -0.9\sqrt{2} & 2\end{bmatrix}\right)$$



$$\mathbf{x} \sim N\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}1 & 0.1\sqrt{2}\\ 0.1\sqrt{2} & 2\end{bmatrix}\right)$$



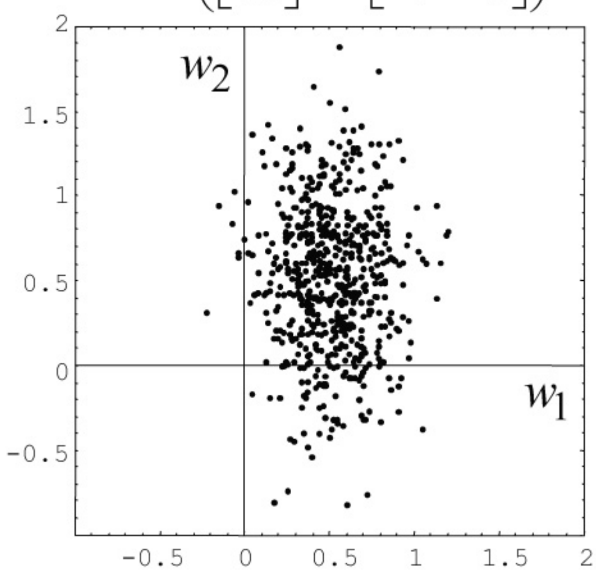
$$\mathbf{x} \sim N\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}1 & 0.9\sqrt{2}\\ 0.9\sqrt{2} & 2\end{bmatrix}\right)$$



A

x_1	x_2	y^*
1	0	0.5
1	0	0.5
1	0	0.5
1	0	0.5
0	1	0.5

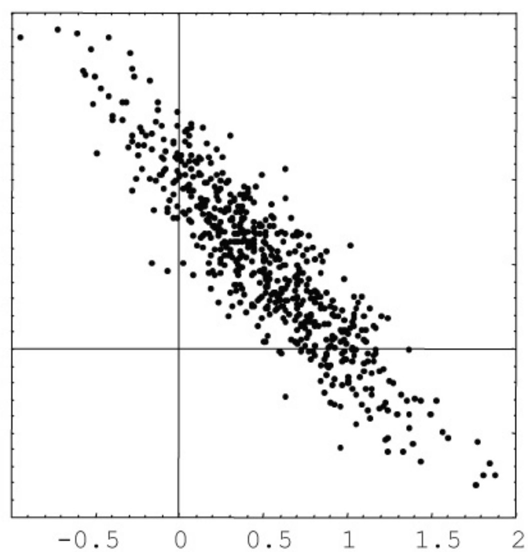
$$\mathbf{w} \sim N\left(\begin{bmatrix}0.5\\0.5\end{bmatrix}, \sigma^2\begin{bmatrix}0.25 & 0\\0 & 1\end{bmatrix}\right)$$



B

x_1	x_2	y^*
1	1	1
1	1	1
1	1	1
1	1	1
1	0	0.5

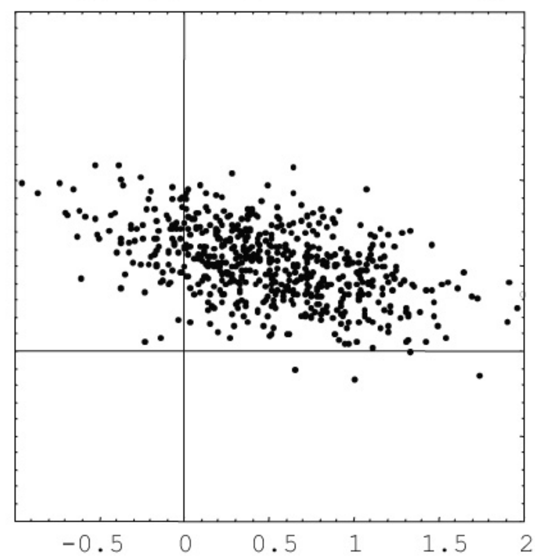
$$\mathbf{w} \sim N\left(\begin{bmatrix}0.5\\0.5\end{bmatrix}, \sigma^2\begin{bmatrix}1 & -1\\-1 & 1.25\end{bmatrix}\right)$$

