The effect of joint attention on visual-tactile integration and recalibration

Michael S. Landy
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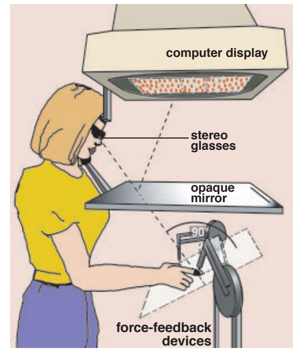
With: Stephanie Badde & Karen Navarro

Badde, Navarro & Landy, *Cognition*, *197*, 104170.

“Traditional” Cue Integration



Maloney & Landy, 1989; Clark & Yuille, 1990; Landy et al., 1995; Ernst & Banks, 2002; etc.

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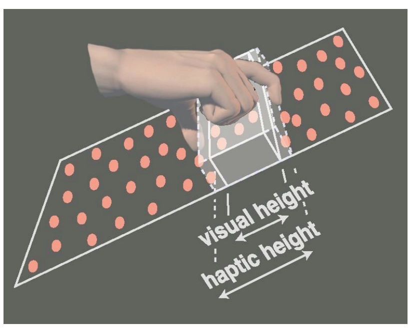

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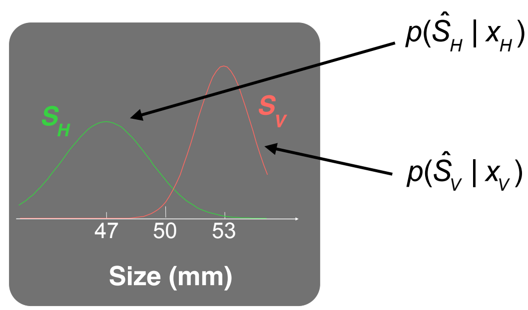

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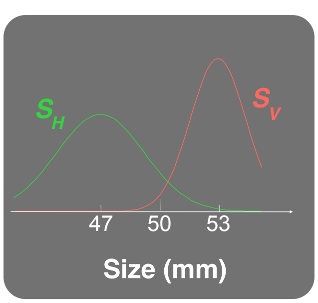

$$\hat{S} = w_H \hat{S}_H + w_V \hat{S}_V$$

$$w_H = \frac{r_H}{r_H + r_V}$$

$$w_V = \frac{r_V}{r_H + r_V}$$

Reliability $r = 1/\sigma^2$

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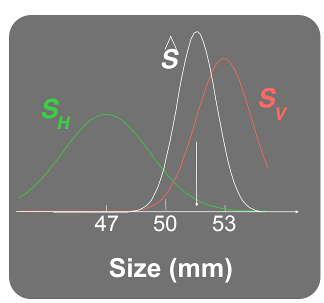

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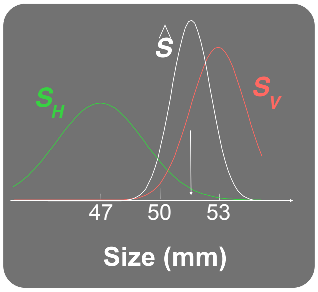


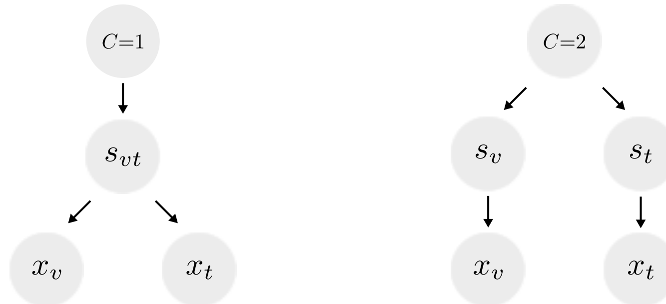
$$\hat{S} = w_H \hat{S}_H + w_V \hat{S}_V$$

