How do we know where we are?

Contribution and interaction of visual and vestibular cues for spatial updating in real and virtual environments

MAX-PLANCK-GESELLSCHAFT

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• Introduction

What is "spatial updating"?

In order to know where we are when moving through space, we constantly update our mental egocentric 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:

How can we quantify spatial updating and how is it triggered?

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.

• Methods

After movements, subjects had to point "as quickly and accurately as possible" to different targets.

The stimuli consisted of twelve targets (the numbers from 1 to 12, arranged in a clockface 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. 4).

For vestibular stimulation, subjects were seated on a Stewart motion platform (see Fig. 2).

After each rotation, the subjects' task was to point without head movements "as quickly and accurately as possible" to four targets announced consecutively via headphones. Spatial updating performance was quantified in terms of response time and pointing error (absolute error and variance) in four different spatial updating conditions:

Four spatial updating conditions were randomized.

(1) UPDATE: Subjects were simply rotated to a different orientation.

(2) CONTROL: Subjects were rotated to a new orientation and immediately back to the original orientation before being asked to point.

(3) IGNORE: Subjects were rotated to a different orientation, but asked to ignore that rotation and "point as if you had not turned".h

(4) IGNORE BACKMOTION: After each IGNORE condition, subjects were rotated back to the previous orientation.

Six cue combinations were used.

Each of the twelve subjects was presented with six stimulus conditions (blocks A-F, 15 min. each) in pseudo-balanced order, with different degrees of visual and vestibular information available (explained in detail in the results section, see also Fig. 5).

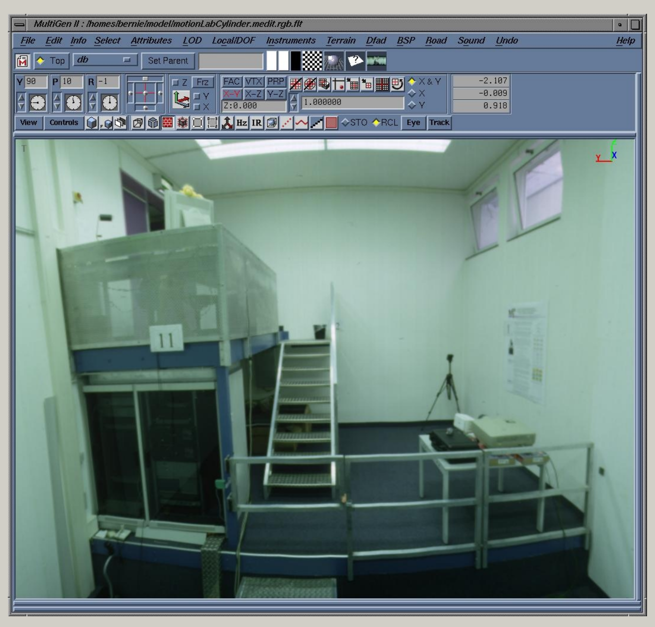

Fig. 1: Photorealistic 3D model of the Motion Lab (used for the HMD-conditions)

