MAX-PLANCK-GESELLSCHAFT

MPI FOR BIOLOGICAL CYBERNETICS

From Virtual Images to Actions

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MPI for Biological Cybernetics

Basic Research
on biological information processing

How does the brain work?

Algorithms of Perception –

Psychophysics Department
Bülthoff, 1993

Biological Hardware –

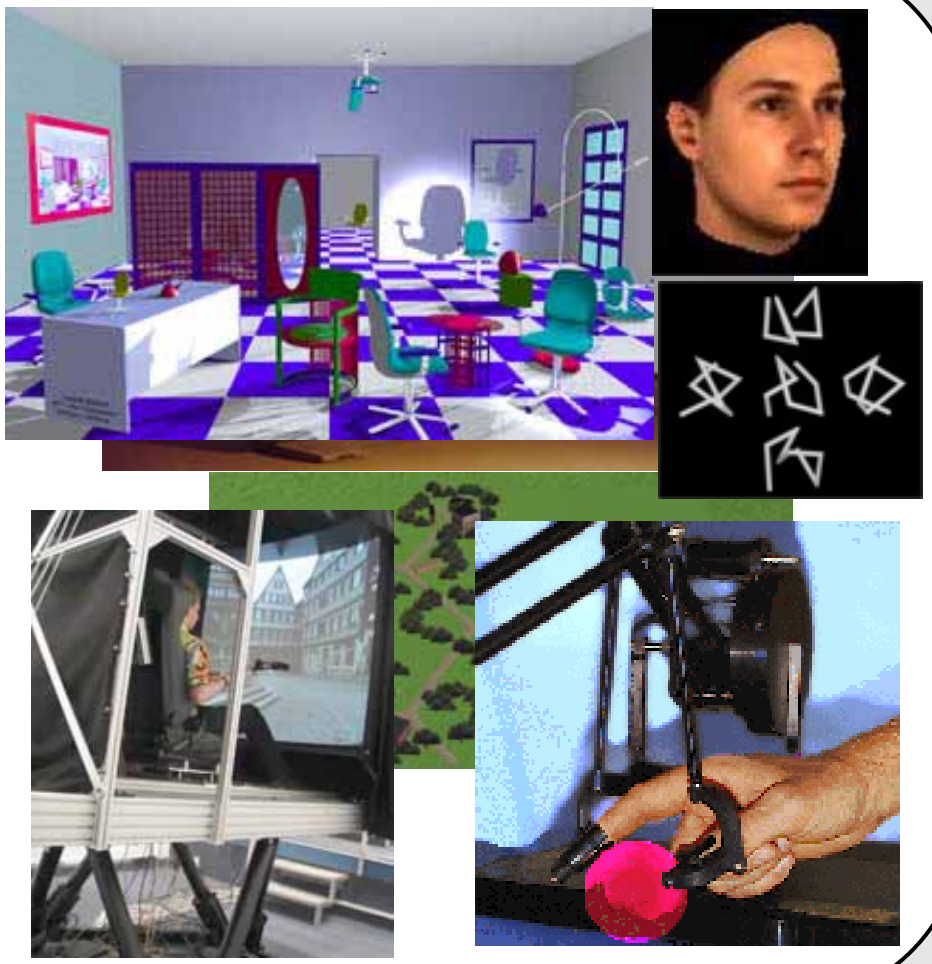
Neurophysiology Department
Logothetis, 1997

Theory –

Empirical Inference Department
Schölkopf, 2001

Psychophysics Department

- **Recognition**
  - scenes and faces
  - categorization
- **Spatial Cognition**
  - navigation
  - spatial updating
- **Sensory Integration**
  - visual-vestibular
  - visual-haptic
  - visual-auditory
  - ...

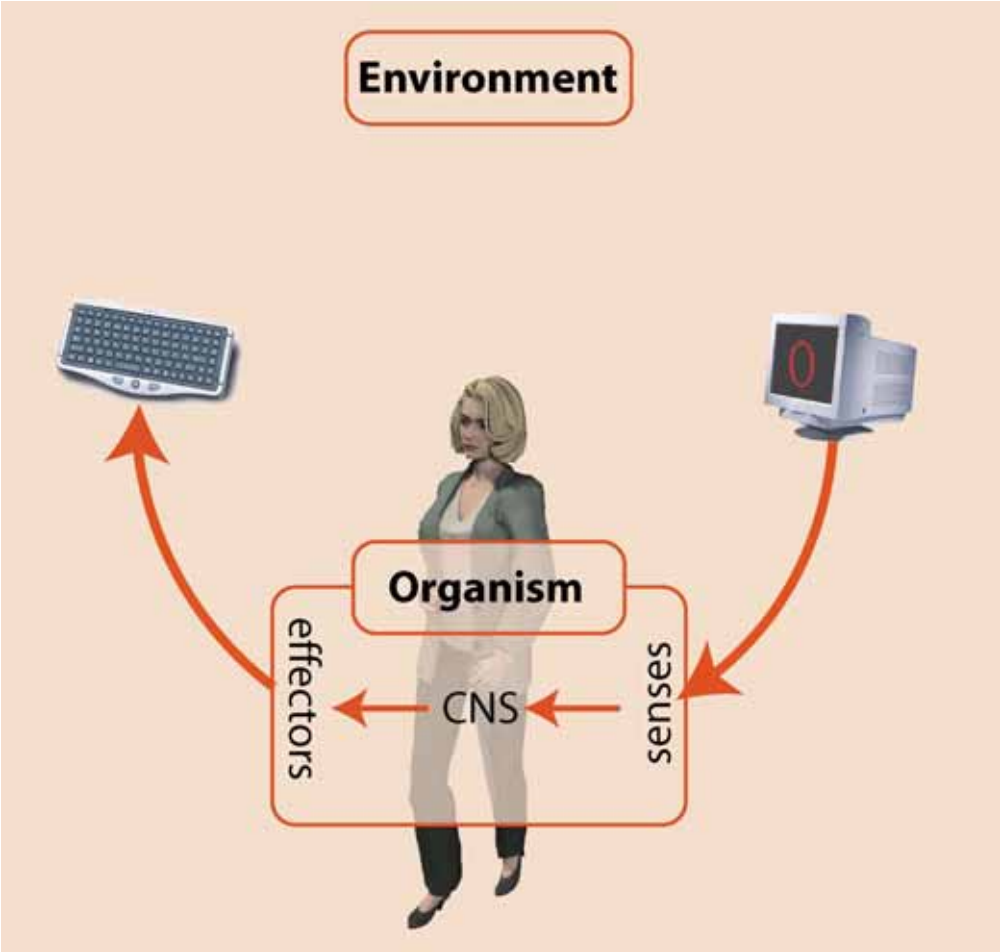


Research Philosophy
image-based computation

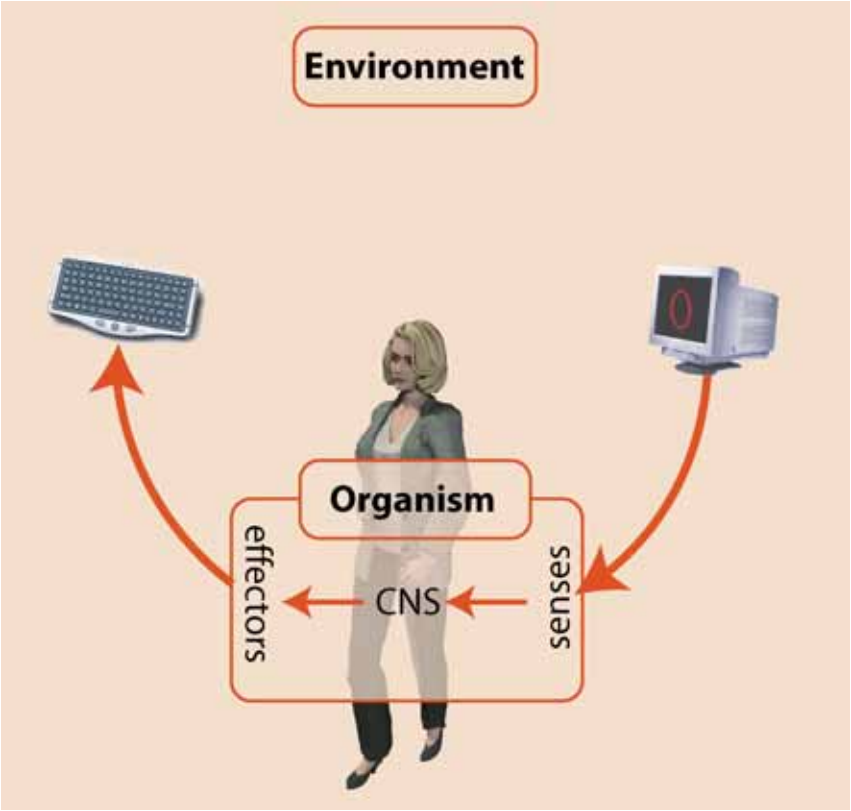
- study human perception in natural settings using
  - **Computer Graphics** to generate natural but well controlled stimuli
    - Image-based material editing
      E. Khan, E. Reinhard, R. Fleming, H. Bülthoff, SIGGRAPH 2006

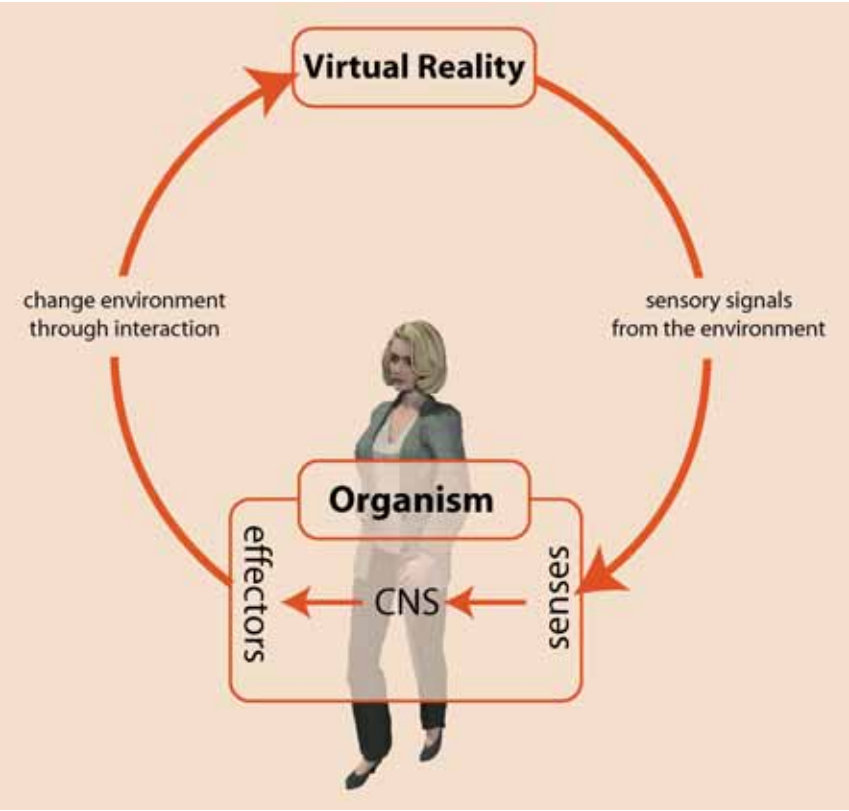
  - **Virtual Reality** to study perception and action in a closed loop
  - imaged-based navigation
  - spatial updating
  - visual capture

