



Visual-Vestibular Sensor Integration Follows a Max-Rule:

Results from Psychophysical Experiments in Virtual Reality



MAX-PLANCK-GESELLSCHAFT

Markus von der Heyde, Bernhard E. Riecke, Douglas W. Cunningham, & Heinrich H. Bühlhoff
email: Markus.von.der.Heyde@Tuebingen.MPG.de

MPI FOR BIOLOGICAL CYBERNETICS

Introduction

How are visual and vestibular information integrated for turning behavior?

Perception of ego turns is crucial for navigation and self-localization. Yet in most Virtual Reality (VR) applications turns are misperceived which leads to disorientation. In following experiments subjects learned and memorized turns and were able to reproduce them even with different gain factors for the vestibular and visual feedback. We focused on two cues providing no absolute spatial reference: optic flow and vestibular cues.

We asked whether:

- (a) both visual and vestibular information are stored and can be reproduced later;
- (b) those modalities are integrated into one coherent percept or if the memory is modality specific; and
- (c) absolute visual information alters performance or strategies.

Independent Variables

Is active learning important?

Which information / modality is memorized?

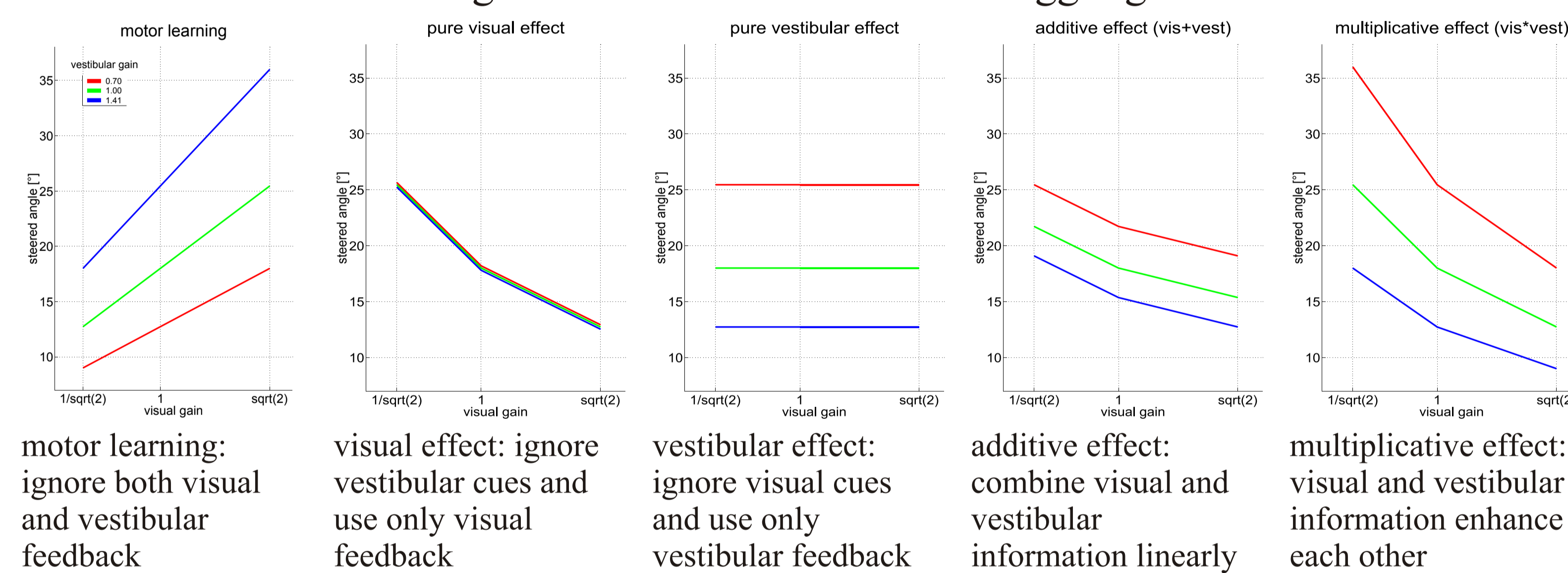
How is optic flow and landmark information used?

