The brain integrates visual and haptic information from different spatial locations when using a tool

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Background

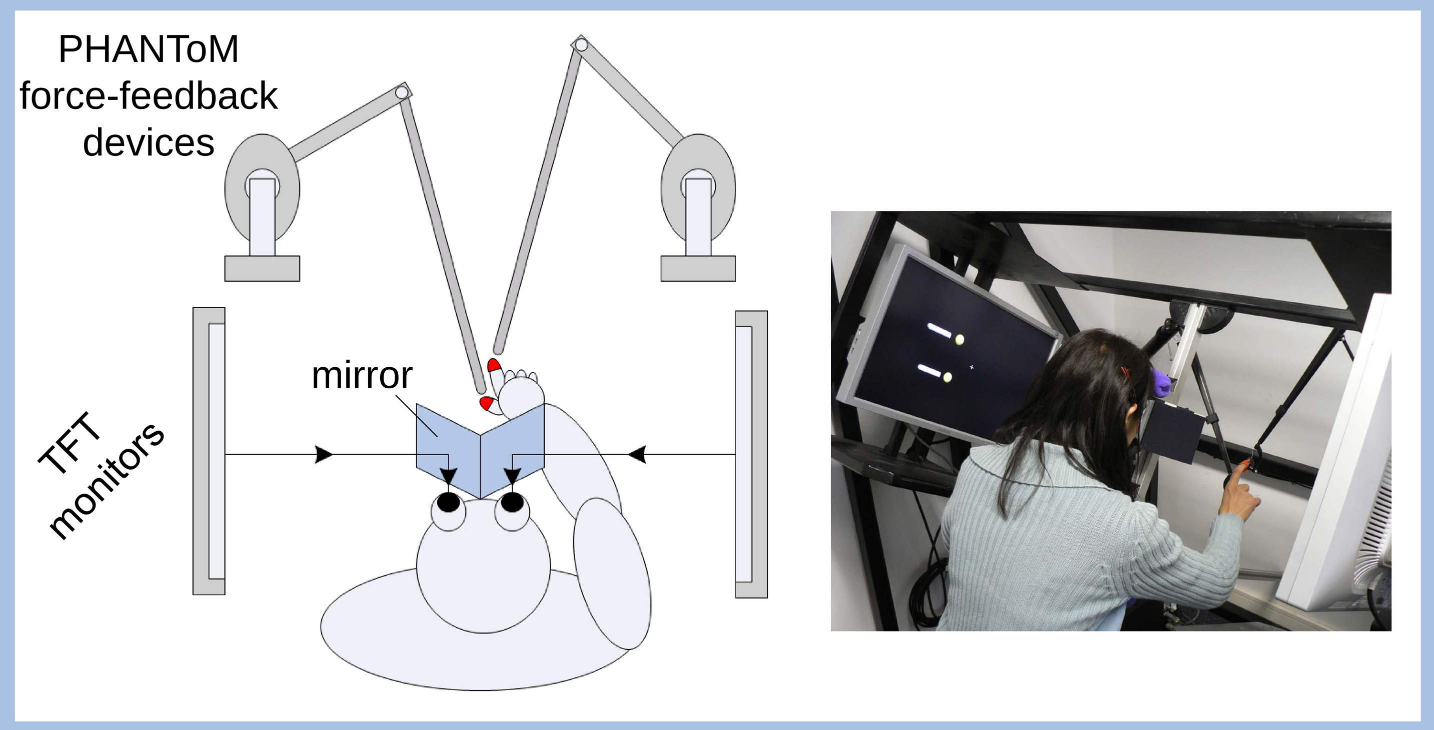
Evidence from physiology, neuropsychology, and studies of visual attention suggests that actively using a tool affects body-related spatial encoding (e.g. Farne & Ladavas, 2000; Holmes, Calvert, & Spence, 2004; Iriki et al., 1996).

Anecdotal reports suggest that when using tools visual and haptic information is integrated: people "see" and "feel" the acting tip of the tool, even though haptic information is only available at the hand.

It has been shown experimentally that visual-haptic integration occurs when the signals originate from the same location (Ernst & Banks, 2002), but reduces with increasing spatial separation (Gepshtein et al., 2005).