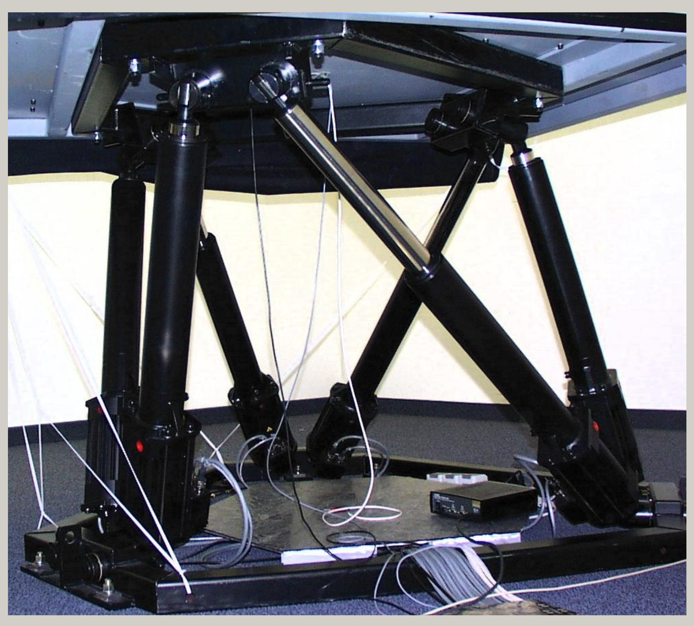

Fig. 2: Electric 6 degrees of freedom motion platform (Motionbase Maxcue)

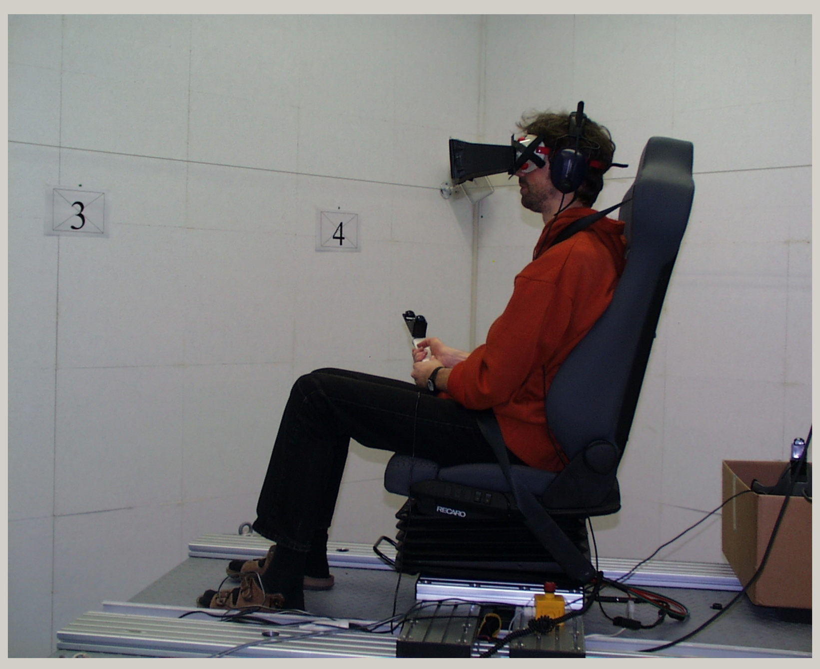

Fig. 3: Subject wearing blinders (vision delimiting cardboard goggles) and active noise cancellation headphones. The subjects is holding the position-tracked pointer in the pointing position. Note the targets on the wall.

Fig. 4: Subject wearing position-tracked Head-Mounted Display (40°x30° FOV, 1024x768 pixel) and headphones. The subject is holding the pointer in the default position.

• Results

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

1.) Influence of available cues

Performance was best with unrestricted vision.

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) to match that of the HMD (40°x30°), 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.

