Spatial updating experiments in Virtual Reality: What makes the world turn around in our head?

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• Introduction

What is "spatial updating"?

During ego-turns, our mental spatial representation of the surround is automatically rotated to stay in alignment with the physical surround. We know that this "spatial updating" process is effortless, automatic, and typically obligatory (i.e., cognitively impenetrable and hard-to-suppress).

We are interested in two main questions here:

Are visual cues sufficient to trigger spatial updating?

(1) Are visual cues sufficient to initiate obligatory spatial updating, in contrast to the prevailing opinion that vestibular cues are required?

(2) How do vestibular cues, field of view (FOV), display method, turn amplitude and velocity influence spatial updating performance?

• Methods

STIMULI: A photo-realistic virtual replica of the Tübingen market place was presented via a curved projection screen (84x63° FOV or restricted to 40x30°) or a head-mounted display (HMD, 40x30°). A Stewart motion platform was used for vestibular stimulation (see figures below).

After simulated ego-turns, participants had to point "as accurately and quickly as possible" to different targets.

TASK: Participants were rotated successively to different orientations and asked to point "as accurately and quickly as possible" to four targets randomly selected from a set of 22 salient landmarks that were previously learned (see Fig. 7 and 8). Targets were announced consecutively via headphones and selected to be outside of the visible range (i.e., between 42° and 105° left or right from straight ahead).

Performance was quantified in terms of pointing error, pointing consistency, and response time in three different spatial updating conditions:

Three spatial updating conditions were used.

(1) UPDATE: Participants were simply rotated to a different orientation. If the available spatial updating cues are sufficient, UPDATE performance should not depend on the angle turned.

(2) CONTROL: Participants were rotated to a new orientation and immediately back to the original orientation before being asked to point. This was a baseline condition: If the available spatial updating cues are sufficient, UPDATE performance should be comparable to CONTROL performance.

(3) IGNORE: Participants were rotated to a different orientation, but asked to ignore that rotation and "point as if you had not turned". If the available cues are more powerful in triggering spatial updating and hence turn the world inside our head (even against our conscious will), those turns should be harder to IGNORE. Spatial updating would then be "obligatory" in the sense of cognitively impenetrable and hard-to-suppress.

Each of the 8 participants was presented with 10 stimulus conditions (blocks A-J, 20 min. each) in pseudo-balanced order (see Fig. 10 and 11).

• Results

Performance, especially response times, varied considerably between participants, but showed the same overall pattern in all three dependent variables:

(1) Spatial updating was always easy.

(1) In general, participants had no problem mentally updating their orientation in space (UPDATE condition) and spatial updating performance was the same as for rotations where they were immediately returned to the previous orientation (CONTROL condition).

(2) Visual turn cues induce obligatory spatial updating and hence turn the world inside our head, even without vestibular cues.

(2) Spatial updating was always "obligatory" in the sense that it was significantly more difficult to IGNORE ego-turns (i.e., "point as if not having turned", see Fig. 11). We observed this data pattern irrespective of turning velocity, display device (HMD vs. projection screen), FOV, or amount of vestibular cues accompanying the visual turn.