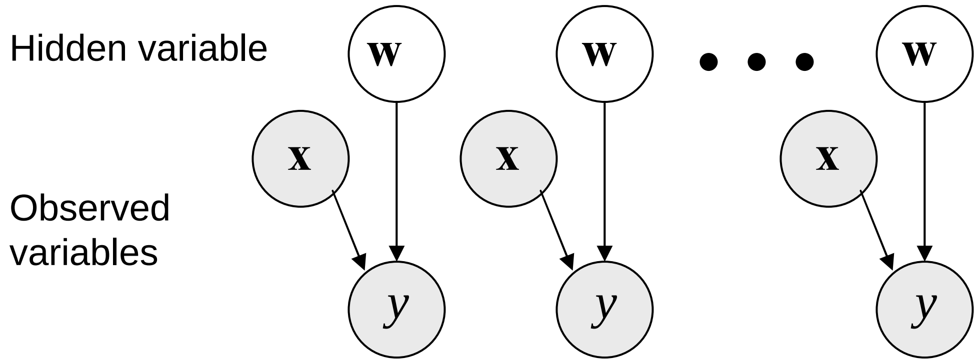


C

x_1	x_2	y^*
0	1	0.5
0	1	0.5
0	1	0.5
0	1	0.5
1	1	1

$$\mathbf{w} \sim N\left(\begin{bmatrix}0.5\\0.5\end{bmatrix}, \sigma^2\begin{bmatrix}1.25 & -0.25\\-0.25 & 0.25\end{bmatrix}\right)$$





Generative model

$$\mathbf{w}^{(n+1)} = \mathbf{w}^{(n)}$$

$$y^{(n)} = \mathbf{x}^{(n)T}\mathbf{w} + \varepsilon^{(n)} \qquad \varepsilon \sim N\left(0, \sigma^2\right)$$

Prior estimate of mean and variance of the hidden variable

$$\hat{\mathbf{w}}^{(1|0)}, P^{(1|0)}$$

Update of the estimate after making an observation

$$\hat{\mathbf{w}}^{(n|n)} = \hat{\mathbf{w}}^{(n|n-1)} + \mathbf{k}^{(n)}\left(y^{(n)} - \mathbf{x}^{(n)T}\hat{\mathbf{w}}^{(n|n-1)}\right)$$

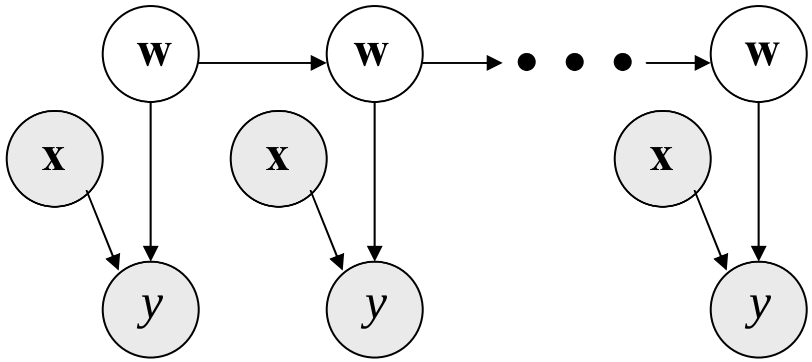
$$\mathbf{k}^{(n)} = \frac{P^{(n|n-1)}\mathbf{x}^{(n)}}{\mathbf{x}^{(n)T}P^{(n|n-1)}\mathbf{x}^{(n)} + \sigma^2}$$

$$P^{(n|n)} = \left(I - \mathbf{k}^{(n)}\mathbf{x}^{(n)T}\right)P^{(n|n-1)}$$

Forward projection of the estimate to the next trial

$$\hat{\mathbf{w}}^{(n+1|n)} = \hat{\mathbf{w}}^{(n|n)}$$

$$P^{(n+1|n)} = P^{(n|n)}$$



Generative model

$$\mathbf{w}^{(n+1)} = A\mathbf{w}^{(n)} + \boldsymbol{\varepsilon}_w^{(n)} \qquad \boldsymbol{\varepsilon}_w \sim N\left(0, Q\right)$$

$$y^{(n)} = \mathbf{x}^{(n)T}\mathbf{w}^{(n)} + \varepsilon_y^{(n)} \qquad \varepsilon_y \sim N\left(0, \sigma^2\right)$$

Prior estimate of mean and variance of the hidden variable

$$\hat{\mathbf{w}}^{(1|0)}, P^{(1|0)}$$

Update of the estimate after making an observation

$$\mathbf{k}^{(n)} = \frac{P^{(n|n-1)}\mathbf{x}^{(n)}}{\mathbf{x}^{(n)T}P^{(n|n-1)}\mathbf{x}^{(n)} + \sigma^2}$$

