Visual-haptic integration: cue weights are varied appropriately, to account for changes in haptic reliability introduced by using a tool

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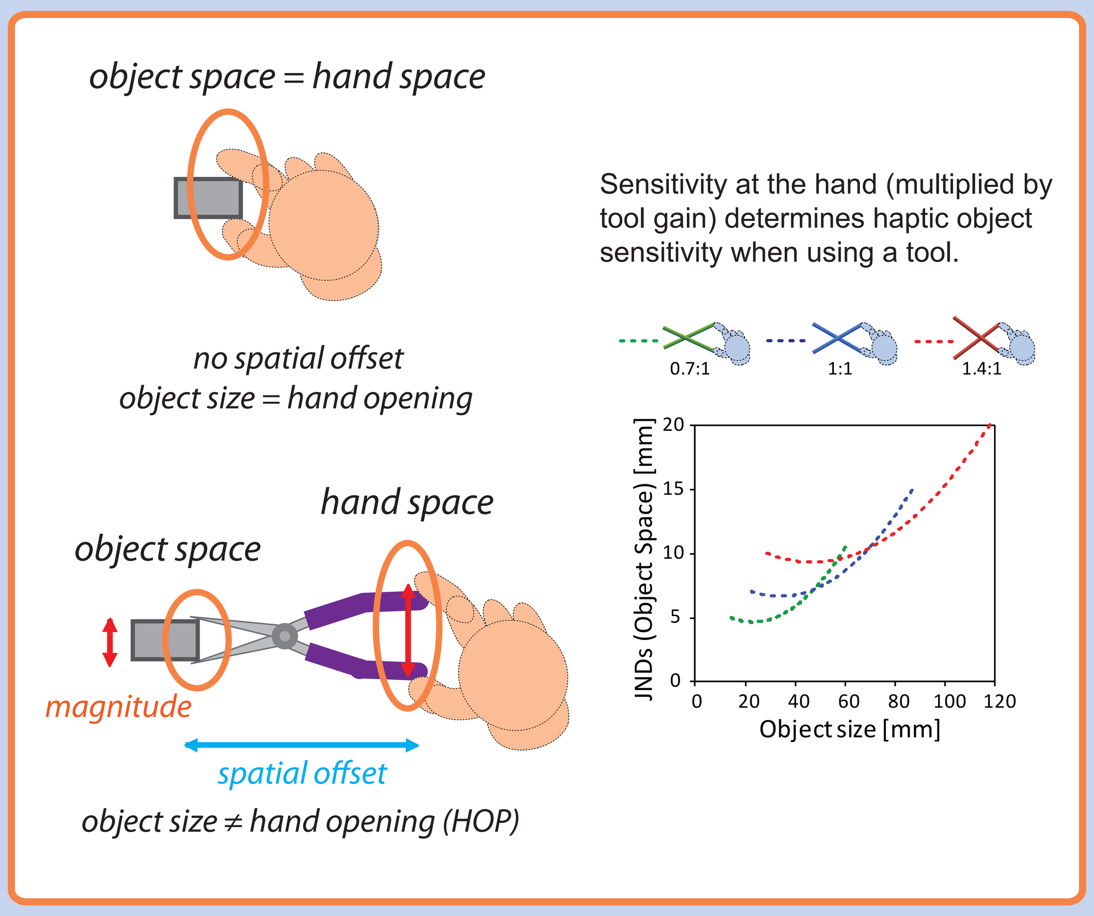
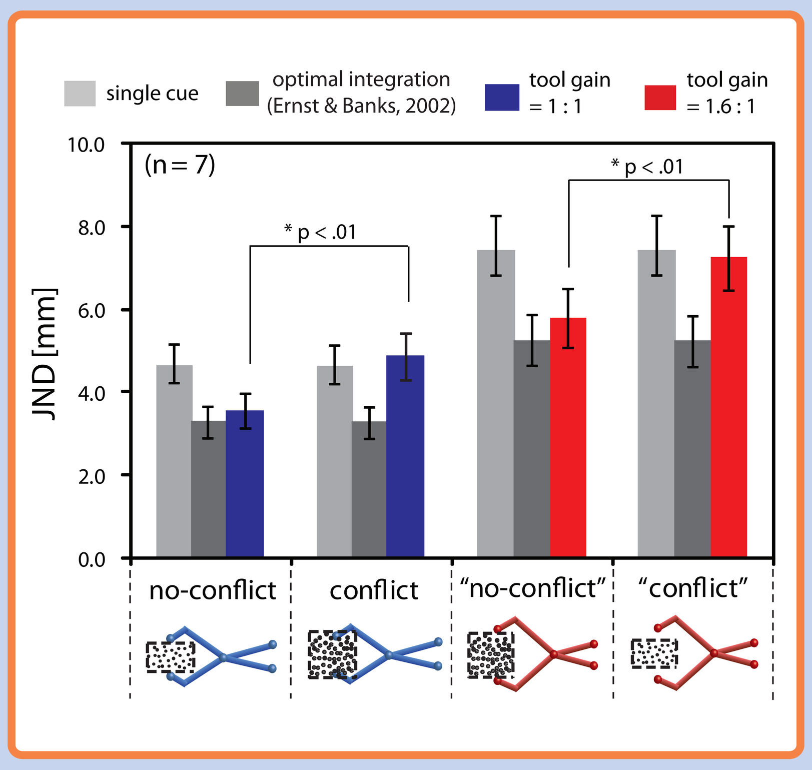
Background

