Consistent Left-Right Errors for Visual Path Integration in Virtual Reality: More Than a Failure to Update One's Heading?

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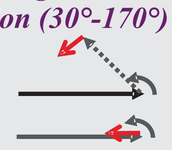
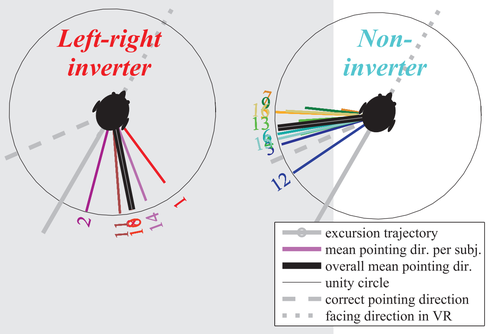
• Introduction & Background

Can we navigate with just optic flow information? The basic components (translations, rotations) are preceived well enough...

Task: Point accurately & quickly back to the origin after visually displayed excursion along 1- or 2-segment paths including a simulated rotation (30°-170°)



6/16 participants showed striking qualitative (left-right) errors in the VR test, but not in a real-world pre-test



Goal: Replicate and explain left-right inversion while avoiding mis-perception of turning angles

Optic flow has been the subject of extensive research, and the literature suggests that optic flow can be used to solve a number of task including, e.g., heading estimation, estimation of distances and turns, and navigation. Hence, one might be tempted to conclude that just about any task that involves self-motion can, in principle, be performed on the basis of optic flow.

Recently, however, Riecke and Wiener (2007) showed that naive participants produced rather drastic errors even for seemingly simple spatial orientation tasks: After visually displayed passive excursions along 1- or 2-segment paths that included one simulated rotation (0°, 30°, 60°, 90°, 120°, 150°, or 170°), participants were asked to point toward the starting point "as accurately and quickly as possible" using a joystick-like pointer (see Fig. 1).

In addition to a high variable error, six of the 16 participants in Riecke and Wiener (2007) also produced consistent qualitative (left-right) errors. That is, even though those six left-right inverters clearly understood the experimental instructions and did not misperceive the simulated turning directions, they consistently pointed into the opposite, left-right mirrored direction.

Only when the upcoming turning angle was announced before each trial and experienced psychophysical observers (lab members) were used did those left-right inversions and high variable errors disappear.

The current study was designed to test if non-experienced, naive participants (N=24) would similarly benefit from advance knowledge of the upcoming turning angles or produce left-right inversions. The experimental procedures closely replicated those of Riecke and Wiener (2007) to allow for direct comparisons.

• Methods

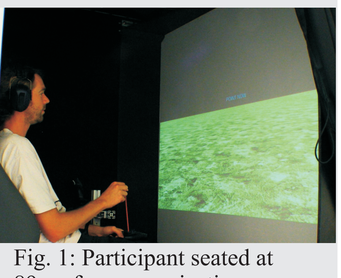


Fig. 1: Participant seated at 89cm from a projection screen.

Task: Point-to-origin after visually displayed excursion along 1- or 2-segment paths including a simulated rotation with announced turning angles (30°-170°)

Stimuli & apparatus: Participants were seated at a distance of 0.89m from a flat projection screen (1.68m width × 1.26m height, corresponding to a field of view of about 84° × 63°), as illustrated in Figure 1. The virtual environment was quite simple and consisted of a textured flat ground plane that did not contain any absolute orientation or distance cues. The visual stimuli were projected non-stereoscopically using a JVC D-ILA DLA-SX21S 1400 × 1050 pixel video projector.

Procedure: 24 naive participants were asked to point back to the origin of locomotion "as accurately and quickly as possible" after visually displayed passive excursions along 1- or 2-segment trajectories including a simulated rotation (0°, 30°, 60°, 90°, 120°, 150°, or 170°; angles announced before each trial). Translation/rotation velocities were 8m/s and 30°/s, respectively. Left and right turns were alternated. Each condition was tested twice. Participants used joystick-like poiner.