- **Active/passive:** In one condition (ACTIVE) subjects continuously adjusted the roll axis of the platform to level position (see Fig. 1&2 for detailed task description). Subjects controlled their heading with a joystick and thereby maintained an upright position. In all other conditions subjects were passively guided through the sequence of heading turns without any roll signal.
- **Visual/vestibular gain:** During the reproduction phase the gain between the joystick control (steered angle) and the resulting visual and vestibular turns were independently varied by a factor of $1/\sqrt{2}$, 1 or $\sqrt{2}$. In one additional block of the PASSIVE condition the gain of one modality was set to zero, resulting in no vestibular turn or straight optic flow (ZERO).
- **Textured plane/complex scene:** The provided visual information was either a textured ground plane (ACTIVE, PASSIVE, ZERO) or a complex town environment with salient landmarks (Fig. 3). In the town environment subjects either started in the SAME ORIENTATION during learning and reproduction phase or in RANDOM ORIENTATION.

Models & Predictions

Models for single modalities and multi-modal cue integration.

Different strategies can be used to integrate the visual and vestibular information. The simplest models predict qualitatively different results as plotted below. Each graph depicts the steering angle (integral of joystick movements), plotted over the different visual gain factors. The vestibular gain factors are color coded. In order to see (or feel) the same amount of turn, one has to steer more for smaller gain factors and steer less for bigger gain factors.



Results

The actual data does not match any of the above models perfectly, but does allow to reject certain ideas: The subjects did not use motor-learning or pure vestibular strategies.

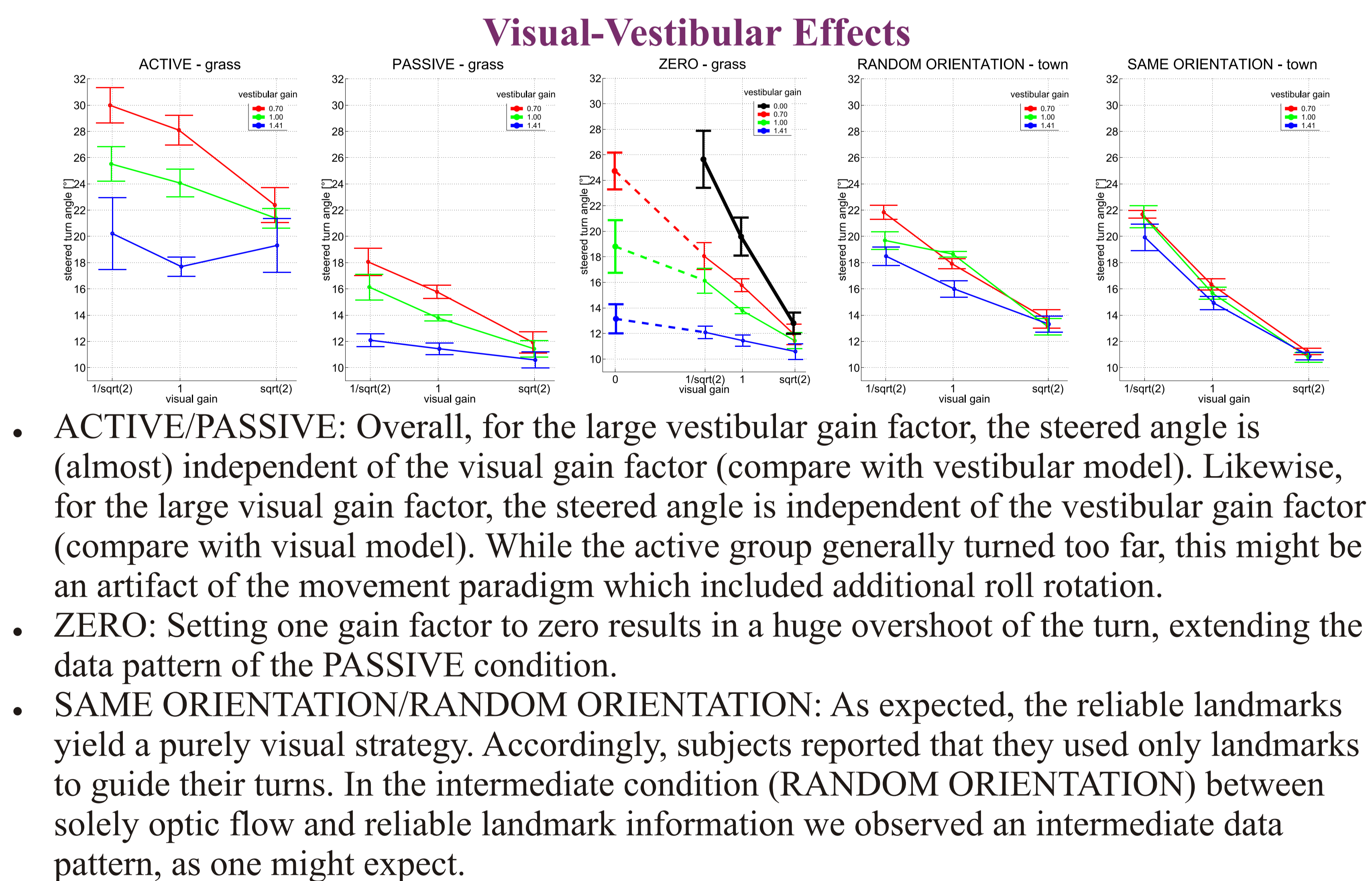
Large visual or vestibular gain factors have a dominant impact when integrating optic flow and vestibular turns.