$$\sigma^2_{HV} = \frac{\sigma^2_H \sigma^2_V}{\sigma^2_H + \sigma^2_V}$$

$$r_{HV} = r_H + r_V$$

Variance of combined estimate lower than variance of either single-cue estimate

Causal Inference



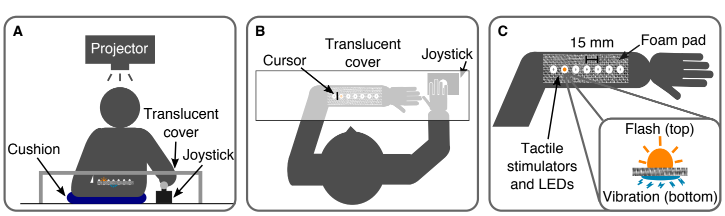
Körding et al., 2007

Ventriloquism and its Aftereffect

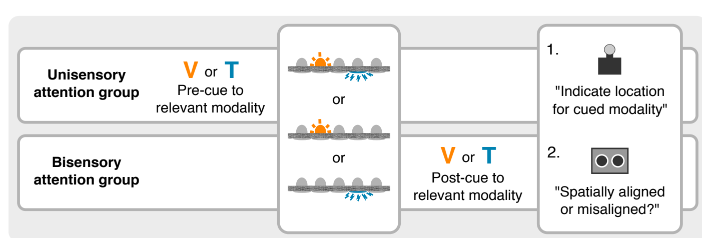
Ventriloquism and its Aftereffect

- Multisensory integration
- Causal inference
- Bayesian modeling (e.g., Körding et al., 2007)
- Recalibration
- Top-down influences on integration and recalibration:
  - Visual-auditory: cognitively impenetrable
  - Visual-proprioceptive: Effects of instructions and attention
  - Visual-tactile (another body sense)?

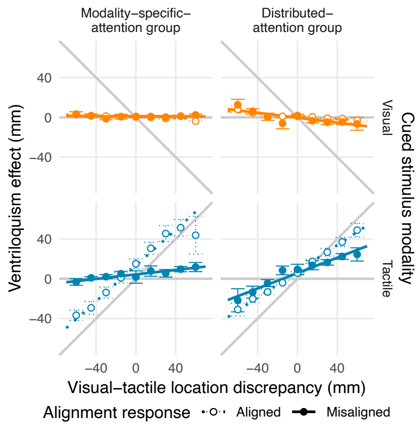
Experimental Apparatus



Ventriloquist Effect: Procedure



Ventriloquist Effect: Results



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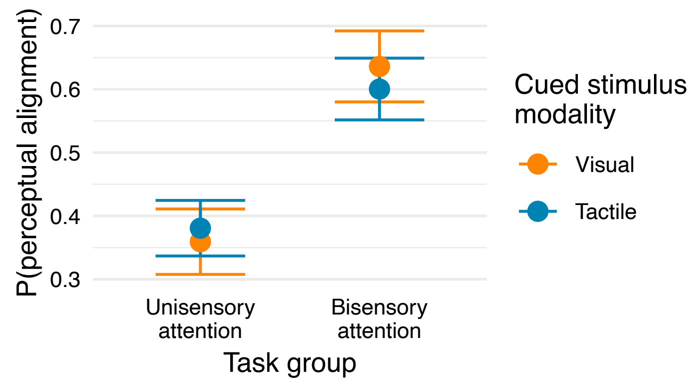
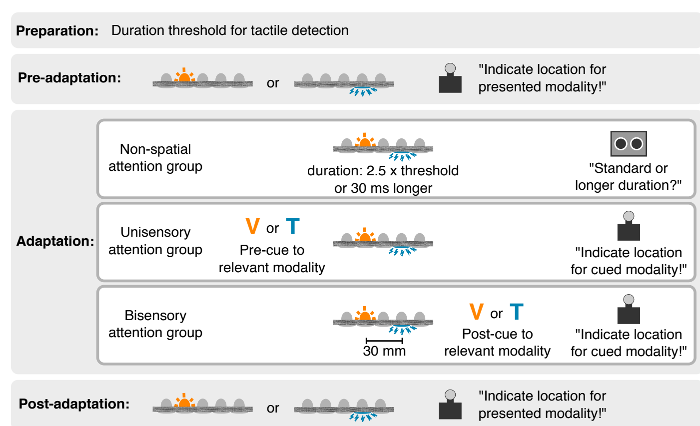


