Reference frames in computing human reach plans

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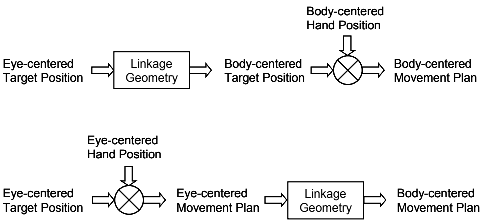
Introduction

At some stage in the process of a sensorimotor transformation for a reaching movement, information about the current position of the hand and information about the location of the target must be encoded in the same frame of reference in order to compute the hand-to-target difference vector.

Two main hypotheses have been proposed: an eye-centered and a body-centered frame.

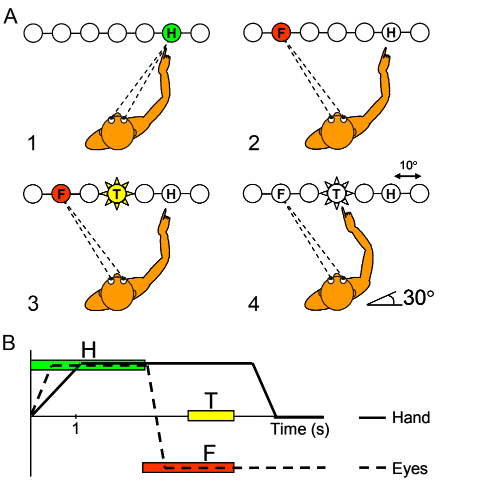


Two schemes for computing the difference vector: in a body-centered (A) or eye-centered (B) frame of reference

We tested between these hypotheses using the pointing errors that subjects make when planning and executing arm movements to memorized targets starting from various initial hand positions while keeping gaze fixed in various directions.

Methods

Experimental setup and paradigm



Experimental paradigm. Subjects were seated with their torso rotated 30° leftward with respect to a horizontal stimulus array, consisting of seven LEDs spaced at distances of 10° (A). H, initial hand position; F, the eye's fixation point; T, target for movement. Schematic representation (B) of the paradigm.

Two conditions:

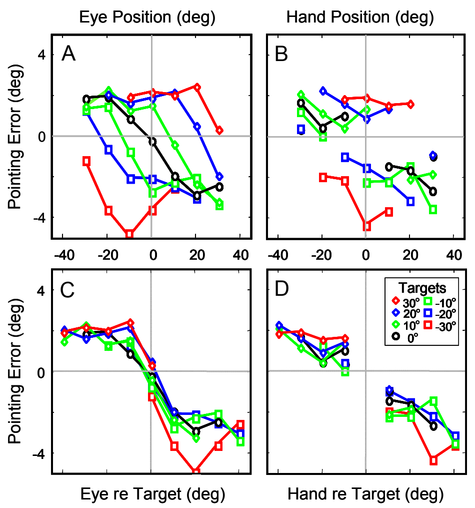
1) **Unseen Hand: no visual feedback about hand position (n=10)**
2) **Seen Hand: LED on fingertip, visual feedback during the planning phase (n=8)**

Measurement techniques

Arm kinematics were recorded using an Optotrak 3020 system. Binocular eye movements were recorded with an Eyelink II gazetracker. Analysis of the pointing errors was performed in Matlab.

Results

Unseen Hand condition



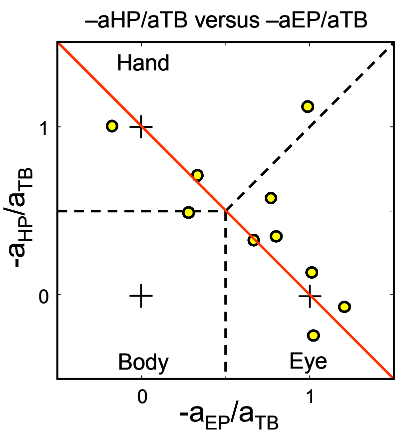
Pointing error as a function of eye position (A) and hand position (B). Pointing error as a function of the eye (C) and the hand (D) relative to the target.

Characterization of reference frames

Fit linear model:

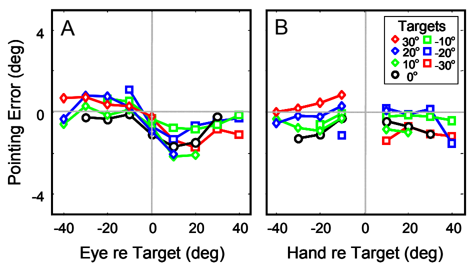
$$Err = a_0 + a_{TB} * Tb + a_{EP} * Ep + a_{HP} * Hp$$

- **Body (Err ~ Tb):** $a_{EP} = a_{HP} = 0$
- **Eye (Err ~ Tb – Ep):** $a_{TB} = -a_{EP}$, $a_{HP} = 0$
- **Hand (Err ~ Tb – Hp):** $a_{TB} = -a_{HP}$, $a_{EP} = 0$



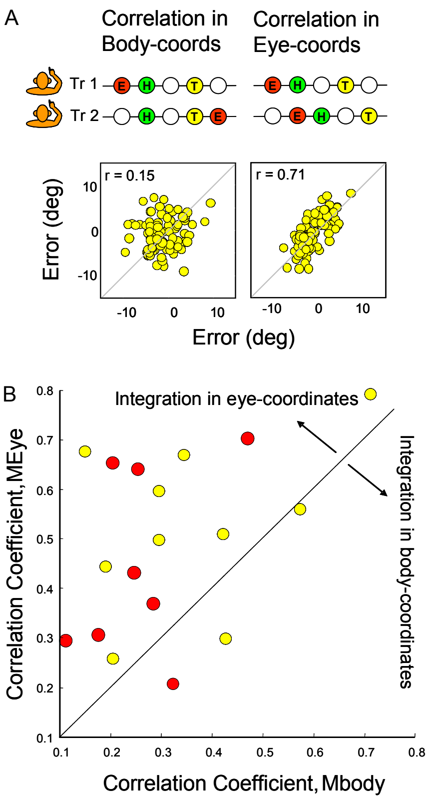
Characterization of reference frames. Data spreads along the red line, depicting $a_{TB} = -a_{EP} - a_{HP}$, indicating that errors do not arise in a body-centered frame.

Seen Hand condition



Pointing errors are smaller than in the Unseen Hand condition; the influence of hand position is virtually absent.

Comparing errors of identical reaches



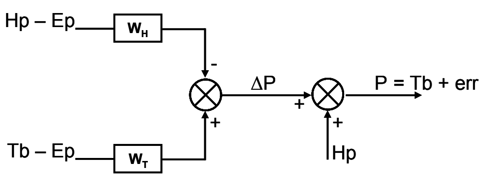
Scatterplots of pointing errors for movements performed with identical target and hand position in body-coordinates (A, left panel) or in eye-coordinates (A, right panel) in one typical subject. Correlation coefficient for eye-centered comparison versus body-centered comparison in all subjects (B). ● Unseen Hand, ● Seen Hand condition.

Conclusions

Initial hand position and gaze direction affect pointing errors. Visual feedback about hand position during planning reduces the errors.

Errors arise either at an eye-centered or hand-centered stage, or both, but not in a body-centered framework.

As a common reference frame is required to specify a movement vector, these results suggest that an eye-centered mechanism is involved in integrating target and hand position for reaching movements.



An eye-centered integration scheme with simple gain elements modulating the eye-centered target and hand position signals.

Computing movement representations in a sensory frame may simplify calibration, coordination and error detection.

This may be a useful principle for the design of autonomous robotic systems.

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