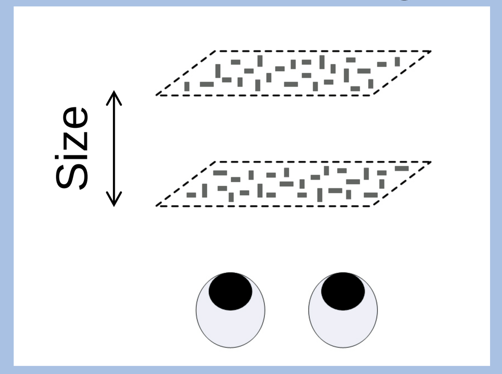
Here we explored quantitatively whether visual-haptic integration occurs during tool use, even though the signals are spatially separated.

Methods



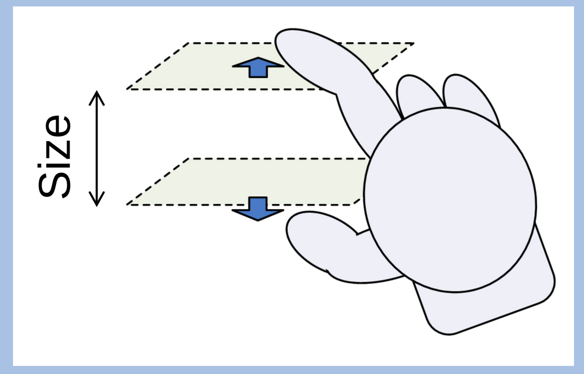
Visual stimulus

Random-dot stereogram



Haptic stimulus

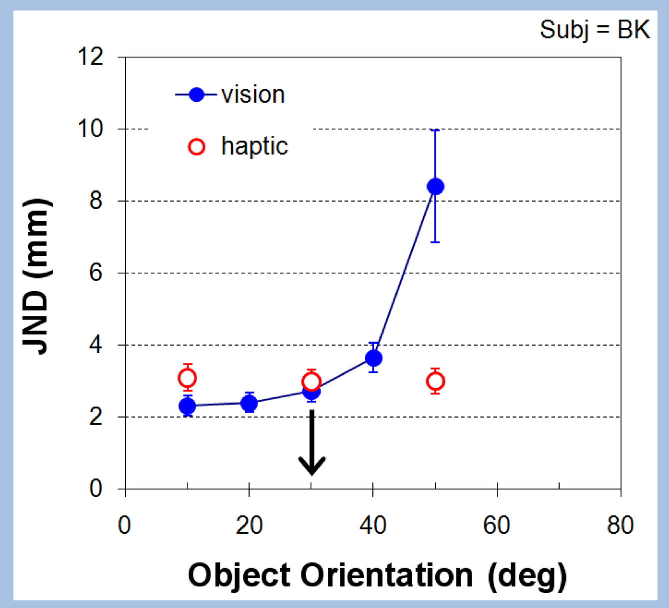
Force-field



2-AFC size discrimination task: standard (50 mm), comparison 41, 44, 47, 49, 51, 53, 56, 59 mm.

Single-cue conditions

We measured size-discrimination thresholds (JNDs) using a 2-AFC task in vision-alone and haptics-alone conditions, in order to predict performance when both cues were available.



Example subject

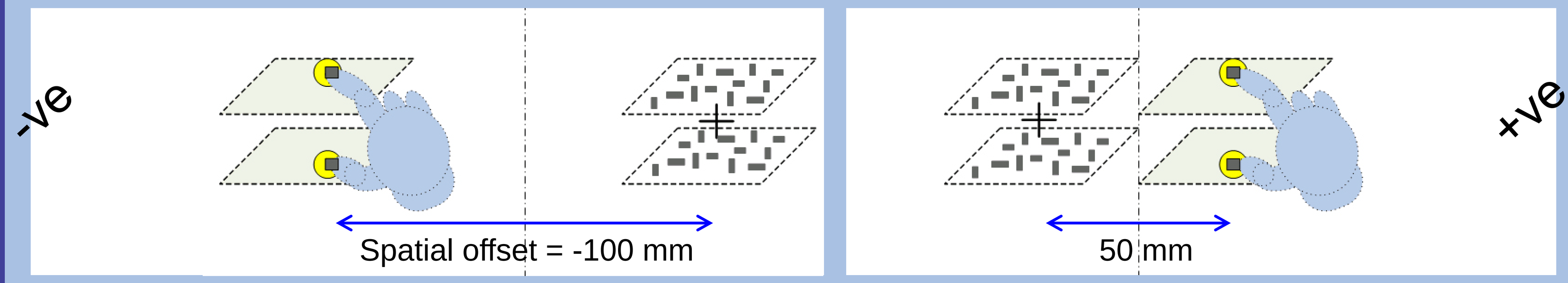
- A reduction in JNDs when both cues are available suggests visual-haptic integration.
- "Optimal cue integration" predicts maximum reduction in JNDs when cue reliabilities are equal.

