Influence of display parameters on perceiving visually simulated ego-rotations - a systematic investigation

MAX-PLANCK-GESELLSCHAFT

Jörg Schulte-Pelkum, Bernhard E. Riecke, & Markus von der Heyde
Max Planck Institut für biologische Kybernetik, Tübingen

MPI FOR BIOLOGICAL CYBERNETICS

• Motivation

What are the specific influences of different display devices, FOVs, and screen curvature on ego-motion perception in VR?

In Virtual Reality (VR), participants typically misperceive simulated turning angles if only visual cues are available. The literature on this topic reports inconclusive data. This may be partly due to the different display devices and field of views (FOV) used in the studies. Our study aims to disentangle the specific influence of display devices, FOV, and screen curvature on the perceived turning angle for visually simulated ego-rotations.

• Methods

Participants performed simulated turns under different visualization conditions.

In Experiment 1, FOV and display devices were manipulated.

In Experiment 2, screen curvature and FOV were manipulated.

In **Experiment 1,** display devices (HMD vs. curved projection screen) and FOV were manipulated. 18 participants performed visually simulated ego-rotations in a within-subject repeated-measures design. Three visualization conditions (projection screen: FOV 86°×64°, HMD: 40°×30°, blinders: 40°×30° (see Fig. 1)), were crossed against five turn angles (45° to 225°, steps of 45°) and four turning velocities (20, 27, 34, and 42°/s). The blinders restricted the FOV on the screen to the same FOV that was visible on the HMD. To provide only optic flow information without any landmarks, a “star field” of limited lifetime dots (dot lifetime 650 ms) on a dark background was used. Target angles were instructed via headphones, e.g. “Turn 90° to the left”, and participants used a joystick to control the simulated turns. No training or feedback was provided at any stage of the experiment.

In **Experiment 2**, screen curvature and FOV were manipulated. The design and task was almost identical to Experiment 1. Subjects performed the task on a flat projection screen and on a curved screen (radius 2m, FOV 86°×64° for both, see Fig. 2) on two different days, with full FOV and restricted FOV (40°×30°).

• Results & Discussion

Generally, target angles were undershot.

Performance was best with the full view on the screen and worst with the HMD.

Unexpectedly, FOV alone did not affect performance on the projection screen.

The size of FOV of the HMD was largely overestimated.

In Experiment 2,we found a significant effect of screen curvature on the perception of turns.

Experiment 1: Generally, all target angles were undershot (see Fig. 3). For turn error as the dependent measure, a within-subject repeated-measures ANOVA showed the following results: The effect of visualization condition was significant, as well as target angle. Bonferroni-corrected post-hoc tests revealed significant differences between the full screen and the HMD ($p<0.001$), and also between HMD and blinders ($p<0.01$), but not between screen and blinders ($p=0.407$). The interaction between visualization condition and target angle was also significant (see Fig. 3). Mean subjective ratings about task difficulty were highest for the blinders (3.7 on a 5-point Likert-scale), as opposed to values of 2.7 for the screen and 2.8 for the HMD (see Fig. 5, left). This is remarkable because performance with the blinders was superior to the HMD and did not differ significantly from the screen with full FOV.

In a post-test interview, the FOV of the HMD was estimated to be more than twice as large on average than the actual FOV (see Fig. 5, right). Participants also reported that the dots appeared to be farther away in the HMD than on the screen, even though dot size in terms of visual angle was equated for the two conditions. The largely overestimated FOV in the HMD and the altered apparent distance to the stars seem to have contributed to the substantial performance deterioration (see HMD-data in Fig. 3 and 5).

In **Experiment 2,** we found a significant effect of screen curvature ($p<0.001$): While subjects turned too far on the flat screen (gain 1.12), they did not turn enough on the curved screen (gain 0.84, see Fig. 5). Reducing the FOV to 40°×30° had no significant effect. Subjects’ verbal reports indicate that on the flat screen, rotational optic flow was misperceived as translational lamellar flow. This may have led them to overestimate turns on the curved screen. Interestingly, only one of 16 participants noticed the difference between the two screens during the experiment.

• Conclusions

Display devices were more crucial for turning performance than FOV.

One has to be cautious when using HMDs for studies in perception.

Screen curvature is an important parameter in ego-motion simulation.

From **Experiment 1,** we can conclude the following:

First, display devices affected the control of visually simulated ego-rotations differentially, the projection screen being superior to the HMD.

Second, the FOV unexpectedly did not affect performance on the projection screen.

Third, one has to be cautious when using HMDs to investigate basic perceptual processes.

From **Experiment 2**, we can conclude that screen curvature is an important parameter to be considered in ego-motion simulation and vection studies, especially if simulated ego-rotations are concerned.

Future studies will further investigate the contributions of peripheral vision, ground projection, and the reference frame provided by the screen geometry on ego-motion perception.