• Results

Despite advance knowledge of turning angles, both constant and variable pointing errors increased significantly with turning angle (seee Fig. 2; $F(5, 110) > 2.5$, $p < .05$), suggesting higher task difficulty and/or uncertainty for larger rotations.

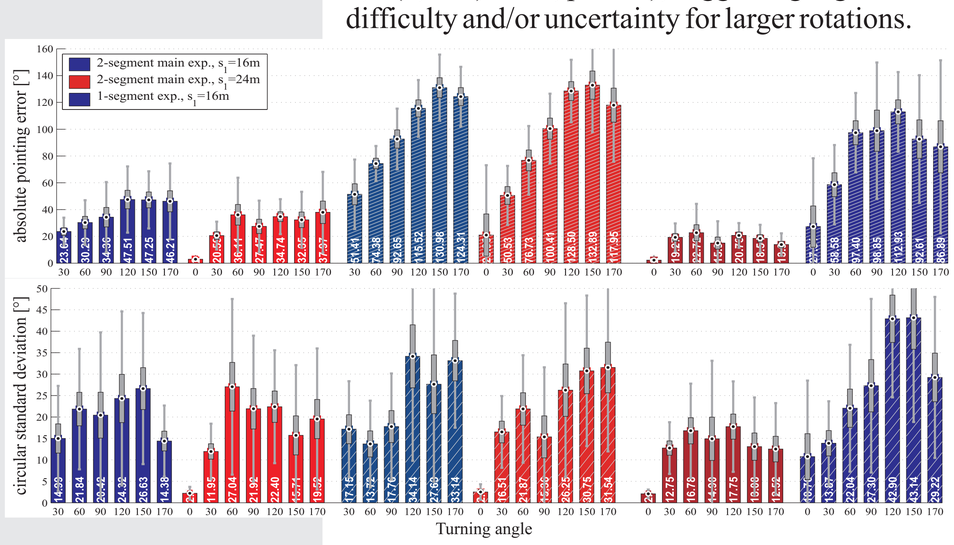
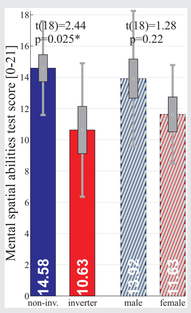


Fig. 2: Bars, boxes, and whiskers indicate the arithmetic mean, one standard error of the mean, and one standard deviation, respectively. Solid and hatched bars represent data from the non-inverters and inverters, respectively.

• Results

11/24 participants showed striking qualitative (left-right) errors in the VR test, but not in a real-world pre-test

The remaining 13 participants showed no such qualitative errors, but still considerable systematic errors



The 1-segment experiment showed consistent left-right inversions for the same 11 participants as before

Psychophysically experienced lab member (Riecke & Wiener, 2007) performed virtually flawless, though

Bimodal participant distribution (inverters vs. non-inverters)