$$\sigma_{VH}^2 = \frac{\sigma_V^2 \sigma_H^2}{\sigma_V^2 + \sigma_H^2}$$

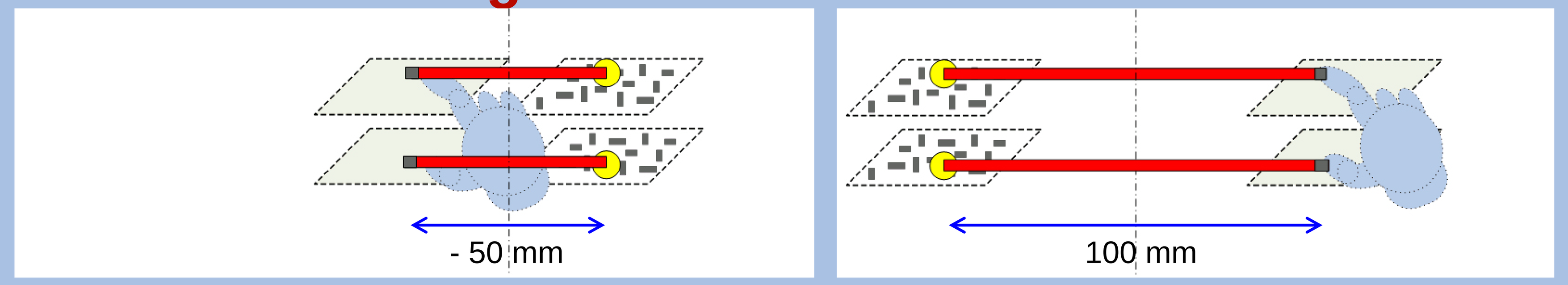
- We varied stimulus orientation to determine this point for each individual subject (c.f. Gepshtein et al., 2005).

