Modeling the impacts of inter-display and inter-lens separation on perceived slant in Virtual Reality Head-mounted displays

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Projective geometry predicts that a mismatch between user interpupillary-distance (IPD) and the inter-axial separation of stereo cameras used to render imagery in VR will result in distortions of perceived scale. A potentially important, but often overlooked, consequence of a mismatch between user IPD and VR lens separation is the impact on binocular convergence. Here we describe a geometric model that incorporates shifts in binocular convergence due to the prismatic effect of decentered lenses, as well as the offset of dual displays relative to the eyes, and predicts biases in perceived slant. The model predicts that when the inter-lens and inter-display separation is less than an observer's IPD, perceived slant will be biased towards frontoparallel. Conversely when the inter-lens and inter-display separation is greater than an observer's IPD, perceived slant will be increased. These predictions were tested and confirmed in a VR headset with adjustable inter-lens and display separation (both coupled). In the experiment, observers completed a fold adjustment task in which they adjusted the angle between two intersecting, textured surfaces until they appeared to be perpendicular to one another. The task was performed at three randomly interleaved viewing distances, monocularly and binocularly. In separate blocks, the inter-lens and display separation was either matched to the observer's IPD (baseline condition) or set to the minimum or maximum allowed by the headset (IPD-mismatch conditions). When the inter-lens and display separation was less than the observers' IPD they underestimated surface slant relative to baseline, and the reverse pattern was seen when the inter-lens and display separation was greater than their IPD. Overall, the geometric model tended to overestimate the effect of IPD-mismatch on perceived slant, especially at the farther viewing distances. We extended the model to incorporate the relative weighting of monocular and binocular cues, resulting in an overall improvement in the model fits. Our model provides researchers and VR-systems-designers a means of predicting depth perception when the optics of head-mounted displays may not be aligned with users' eyes.

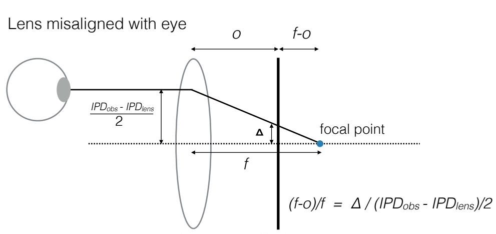

Fig. 1: When the lens and display are misaligned with the eye, the vergence angle of each eye changes to compensate for the lateral shift, Δ, between the display center (equivalent to optical axis) and where the refracted line of sight, due to the prismatic effect, intersects the display. The principle of similar triangles can be used to solve for Δ, given the expression on the right.

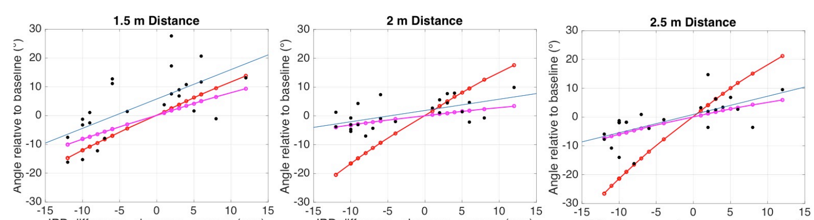

Fig. 2: The adjusted angle in IPD-mismatch conditions relative to baseline (baseline – mismatch), plotted as a function of the difference between observer and headset IPD, for three tested viewing distancnce**.** Solid points are individual observer data points; the blue line is the linear regression best-fit, the original (binocular only) model predictions are shown in red and the cue-combination extended model predictions are shown in magenta.