- Visual and haptic information should only be integrated when it refers to the same object — the brain must solve a "correspondence problem".
- The visual-haptic correspondence problem could be solved NOT on 'raw' haptic signals, but on remapped haptic estimates, in 'object coordinates' (VSS-2009).
- The brain dynamically rescales haptic estimates, taking account of the geometry of tools. This rescaling is incomplete, however (IMRF-2010, ECVP-2010).
- Variations in tool geometry also affect the reliability of haptic size estimates, because they alter the change in hand opening caused by a given change in object size.
- **Here we ask, does the brain appropriately adjust the weights given to visual and haptic size signals when tool geometry changes?**

The visual-haptic "correspondence problem"

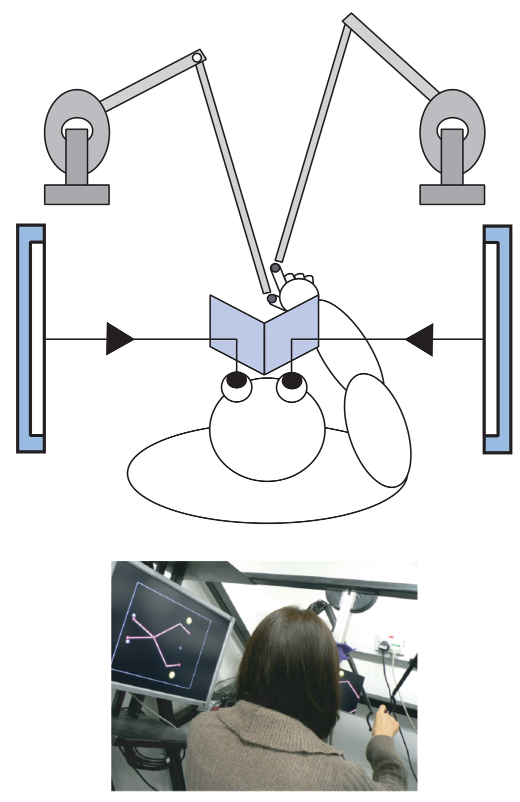