Landmark information dominates over vestibular turns.

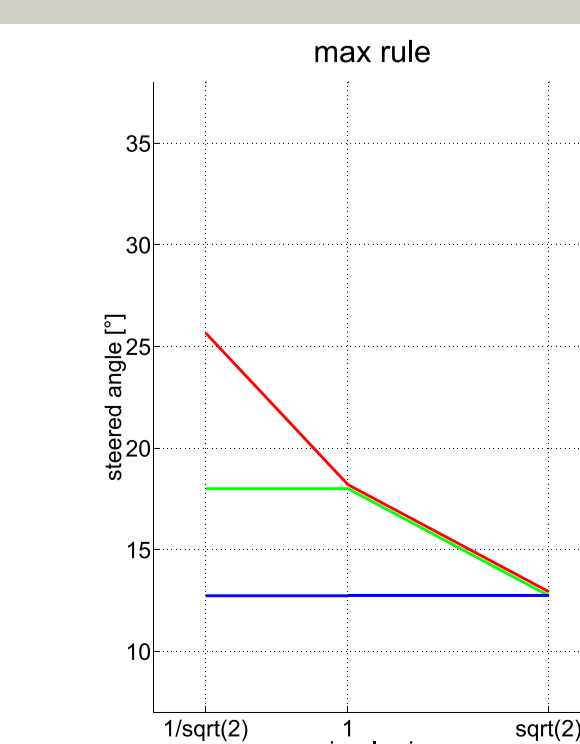
Conclusions

Subjects stored both visual and vestibular information.

Cue integration can qualitatively be described by a "max-rule".



- Subjects in all conditions learned and memorized curves of the vestibularly defined virtual path and were able to reproduce the amplitudes of the turns. The ACTIVE, PASSIVE, and ZERO conditions demonstrated the relevance of the vestibular signals for spatial orientation in Virtual Reality.
- The modality with the bigger gain factor had a dominant effect on the reproduced turns for the ACTIVE and PASSIVE groups. This integration of visual and vestibular information seems to follow a "max rule", in which the larger signal is responsible for the perceived and memorized heading change.



