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Screen curvature does influence the perception of visually simulated ego-rotations

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Motivation

Is there any influence of screen curvature on the perception of visually simulated ego-rotations?

In general, the literature suggests that visual information alone is insufficient to control rotational self-motion accurately. Typically, subjects misperceive simulated turn angles when no vestibular or proprioceptive cues are available (see Bakker et al., 1999; 2001 - these studies used head-mounted displays (HMDs)). However, Riecke et al. (2002) found nearly perfect visual turning performance when a curved, half-cylindrical projection screen with a large field of view (FOV) of 180° was used. Apart from the largely different FOVs in the two studies, screen curvature is a potential source for the differing results (see Fig. 1).

This study aims to systematically investigate the influence of screen curvature and FOV on ego-motion perception.

Figure 1: 180° half-cylindrical projection screen and HMD (FOV 40°×30°)

Methods

Participants performed simulated turns using either a flat or a curved projection screen with identical FOVs.

On both screens, FOV was also varied.

18 participants performed visually simulated ego-rotations using a flat projection screen (FOV 86°×64°) and a curved projection screen (radius 2m, identical FOV) in a within-subject repeated-measures design (see Fig. 3). The experiment was run in two blocks (flat vs. curved screen) on two different days. Six turn angles (45° to 270°, steps of 45°) were crossed against four turning velocities (28, 33, 38, and 43°/s). We also varied the FOV on both screens using "blinders" that restricted the FOV to 40°×30° (see Fig. 2, right). 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.