Two-cue conditions

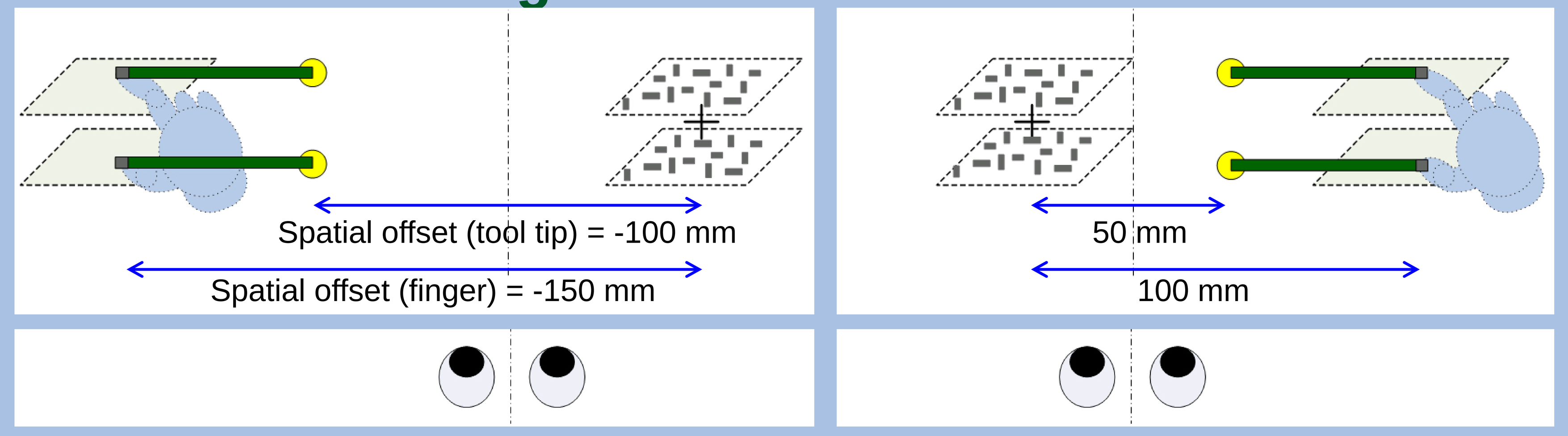
1. No-tool condition



2. Variable-length tool condition

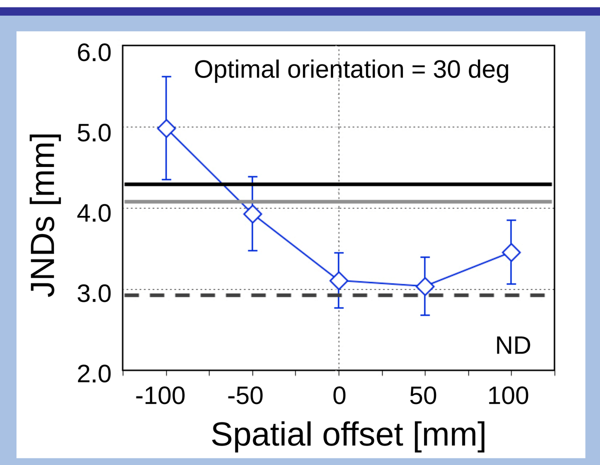


3. Constant-length tool condition

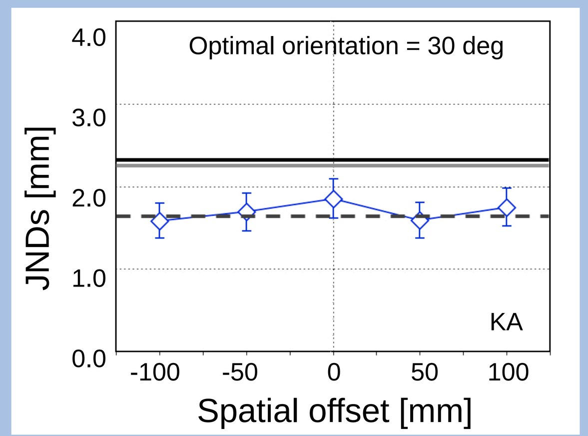


- The visual stimulus was triggered by contact with the haptic object. Visual and haptic stimuli were presented for the same time.
- The tool was extinguished before visual and haptic stimulus presentation.
- **Therefore the information available was identical in no-tool and tool-use conditions.**