Figure 1: Experimental visualization conditions in **Experiment 1**. Left: projection screen (FOV 86°×64°), middle: blinders (40°×30°), right: HMD (FOV 40°×30°). Subjects performed visually simulated rotations watching a “star field” of limited lifetime dots on a dark background.

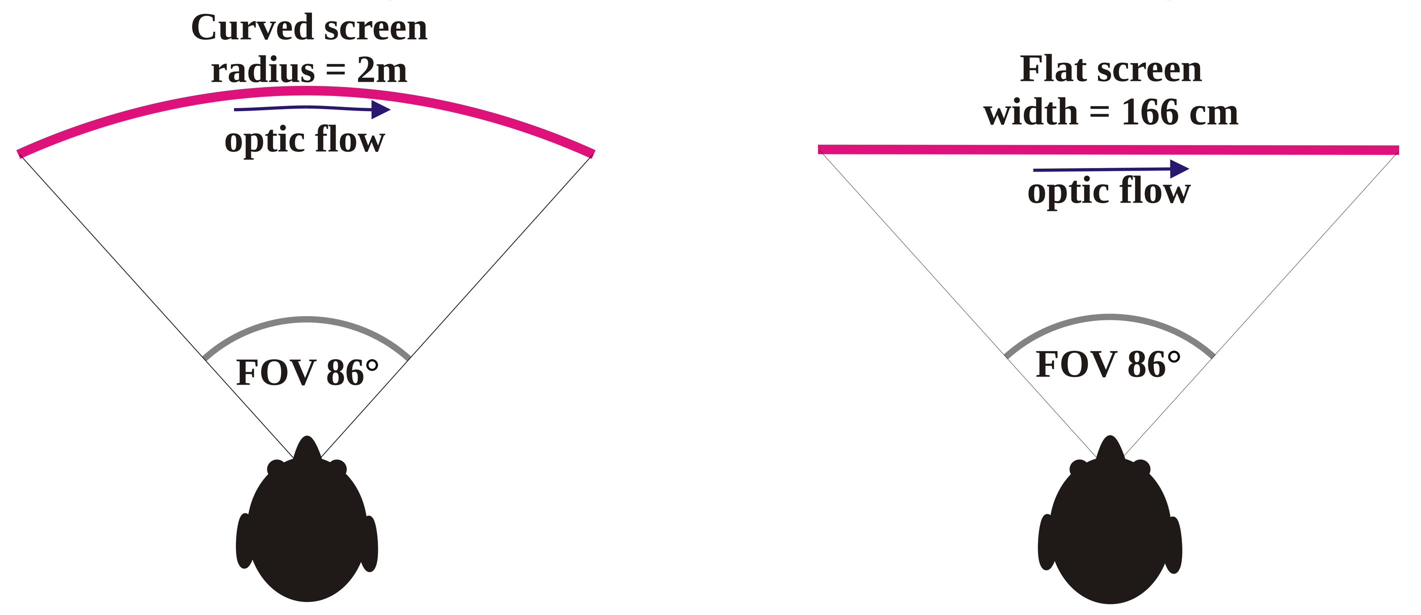

Figure 2: Schematic of **Experiment 2**: Left: Curved screen; Right: Flat screen; FOV 86°×64° for both. Viewing distance was 89 cm. The identical visual stimuli as in Experiment 1 were used.