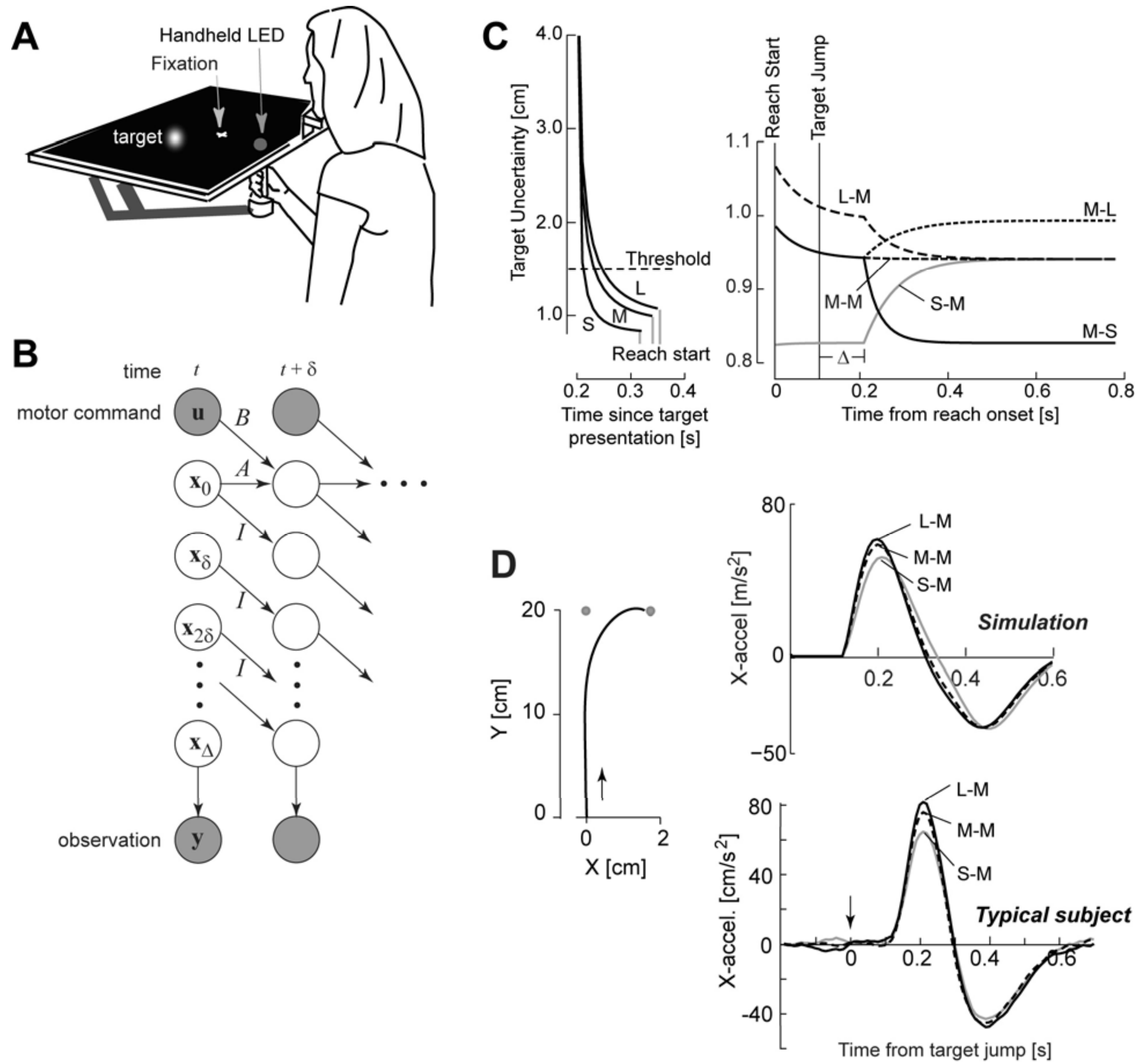
$$\hat{\mathbf{w}}^{(n|n)} = \hat{\mathbf{w}}^{(n|n-1)} + \mathbf{k}^{(n)}\left(y^{(n)} - \mathbf{x}^{(n)T}\mathbf{w}^{(n|n-1)}\right)$$

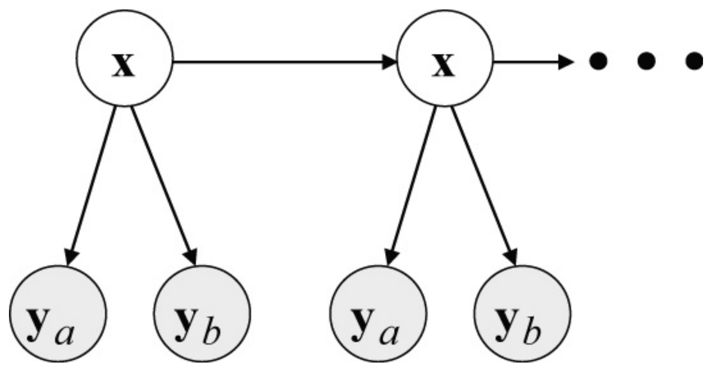
$$P^{(n|n)} = \left(I - \mathbf{k}^{(n)}\mathbf{x}^{(n)T}\right)P^{(n|n-1)}$$