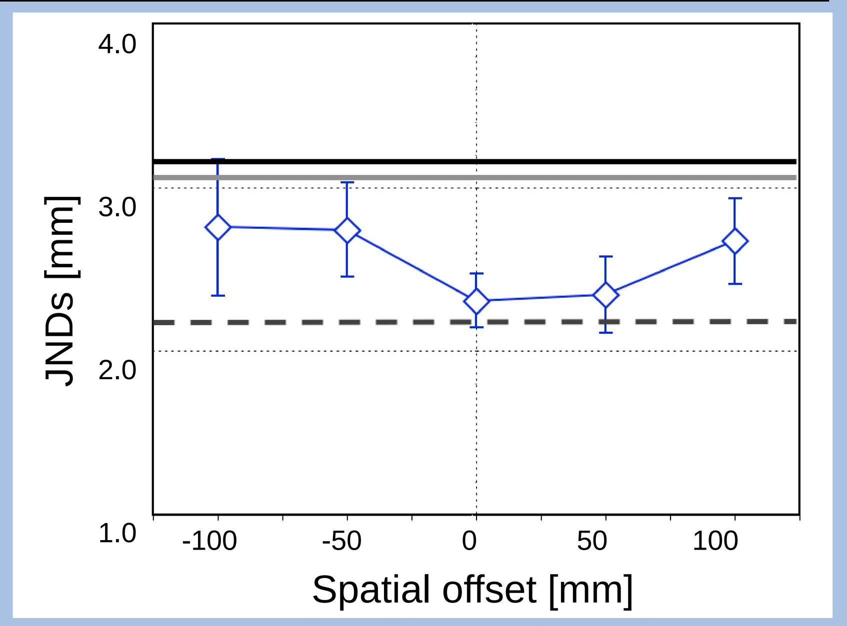
Results: no-tool



Example subject 1



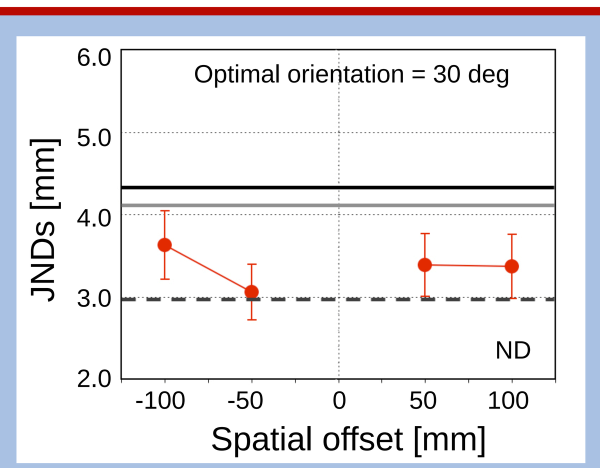
Example subject 2



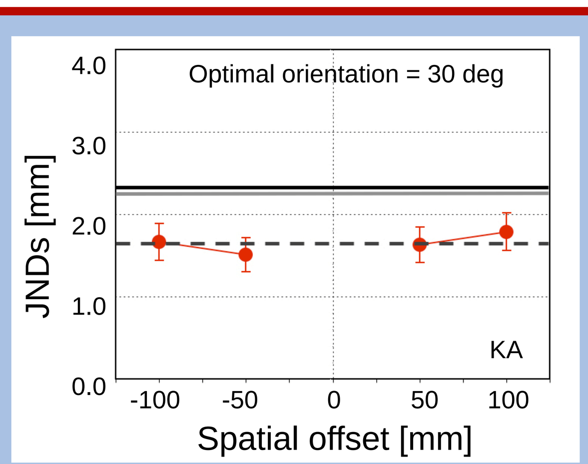
All subjects (n = 7)

- Cue integration depended on spatial proximity (as found by Gepshtein et al., 2005).