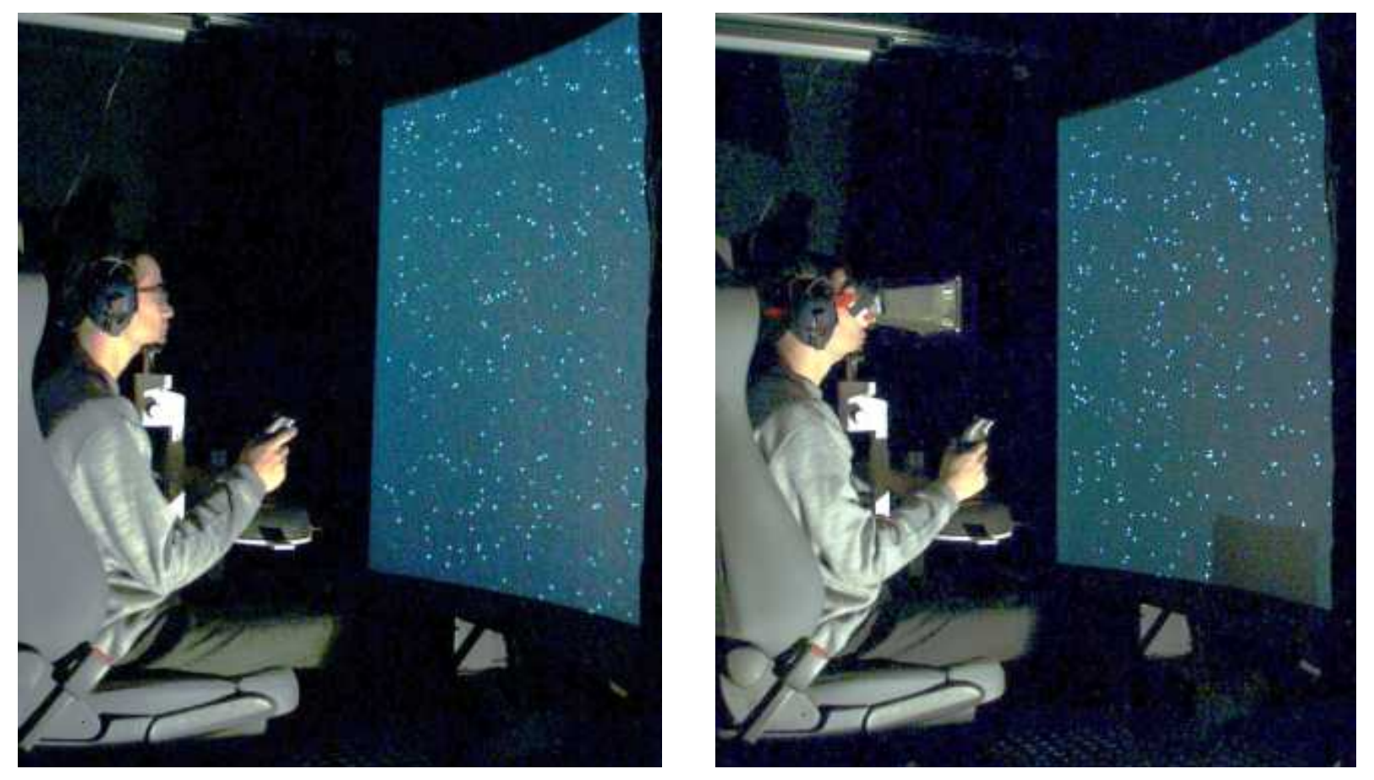

Figure 2: Experimental visualization conditions on the curved screen. Left: (FOV 86°×64°), right: blinders (40°×30°). Each subject performed the task both on the curved and on the flat screen in two sessions on different days.

