Contribution and interaction of visual and vestibular cues for spatial updating in real and virtual environments

Bernhard E. Riecke,
Markus von der Heyde, &
Heinrich H. Bülthoff

Max Planck Institute for Biological Cybernetics, Tübingen, Germany
Red Thread

• Problem: Disorientation in Virtual Reality

• Why? What is missing? Vestibular cues?

• What did we find?
  – Vestibular cues *not* required
  – Visual cues *can* be sufficient

• What was missing? “Spatial updating”!
generalized spatial updating
= transformation of egocentric mental
  spatial reference frame, e.g.,
during imagined ego-motions or perspective-taking

(automatic) spatial updating
  automatized, quick, intuitive,
  low cognitive load,
  does not require (much) attention,
  --> spatial cues CAN be used for spatial updating

obligatory spatial updating
  reflex-like, hard-to-suppress,
  cognitively mostly impenetrable,
  --> spatial cues MUST be used for spatial updating

“Automatic” vs. “Obligatory” Spatial Updating?
Goals

Goal 1: What is needed for *automatic* spatial updating?
1 a) Can visual cues alone be sufficient?
1 b) When do vestibular motion cues become important?
   - Task: UPDATE vs. CONTROL

Goal 2: How can we obtain *obligatory*, reflex-like spatial updating?
i.e., What spatial cues are powerful enough to transform the world inside our head even against our own conscious will
   - Task: IGNORE vs. UPDATE

Ultimate goal: Understanding
a) Spatial cognition: How is spatial information used in human brain
b) Human factors: How to cheat intelligently
Methods – Virtual Scenery

Targets: 22 landmarks
Methods - Setup

- **Vestibular stimuli: 6 dof Motion Platform**
- **Visual stimuli: LCD video projection setup**
  - 86 x 63deg FOV

**Task: Speeded pointing after consecutive rotations**

1. Auditory announcement of next trial
2. Motion phase (turn)
3. Pointing phase:
   - Auditory target announcement
   - Subsequent speeded pointing to currently invisible targets: Point “as accurately and quickly as possible!”
   - Raising pointer to upright (default) position
   - Repeat 4 times
Methods – Experimental Design

- N=17 participants
- Within-subject design
- 3 spatial updating conditions were alternated
  - CONTROL (baseline for “optimal” performance)
  - UPDATE (can spatial cues be used for spatial updating? → test automatization, i.e., automatic spatial updating)
  - IGNORE (must spatial cues be used for spatial updating? → test reflex-like character, i.e., obligatory spatial updating)
- 3 independent variables were balanced:
  - 3 spatial updating conditions (update, control, ignore)
  - 2 visual conditions
  - 2 vestibular conditions

<table>
<thead>
<tr>
<th></th>
<th>landmarks</th>
<th>optic flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>platform ON</td>
<td>blue</td>
<td>red</td>
</tr>
<tr>
<td>platform OFF</td>
<td>green</td>
<td>yellow</td>
</tr>
</tbody>
</table>
Goal: What is needed for good baseline (control) performance?

→ Landmarks are needed for optimal baseline performance (Optic flow is not quite insufficient)

→ Vestibular cues don’t help
Goal 1: What is needed for good spatial updating? (What spatial cues *can* be used?)

→ Photo-realistic visual stimuli (landmarks) are sufficient for enabling good spatial updating (update ∼ control), irrespective of vestibular cues

→ Vestibular cues are only relevant when visual cues are insufficient (optic flow)
Results – *Obligatory* (reflex-like) Spatial Updating

Goal 2: How can we obtain *obligatory*, reflex-like spatial updating? (What spatial cues *cannot be suppressed*)

→ Photo-realistic visual stimuli (landmarks) are sufficient for inducing obligatory, reflex-like spatial updating (ignore >> update),

→ Optic flow is insufficient (ignore < ~ update)

→ This is true irrespective of concurrent vestibular cues
Schlussfolgerungen

• **Landmarken:** Photorealistische visuelle Reize einer bekannten Szene ermöglichen *automatisches spatial updating* und können *obligatorisches spatial updating* auslösen, unabhängig von vestibulären Reizen. → Dominanz visueller Landmarken

• **Optischer Fluss:** reicht *nicht* aus für schnelles und genaues spatial updating (weder obligatorisches noch automatisches)
  – IGNORE einfacher als UPDATE, aber nicht so einfach wie CONTROL
  – → Optischer Fluss beeinflusst die mentale Raumrepräsentation

• **Vestibuläre Reize:** Helfen unzureichende visuelle Reize teils zu kompensieren → reduzierter Konfigurationsfehler (& Desorientierung?)