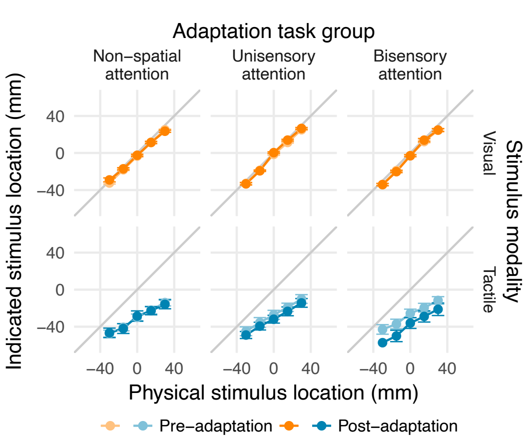
Ventriloquism Effect: Conclusions

- A small shift of vision toward tactile - larger when both modalities are attended; no effect of perceiving a common cause
- A much larger shift of touch toward vision, maximal when a common cause is perceived. When perceived as misaligned, there is a larger shift when both modalities are attended
- A weak link between vision and touch is strengthened when both modalities are attended

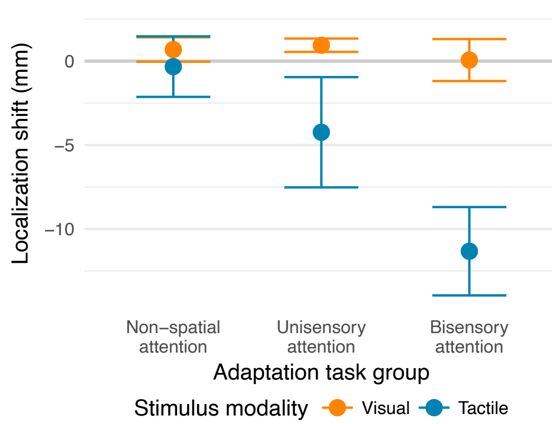
Ventriloquist Aftereffect: Procedure



Ventriloquist Aftereffect: Results



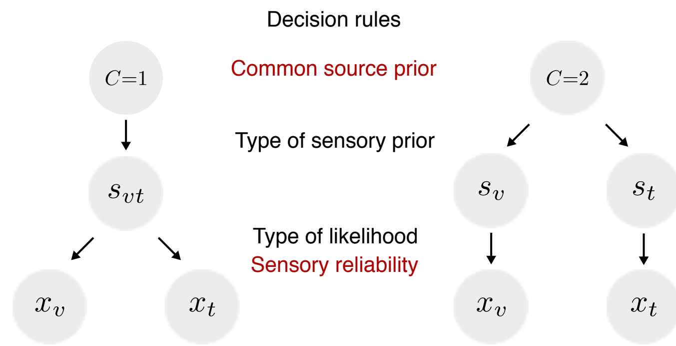
Ventriloquist Aftereffect: Results



Ventriloquism Aftereffect: Conclusions

- No recalibration of vision (when tested vs. visual cursor)
- Recalibration of touch significant only when both modalities' locations must be attended
- Is this due to the degree of integration during the adaptation phase?

Ventriloquism Effect: Models



Ventriloquism Effect: Models

- Signals: s_v, s_t
- Noisy measurements: $x_t \sim N(s_t, \sigma_t^2)$, $x_v \sim N(s_v, \sigma_v^2)$
- Number of causes $C = 1$ or 2
- Priors, possibly different for visual, tactile or combined
- Tactile priors possibly bimodal (e.g., centered on wrist and elbow)
- Ideal observer uses Bayesian inference and model averaging over $C = 1$ and $C = 2$
- Late noise on observer's estimates
- Measurements are unobservable; to predict responses, integrate over possible measurements