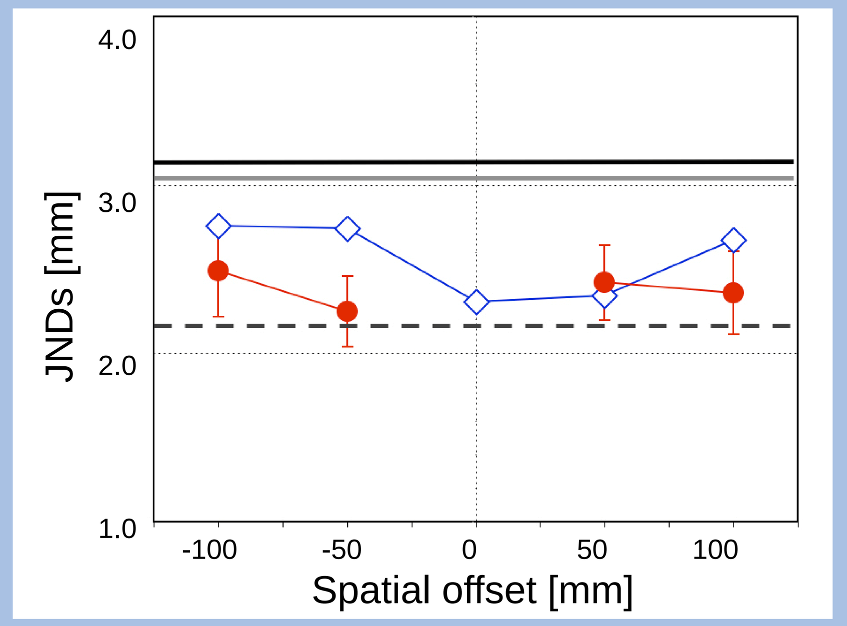
Results: variable-length tool



Example subject 1



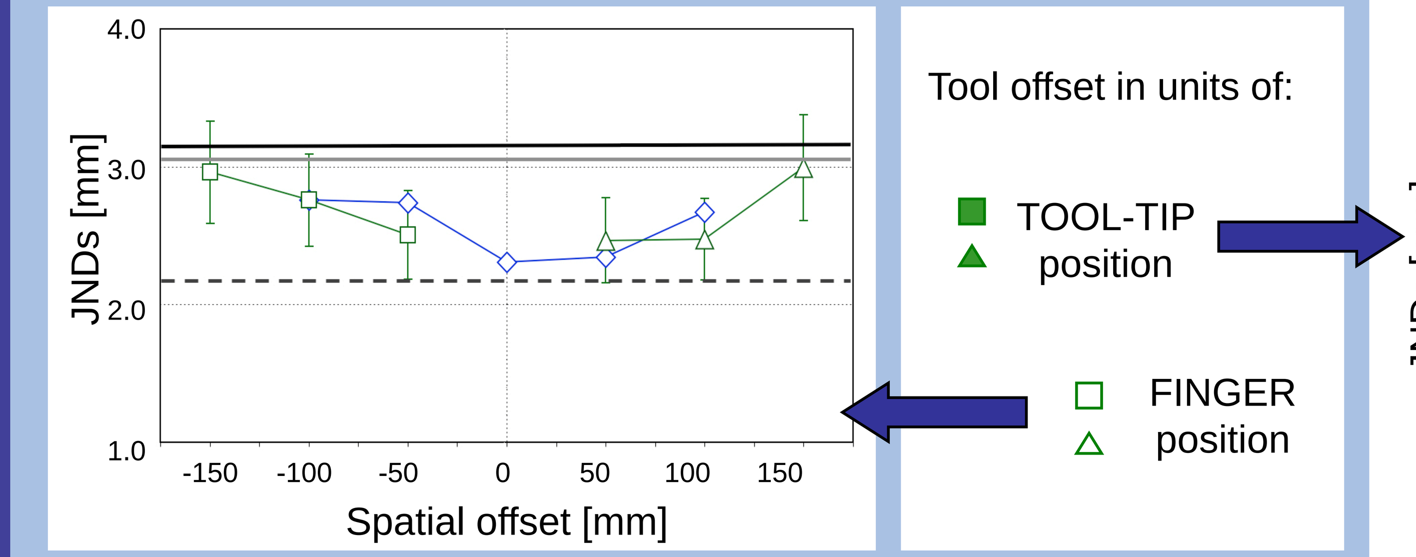
Example subject 2

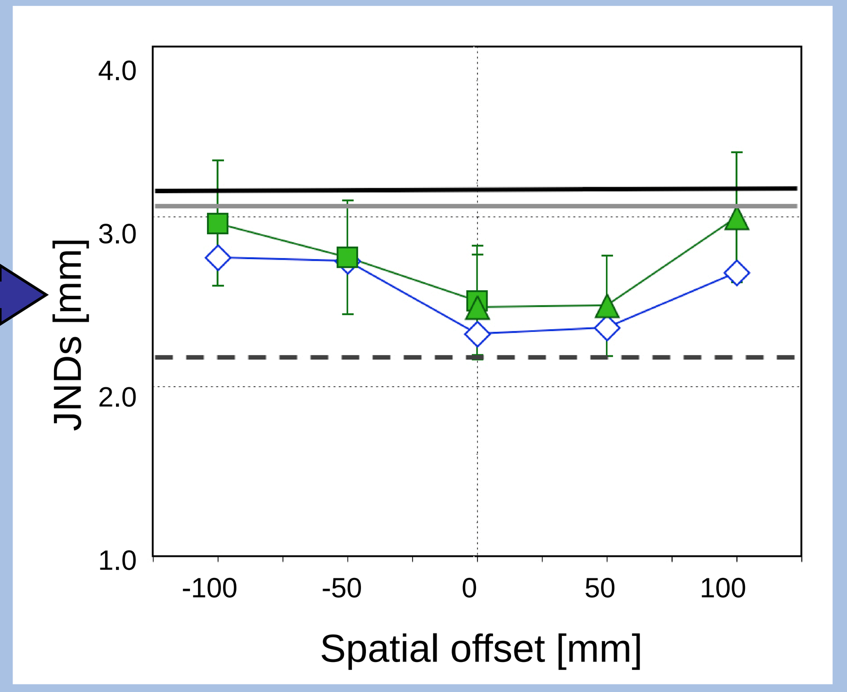


All subjects (n = 7)

- During tool-use, optimal visual-haptic integration was largely restored despite the spatial separation.

Results: constant-length tool





All subjects (n = 6)

- When the tip of the tool was offset from the object, performance resembled the no-tool condition.

Conclusions

The spatial rule governing the combination of visual and haptic information is not based solely on proximity, but appears to involve a more sophisticated mapping process, taking into account the dynamics and geometry of tools.

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