Assessment and training of visuospatial cognitive functions in virtual reality: proposal and perspective

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Visuospatial functions

- detection, representation, manipulation, and storage
- allow us to perceive objects, locate their position in space, orient our attention, infer spatial relations, and remember the scene
- enable performing judgments related to direction and distance among external objects and thus allow us to navigate
- focus of psychologists and neuroscientists who have tools how to measure, train and restore them (Baddeley, 2012; Shepard & Metzler, 2011; Polaná et al., 2012; Toril et al., 2016; Barman et al., 2016)
Linking behavior to brain

- cognitive neuroscience approach
Testing visuospatial functions

- focus on either simple (automatic) processes or complex ones (deliberative), involving visuospatial short-term or working memory, mental rotations, and executive visual attention (Dijkstra, et al, 2017; Shipstead, 2012)

- Trainings and restoration programs employ brain plasticity (Paulus, 2011)

- Typical training/testing in 2D (reduction of real-life complexity)

- Concerns can be raised w.r.t. (Neubauer et al., 2010)
  - ecological validity
  - generalization of the findings
  - optimization of the training and restoration programs
Using virtual reality games

- (3D) virtual environments may modulate neuropsychological measures (Schultheis et al, 2002; Matheis et al, 2007; Parsons et al, 2017)

- Research question: Which elements of VR games can lead to improvements of selected cognitive functions?

- Design criteria:
  - natural inclusion of physical space (of the CAVE) to game design
  - adherence to the cognitive goals
  - appropriate difficulty
  - relatively fast and effective implementation
**Experiment design**

- **Experimental group (n=15+):** 2-3x CDT to control learning effect, 2-3 EEG measurements (16 channels in posterior cortex), 10 trainings within 2-3 weeks
- **Control group (n=15+):** no treatment (training)
- **User questionnaire to fill-in** (current emotions, immersion...)
- **Preselection of participants, match-pairs,...**
CAVE system

- Compact fully immersive VR environment - 2.5 x 2.5 x 3 m display area
- 250 degree panoramic view
  - provided by 20 LCD screens
- 7 sided hexagon shape
- Computing cluster structure
- Head Tracking (OptiTrack)
- OpenSG visualisation core

(Built at LIRKIS lab, TU Košice)
Tower defense game

- Several levels of difficulty (increasing → CogInfoCom)
  - to preserve “flow” (Csíkszentmihályi, 1975)
- Friendly objects can change after some time, partial visibility possible
TD game parameters and visualization

<table>
<thead>
<tr>
<th>Property</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed</td>
<td>speed of the drone.</td>
</tr>
<tr>
<td>droneShotPower</td>
<td>turret damage by one drone shot.</td>
</tr>
<tr>
<td>droneShotProb</td>
<td>probability that the drone hits the turret.</td>
</tr>
<tr>
<td>droneShotFreq</td>
<td>drone fire rate.</td>
</tr>
<tr>
<td>dronePassEv2City</td>
<td>defines how the drone affects the defended location.</td>
</tr>
<tr>
<td>dronePassEv2Turret</td>
<td>after passing the turret (positively or negatively).</td>
</tr>
<tr>
<td>dronePassEvProb</td>
<td>defines how the drone affects the turret after passing it (positively).</td>
</tr>
<tr>
<td></td>
<td>probability that the previous two effects happen.</td>
</tr>
</tbody>
</table>

YOU LOST
Enemies drons destroys city
Your time: 37 s
Destroyed drones: 4
Escaped drones: 15
Change detection task (CDT)

- applied before and after training in VR, responses stored
Measuring brain signatures

- event-related potentials (ERPs), i.e. time- and phase-locked electrical responses of the brain to a specific event
- due to background EEG (“noise”), averaging over more trials (40+) necessary
- ERP protocols for testing visual working memory and spatial attention were implemented
- experimental design (Vogel & Machizawa, 2004) – elicits contralateral delay activity (CDA) component of ERP
- CDA = well-defined neural correlate of working memory capacity (Luria et al, 2016)
  - (cognitive operations of) maintenance and filtering
Contralateral delay activity (CDA)

Vogel & Machizawa (2004)
Summary

- We outlined a more ecologically valid experiment using 3D training (testing in 2D)
- Game design (for CAVE) is being finalised, preliminary testing done
- CDT (for pre/post test) protocol is ready
- Experimental group ready-to-go in October
- Our goal: to find an effect (of VR), both behaviorally and neurally

Thank you for your attention.