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# Dealing with uncertainty in reaching

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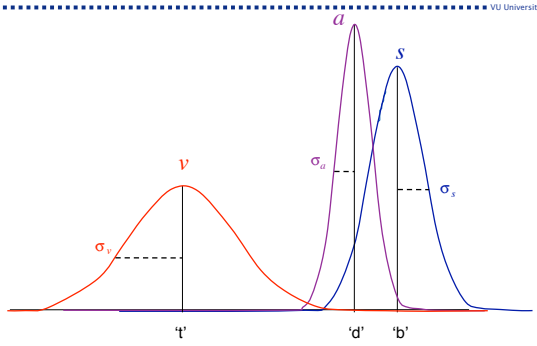
## Uncertainty in information.

The McGurk effect

- You combine sound and vision to a single percept.
- You do not re-calibrate!

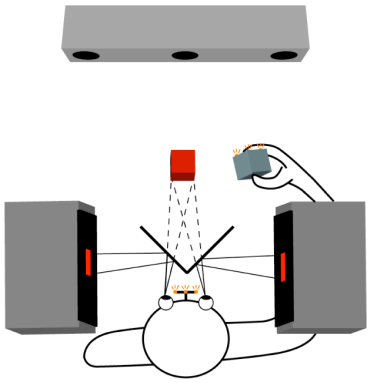
## Optimal and uncertainty




- $a = wv + (1\text{-}w)s$ $\quad a = \frac{\sigma_s^2}{\sigma_v^2 + \sigma_s^2} v + \frac{\sigma_v^2}{\sigma_v^2 + \sigma_s^2} s$

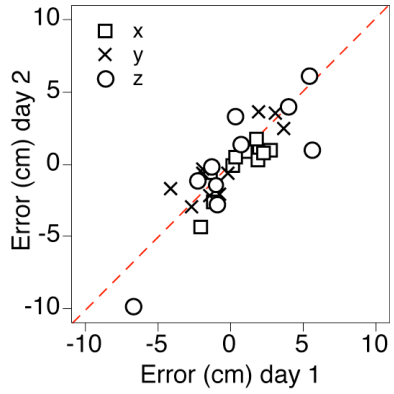
## Experiment 1a: matching

- Start in the dark
- Put cube in hand at visual location
- Repeat the experiment the next day



(Smeets et al., PNAS, 2006)

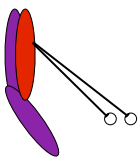
## Subjects have different errors




(Smeets et al., PNAS, 2006)

## Where is my hand?

Vision



- At the average of proprioceptive and visual location.

## Where is a visual target?

- Hand is at a combination of visual and proprioceptive information.
- Is target at its visual estimated location?
  - Consequence: if hand is at target, we would perceive hand & target at different locations!!
- Target is at a combination of visual and extended proprioceptive information:

Visual target = Eye orientation + Position target relative to eye

Extended proprioceptive target = Hand position + Position target relative to hand (vision)

Distorted / removed in experiment

## What if hand out of view?

- Perceived location of hand *and* target change!

Visual target = Eye orientation + Position target relative to eye

Extended proprioceptive target = Hand position + Position target relative to hand (vision)

Visual hand = Eye orientation + Position hand relative to eye

Proprioceptive hand = Hand position

*Uncertain if hand out of view ⇨ less weight*

## Consequence of uncertainty

- When the hand is out of view, the position of the hand relative to target and fovea is updated based on efferent information.
- This update is needed every movement.
- Every update introduces an additional motor uncertainty (and thus less weight).

$$\hat{x}_{hand} - \hat{x}_{target} = \frac{n\sigma_{ex}^2}{n\sigma_{ex}^2 + \sigma_p^2 + \sigma_v^2}$$

## Predictions

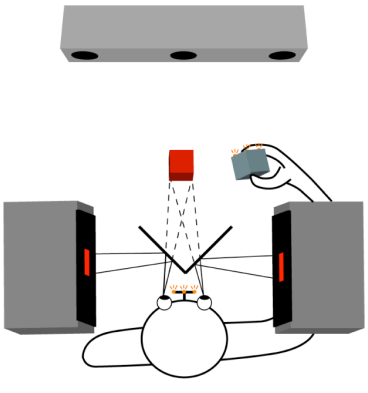
- Proprioception and vision are not calibrated.
  1. After veridical feedback drift to systematic error
  2. Variable error should increase from bimodal to unimodal percept
- After-effect of incorrect visual feedback is not due to re-calibration.
  2. De-adaptation and drift are equivalent.
- De-adaptation depends on # changes in visuo-motor match
  3. Any movement will lead to de-adaptation

## Experiment 1b: drift

- Start in the dark
- Learn with veridical info
- Measure after-effect.