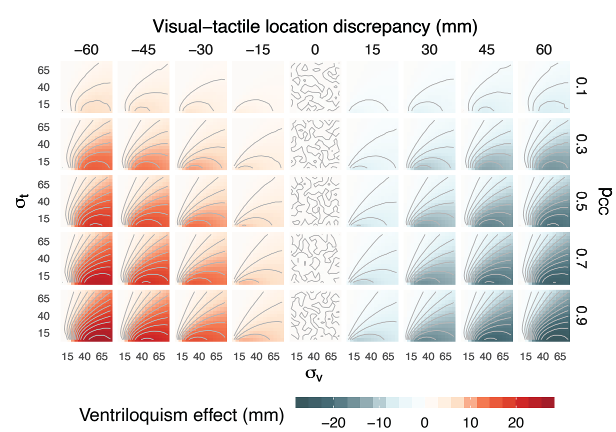
Ventriloquism Effect: Models

- Effect of modality-specific attention on $\sigma_t^2, \sigma_v^2, p_{CC}$
- Location estimate models: model averaging, or report integrated estimate when measurements or independent estimates are sufficiently close
- Common-cause decision models: Say "$C = 1$" when $p(C = 1 | x_v, x_t) > 0.5$ or when measurements or independent estimates are sufficiently close

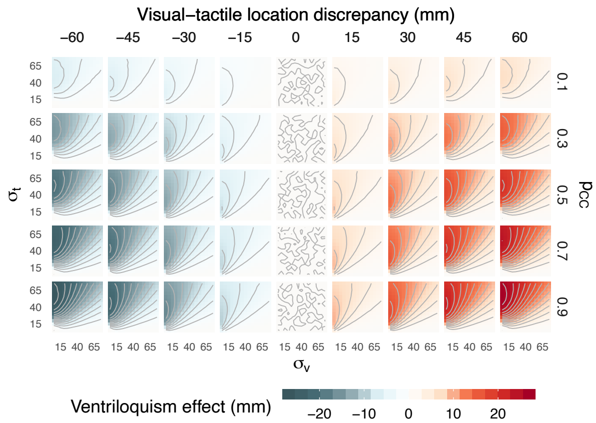
Ventriloquism Effect: Models

- The winning model (using AIC) was the same for the unisensory and bisensory attention groups
- Localization responses based on the ideal observer, but common-cause judgments based on a heuristic: the distance between the unisensory location estimates
- Required shifted likelihoods and a bimodal tactile prior

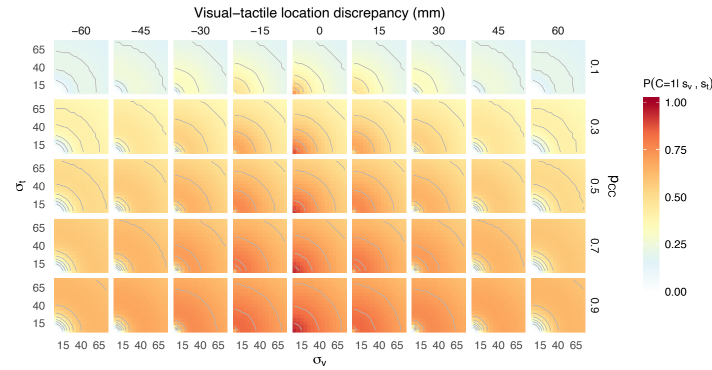
Ventriloquism Model Simulations: Visual Shifts



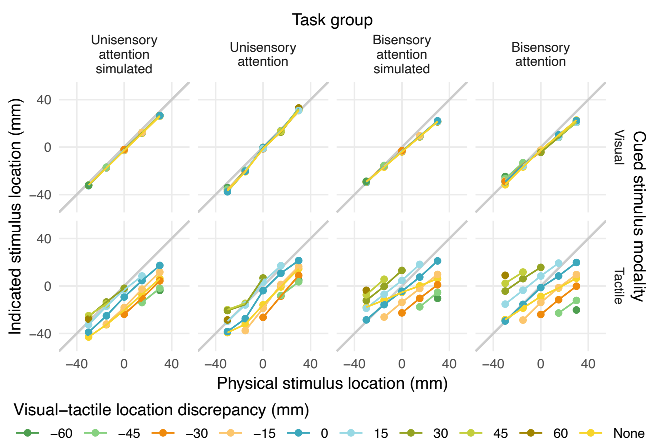
Ventriloquism Model Simulations: Tactile Shifts