Classical Psychophysics
open loop



VR Psychophysics closed loop





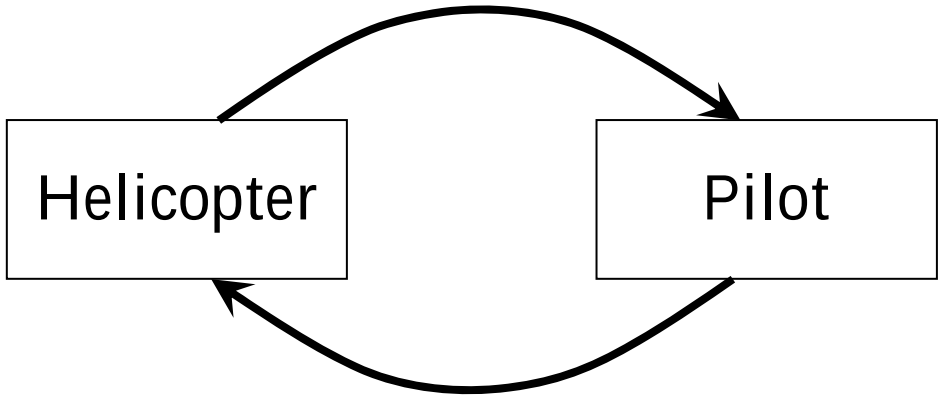
Multimodal Integration for Control tasks

- control task pose a whole new set of problems for integration
- new research direction of our lab
- how are cues integrated during active control of orientation in space
  - 3D maze navigation *(Vidal & Berthoz, 2005)*
  - body sway (*Cunningham et al, 2006*)
  - flight control *(Beykirch et al, 2006)*
  - **helicopter stabilization** *(Terzibas and Berger, 2005)*

Unstable Helicopter Control

- a helicopter behaves like an inverse pendulum
- accelerates roughly in the direction it is tilted to
- different axes are dynamically coupled, so compensation for one axis effects other axes
  - e.g., forward acceleration with *cyclic stick* tilts the rotor plane and therefore reduces the lift force. This has to be compensated by lifting the *collective* and the resulting increase in torque induces yaw rotation which has to be corrected with the *pedals.*

Experimental Question



- How are cues from multiple modalities integrated for *action* in a control task with the human 'in-the-loop'?

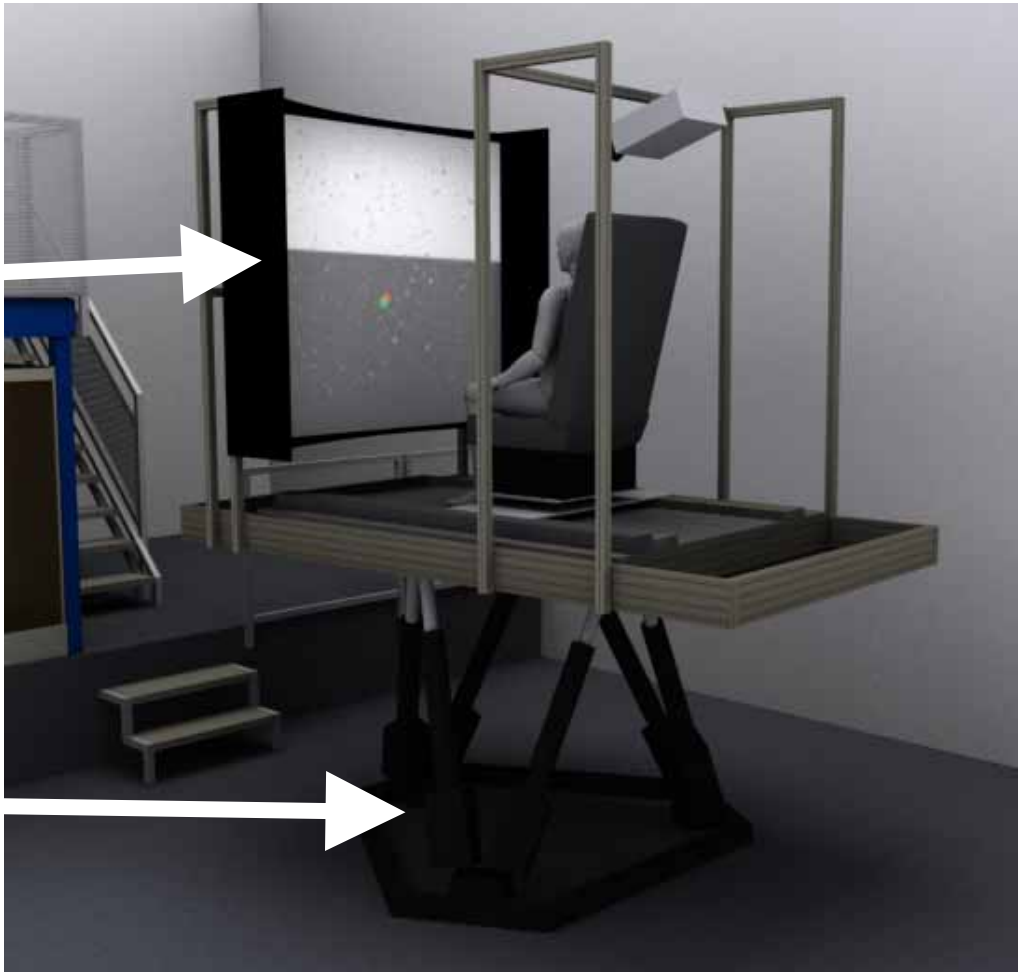
Experiment

- Let participants stabilize a simulated helicopter at a target location
- Measure stabilization performance in different visual and body motion cueing conditions
- Analyze which cues have significant influence on the subject's performance, and how different cues interact

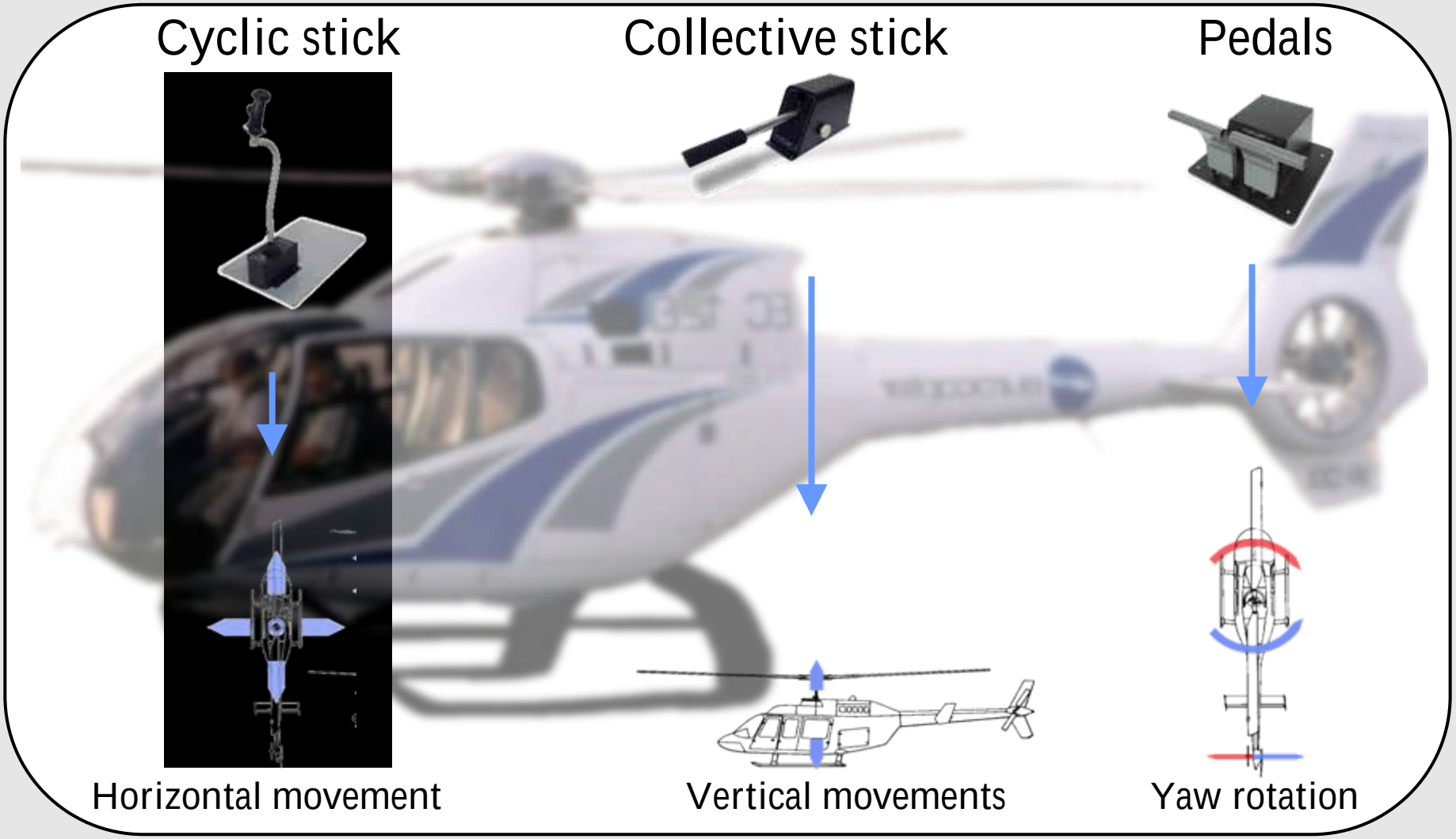
Experimental Setup

Projection system for real-time computer-generated scenes

Motion base with six degrees of freedom



Helicopter Control Devices



Sensory cues usable for helicopter stabilization

Inertial information

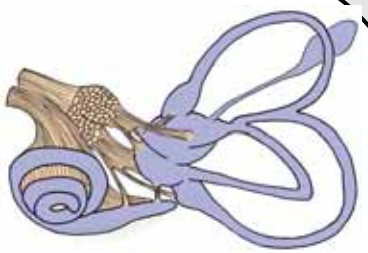
- vestibular sense
- body senses for orientation and self-motion

