Virtual reality, a new therapeutic tool for neurological care

Sonia Crottaz-Herbette, MER PD
Service de Neuropsychologie et Neuroréhabilitation
CHUV
Disclosure

Part-time employee at MindMaze SA (Lausanne)
Virtual reality, a new therapeutic tool for neurological care

Outline

- What is virtual reality based rehabilitation?
- Examples of treatments using virtual reality
- Is virtual reality effective for (stroke) rehabilitation?
- How to integrate VR-based treatment into standard of care?
- Conclusion, added value of VR-based rehabilitation
Virtual reality, a new therapeutic tool for neurological care

Outline

What is virtual reality based rehabilitation?
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What is virtual reality based rehabilitation?

**VR technology in rehabilitation**

- **Immersive virtual reality (VR):** complete immersion in a simulated experience that can be similar to or completely different from the real world
  - www.realite-virtuelle.com/zelda-vr-images-details/
  - www.fun-simulations.fr

- **Augmented reality (AR):** adds digital elements to a live (real) view
  - https://www.fi.edu/difference-between-ar-vr-and-mr

- **Mixed reality (MR):** combines elements of both immersive VR and AR, use head mounted display
  - https://www.tom.travel/2020/02/21/quest-ce-que-la-realite-mixte/

- **2D screen-based digital environment**
What is virtual reality based rehabilitation?

Non immersive VR
2D environment displayed on a screen, hand controllers, trackers on limbs

Immersive VR
3D environment, head mounted display, hand controllers, trackers on limbs

Cogniplus
www.schuhfried.com/cogniplus/trainings/
Computer Assisted Rehabilitation Environment (CAREN) Laboratory, Bethesda USA
Brandin-De la Cruz et al., Rev Neurol., 2020
San Jorge University, Spain
Tyromotion
www.tyromotion.com
DIEGO Arm robot therapy

All of these set-ups can be used in VR based rehabilitation
Virtual reality, a new therapeutic tool for neurological care

Outline

What is virtual reality based rehabilitation?

Examples of treatments using virtual reality

Is virtual reality effective for (stroke) rehabilitation?

How to integrate VR-based treatment into standard of care?

Conclusion, added value of VR-based rehabilitation?
Motor deficits

Cognitive deficits
Virtual reality and **motor** rehabilitation

With VR: increase frequency and intensity
Virtual reality and **motor** rehabilitation

With VR: increase frequency and intensity

Bitensky et al., Stroke engine, 2010

Smart Glove
www.neofect.com

**Electrode Placement**
**Wrist and Finger Extension**

Functional electrical stimulation

quality of movements

**www.neofect.com**
Virtual reality and motor rehabilitation

C-Mill virtual reality treadmill
https://agapephysicaltherapy.com/services/c-mill-virtual-reality-treadmill

Virtual reality and motor rehabilitation

Gamification of gait training

Kern et al. IEEE Conference on Virtual Reality and 3D User Interfaces (VR). 2019
Virtual reality and motor rehabilitation

Scores on the User Experience Questionnaire in the Non-VR and VR groups

With VR: increase motivation and attractiveness of the therapy

Kern et al. IEEE Conference on Virtual Reality and 3D User Interfaces (VR). 2019
Virtual reality and cognitive rehabilitation

Standard cognitive rehabilitation of visual neglect deficits
Virtual reality and cognitive rehabilitation

Our pilot study

New VR-based rehabilitation of visual neglect deficits
Virtual reality and cognitive rehabilitation

Our pilot study

New VR-based rehabilitation of visual neglect deficits
Is VR a useful therapeutic tool?

Is VR-based rehabilitation effective?
Virtual reality, a new therapeutic tool for neurological care

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Is virtual reality effective for (stroke) neurorehabilitation?

Virtual reality for stroke rehabilitation (Review)
Laver KE, Lange B, George S, Deutsch JE, Saposnik G, Crotty M

Number of studies increased of more than 50%

Upper limb function and activity
Is virtual reality effective for (stroke) neurorehabilitation?