Update performance

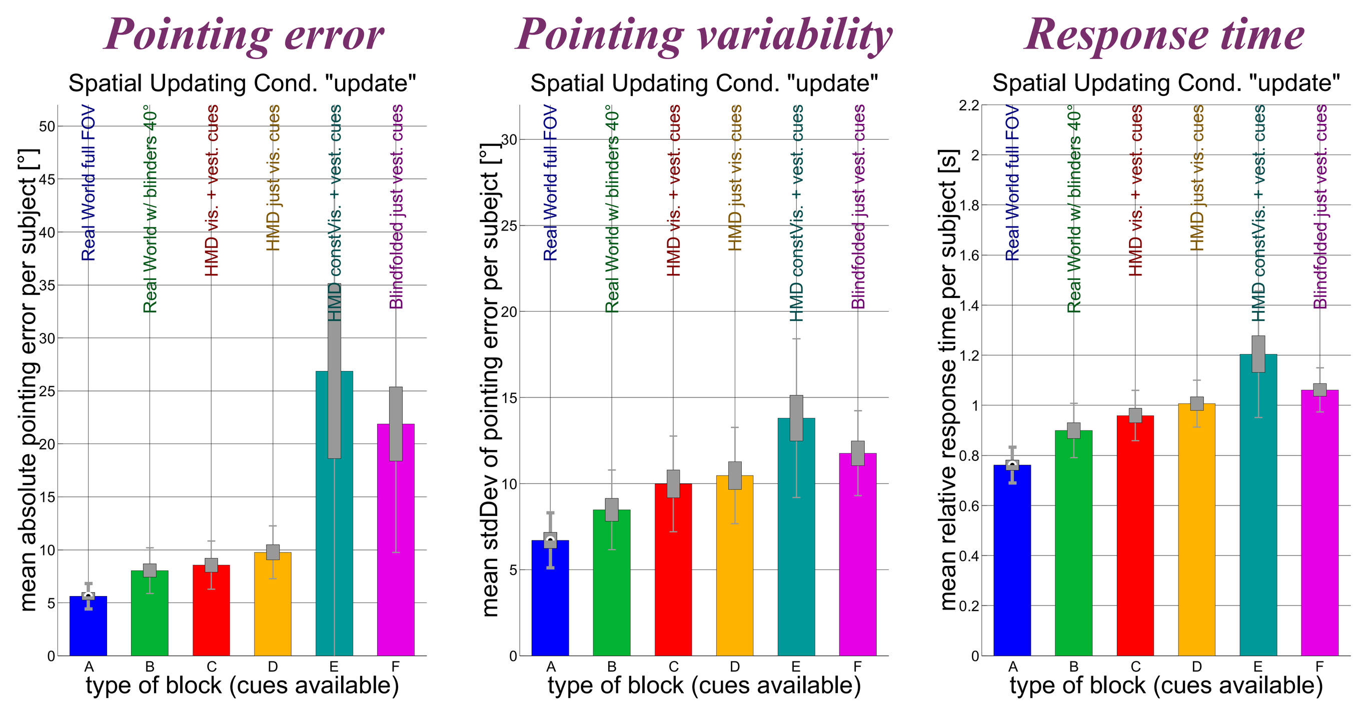

Fig. 5: Spatial updating performance for the 6 different cue combinations (blocks), quantified as mean absolute pointing error (left plot), variability (one standard deviation) of signed pointing error (middle plot), and mean relative response time (right plot).

Note the performance decrease from block A through block E.

Box and whiskers denote one standard error of the mean and one standard deviation, respectively.

2.) Importance of visual turn information

Visual turn information induced obligatory spatial updating.

In those 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 part). Performance in the IGNORE 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

Vestibular cues did not induce (obligatory) spatial updating.

In two more conditions, subjects had conflicting or no visual information, i.e., subjects saw a constant image of the scene (block E) or were blindfolded (block F).This lack of useful visual information resulted in rather large absolute pointing errors, as path integration errors for inferred ego-orientation accumulated and subjects lost track of their physical orientation.

Without useful visual information, IGNORE 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.

Subjects probably used visual reference frames.

Furthermore, spatial updating itself seems to be impaired, as UPDATE performance was consistently inferior to CONTROL performance. To be more precise, non-visual UPDATING performance (block E & F) decreased to exactly the same level as the IGNORE 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 frames when asked to point to (visually learned) targets.