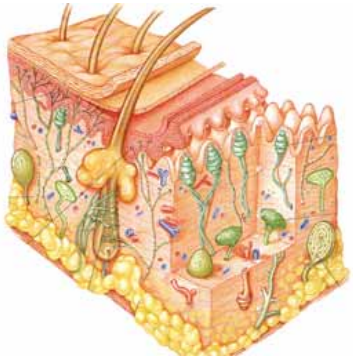
Visual Information

- horizon
- optic flow
- movement of objects (landmarks)

Inertial Information

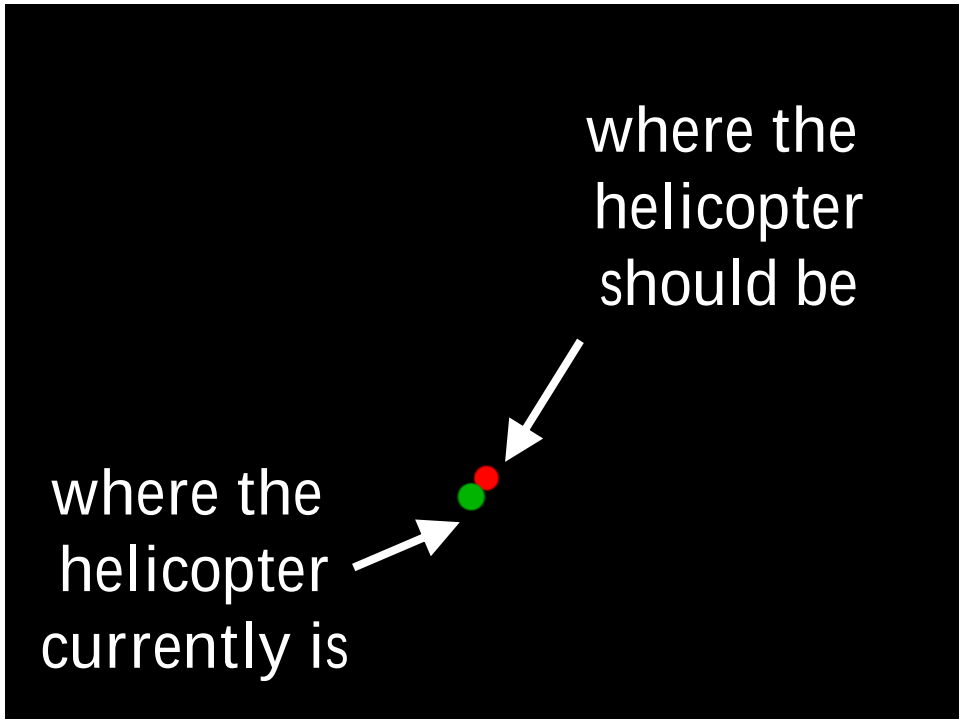
- Vestibular system signals rotations (canals) and linear accelerations including gravity (otoliths)
- Accelerations are also sensed by somatosensory receptors (skin, tendons)





In this experiment, we used whole-body rotation cueing ⇨ vestibular + seat-of-the-pants

Visual Information – Target and Helicopter Sphere

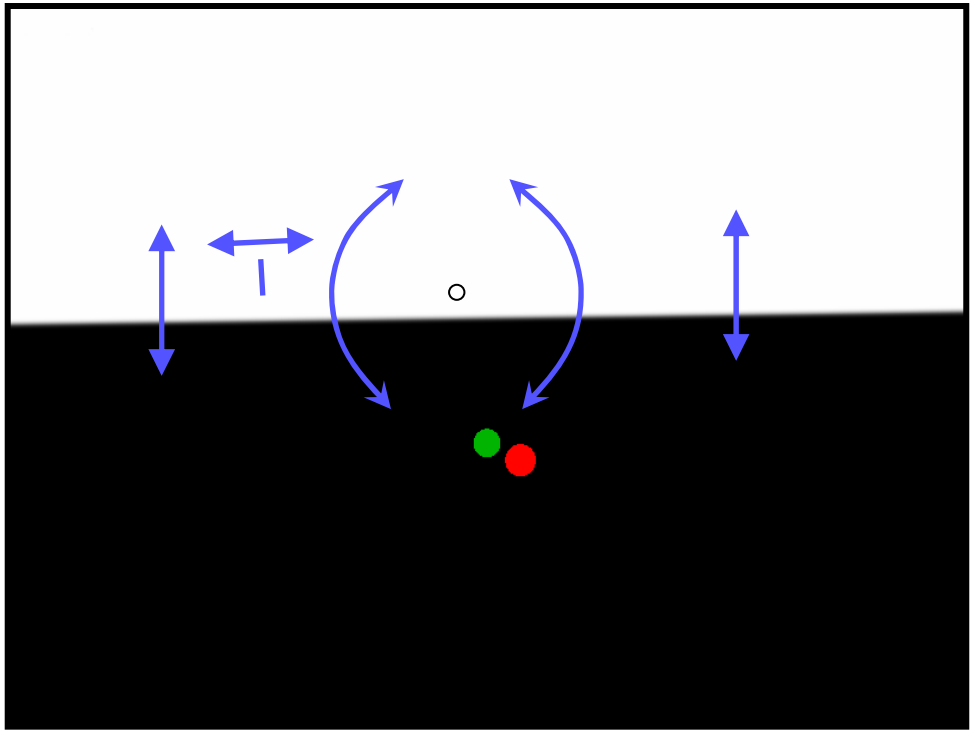


Object (landmark) position and motion:

How much information is provided by the two spheres alone?

The two spheres had to be shown in all conditions to provide feedback about helicopter and target position

Visual information – Horizon



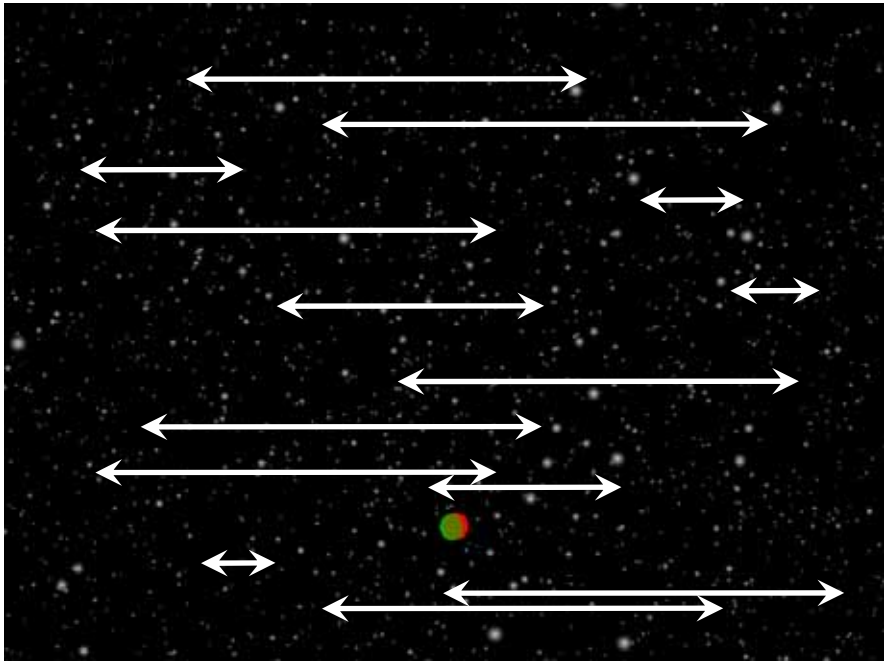
Horizon indicates the *absolute orientation* of the observer with respect to

- earth-vertical --sideways roll
- forwards/backwards pitch

Sideways movement of objects at the horizon (far away) tells about rotations around the earth-vertical axis

In a helicopter, tilt of the observer is roughly equal to the direction of acceleration!

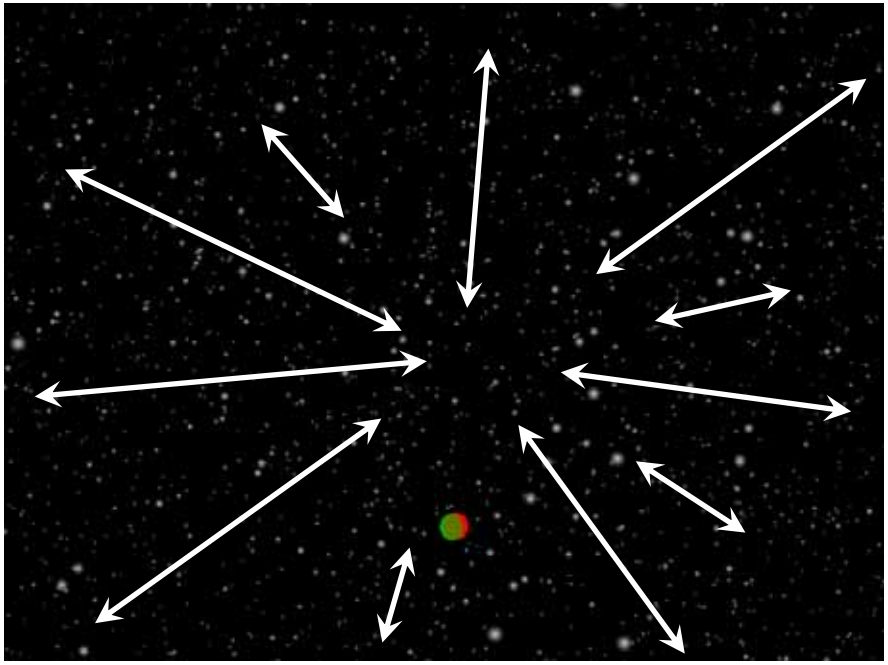
Visual information – Optic flow



Different motion vector fields signal self-motion:

- Rotation around a vertical axis
- Sideways translation

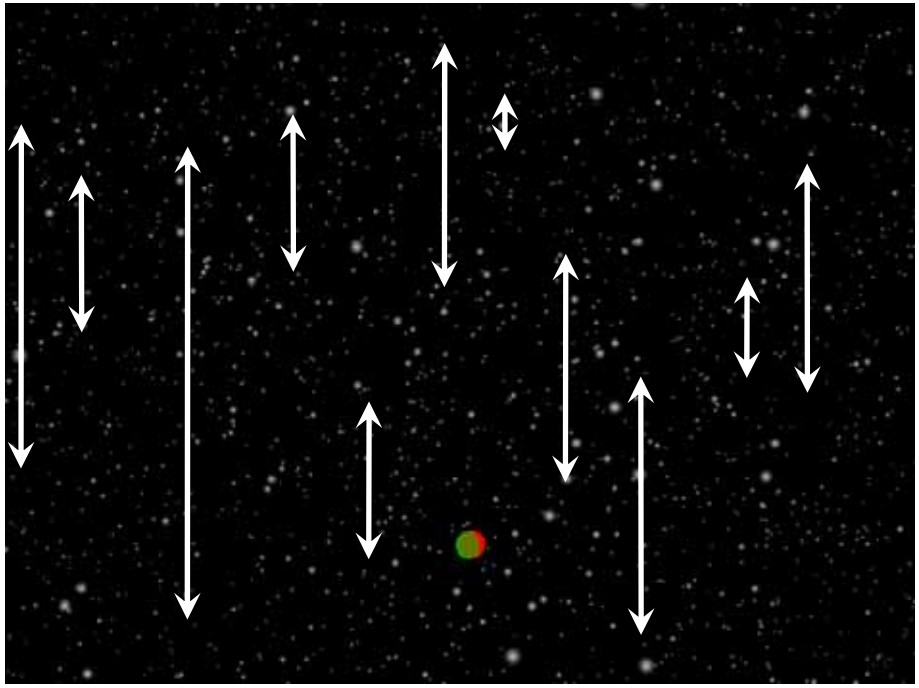
Visual information – Optic flow



Different motion vector fields signal self-motion:

- rotation around a vertical axis
- sideways translation
- forward / backward translation

Visual information – Optic flow



Different motion vector fields signal self-motion:

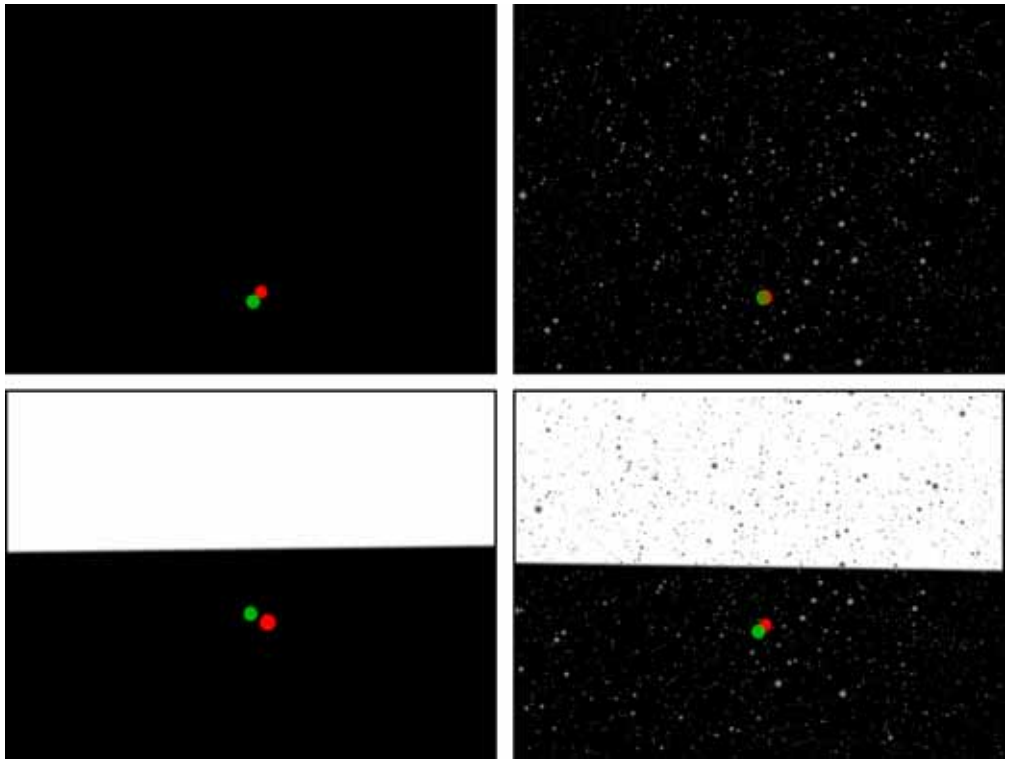
- rotation around a vertical axis
- sideways translation
- forward / backward translation
- up / down translation

.. as well as other rotations and translations

Motion fields mix for more complex movements

Optic flow can only signal *relative* position and movements

Experimental Stimuli



Visual Stimuli:

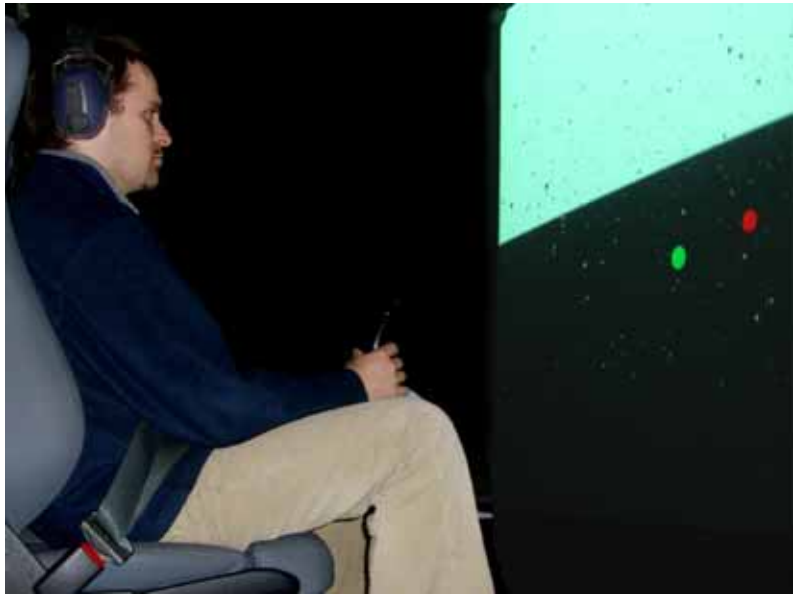
- black background (B)
- optic flow (OF)
- horizon (H)
- optic flow + horizon

Inertial Stimuli:

Platform rotations On/Off

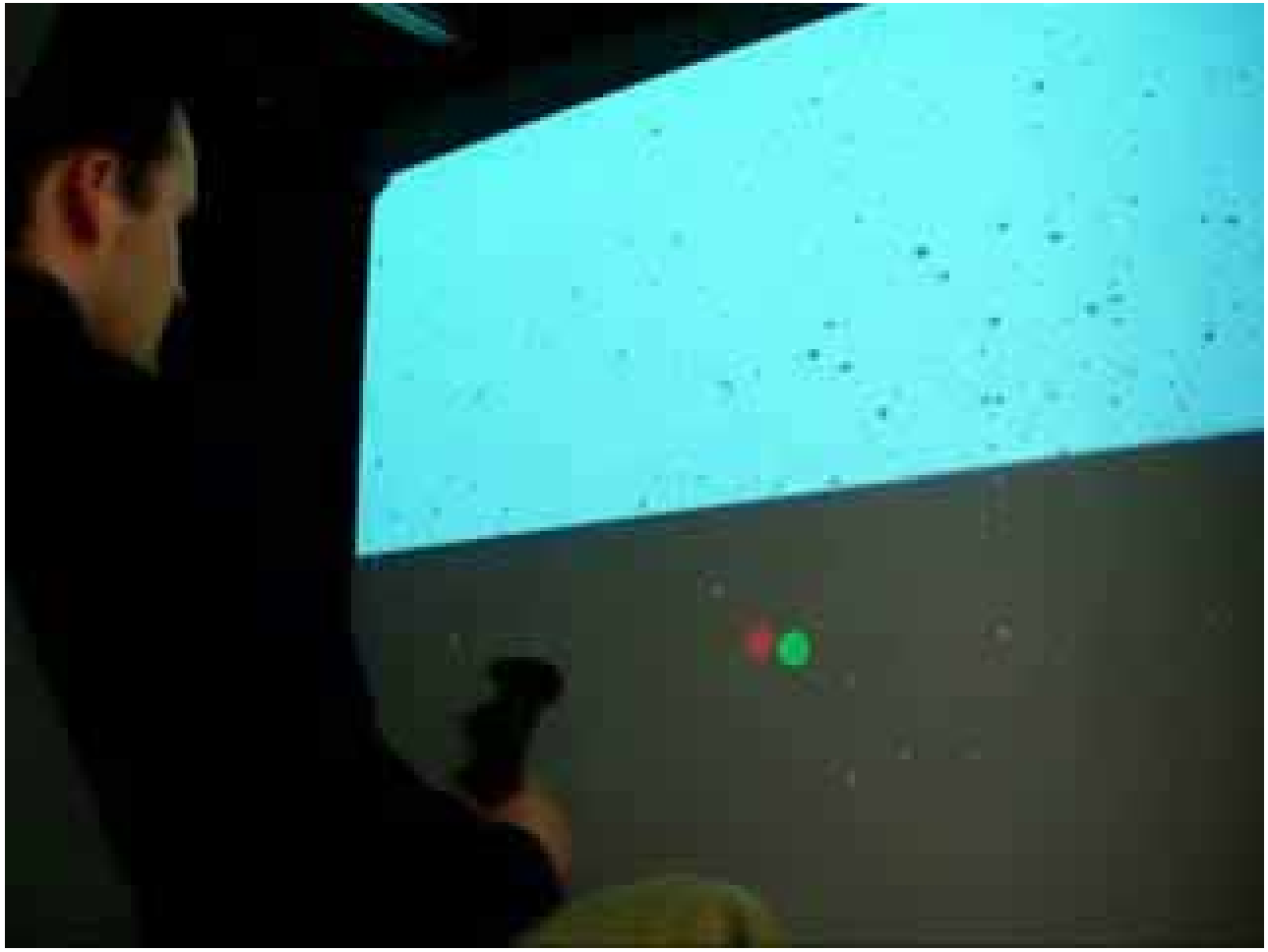
- **Task**: stabilize helicopter at a target spot
- **Measure**: mean distance, velocity, and tilt angles