VR therapy versus Conventional therapy

VR only versus OT only

Comparison 1.1: Upper limb function and activity
Twenty-two studies presented outcomes for upper limb function and activity in a form suitable for inclusion in the meta-analysis (1038 participants) (Adie 2017; Byl 2013; Crosbie 2008; da Silva Cameirao 2011; da Silva Ribeiro 2015; Galvao 2015; Givon 2016; Housman 2009; Kiper 2011; Kong 2014; Levin 2012; Piron 2007; Piron 2009; Piron 2010; Prange 2015; Reinkensmeyer 2012; Saposnik 2010; Saposnik 2016; Subramanian 2013; Sucar 2009; Thielbar 2014; Zucconi 2012). The impact of virtual reality on upper limb function was not significant: standardised mean difference (SMD) 0.07, 95% confidence interval (CI) -0.05 to 0.20, low-quality evidence (Analysis 1.1). Statistical heterogeneity was moderate ($I^2 = 43\%$).

<table>
<thead>
<tr>
<th>Study or subgroup</th>
<th>Virtual reality</th>
<th>Conventional therapy</th>
<th>Std. Mean Difference</th>
<th>Weight</th>
<th>Std. Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adie 2017</td>
<td>101</td>
<td>47.6 (14.2)</td>
<td>108</td>
<td>49 (13.6)</td>
<td>20.73%</td>
</tr>
<tr>
<td>Byl 2013</td>
<td>5</td>
<td>27.8 (7.9)</td>
<td>2</td>
<td>30.6 (6.9)</td>
<td>0.56%</td>
</tr>
<tr>
<td>Byl 2013</td>
<td>3</td>
<td>28.2 (4.6)</td>
<td>3</td>
<td>30.6 (6.9)</td>
<td>0.72%</td>
</tr>
<tr>
<td>Byl 2013</td>
<td>9</td>
<td>52.8 (6.9)</td>
<td>9</td>
<td>50.2 (18.9)</td>
<td>1.78%</td>
</tr>
<tr>
<td>da Silva Cameirao 2011</td>
<td>8</td>
<td>60.4 (7.6)</td>
<td>8</td>
<td>53.4 (8.1)</td>
<td>1.42%</td>
</tr>
<tr>
<td>da Silva Ribeiro 2015</td>
<td>15</td>
<td>38.7 (19.6)</td>
<td>15</td>
<td>44.7 (14.2)</td>
<td>2.93%</td>
</tr>
<tr>
<td>Galvao 2015</td>
<td>18</td>
<td>120.9 (11.7)</td>
<td>10</td>
<td>110.7 (13.0)</td>
<td>2.14%</td>
</tr>
<tr>
<td>Givon 2016</td>
<td>20</td>
<td>28.4 (23.1)</td>
<td>21</td>
<td>23.7 (24)</td>
<td>4.06%</td>
</tr>
<tr>
<td>Housman 2009</td>
<td>14</td>
<td>24.9 (7.4)</td>
<td>14</td>
<td>19.6 (6.7)</td>
<td>2.58%</td>
</tr>
<tr>
<td>Kiper 2011</td>
<td>40</td>
<td>48.9 (15.2)</td>
<td>40</td>
<td>46.4 (17.1)</td>
<td>7.93%</td>
</tr>
<tr>
<td>Kong 2014</td>
<td>33</td>
<td>32.8 (18.2)</td>
<td>34</td>
<td>29.2 (17.5)</td>
<td>6.63%</td>
</tr>
<tr>
<td>Levin 2012</td>
<td>6</td>
<td>47.3 (11.9)</td>
<td>6</td>
<td>44.9 (11.7)</td>
<td>1.19%</td>
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<tr>
<td>Piron 2007</td>
<td>25</td>
<td>51.4 (9.8)</td>
<td>13</td>
<td>45.4 (9.3)</td>
<td>3.25%</td>
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<tr>
<td>Piron 2009</td>
<td>18</td>
<td>53.6 (7.7)</td>
<td>18</td>
<td>49.5 (8.4)</td>
<td>3.39%</td>
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<tr>
<td>Piron 2010</td>
<td>27</td>
<td>49.7 (10.1)</td>
<td>20</td>
<td>46.5 (9.7)</td>
<td>4.51%</td>
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<tr>
<td>Prange 2015</td>
<td>35</td>
<td>29.6 (17.2)</td>
<td>33</td>
<td>21.7 (13.3)</td>
<td>6.58%</td>
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<tr>
<td>Reinkensmeyer 2012</td>
<td>13</td>
<td>27.4 (11.4)</td>
<td>13</td>
<td>23.8 (8)</td>
<td>2.54%</td>
</tr>
<tr>
<td>Saposnik 2010</td>
<td>9</td>
<td>-19.8 (3.4)</td>
<td>9</td>
<td>-27.6 (8.7)</td>
<td>1.29%</td>
</tr>
<tr>
<td>Saposnik 2016</td>
<td>71</td>
<td>-64.1 (104)</td>
<td>70</td>
<td>-39.8 (35.5)</td>
<td>13.85%</td>
</tr>
<tr>
<td>Subramanian 2013</td>
<td>32</td>
<td>43 (15.2)</td>
<td>32</td>
<td>43.9 (14.7)</td>
<td>6.36%</td>
</tr>
<tr>
<td>Sucar 2009</td>
<td>11</td>
<td>30 (12.4)</td>
<td>11</td>
<td>26.3 (2.3)</td>
<td>2.14%</td>
</tr>
<tr>
<td>Thielbar 2014</td>
<td>7</td>
<td>50.4 (10.4)</td>
<td>7</td>
<td>47.6 (8.3)</td>
<td>1.29%</td>
</tr>
<tr>
<td>Zucconi 2012</td>
<td>35</td>
<td>42.5 (20.3)</td>
<td>35</td>
<td>51.8 (13.1)</td>
<td>2.14%</td>
</tr>
</tbody>
</table>