Visual-haptic integration during tool use *(Takahashi et al., VSS2009)*



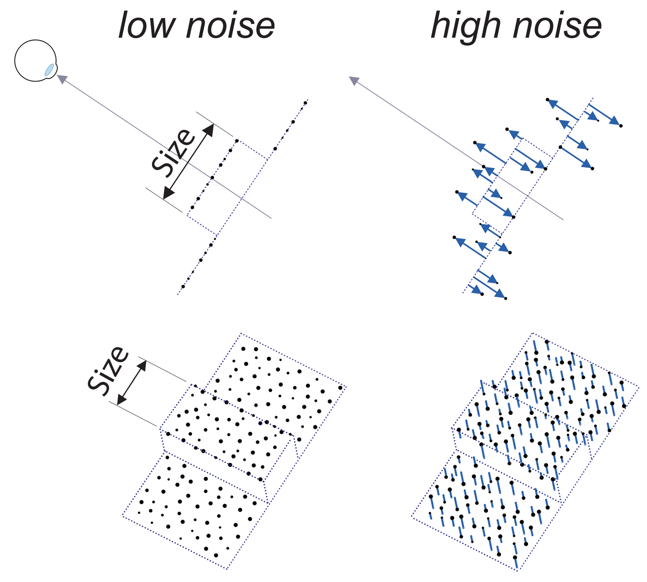
Method

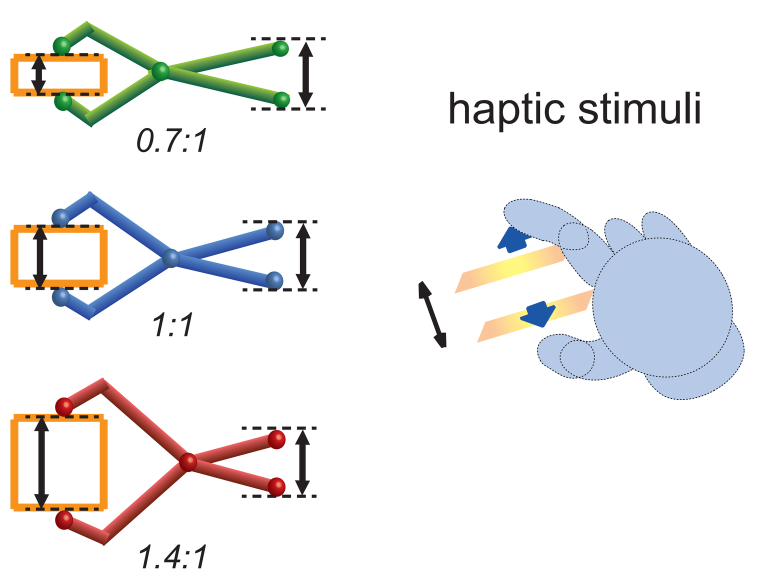
PHANToM devices



Measuring visual and haptic reliabilities

- Vision- and haptics-alone size-discrimination thresholds measured using a 2-IFC task.





- Aiming to roughly match visual and haptic reliabilities in a size-estimation task
- <u>**Three tools were randomly assigned**</u>

Measuring size estimates in haptics-alone and vision-plus-haptics

- We measured BIAS in haptics-alone ($\hat{S}_H$) and vision-haptics ($\hat{S}_{VH}$) using a size-estimation task.
- Visual and haptic sizes were varied independently

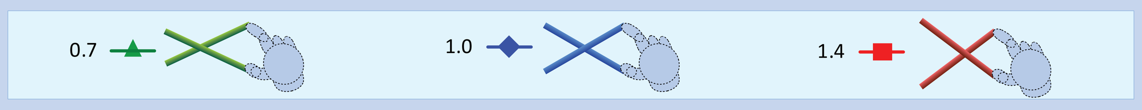
occluder

The object was located behind an occluder: the tool was invisible during haptic stimulus presentation