Methods

Course of the experiments

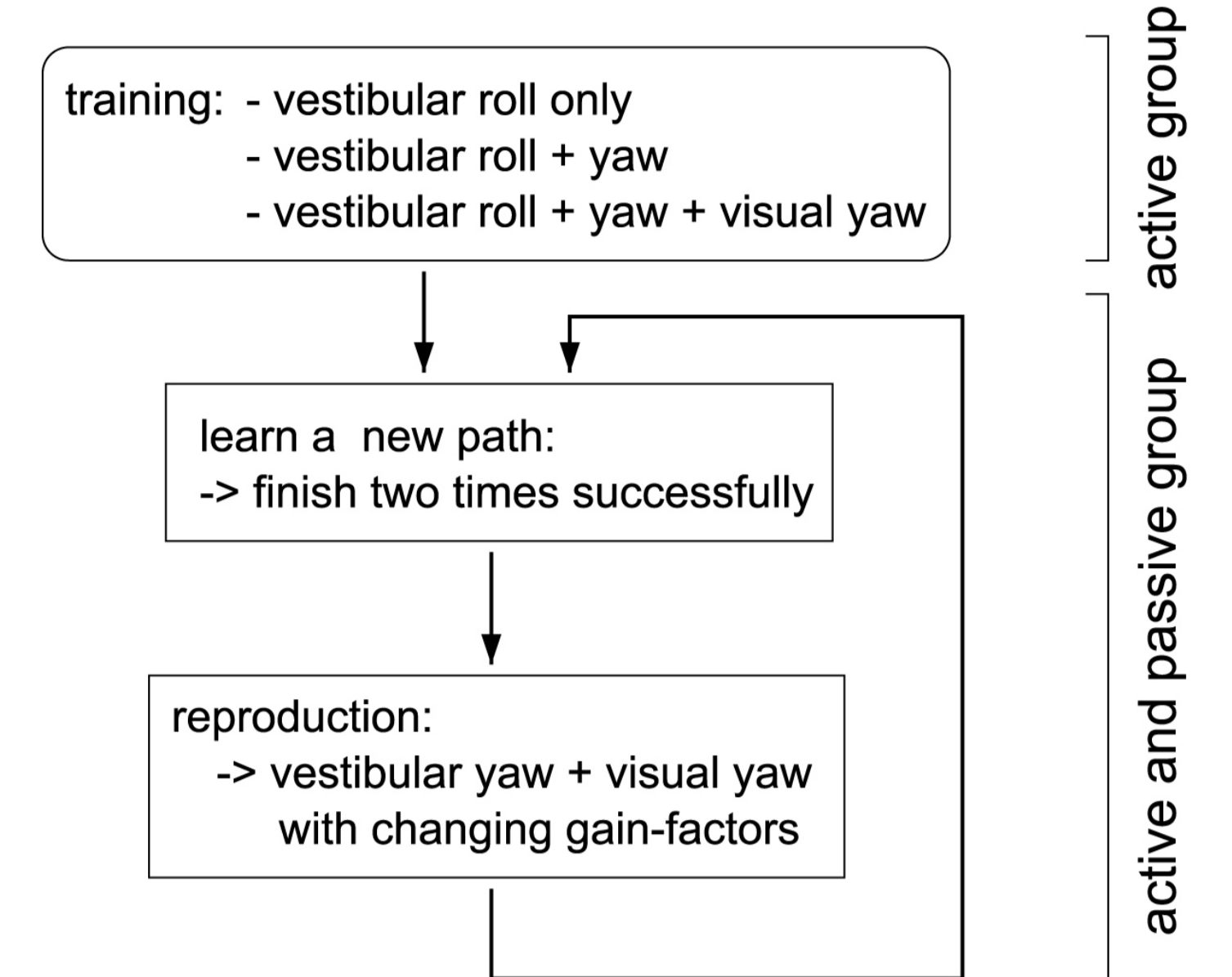


Fig. 1: After successfully following a vestibularly defined path twice, subjects (six in each group) were asked to reproduce it from memory.