Ventriloquism Model Simulations: Perceived Spatial Alignment



Ventriloquist Effect: Modeling



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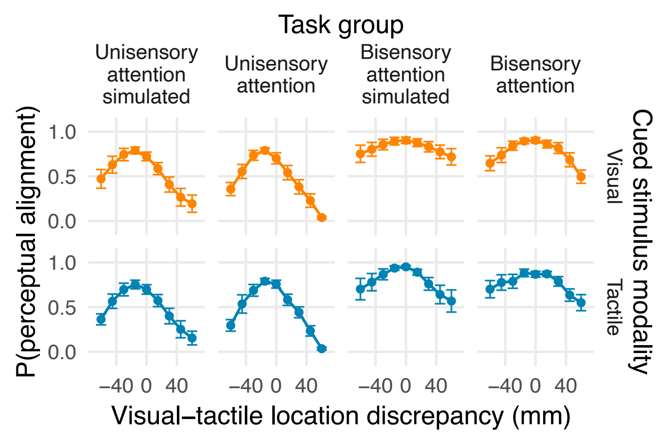
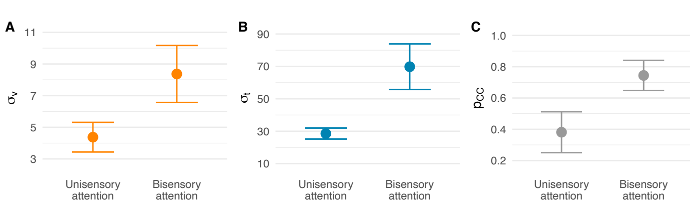


Ventriloquist Effect: Modeling



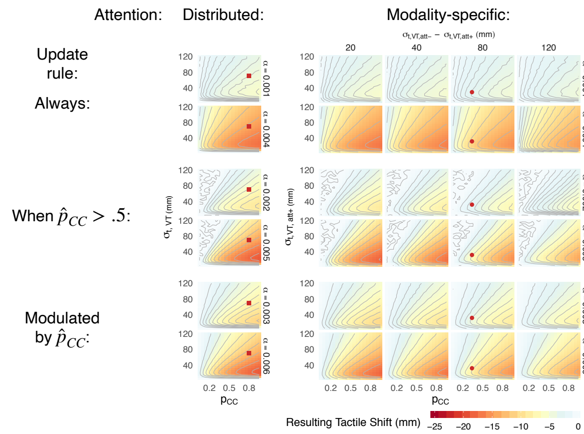
Ventriloquism Effect: Modeling Results

- Model fits indicate that bisensory attention increases sensory noise (perhaps due to limited capacity) and increases the assumed prior probability of a common cause

Ventriloquism Aftereffect: Models

- On each trial, likelihood shifts are updated based on the discrepancy between cue measurements and estimates
- Cue estimates depend on measurements, priors, and the estimated probability of a common cause
- Updates can occur
  - Always
  - Only when the probability of a common cause > 0.5
  - Always, but modulated by the probability of a common cause

Ventriloquist Aftereffect: Modeling



Ventriloquism Aftereffect: Model Results

- All three models predict greater recalibration with larger p_{CC} and update rate (α)
- The dependence of recalibration on reliability (of both the attended and unattended tactile stimulus) is non-monotonic: For higher tactile reliability, reducing tactile reliability leads to greater tactile recalibration, but when reliability is low enough, reducing it further leads to *less* recalibration (as a result of noisier measurements and the effects of causal inference)

Ventriloquism Aftereffect: Model Results

- All three models predict greater recalibration in the bisensory attention condition
- However, only the second model, in which updates only occur if the estimated probability of a common cause is high, predicts an effect large enough to accord with the observed results

Conclusions

- The ventriloquist effect and aftereffect have analogues for combinations of visual and tactile stimuli
- Visual attention has substantial contributions to both effects
- Attention to a cue contributes in two ways
- The affect of attention on reliability/discriminability is well-known
- However, the strongest contribution of attention is surprising: it strengthens the “prior” of the two cues as having a common cause, thus “priors” aren’t really prior, but depend on context/state variables

Tactile/Proprioceptive Integration

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Vector sum
(not average)