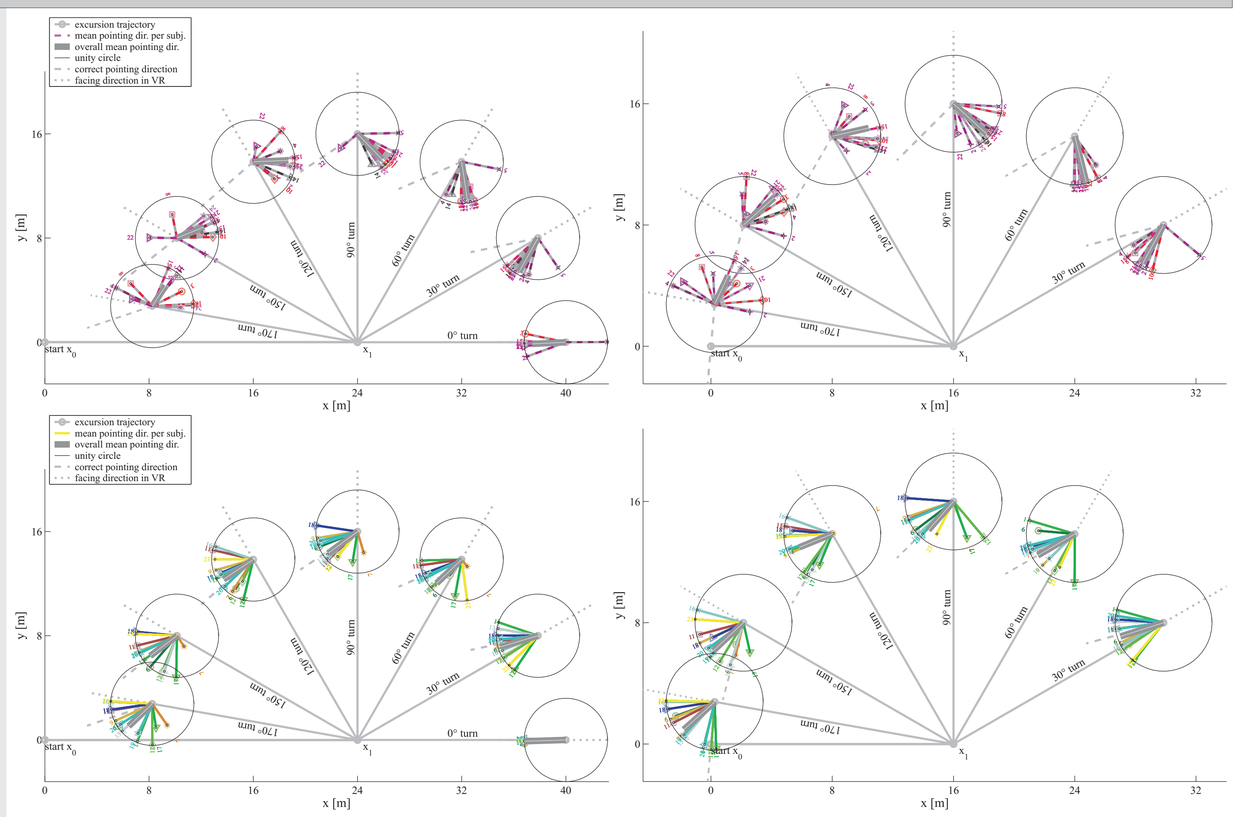


Fig. 3: Top-down schematic view of the excursion path. The circular mean pointing direction of each participant is indicated by the colored bars and subject IDs. The length of the mean pointing vector indicates the consistency of the individual pointing directions: Shorter mean pointing vectors indicate higher circular standard deviations between the individual pointing, whereas mean pointing vectors close to the surrounding black unity circle indicate high consistency and low circular standard deviations between the individual pointings. **Top:** Left-right inverters. **Bottom:** Non-inverters.

11 of the 24 participants showed consistent left-right inversion for both the 2- and 1-segment experiments, as illustrated in Figure 3-5. Left-right errors were associated with lower overall mental spatial abilities (corroborating Riecke and Wiener, 2007), but not gender.

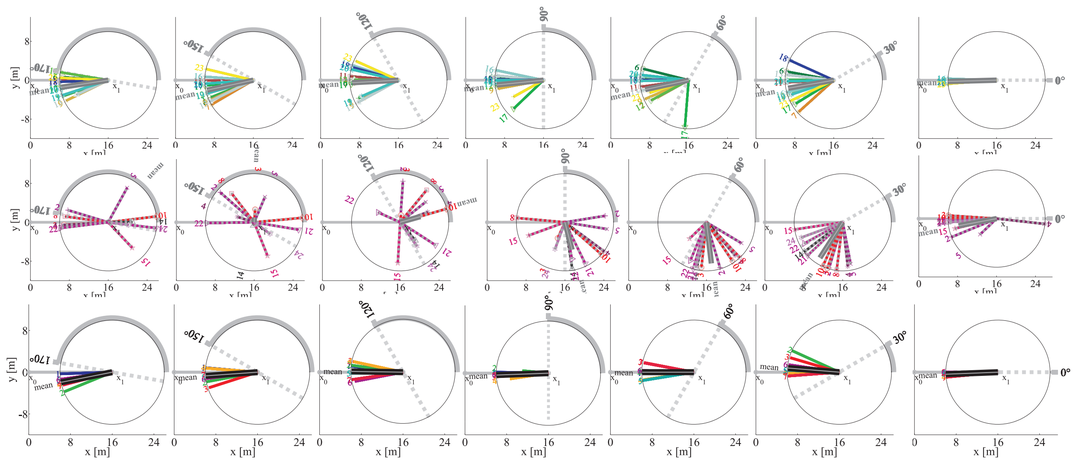


Fig. 4: Pointing data for the 1-segment experiment: **Top:** Non-inverters **Middle:** Left-right inverters **Bottom:** Replotting of data from VR-experienced lab members of Riecke and Wiener (2007).