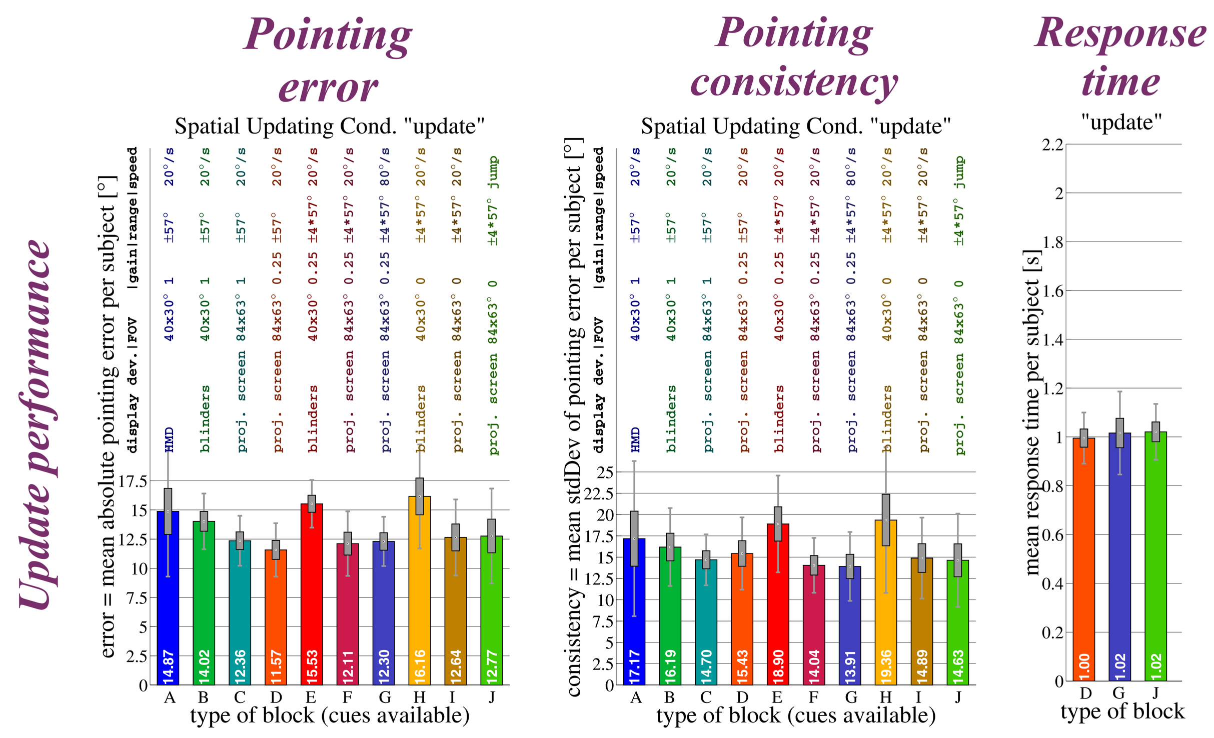

Fig. 10: Spatial updating performance in the ten different stimulus conditions (blocks). Boxes and whiskers denote one standard error of the mean and on standard deviation, respectively. As the stimulus conditions had no clear effect on the response time, only three representative stimulus conditions are shown in th right plot.

(3) Small FOVs impair spatial updating.

(3) Increasing the visual field of view (from 40x30° FOV to 84x63°) increased UPDATE performance, especially for larger turns, (i.e., potentially more difficult tasks). IGNORE performance, however, was not influenced by the change in FOV.

(4) Larger turns induce more obligatory (hard-to-suppress) spatial updating.

(4) Large turns (>80°) were almost as easy to UPDATE as small turns, but much harder to IGNORE, especially for higher turn velocities. This suggests that larger turns result in a more obligatory (hard-to-suppress) spatial updating of the world inside our head.