Total*** 533

Heterogeneity: Tau^2=0; Chi^2=38.77; df=12; P=0.002; $I^2=42.67\%$

Test for overall effect: Z=1.14 (P=0.25)
Is virtual reality effective for (stroke) neurorehabilitation?

Effect on the Fugl Meyer UE scale

VR only versus OT only

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Comparison 1.2: Upper limb function (Fugl Meyer Upper Extremity Scale)

Sixteen of the trials (with 599 participants) used the Fugl Meyer Upper Extremity (UE) Scale as an outcome measure (Byl 2013; da Silva Cameirao 2011; da Silva Ribeiro 2015; Galva 2015; Housman 2009; Kiper 2011; Kong 2014; Levin 2012; Piron 2007; Piron 2009; Piron 2010; Prange 2015; Reinkensmeyer 2012; Subramanian 2013; Sucar 2009; Zucconi 2012). The impact of virtual reality as measured by the Fugl Meyer UE Scale showed a small significant effect: mean difference (MD) 2.85, 95% CI 1.06 to 4.65 (Analysis 1.2).

“….virtual reality and interactive video gaming was more beneficial on the Fugl Meyer score than conventional therapy approaches in improving upper limb function…”
Is virtual reality effective for (stroke) neurorehabilitation?

Increase dosage thanks to VR interventions

OT+VR versus OT only

“Virtual reality may be beneficial .... when used as an adjunct to usual care (to increase overall therapy time).”
Is virtual reality effective for (stroke) neurorehabilitation?