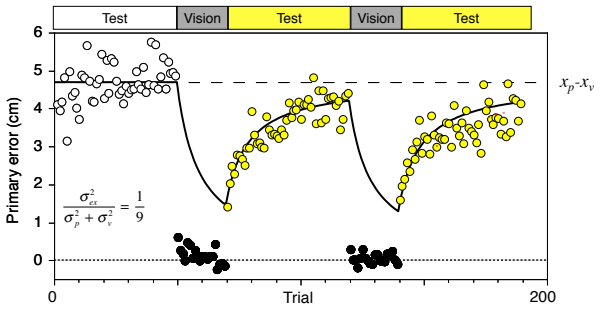
Prediction:

- After learning no error (seems adapted)
- But drift back to original error



(Smeets et al., PNAS, 2006)

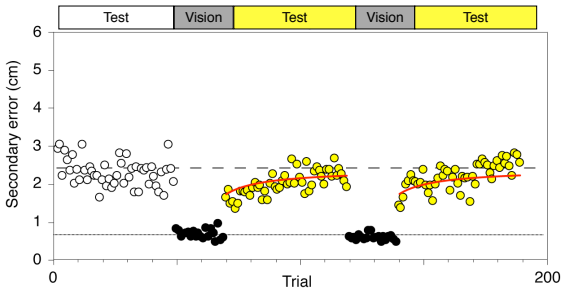
## Averaged across subjects




- Model predicts time-course of drift well

(Smeets et al., PNAS, 2006)

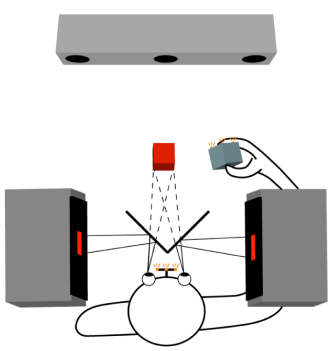
## 2nd cue combination prediction

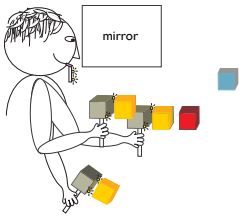



- "Variable error" increases with # trials
- Not predicted with de-calibration explanation

(Smeets et al., PNAS, 2006)

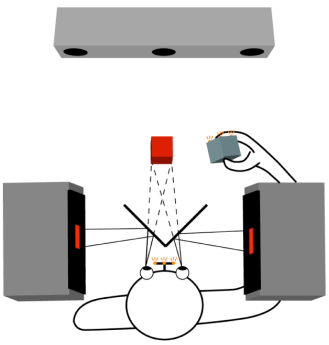
## Experiment 2: 'real' adaptation

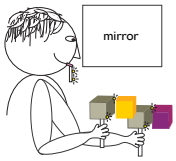





- Real cube invisible
- Visual hand cube ± 5 cm displaced.
- Judge target (10x).
- Reachable? Yes/No

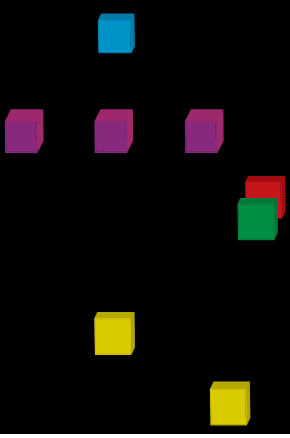
## Hand percept & visual feedback



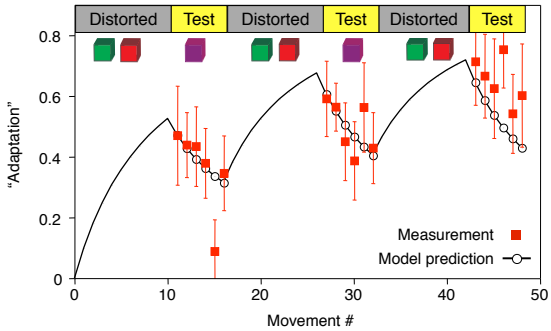



- Hand cube hidden
- Move to target (6x).
- Repeat with hand cube displaced in opposite direction.