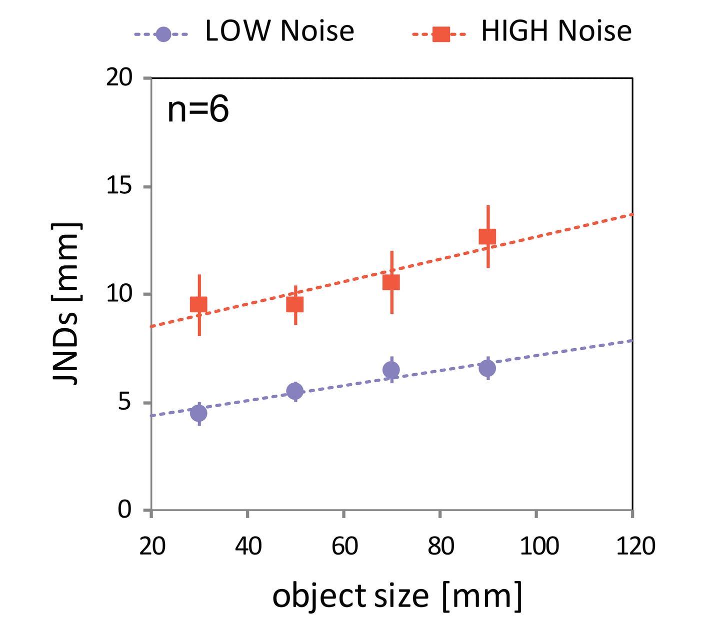
Visual response

Adjusted size with keypress

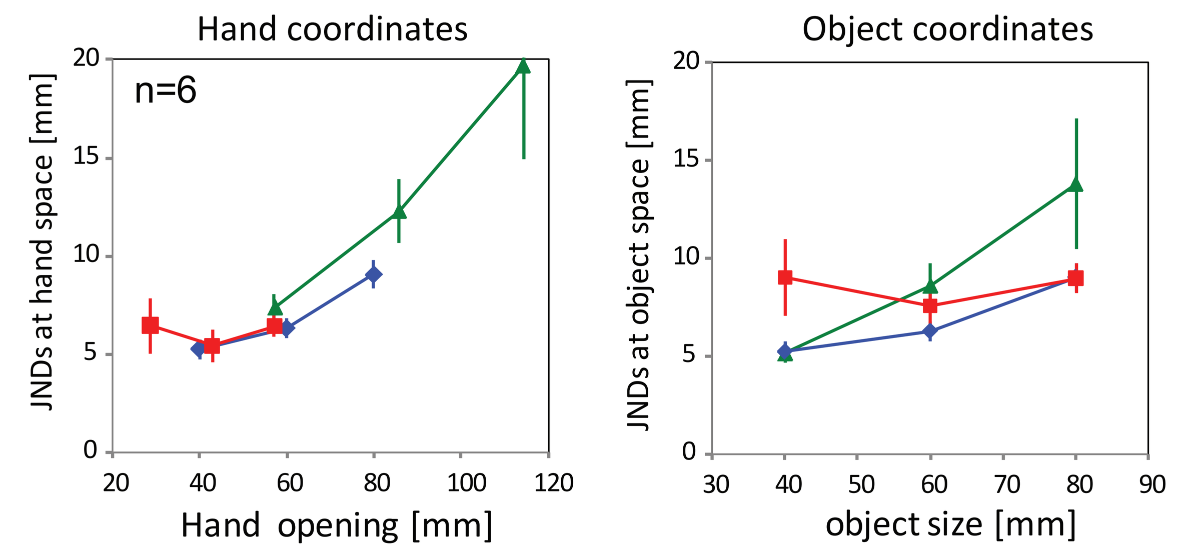
Results



JNDs, vision-alone



JNDs, haptics-alone with tool



- hand sensitivity determines haptic sensitivity with a tool

weighted linear summation model

(1) $\hat{S}_{VH} = w_V\hat{S}_V + w_H\hat{S}_H$, $w_V + w_H = 1$

(2) $w_V=(1/\sigma_V^2)/(1/\sigma_V^2+1/\sigma_H^2)$, $w_H=(1/\sigma_H^2)/(1/\sigma_V^2+1/\sigma_H^2)$