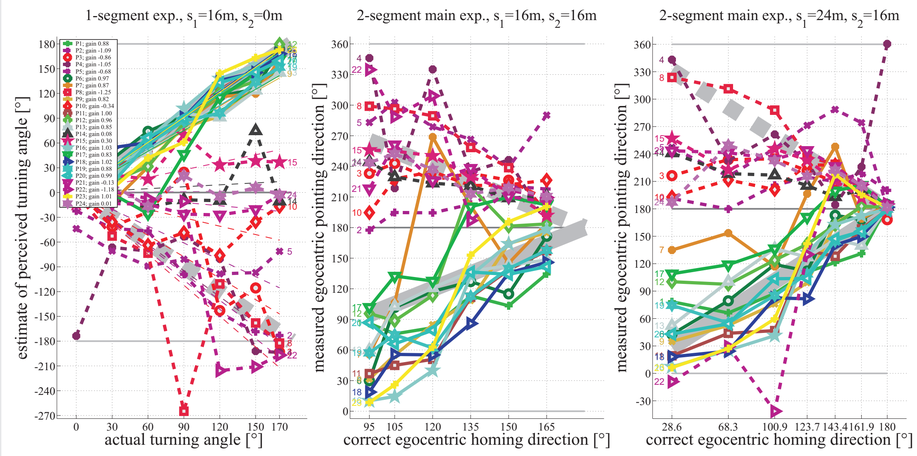


Fig. 5: Illustration of bimodal participant distribution into left-right inverters (reddish colors, dashed lines) and non-inverters (greenish colors, solid lines). The solid thick gray line indicates perfect performance, the dashed thick gray line indicates left-right inverted performance. Note the overall large errors for all but a few participants, despite knowledge of the turning angles.

• Discussion & Conclusions

Some - but not all - participants apparently failed to update their heading during visually stimulated rotations

Despite the seemingly simple task and knowledge of turning angles, participants had no natural or intuitive spatial orientation in VR

Point-to-origin tasks could serve as simple benchmarks for VR setups, as left-right inversion implies lack of natural & intuitive spatial orientation.

We were able to replicate the occurrence of consistent left-right inversion errors in more than 40% of naive, psychophysically inexperienced observers. A detailed analysis suggests that failure to update one's heading during rotations seems to be the origin of the observed left-right inversion for some – but not all – of the left-right inverters: All inverters clearly did update their heading for the 1-segment experiment – albeit producing left-right errors. Moreover, some inverters pointed forward for larger rotations (and thus produced egocentric pointing angles outside of the interval [90°, 270°], see Fig. 5), which is incompatible with a failure to update heading as proposed by Klatzky et al. (1998) or Gramann et al. (2005).

One of the most striking results was the poor overall performance for all but a few participants, especially given that they had advance information about the exact turning angle, perceived the simulated turning direction correctly, and were able to perform virtually flawless in a real-world pre-test.

Overall rated task difficulty was surprisingly high, and not a single participant reported having any kind of natural or intuitive spatial orientation in VR – not even the VR-experienced lab members in Riecke and Wiener (2007).

Thus, at least for the current VR setup, optic flow seems insufficient for enabling natural and intuitive spatial orientation for even the most basic and seemingly trivial trajectories, even when additional information about the turning angles is provided.

We posit that investigating qualitative errors for basic spatial orientation tasks using, e.g., rapid point-to-origin paradigms can be a powerful tool for evaluating and improving the effectiveness of VR setups in terms of enabling natural and unencumbered spatial orientation and performance.

References

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