Visual-motor mapping in VR: Detection thresholds for distortions of hand position

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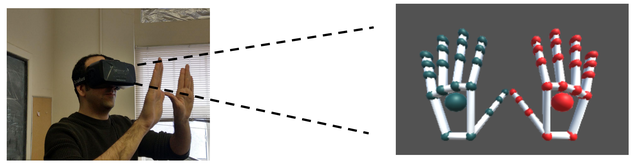
Introduction

Using visual reafferences for motor control requires a mapping between proprioceptive space and visual space. Interestingly, this mapping is flexible and can quickly adapt. A classic paradigm to demonstrate this flexibility is prism adaptation (e.g. Welch 1978, Wallace 1980).

Distortions introduced by optical prisms are typically homogeneous across the visual field. The same can be implemented using Virtual Reality. Here, however, it is possible to also test an observer's tolerance to non-linear types of visual-proprioceptive remapping.

In the current study, observers enter VR and see renderings of their hands. They are asked to hold both hands at a defined location. The renderings of the two hands are then gradually moved such that maintaining their positions in visual space can only be achieved by moving the hands in the opposite direction. Displacements can be either identical for the two hands or in opposite directions. We measure the amount of the displacement required for participants to correctly indicate the direction of the displacement in a number of different conditions.



Methods

Apparatus and procedure

The setup consisted of an Oculus Rift DK2 head-mounted display equipped with an Oculus tracker, and a Leap Motion Controller that was mounted directly on the HMD to track the position and pose of the hands. The hands were rendered in Unity3D using the default hand model provided with the Leap Motion Controller.

Participants

Ten participant were asked to raise their hands in front of their face such that the palms of the open hands were facing away and parallel to the frontoparallel plane. They were told to keep a distance of 2 cm between the thumbs. Participants were then asked to move both hands in counterphase along a circular path in the medial plane at a comfortable frequency.

Oculus Rift DK 2 head mounted display
- 960 x 1080 resolution per eye
- 75 Hz refresh rate
- Field of view: 94×105 degree horizontally and vertically

Design

During each trial, the initially veridical renderings of the two hands were slowly displaced. The motion was such that the two hands either moved together in the same direction or they moved in opposite directions (factor **Main**). In each case, the hands could move in one of three **Dimensions**: left-right, up-down, towards-away – each having two **Directions**.

After **Displacement**s of the hands of 1.5, 3, 4.5 and 6 cm, the trial was terminated and the participant had to indicate the direction of the displacement (6-AFC: left, right, up, down, closer, farther).

The total number of trials (conditions x directions x displacements x repetitions) was 2 x 6 x 4 x 3 = 144. Factor **Main** was blocked and the order of the two blocks was counterbalanced. The order of trials within blocks was randomized.

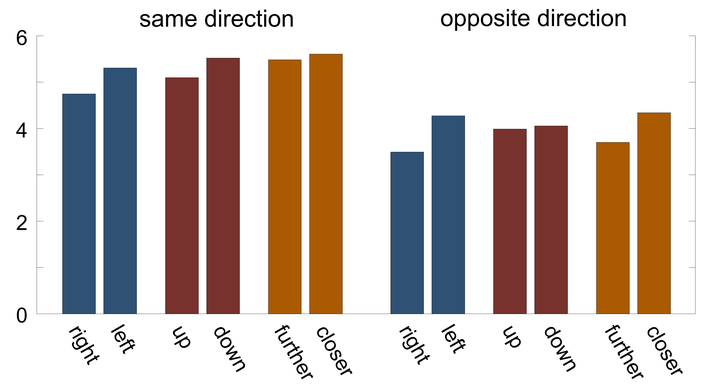
Data analysis

A psychometric function (response as a function of **Displacement**) with asymptotes at 1/6 and 1 was fitted to the data for each participants and each condition. The function's value at (1/6 + 1)/2=0.58 was used to define discrimination **Threshold**.

A two-way repeated measures ANOVA was conducted on **Threshold**s with factors **Main** and **Dimension** as independent variables.

Leap motion controller
- mounted on the HMD
- tracks hands and fingers in real time

Results

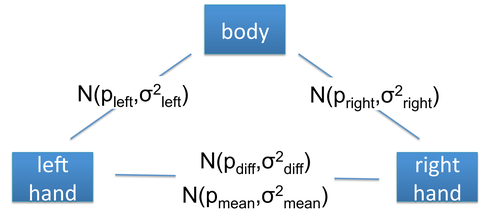


Source of Variation	*SS*	*df*	*MS*	*F*	*p*
Main	26.06	1	26.06	75.22	0.00
Dimension	1.10	2	0.55	1.59	0.21
Main x **Dimension**	0.36	2	0.18	0.52	0.60
Within	18.71	54	0.35		

Predictions

If position of hands is encoded independently: $\sigma^2_{mean} < \sigma^2_i$, $\sigma^2_{diff} > \sigma^2_i$

If positions are encoded relative to each other: $\sigma^2_{mean} > \sigma^2_i$, $\sigma^2_{diff} <= \sigma^2_i$



An initial ANOVA showed that **Direction** did not affect thresholds and did not interact with other factors either. Results of the 2 x 3 repeated-measures ANOVA are presented in Table 1. In summary:

- Participants are much more sensitive to proprioceptive drift if the hands are moved in opposite directions (factor **Main**).
- Threshold for the three **Dimensions** are about the same.
- No interaction between factors **Main** and **Dimension**.

Discussion & Conclusions

- Encoding of hand position is dominated by relative rather than absolute position.
- Detection thresholds are in the order of 4 – 6 cm.
- Knowing detection thresholds informs the design of haptic devices for mixed VR.
- Thresholds are about the same in all directions.

References

Welch RB (1978) Perceptual Modification: Adapting to altered sensory environments. Academic Press: New York.

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C. Farrer, N. Frank, J. Paillard, M. Jeannerod (2003) The role of proprioception in action recognition Consciousness and Cognition 12:609-6013.

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