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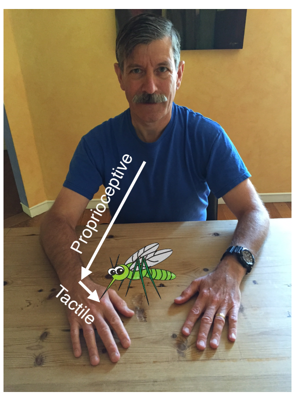


Ideal Observer:

Proprioceptive:

$$\hat{x}_p \sim N(\mu_p, \sigma_p^2)$$

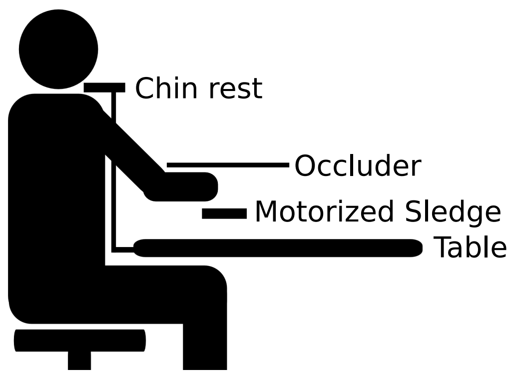
Tactile:

$$\hat{x}_t \sim N(\mu_t, \sigma_t^2)$$

Combined:

$$\hat{x}_c \sim N(\mu_p + \mu_t, \sigma_p^2 + \sigma_t^2)$$

Apparatus



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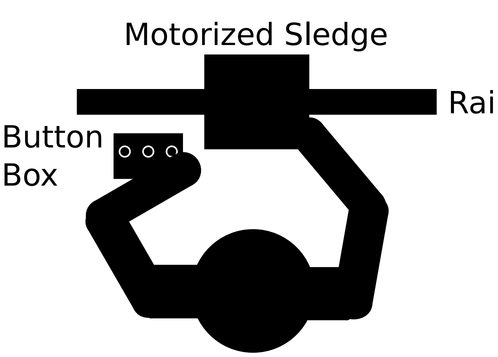

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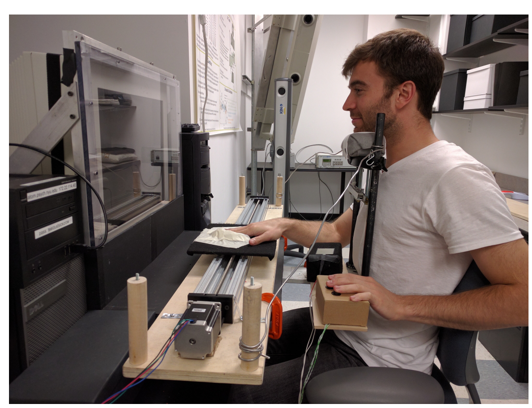

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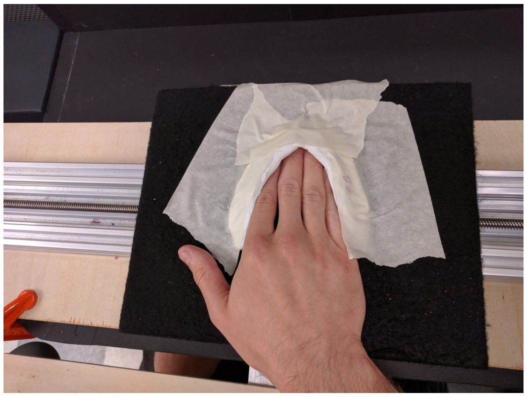

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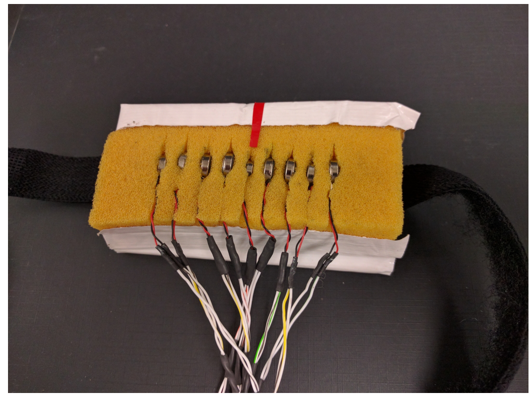