The vestibular path

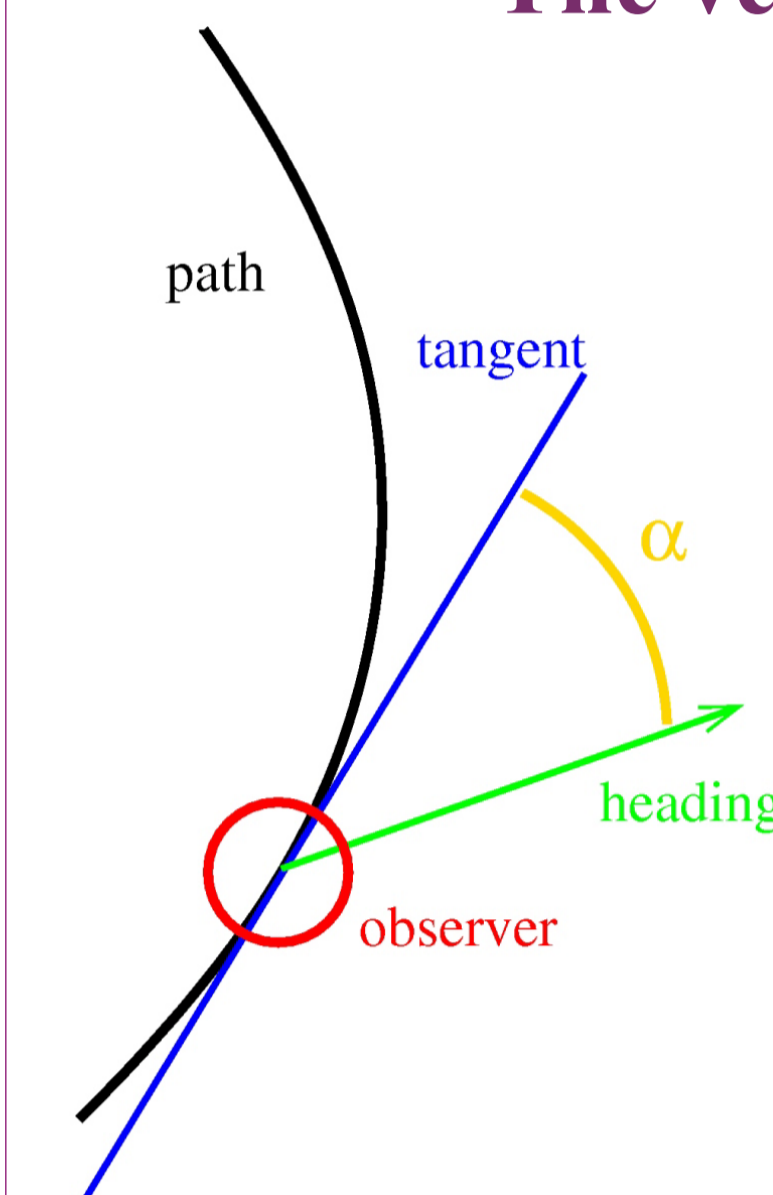


Fig. 2: Subjects followed an invisible randomly generated path including heading changes between 8.5 and 17 degrees. Heading deviations from this path were presented as vestibular roll rotation for the ACTIVE group. Hence the path was solely defined by vestibular (and proprioceptive)