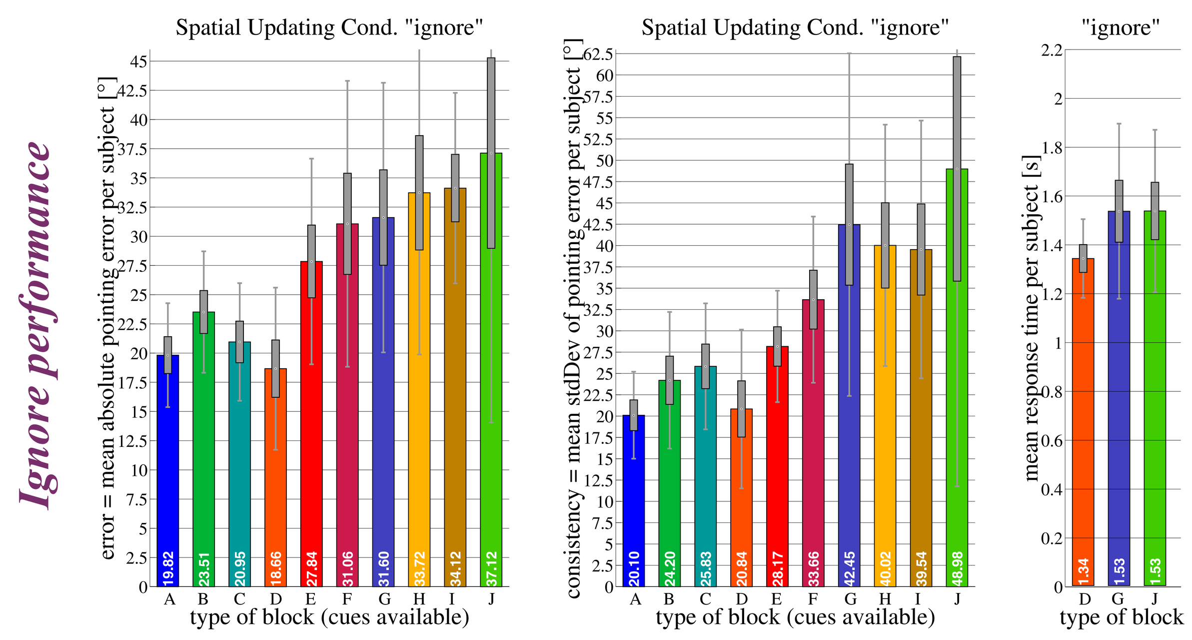

Fig. 11: Ignore performance, plotted as in Figure 10 above.

(5) For a known, landmark-rich environment, smooth spatial updating is not necessary. A "jump" mechanisms seems to suffice.

(5) UPDATE performance was unimpaired when participants were presented with a new view *without* continuous motion in between ("jump" condition, block J). Furthermore, jumps to new orientation were as hard to IGNORE as smooth, continuous turns to new orientations. Consequently, merely displaying an image of a new orientation without continuous motion in between can induce obligatory spatial updating. Hence, visual landmark information proved sufficient to trigger a spatial reference frame from a new orientation.

• Conclusions

Visual cues alone can induce obligatory spatial updating and hence turn the world inside our head.

Photo-realistic visual stimuli from well-known environments including an abundance of salient landmarks are sufficient to trigger spatial updating and hence turn the world inside our head, even without corresponding vestibular cues. This result conflicts with the prevailing opinion that vestibular cues are required for proper updating of ego-turns. We believe that this apparent conflict can be primarily explained by the immersiveness of our visualization setup and the abundance of natural landmarks in a well-known environment.

Discontinuous (jump-like) spatial updating yielded similar performance.

Apart form the well-known **smooth spatial updating** induced by *continuous* movement information, we found also a *discontinuous*, **jump-like spatial updating** that allowed participants to quickly adopt a new orientation without any explicit motion cue.

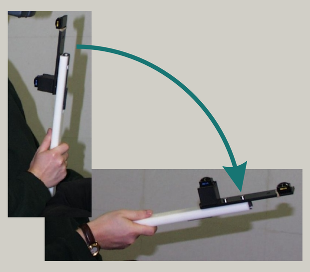

Fig. 1: Position-tracked pointer in the default position (upright) and pointing position.

Fig. 2: Participant wearing position-tracked head-mounted display (40°x30° FOV, 1024x768 pixel) and active noise cancellation headphones.