The Experiment

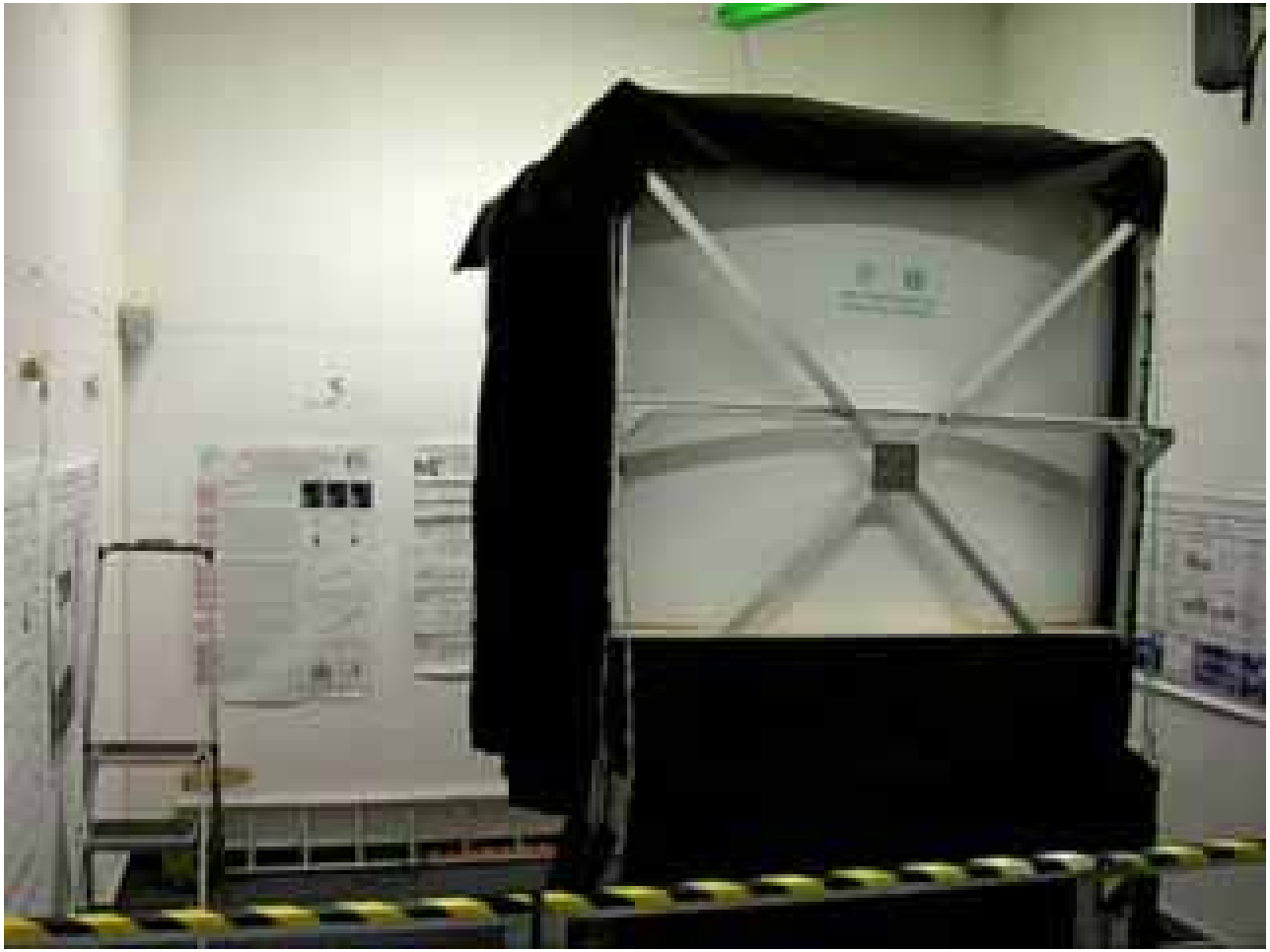


- Subjects had several hours of training before the experiment (all participated in a previous experiment)
- In each trial, participants had to stabilize for 2 minutes
- 5 experimental blocks with 10 trials each (10 conditions, overall 20 minutes per condition)