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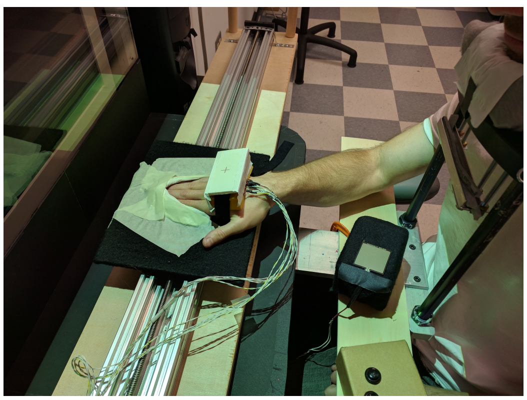

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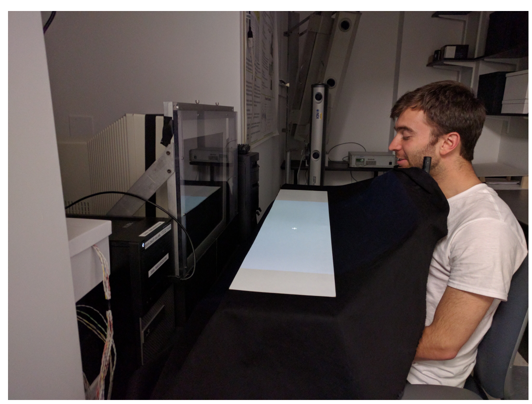
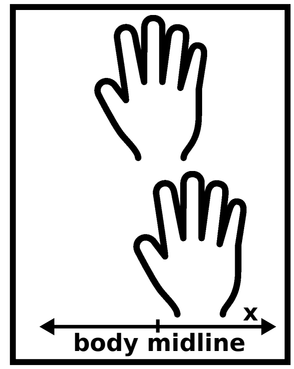


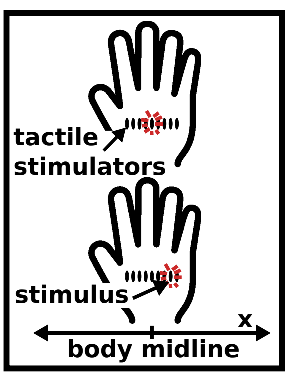
Expt. 1: Location Discrimination

- Left-right location discrimination
- Determine whether predictions of vector-sum model hold