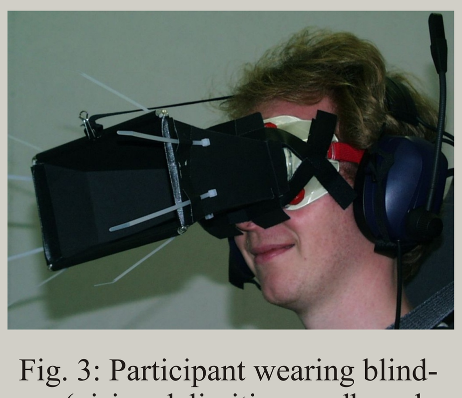

Fig. 3: Participant wearing blinders (vision delimiting cardboard goggles) and headphones reducing the FOV to that of the HMD (40°x30°).

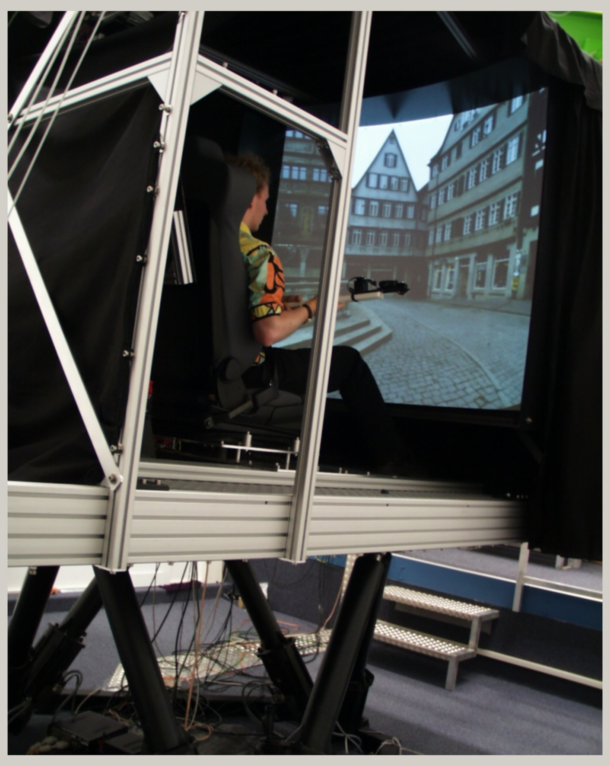

Fig. 4: Participant sitting on the motion platform and facing the curved projection screen. The physical field of view is 86°x63° and matches the simulated FOV.

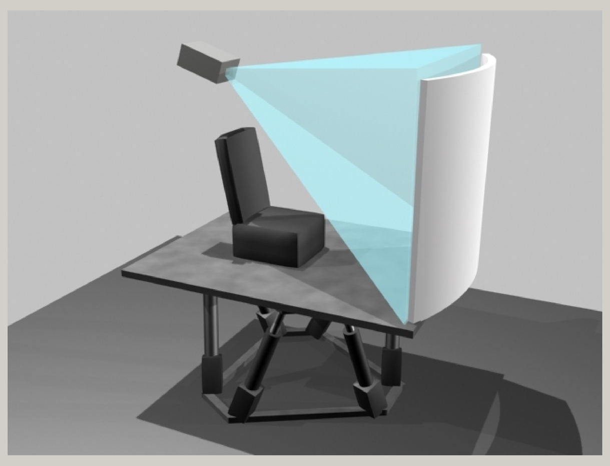

Fig. 5: Schematic experimental setup showing the 6 degree of freedom motion platform and the projection setup.

Fig. 6: The model was created by wrapping a 360° round shot photograph of the Tübingen market place (see Figure below) onto a cylinder. This creates an undistorted view for the observer positioned in the center of the cylinder.

Fig. 7: Full 86°x63° view of the market place, displaying the landmarks "Lammhofpassage", "Briefkasten", "Kreissparkasse", "Marktschenke", "Bäckerei", and "fotomarkt", indicated by little red dots.

Fig. 8: Same view as in Fig. 7, but with the reduced FOV of 40°x30° (blinders or HMD conditions).

Fig. 9: 360° round shot of the Tübingen market place.

Poster presented at the 5. Tübinger Wahrnehmungskonferenz (TWK) 2002.
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