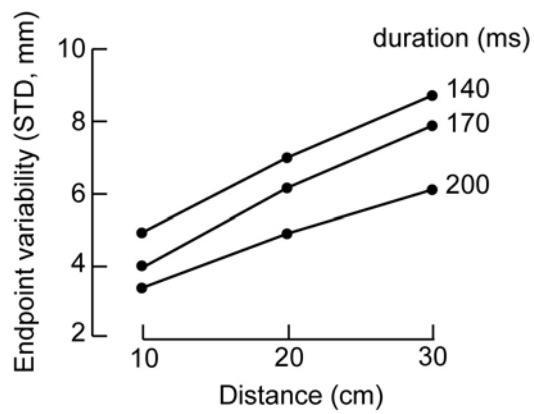
Forward projection of the estimate to the next trial

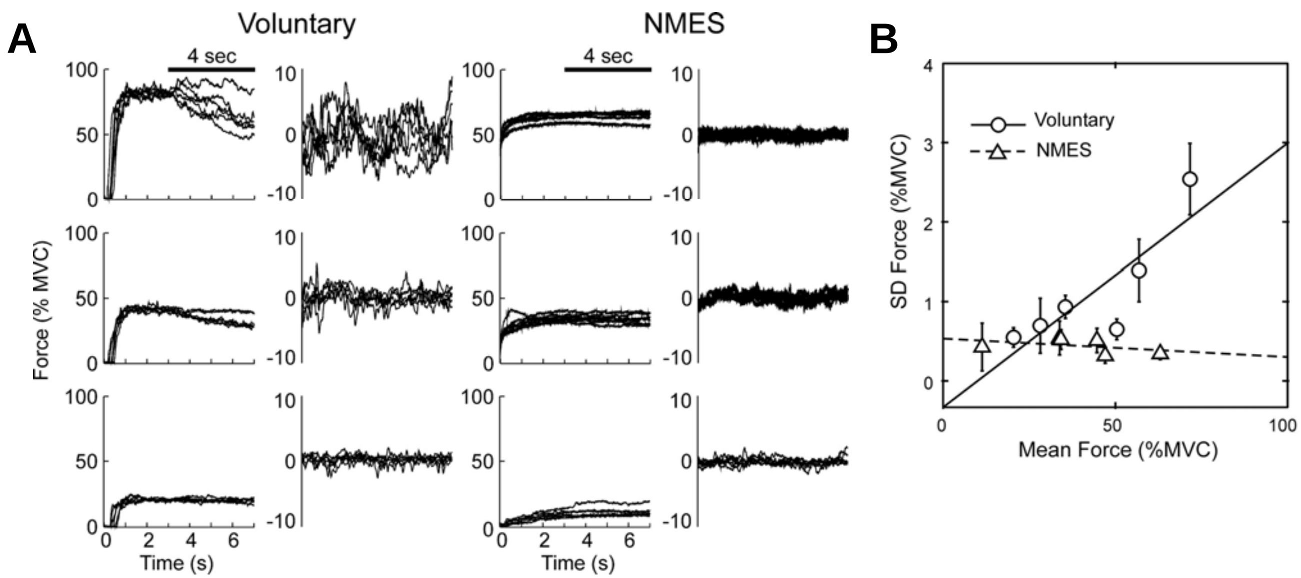
$$\hat{\mathbf{w}}^{(n+1|n)} = A\hat{\mathbf{w}}^{(n|n)}$$

$$P^{(n+1|n)} = AP^{(n|n)}A^T + Q$$


A
Handheld LED
Fixation
target
B
time
t
t + δ
motor command
u
B
A
I
I
I
observation
y
C
Target Uncertainty [cm]
Threshold
L
M
S
Reach start
Time since target presentation [s]
Reach Start
Target Jump
L-M
M-L
M-M
S-M
M-S
Δ
Time from reach onset [s]
D
Y [cm]
X [cm]
X-accel [m/s2]
L-M
M-M
S-M
Simulation
X-accel. [cm/s2]
Typical subject
Time from target jump [s]


x
x
$\mathbf{y}_a$
$\mathbf{y}_b$
$\mathbf{y}_a$
$\mathbf{y}_b$


Endpoint variability (STD, mm)
10
8
6
4
2
duration (ms)
140
170
200
10
20
30
Distance (cm)


A
Voluntary
NMES
4 sec
Force (% MVC)
Time (s)
B
Voluntary
NMES
SD Force (%MVC)
Mean Force (%MVC)