Snapshots of the visual scenes



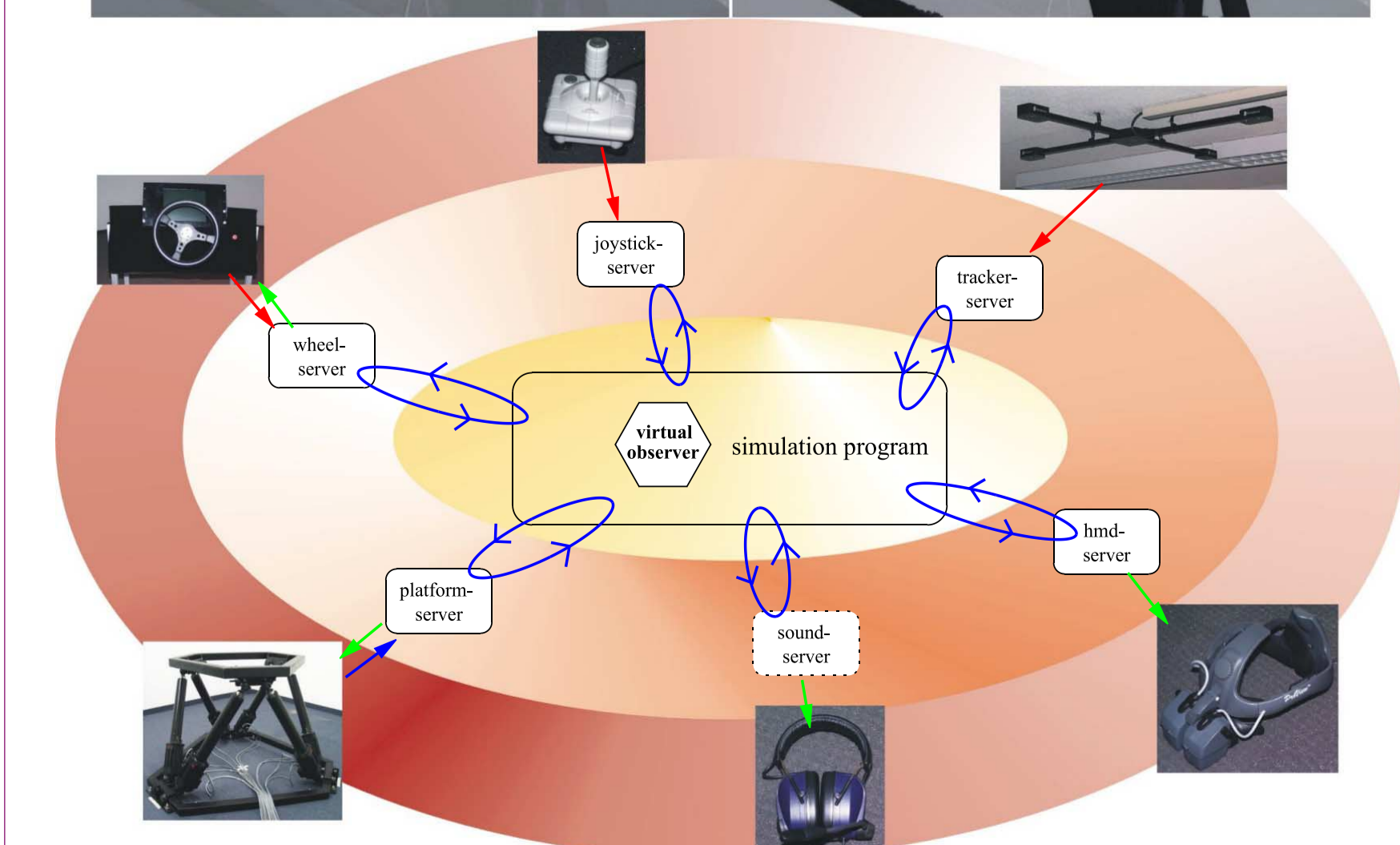
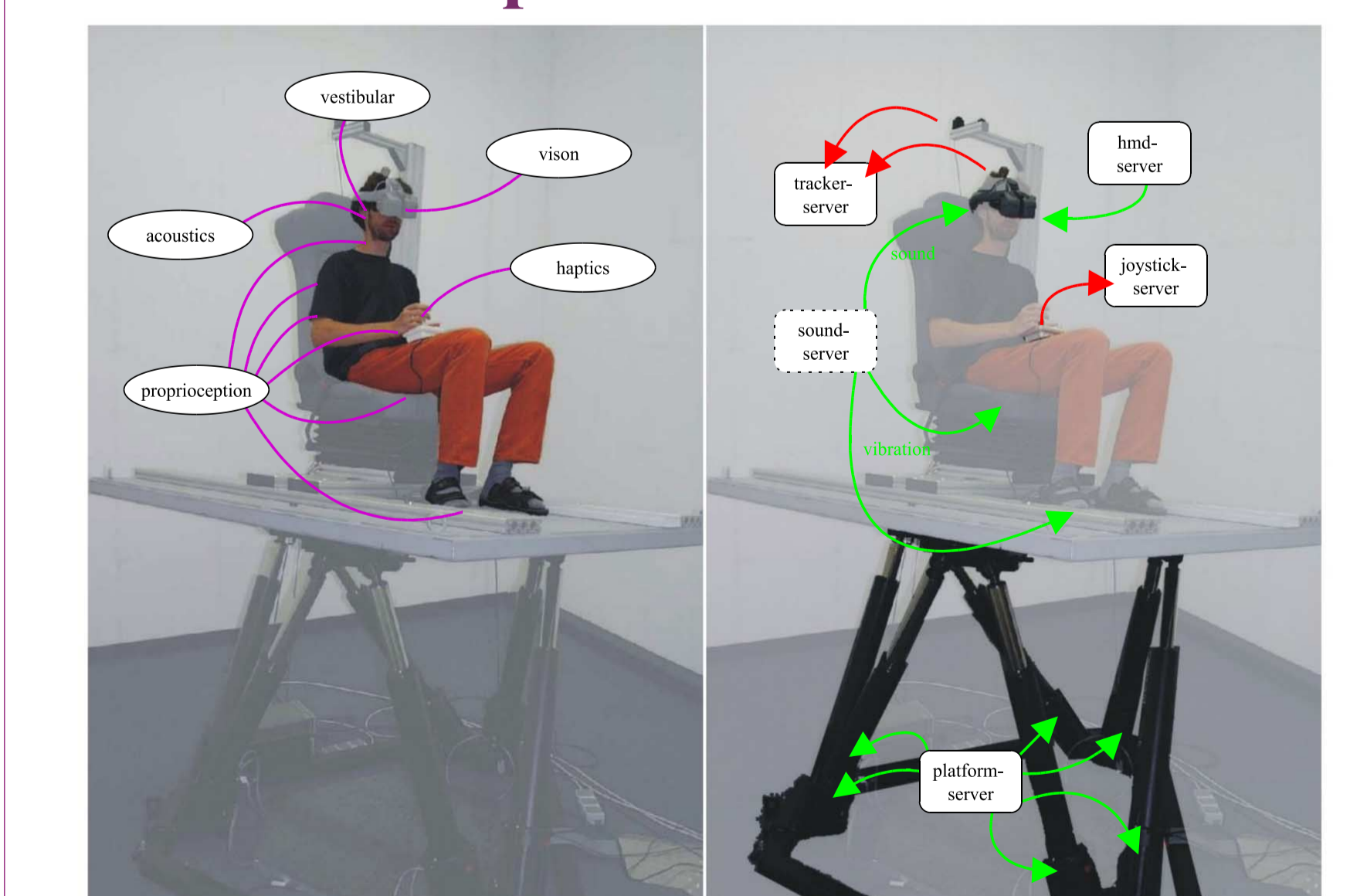
Fig. 3: The textured ground plane (grass) provides optic flow information only (ACTIVE, PASSIVE, ZERO). The town scene provides additional landmark information and absolute size cues (SAME ORIENTATION & RANDOM ORIENTATION).

Bird's eye view of town scenery



Subjects never saw any bird's eye view of the scenery.

VR setup in the Motion-Lab



We used a VR system including a motion simulator (Stewart platform) and a head-mounted display for presenting vestibular and visual stimuli, respectively.