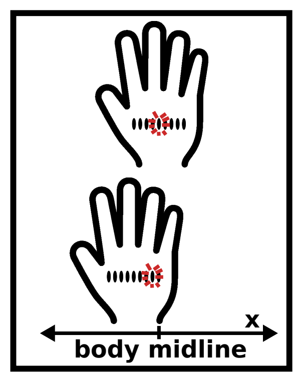
Task - Proprioceptive



Task - Tactile



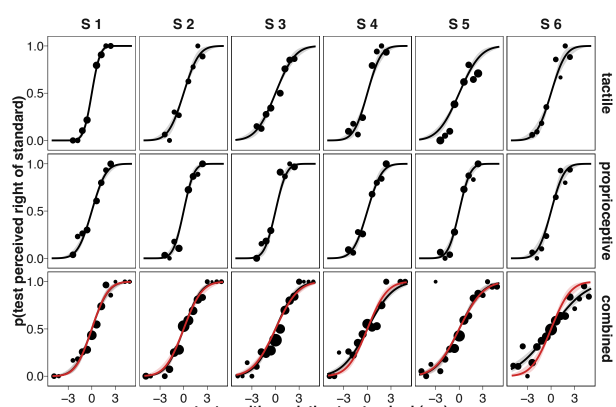
Task - Combined



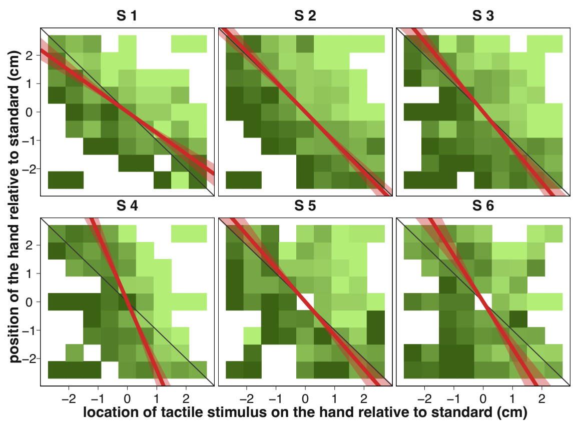
Task

- 2IFC spatial discrimination
- One interval at midline, other varied
- Procedure (combined condition)
  - Mold moves to new location
  - Insert hand
  - One buzzer stimulated
  - Remove hand to pressure plate, hit button
  - Repeat for interval 2
  - Choose rightmost using button box
- White noise in headphones

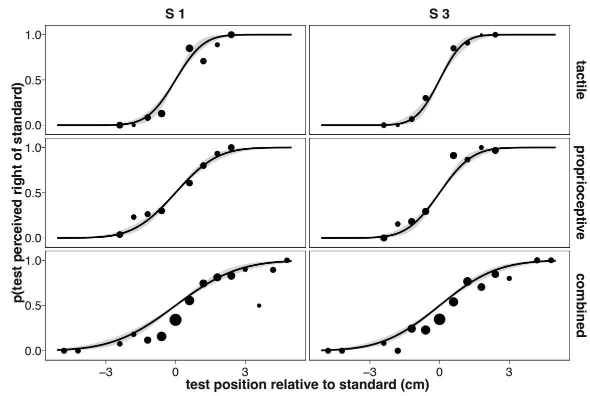
Data



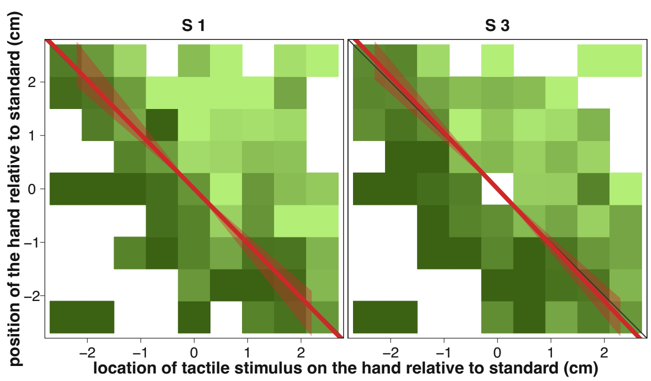
Data



Data - Palm



Data - Palm



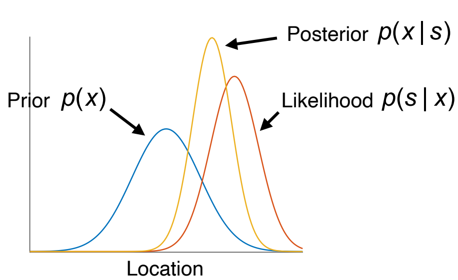
Conclusions

- Slopes of psychometric functions are indistinguishable from optimal (variances sum)
- Yet, observers give the more reliable cue higher weight in a circumstance where that is irrational

Just-so Story

- Perceptual estimates combine sensory and prior information, i.e., is Bayesian:

$$P(x \mid s) \propto p(s \mid x) p(x)$$



Just-so Story

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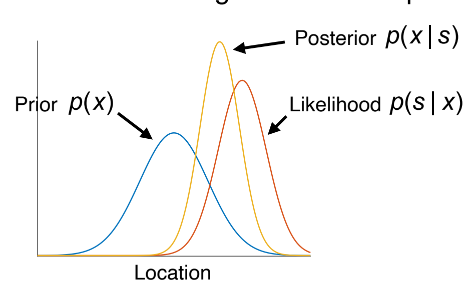
- The posterior/estimate "regresses" to the prior.



Just-so Story

- Perceptual estimates combine sensory and prior information, i.e., is Bayesian.
- The posterior/estimate “regresses” to the prior.
- Thus, if proprioception is more precise than haptic localization, the proprioceptive estimate will regress to its prior less than the haptic estimate and, once combined, will appear to have higher weight.