How Real is Virtual Reality Really?
Quantifying and Comparing Spatial Updating using Pointing Tasks in Real and Virtual Environments.

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In order to know where we are when moving through space, we constantly update our mental representation of our surroundings, matching it to our motion. This process, termed "spatial updating," is mostly automatic, effortless, and obligatory (i.e., hard-to-suppress). Our goal here is twofold:

1) To quantify spatial updating using a speeded pointing paradigm.
2) To investigate the importance and interaction of visual and vestibular cues for spatial updating.

The stimuli consisted of twelve targets (the numbers from 1 to 12, arranged in a clockwise manner) attached to the walls (see Fig. 3). Subjects saw either the real room or a photo-realistic model of it (see Fig. 1) presented via a head-mounted display (HMD; see Fig. 2).

For vestibular stimulation, subjects were seated on a Stewart motion platform (see Fig. 2). After each rotation, the subjects' task was to point to the nearest object without a head movement. Spatial updating was quantified in terms of response times and pointing error (absolute error and variance) in four different spatial updating conditions:

(1) UPDATE: Subjects were rotated to a different orientation.
(2) CONTROL: Subjects were rotated to a different orientation, but asked to ignore the rotation and "point as if you had not turned".
(3) IGNORE: Subjects were rotated to a different orientation, but asked to ignore the rotation and "point as if you had not turned".
(4) IGNORE BACKMOTION: After each IGNORE condition, subjects were rotated back to the previous orientation.

Subjects were presented with six stimulus conditions (blocks A-F, 15 min. each) in pseudo-randomized order, with different degrees of visual and vestibular information available (explained in detail in the results section).

Results: Performance, especially response times, varied considerably between subjects, but showed the same overall pattern for all three dependent variables:

1) Influence of available cues
Performance was best in the Real World condition (block A, see Fig. 5). When the field of view (FOV) was limited via cardboard blinders (block B) or match that of the HMD (40°x40°), performance decreased considerably and was only slightly better than in the HMD condition (block C). Presenting only visual information for the turns (through the HMD; block D) decreased the performance slightly further.

2) Importance of visual turn information
In four blocks (A-D) where there was visual information available about the rotation, subjects performed equally well in the UPDATE, CONTROL, and IGNORE BACKMOTION conditions (see Fig. 6, left panel). Performance in the IGNOR condition, however, was significantly impaired, indicating that spatial updating was indeed obligatory in the sense of being hard-to-suppress.

3) Effect of missing visual turn information
In two more conditions, subjects had conflicting or no visual information, i.e., subjects saw a constant image of the scene (block E) or wore blindfolded (block F). This lack of useful visual information resulted in large absolute pointing errors, as path integration errors for inferred ego-orientation contradicted subjects lost track of their physical orientation without useful visual information. IGNOR performance increased (decrease in pointing error variability and response time) and was no longer worse than the UPDATE performance (see Fig. 6). This suggests that spatial updating was no longer obligatory when visual cues about the motion were removed.

Furthermore, spatial updating itself seems to be impaired as UPDATE performance was commonly inferior to CONTROL performance. To be more precise, non-visual UPDATING performance (block E & F) decreased to exactly the same level as the IGNOR performance for blocks A-D with useful visual information, suggesting a similar underlying process. In addition, CONTROL performance remained unchanged. One possible explanation is that subjects accessed a visual reference frame when asked to point to visually learned targets.

We conclude that, at least for the regular target configuration and limited turning angles used (<60°), the Virtual Reality simulation of ego-rotation was as effective and convincing (i.e., hard to ignore) as its real world counterpart, even when only visual information was available.

Conclusions:

- Speeded pointing tasks prove to be a viable method for quantifying "spatial updating".
- Subjects seem to refer to a visual reference frame when asked to point to visually learned targets.
- We conclude that at least for the regular target configuration and limited turning angles used (<60°), the Virtual Reality simulation of ego-rotation was as effective and convincing (i.e., hard to ignore) as its real world counterpart, even when only visual information was available.

Fig. 2: Subject wearing blinders (vision delimiting cardboard goggles) and active noise cancellation headphones. The subject is currently pointing towards target '4' using the position-tracked pointer. Note the targets on the wall.

Fig. 3: Subject wearing position-tracked Head-Mounted Display (40°x30° FOV, 1024x768 pixel) and headphones. The subject is holding the position-tracked pointer in the default position (left subfigure) and pointing position (right subfigure).

Fig. 4: Visual turn information induced obligatory spatial updating.

Fig. 5: Performance error (left), pointing variability (middle), and response time (right) for different spatial updating conditions (block D). Error bars indicate one standard error of the mean; +, standard deviation.

Fig. 6: Performance, especially response times, varied considerably between subjects, but showed the same overall pattern for all three dependent variables.