## Subject's view



## Drift equals de-adaptation




- Prediction 2: (de)adaptation = drift.
- No need to assume re-calibration.

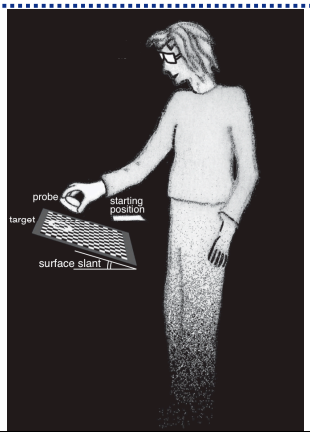
## Interim Summary

- Subjects' vision and proprioception are not mutually calibrated.
- Target and hand are both located based on a combination of vision and proprioception.
- The "drift" or "de-adaptation" is a change of weight due to making movements.
- Adaptation to non-veridical feedback is also just optimal combination.

## What is optimal?

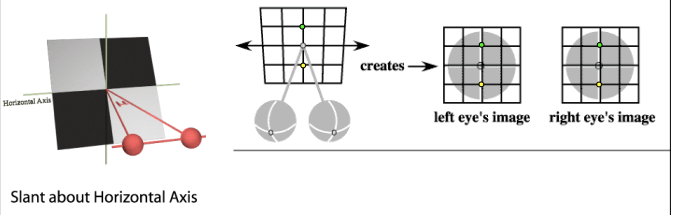
- No re-calibration is found, just optimal combination.
- Optimal was defined on the basis of uncertainty.
- Can we change the weights chosen (and thus what is optimised)?

## Put object on table




- Table not horizontal
- Relevant attribute: slant
- Cues: binocular and retinal shape
- At end of movement a third information source is present: haptics

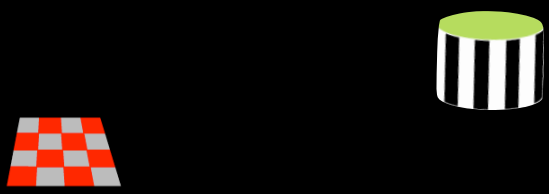
## Two cues for slant perception




Slant about Horizontal Axis

Shape Binocular

## Subject's view



## Determine weights by conflict

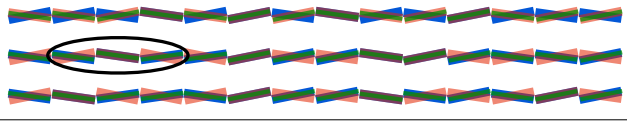
- The orientation of the object before contact relates to perceived slant.
- If binocular info and retinal shape indicate different slants, the orientation of the object will reveal the weights given to the cues
- Question: Do the weights depend on more than precision?

## The experiment

- Slant of invisible **table** varies
- One cue always indicates the correct slant

| **Slant table** | Consistent | | Conflict | |
|---|---|---|---|---|
| Binocular | | | | |
| Shape | | | | |

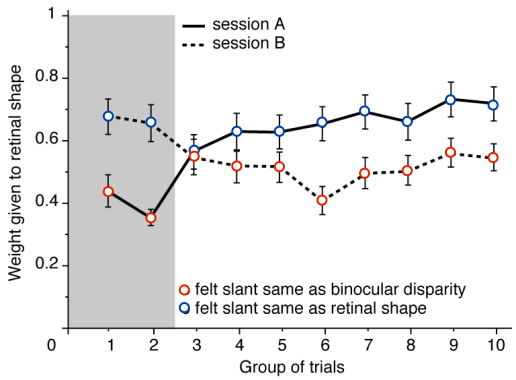
- Which cue is correct changes once in block



## Possible strategies

1. Choose correct cue
2. Use weighted average
   - 2.A) Based on precision (“optimal”)
   - 2.B) Based on precision (“optimal”), but cues re-calibrated
   - 2.C) More weight to prior
   - 2.D) Based on precision and correctness

## Results on weights




## Summary part 2

- Subjects continue to use a weighted average when one information source is incorrect
  - but change weights very fast although uncertainty stays the same.
- These **do not** maximise precision in the perceptual judgement, but are optimal in another sense.
- Haptics can teach vision!

## Summary

- Adaptation to non-veridical feedback and drift are the consequence of ‘optimal’ combination of uncertain information, not calibration.
- Effect of non-veridical feedback on reachability is not due to adaptation.
- Optimality is not only determined by actual uncertainty, but also influenced by knowledge of result.

Thank you