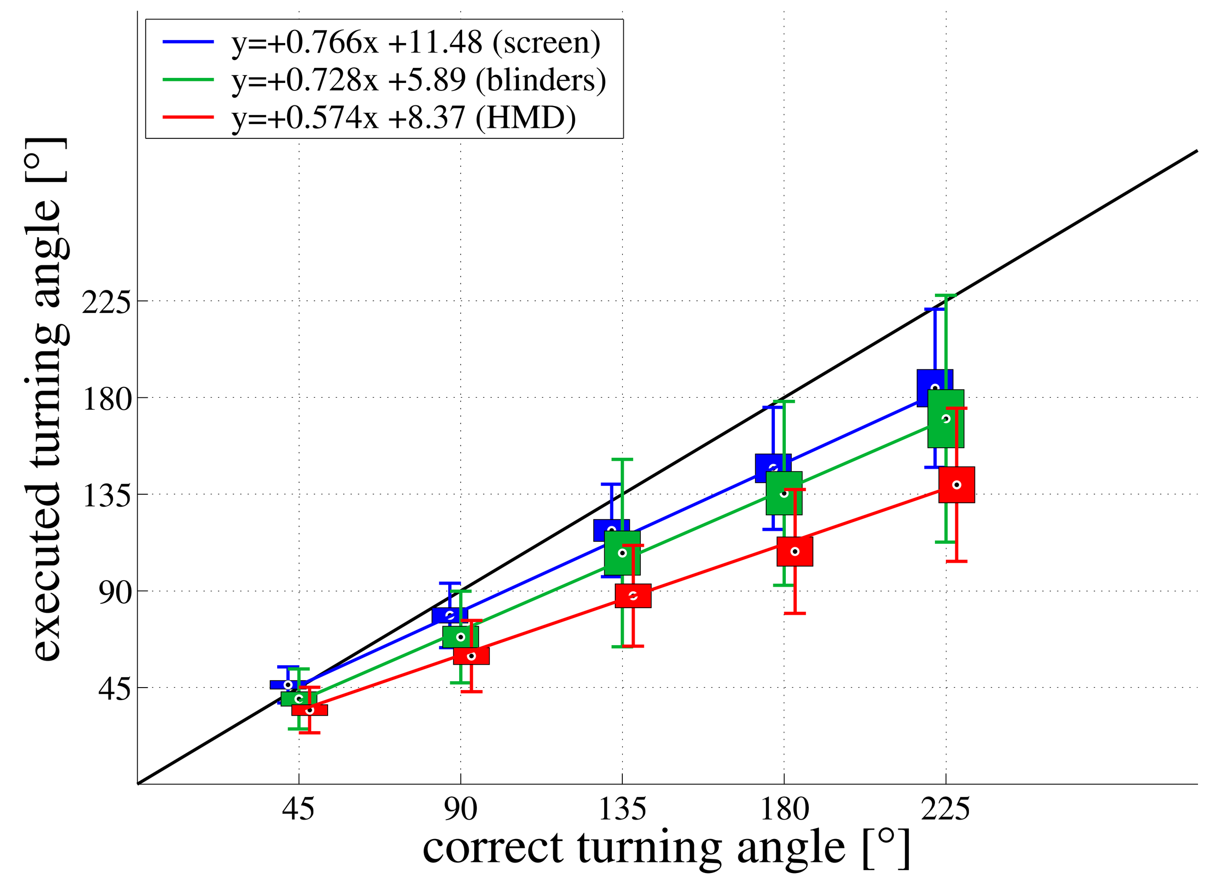

Figure 3: Results from **Experiment 1**: Means of turned angles per visualization condition plotted against the correct target angles. Boxes show one standard error of the mean, whiskers indicate one standard deviation. The slopes of the fitted lines correspond to the gain factors. The different slopes illustrate the interaction between condition and angle. The equations for the linear fit are shown in the inset on top. A gain factor of 1 describes perfect performance.