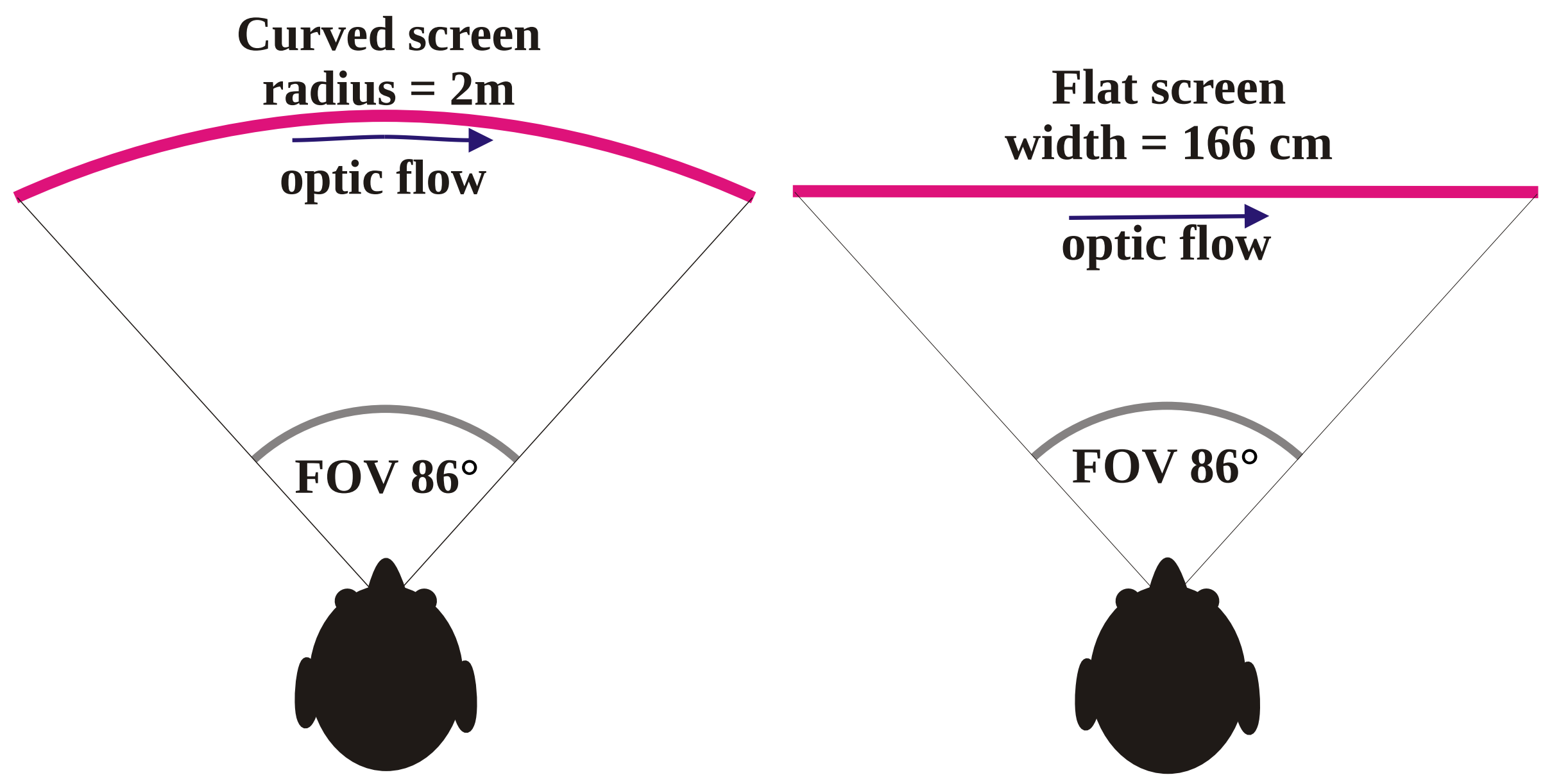

Figure 3: Schematic of the Experiment: Left: Curved screen; Right: Flat screen; FOV 86°×64° for both. Viewing distance was 89 cm to the flat screen and 106 cm to the center of the curved screen. The identical visual stimuli were used for both conditions.

Results & Discussion

Screen curvature had a significant effect:

- Turns were overestimated on the curved screen.
- Turns were underestimated on the flat screen.

On both screens, the reduction of FOV had no significant effect.

Rotational flow on the curved screen was perceived as "more realistic" than on the flat screen.

A repeated-measures ANOVA with turn error as the dependent variable revealed a significant effect of screen curvature, turning velocity, and also an interaction between curvature and turn angle: While target angles were undershot on the curved screen (gain factor 0.84), a surprising overshoot was observed for the flat screen (gain factor 1.08; see Fig. 4). The presentation order of the randomized blocks (flat vs. curved screen) had no significant effect (see Table 1 for F-values).

Paired-samples t-tests showed a significant difference for gain factors between the flat and curved screen in the full view condition: t(15)=-2.72, p<.02. However, here was no significant difference for the reduced FOV on both the curved and the flat screen (p=.96 and p=.14, respectively).

In the experiment, subjects had been instructed to trust their sense of ego-motion to estimate their turn angles. Interestingly, subjects' verbal reports after the experiment indicated that on the curved screen, the simulated self-rotations looked "more realistic" than on the flat screen. This may have led them to overestimate turns on the curved screen (thus to undershoot target angles) and to underestimate turns on the flat screen (thus to overshoot target angles). Fig. 5 illustrates the optical difference of the stimuli on the two screens. The longer vector on the curved screen for stimuli with the same angular velocity predicts that turns should be overestimated on the curved screen compared to the flat screen. Indeed, this was found in our study. Participants also reported that rotational flow on the flat screen looked more like translational lamellar flow (e.g. like looking to the side when walking forward).

Conclusions & Outlook

Screen curvature is a critical parameter for ego-motion simulation.

Reducing the FOV did not affect turning accuracy significantly.

The two main findings of the present study are:

- First, screen curvature is a critical parameter to be considered for ego-motion simulation and vection studies, especially if rotational ego-motion is concerned.
- Second, reducing the FOV did not significantly affect turning accuracy on both projection screens.

Comparing the results with the Riecke et al. (2002) study, it is notable that performance with both 86°×64° screens was inferior to the 180° half-cylindrical screen, where nearly perfect turning performance was found (see Fig.1 (left) and Fig. 4). Taken together, these results show that further systematic research is needed to understand the parameters that influence spatial perception in Virtual Reality (VR) applications, given that VR technology is already being used as a standard research tool for studies in perception and psychophysics. Follow-up studies will specifically investigate the contributions of peripheral vision and the physical reference frame provided by the screen geometry.

References:

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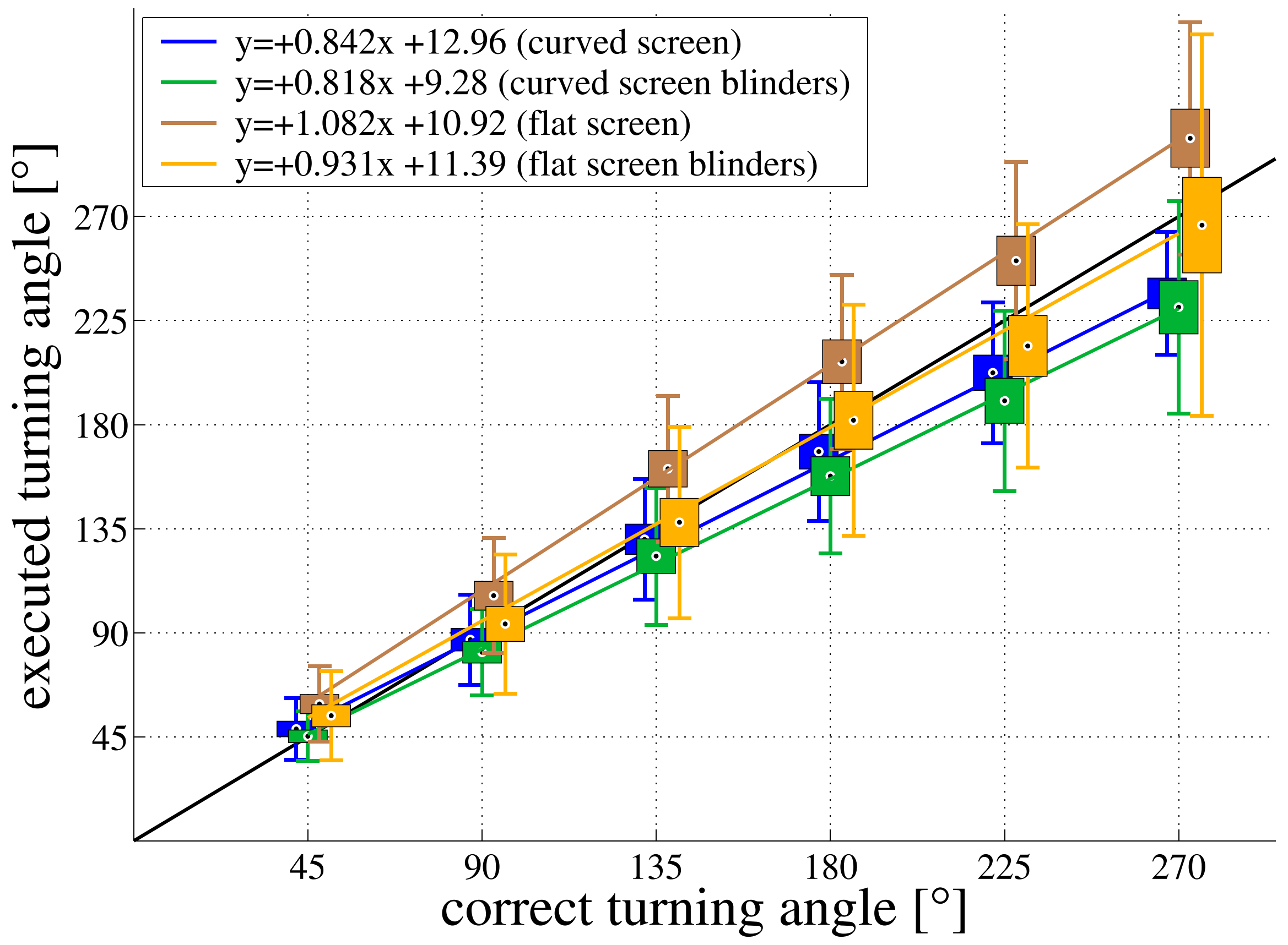

Figure 4: Means of turned angles per visualization condition plotted against the correct target angles. Boxes show one standard error of the mean, whiskers indicate one standard deviation. The slopes of the fitted lines correspond to the gain factors. The different slopes illustrate the interaction between condition and angle. The equations for the linear fit are shown in the inset on top. A gain factor of 1 describes perfect performance.