Pointing error

Pointing variability

Response time

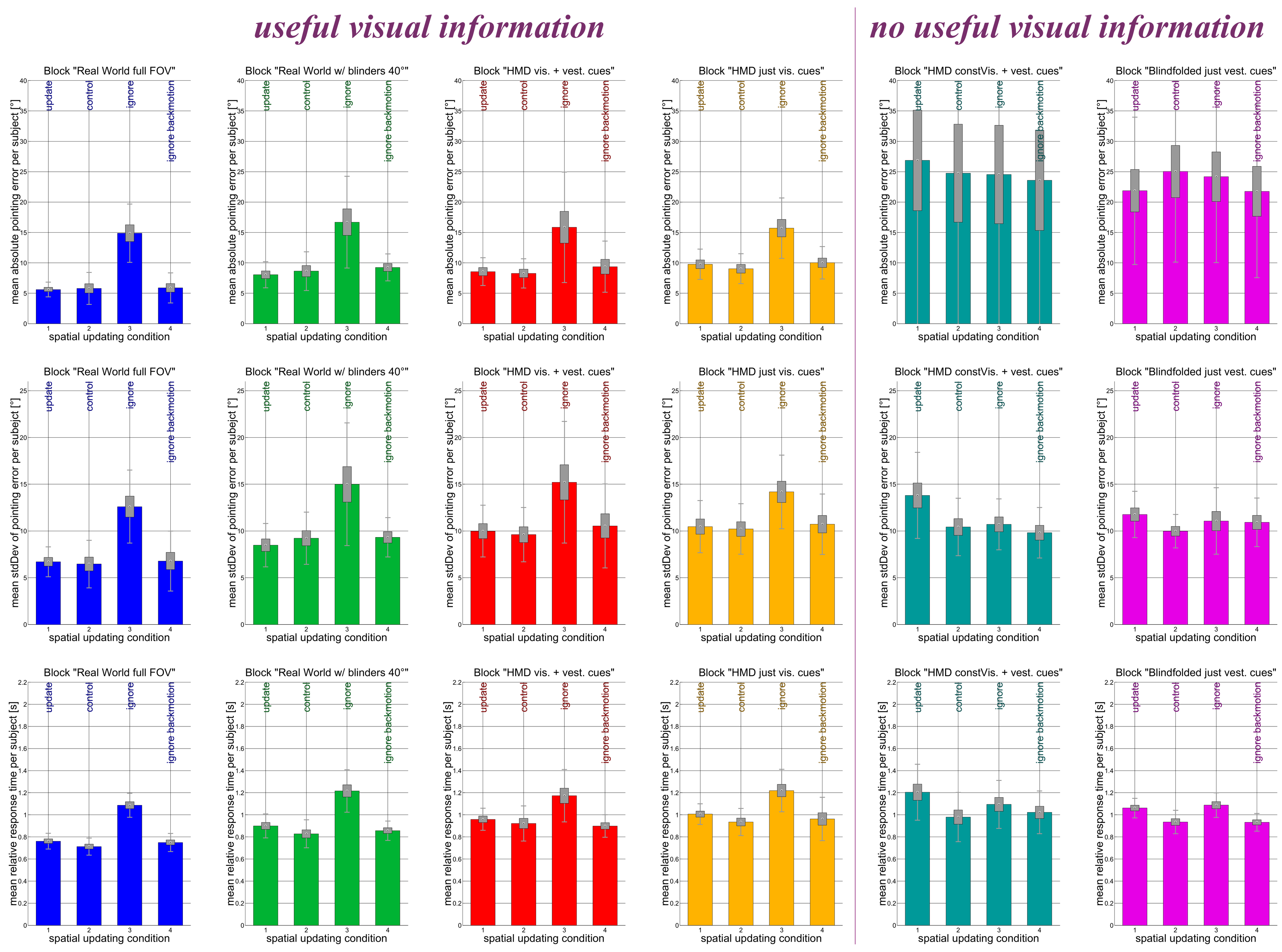

Fig. 6: Comparison of the 4 spatial updating conditions for all three dependant variables (vertically) and all cue combinations (blocks, horizontally). Note the similar response pattern (ignore performance is worst) for all blocks with useful visual information (left four blocks).

• Conclusions

- Speeded pointing tasks proved to be a viable method for quantifying "spatial updating".
- Subjects seem to refer to a visual reference frame when asked to point to visually defined 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.