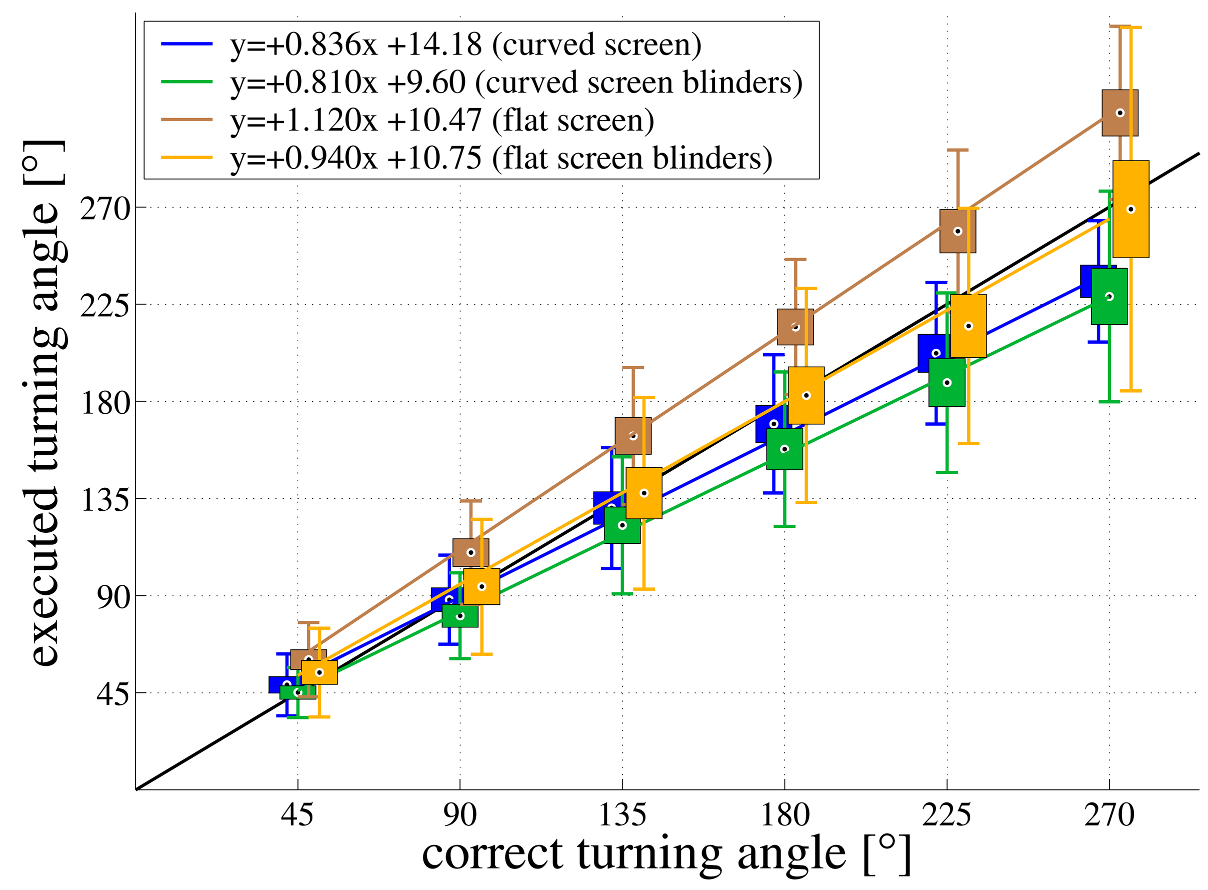

Figure 4: Results from **Experiment 2**:Same legend as in Experiment 1. Consistent with Experiment 1, participants undershoot on the curved screen, whereas they overshoot on the flat screen. The reduction of the FOV had no significant effect.

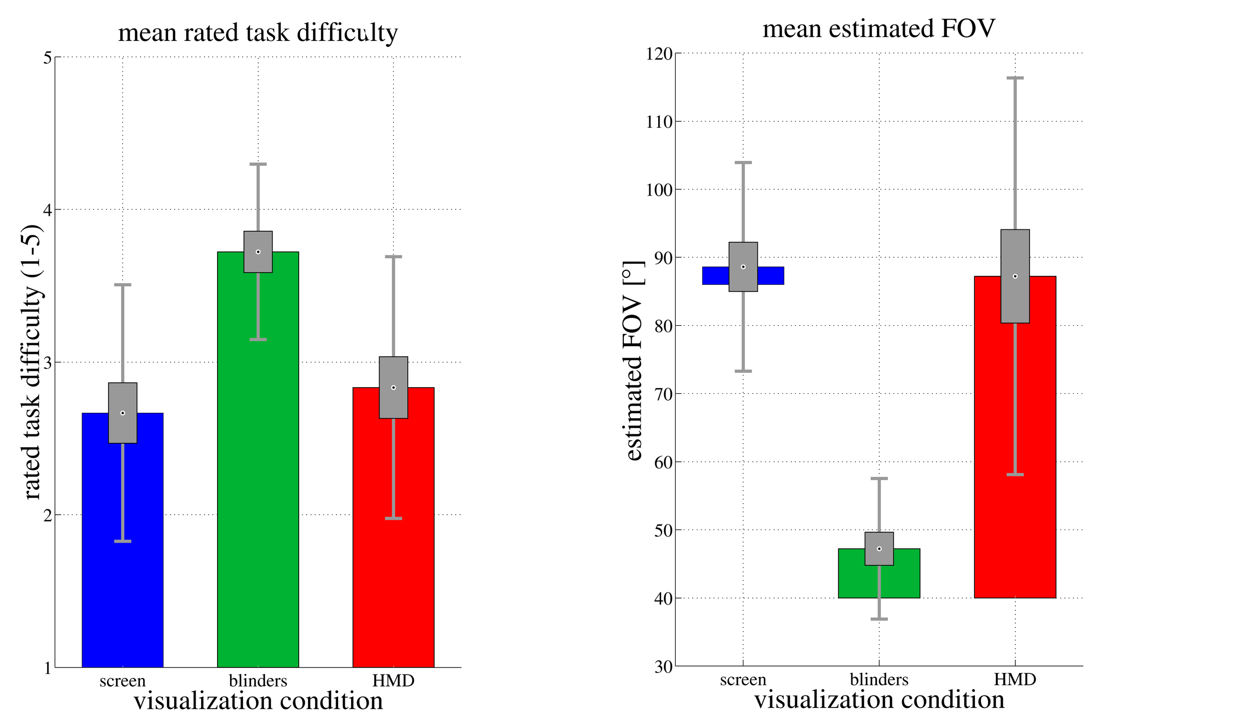

Figure 5. Further results from **Experiment 1**: Left: Mean rated task difficulty. Boxes show one standard error of the mean, whiskers indicate one standard deviation. Right: Mean estimated FOVs. The heights of the colored boxes indicate the amount of deviation from the actual FOVs. In Experiment 2, no significant differences were found between flat and curved screens.

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