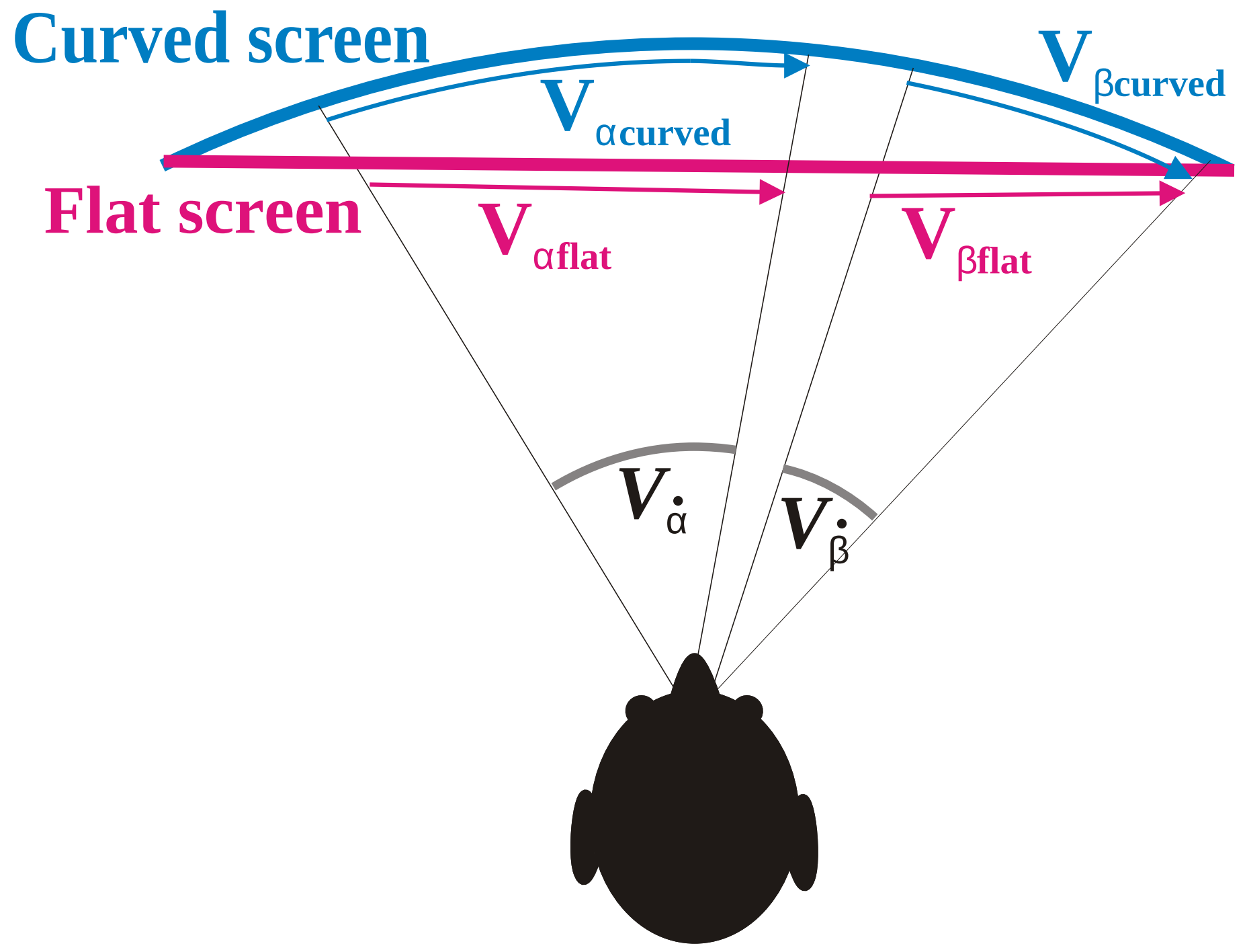

Figure 5: Optical difference of rotational optic flow viewed on the flat and the curved screen. Due to the fact that FOV was kept constant, the center of curved screen is farther away from the observer than the flat screen. While the angular velocity ($V_{\dot{\alpha}}$ and $V_{\dot{\beta}}$) of optic flow is unaffected, the linear velocity (V_α and V_β) on the projection screen is both dependent on the distance to the observer and on curvature: Vectors of linear velocity are longer in the center of the curved screen than on the flat screen, while the difference becomes less towards the periphery.

Factor	*df* and F-value	Significance
Visualization condition	F(1.95,15.6) = 8.21	p<0.001
Velocity	F(1.22,9.75) = 9.32	p <0.01
Visualization condition × Target angle	F(2.96,23.65) = 6.79	p<0.002
Presentation order	F(1,7) = 0.13	p=0.993

Table 1: ANOVA results. Note: *df* and F-values for repeated-measures tests are Greenhouse-Geisser corrected.

Poster Nr. SA71, presented at VSS 2003, Sarasota, USA | http://www.kyb.tuebingen.mpg.de/~jsp | email: joerg.sp@tuebingen.mpg.de