• Spatial updating wurde durch zusätzliche vestibuläre Reize jedoch nicht obligatorischer!

• **Fazit:** „Gute“ Landmarken, in eine konsistente, bekannte Umgebung eingebettet, können den visuo-vestibulären Konflikt und das Fehlen vestibulärer Drehreize überdecken und obligatorisches spatial updating auslösen

Weitere Info: [http://www.kyb.tuebingen.mpg.de/~bernie](http://www.kyb.tuebingen.mpg.de/~bernie) or bernhard.riecke@tuebingen.mpg.de
Conclusions

• Optic flow is insufficient for quick and accurate spatial updating
  – IGNORE easier than UPDATE, but not as easy as CONTROL
  – Optic flow did have effect on mental spatial representation

• Photo-realistic visual stimuli from a well-known scene can enable automatic spatial updating as well as initiate obligatory spatial updating, irrespective of vestibular cues.

→ Visual dominance for landmarks

• Vestibular cues can be used to partially compensate for insufficient visual cues (configuration error decrease)

• However, vestibular cues do not render spatial updating more obligatory!

• This suggests that “good” landmarks imbedded in a consistent, well-known scene can overcome the visuo-vestibular cue conflict and lack of vestibular turn cues and initiate obligatory spatial updating.

Further info: http://www.kyb.tuebingen.mpg.de/~bernie or bernhard.riecke@tuebingen.mpg.de
• (not used in the talk)
Results – Landmark Conditions, Platform On

- **Can visual landmarks + vestibular cues be used for spatial updating?**
  → Yes, update is almost as easy as control

- **Must landmarks be used for spatial updating? I.e., are they capable of triggering obligatory spatial updating?**
  → Yes, IGNORE >> UPDATE (p>0.0005 ***)

\[
\text{absolute error} = \frac{\text{mean absolute pointing error per subject}}{p > 0.05} = \frac{17.49}{3.86} = \frac{17.12}{3.34} = \frac{16.34}{3.94} = \frac{16.47}{3.44} = \frac{16.50}{3.74} = \frac{16.59}{3.79}
\]

\[
\text{response time} = \frac{\text{mean relative response time per subject}}{p > 0.05} = \frac{1.19}{1.5} = \frac{1.15}{1.66} = \frac{1.16}{1.51} = \frac{1.18}{1.62}
\]
Can visual landmarks without vestibular cues be used for spatial updating?  
Yes, but performance without vestibular cues seems more impaired.

Must landmarks be used for spatial updating? I.e., are they capable of triggering obligatory spatial updating?  
→ IGNORE >> UPDATE (p>0.0005 ***) → Yes

Are vestibular cues required?  
platform on ~ platform off (p>0.05)

Results – Landmark Conditions, Platform Off

- **p=0.004**  
- p>0.05  
- p=0.033

Bernhard E. Riecke et al.  Contribution and interaction of visual and vestibular cues for spatial updating  MPI for Biological Cybernetics, Tübingen
Can optic flow + vestibular cues be used for spatial updating? 
→ UPDATE >> CONTROL → No!

Are optic flow + vestibular cues able of triggering *obligatory* spatial updating? 
→ IGNORE < UPDATE → No!
Can optic flow without vestibular cues be used for spatial updating?
→ UPDATE >> CONTROL → No!

Is optic flow without vestibular cues able of triggering obligatory spatial updating?
→ IGNORE << UPDATE → No, even less than with vestibular cues

**Results – Optic Flow, Platform Off**

- **Absolute Error**
- **Inconsistency**
- **Response Time**

![Graphs showing results](image-url)