The Experiment



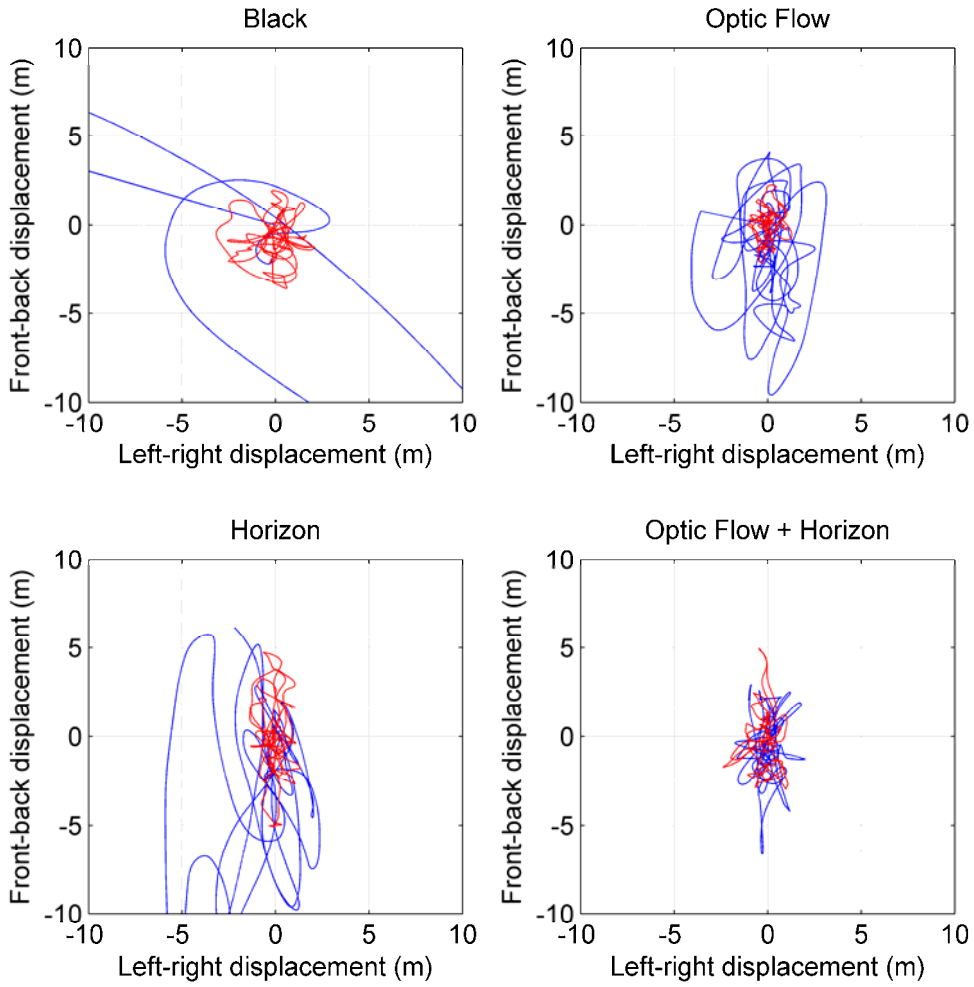
The Experiment

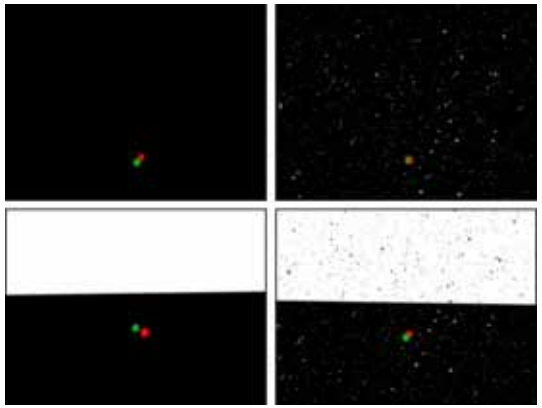


Optic flow + Horizon

Black background

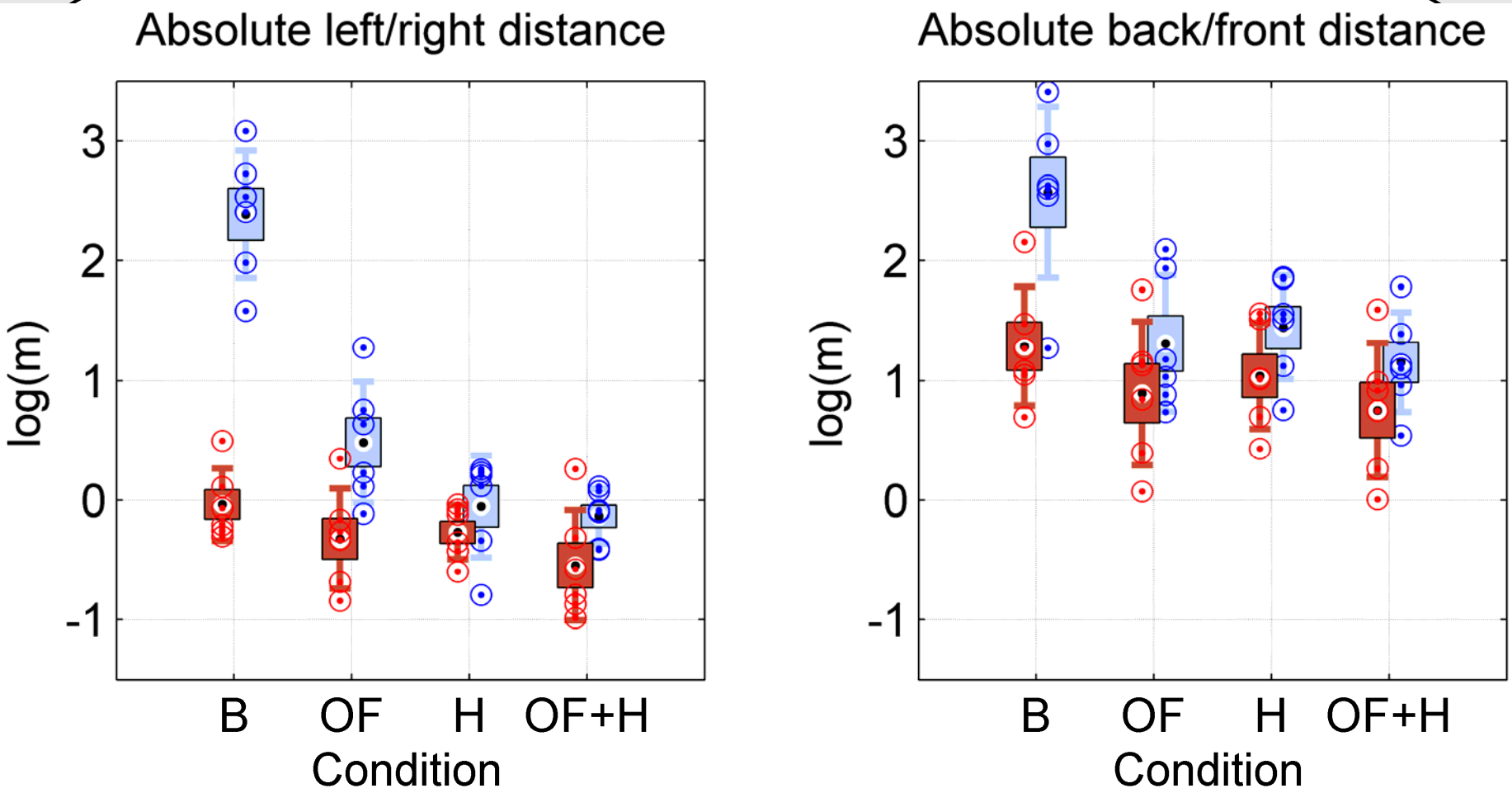
Example trajectories





Platform off
Platform on

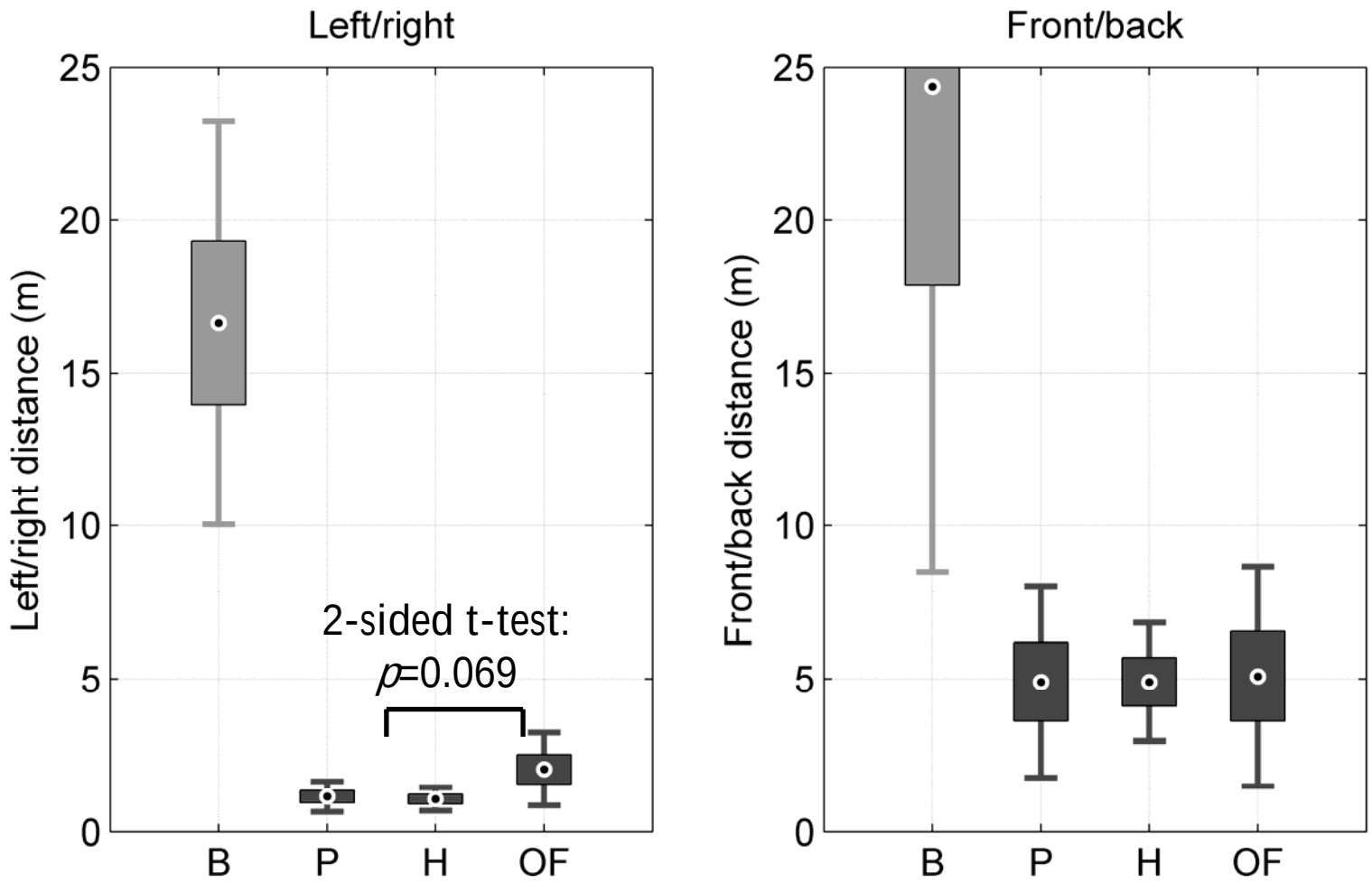
Results


Absolute left/right distance
log(m)
3
2
1
0
-1
B
OF
H
OF+H
Condition
Absolute back/front distance
log(m)
3
2
1
0
-1
B
OF
H
OF+H
Condition

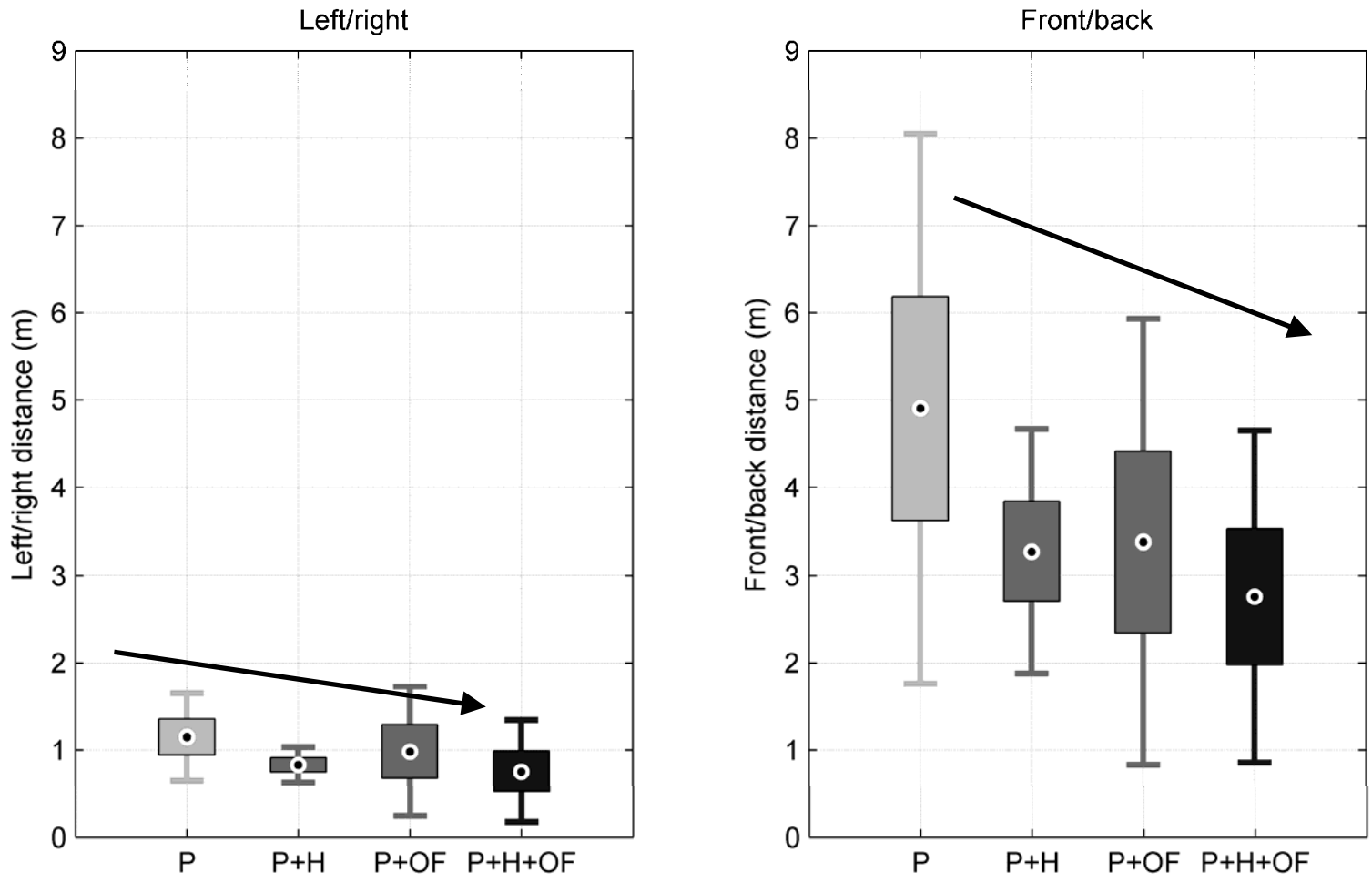
ANOVA Results

- ANOVA with direction (front/back vs. left/right), platform (on/off), optic flow (on/off), and horizon (on/off) as within-subject factors:
- All main effects are significant, as are most interactions
- Front/back stabilization worse than left/right
- Adding cues improves performance