σ_V, σ_H

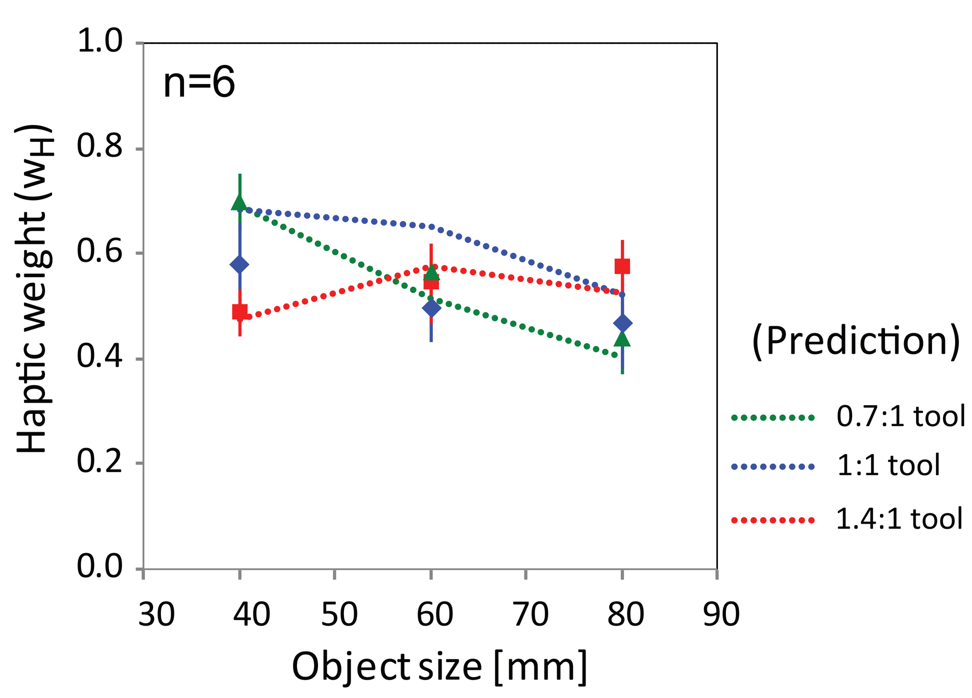
(2) prediction

$\hat{S}_{VH}$, $\hat{S}_V$, $\hat{S}_H$

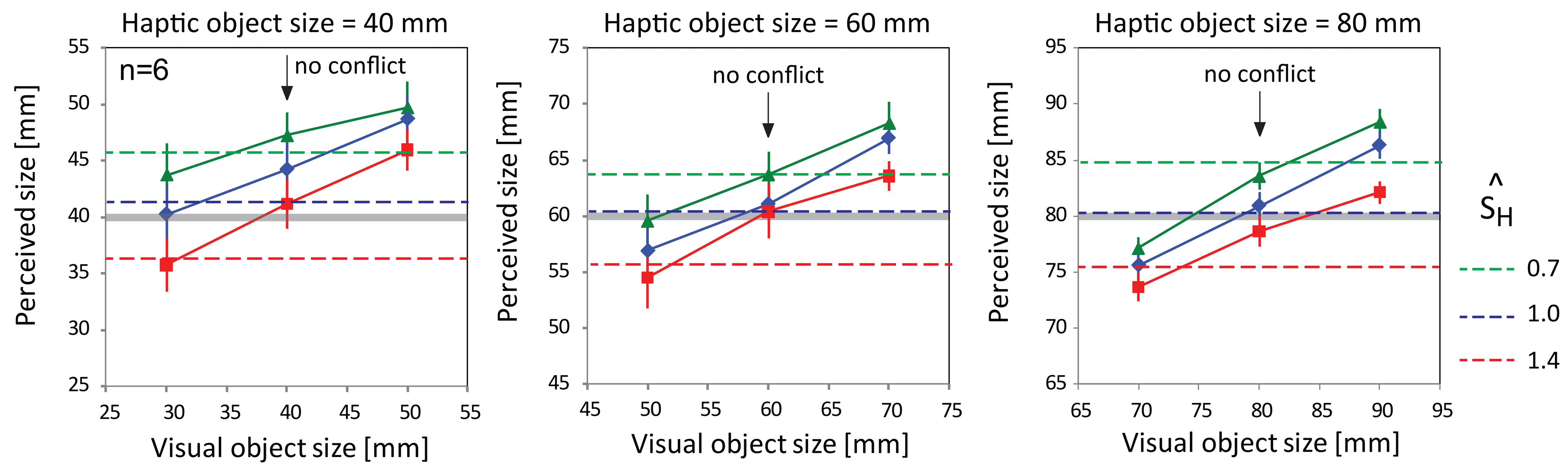
(1) (slope of a line)

- haptic bias ($\hat{S}_H$) from haptics-alone condition
- assuming visual bias ($\hat{S}_V \sim S_V$)

Haptic weight change



size estimates, vision-plus-haptics with tool



- The weight given to haptics varied with tool type in a manner that was well predicted by the single-cue reliabilities, assuming the linear weighted cue combination rule (also, MLE model; c.f. Ernst & Banks, 2002).

Conclusions

- When grasping the same object with different tools, the reliability of (and therefore optimal weight for) haptics changed.
- The brain took this into account appropriately, and altered cue weights in a way that was consistent with reliability-based cue weighting.
- The dynamic cue weight change was a good demonstration that haptic sensitivity to object size was affected by the sensitivity at the hand.
- The process of visual-haptic integration accounts for variations in haptic reliability introduced by different tool geometries.

Bayesian model of common-cause decision (Ernst, 2007; Körding et al., 2007)