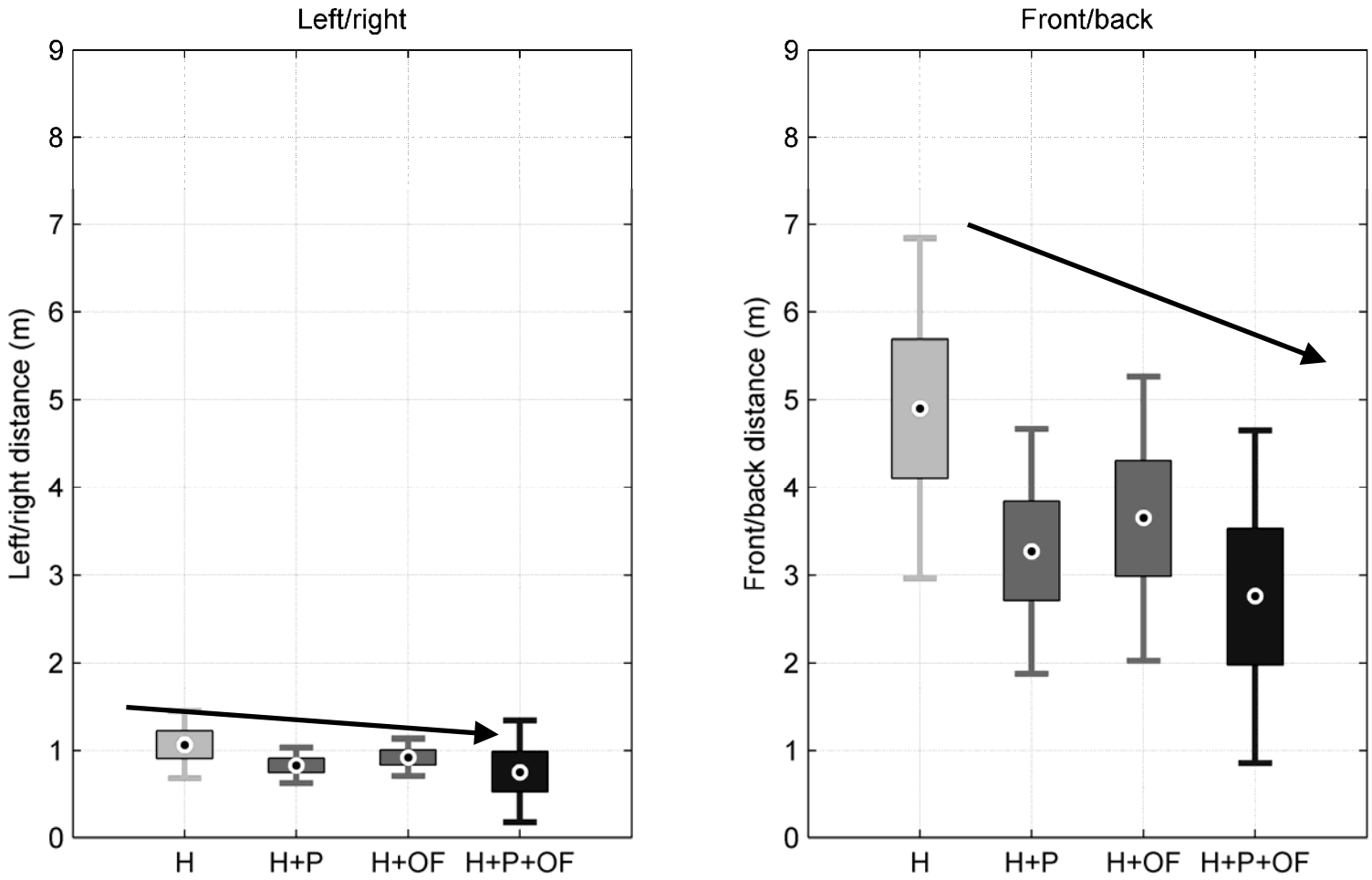
Effect of single cues



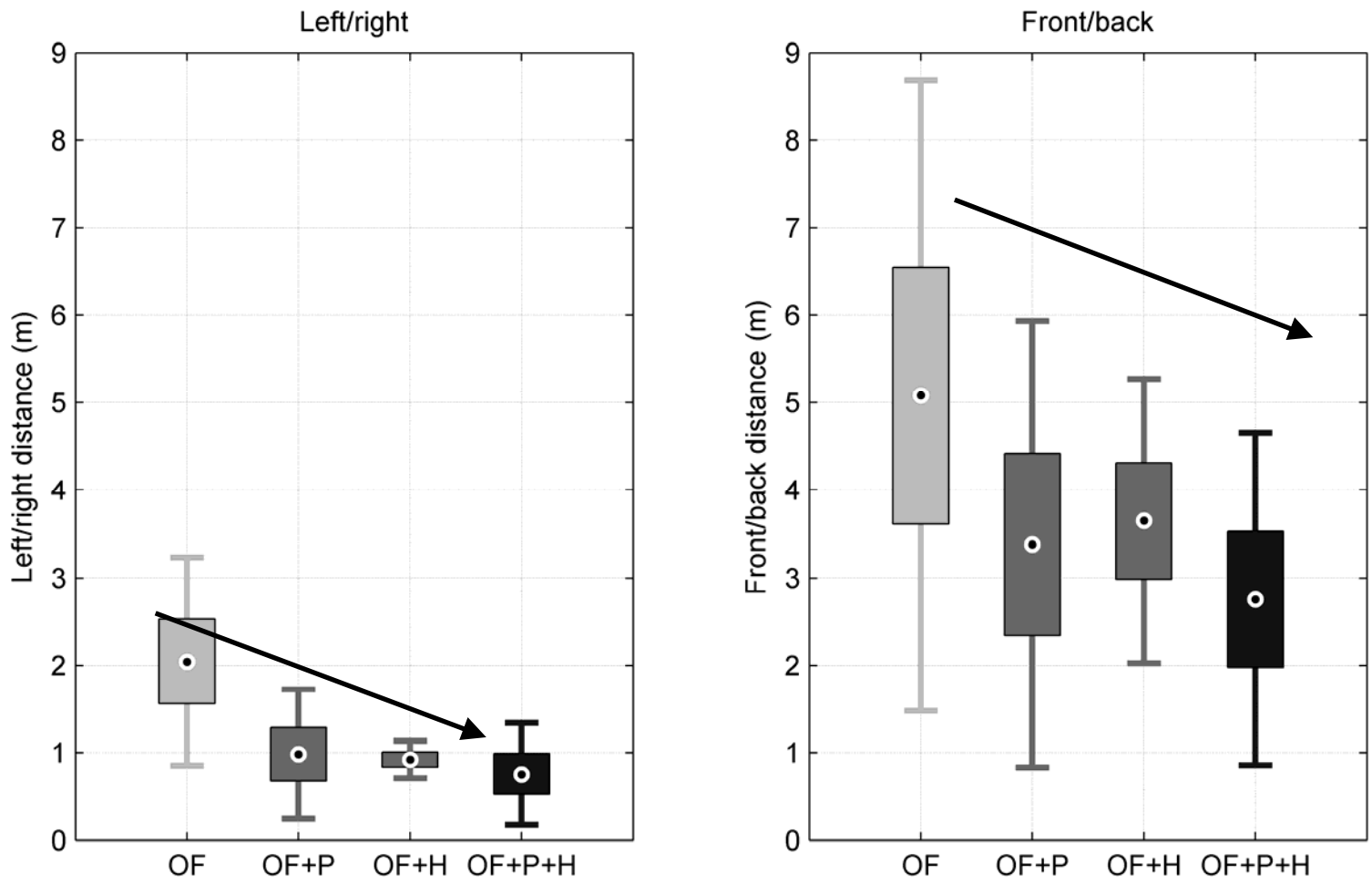
Platform and additional cues



Horizon and additional cues



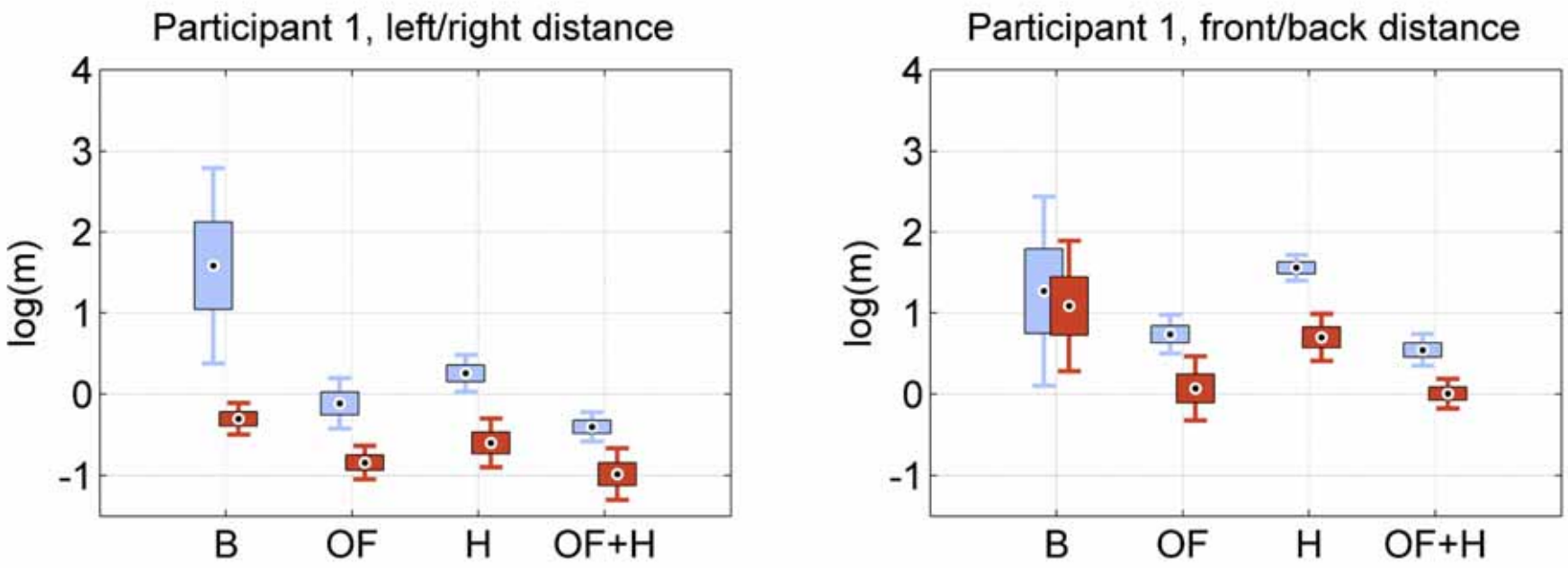
Optic flow and additional cues



Maximum Likelihood (MLE)?

- Measured response is the output of a complex dynamic helicopter-pilot system
- No easy way to estimate the cue reliabilities from the responses
- However, reliabilities and response quality should be correlated: better self-motion perception (for example if additional cues are provided) should lead to better control
- General results are consistent with MLE

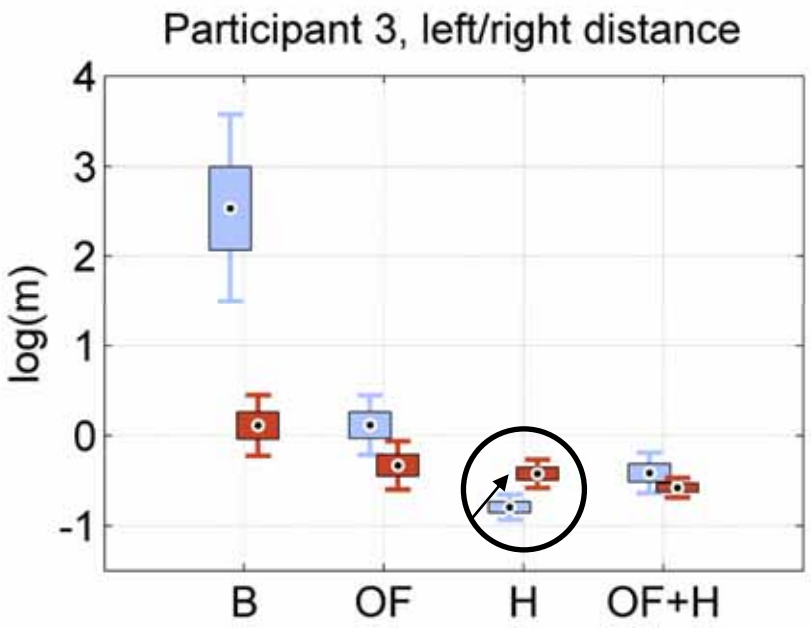
Responses consistent with MLE: Effect of platform rotations

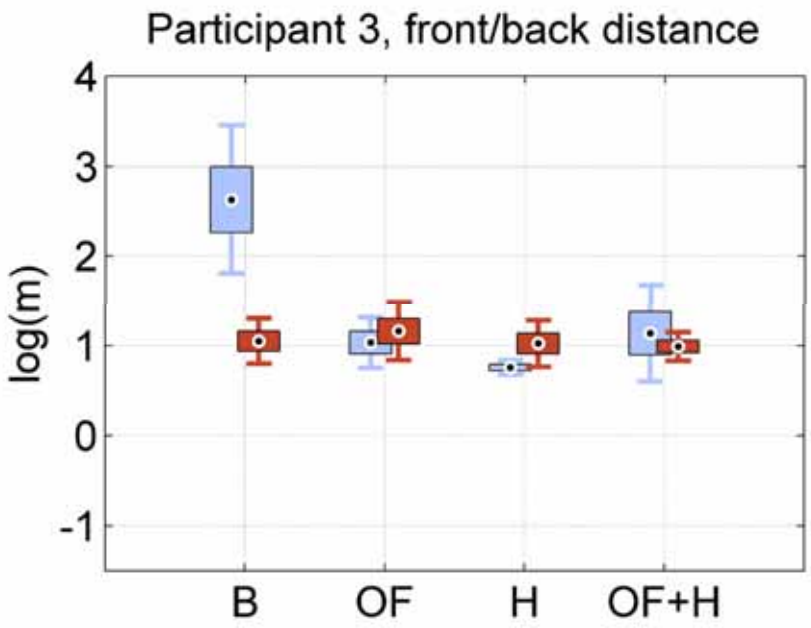


- Platform off
- Platform on

B: black background, **OF**: optic flow
H: horizon, **OF+H**: optical flow and horizon

But…





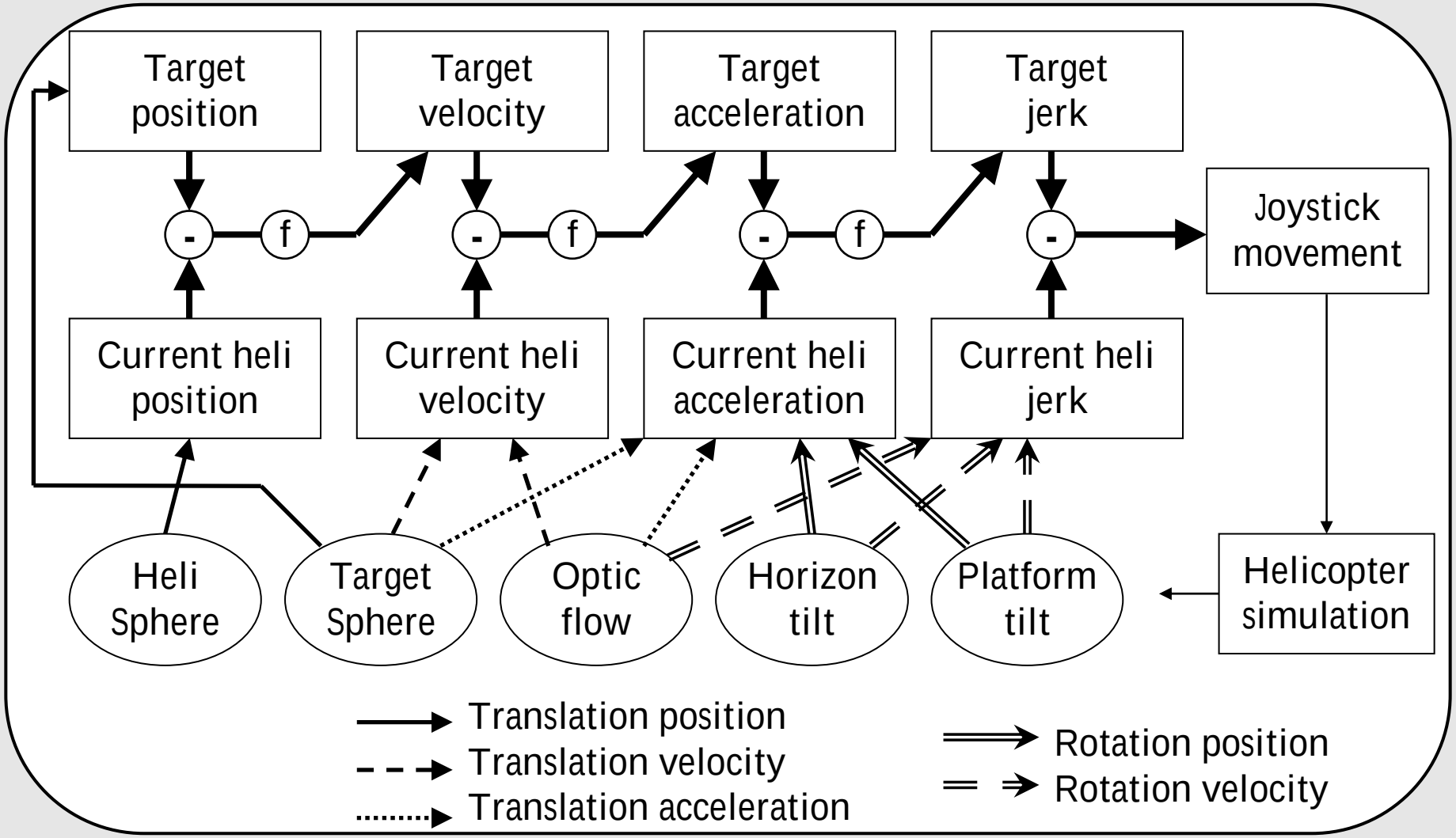
- Platform off
- Platform on

B: black background, **OF**: optic flow
H: horizon, **OF+H**: optical flow and horizon

Results

- All three cues (platform, horizon, optic flow) significantly helped participants to stabilize
- Horizon position less important than horizon motion
- If more cues are available, stabilization performance increases (consistent with MLE)
- *But:* for some participants in some conditions, adding a cue decreases performance
- Not explainable with a statistically optimal Bayesian integration framework
- Possibly evidence for a *strategy change*

A model of a helicopter pilot



Outlook

- More participants
- Model helicopter pilot as dynamical system and fit model to responses
- Include platform translation
- Investigate different motion cueing algorithms

Members of the perception-action lab


Daniel Berger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Andreas Wacker


Bernhard Riecke


Cengiz Terzibas


Jörg Schulte-Pelkum


Michael Weyel


Marc Ernst

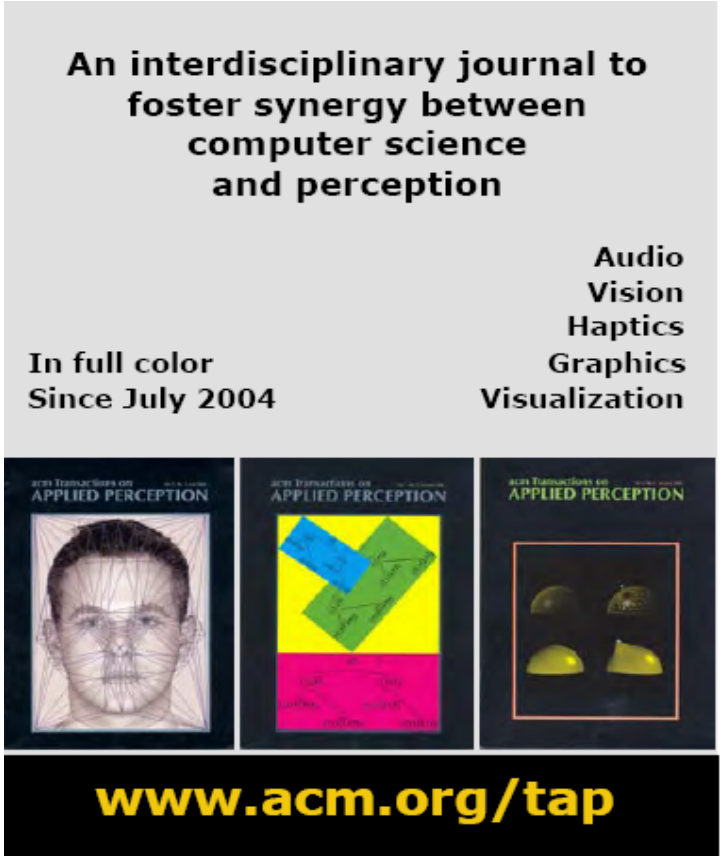

Harald Teufel


Heinrich Bülthoff


Jan Wiener


Manuel Vidal

ACM Transactions on Applied Perception



APGV

Applied Perception in Graphics and Visualization

Boston, before SIGGRAPH

- Interdisciplinary meeting to foster synergy
  - between perception and computer science
  - every year
- alternating between SIGGRAPH and ECVP

  This symposium seeks to provide a forum
  for the wider exchange of ideas and information
  - between members of the graphics and visualization communities who are using insights from visual/auditory/haptic perception to advance the design and guide the evaluation of methods for more effective visual/auditory/haptic representation,
  - and members of the vision sciences community who are using computer graphics to facilitate the investigation of fundamental processes of perception.