Specialized VR system versus “off the shelf” system

Comparison 2.3: Specialised virtual reality system or commercial gaming console

Studies utilising virtual reality programs specifically designed for rehabilitation settings demonstrated statistically significant benefits over alternative intervention (SMD 0.17, 95% CI 0.00 to 0.35). In contrast those involving off-the-shelf gaming programs were not found to be significant (SMD -0.02, 95% CI -0.20 to 0.15)
Is virtual reality effective for (stroke) neurorehabilitation?

Yes! But:

- effects not always captured (e.g. Fugl Meyer but not composite score)
- when used in addition to standard of care, to increase intensity
- when specific VR programs are used (not “off-the-shelf” program)
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Current management of stroke patients

Stroke Unit

~ No rehab

Acute-Subacute care

Some rehab
Up to 3 h/day?

Rehab clinic

"Intense rehab"
> 4 h/day

Home

~ Some rehab

Where should VR therapy be added?
**Smart-2 trial**

Early post-acute patients (< 6 weeks) - N=24

Groups: VR + OT versus OT + OT

2 hours/day (2x1hour), 5 days/week

3 weeks (30 sessions)

Finding 1: All outcomes: Improvement VR+OT group = OT+OT group

Finding 2: Improvement VR+OT and OT+OT groups > Usual OT care group (retrospective)

SMARTS2 19.0 days post-stroke IQR 12.0, 33.0

Usual care 14.0 days post-stroke IQR 12.5, 35.5

**How to integrate VR-based treatment into standard of care?**

**Early post acute - In clinic**

MindPod Dolphin (MindMaze SA) and Armeo power (Hocoma AG)

Kraakauer et al., Neurorehabilitation and Neural Repair, 2021
How to integrate VR-based treatment into standard of care?

**The Queen Square Trial**

Chronic patients ( > 6 months) - N=224 (no control group)

6 hours/day, 5 days/week, 3 weeks (90 sessions)

Motor tasks: passive or active, assisted or unassisted (robot), functional or nonfunctional (PT + OT)

Finding 1: Improvement between scores at admission and discharge

Finding 2: Improvement continued after discharge

Ward et al., JNNP, 2019
How to integrate VR-based treatment into standard of care?

**Chronic**

Home telerehabilitation vs In-clinic

Chronic patients (4-36 weeks post-stroke) - N=124

70 min/day (~1 session/day), 6-8 weeks

36 sessions (18 supervised, 18 unsupervised)

Groups: Home versus In-clinic

**Finding 1:** Significant improvement for both groups

**Finding 2:** Similar improvement for both groups

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Cramer et al., JAMAN, 2019
How to integrate VR-based treatment into standard of care?

**Early post acute - In clinic**

SMART-Z trial

- Early post-acute patients (16 weeks) - N=24
- 2 hours / day, 5 days / week
- 3 weeks (30 sessions)

Kerkavara et al., Neurorehabilitation and Neural Repair, 2021

**Chronic - In clinic**

The Queen Square Trial

- Chronic patients (>6 months) - N=224 (no control group)
- 6 hours / day, 5 days / week, 3 weeks (90 sessions)
- Motor tasks: passive or active, assisted or unassisted (robot), functional or non-functional (PT + OT)

Finding 1: Improvement between scores of performance and discharge
Finding 2: Improvement continued after discharge

Ward et al., JNPR, 2019

**Home telerehabilitation vs in-clinic**

Chronic patients (4-36 weeks post-stroke) - N=124

- 70 min/session, 6-8 weeks
- 36 sessions (18 supervised, 18 unsupervised)

Cramer et al., JAMA, 2019

VR in addition to standard therapy

- Stroke Unit
- Acute/Subacute care
- Rehab clinic
- Home

~ No rehab

Some rehab

Up to 3 h/day?

"Intense rehab"

> 4 h/day

~ Some rehab
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Increase dose therapy
(intensity, frequency and/or duration of session)

Standard motor rehabilitation (OT): upper limb training 30 repetitions/session
Lang et al., Arch Phys Med Rehabil., 2009

Non-human primates: upper limb training 600 repetitions/session
Nudo et al., Science, 1996
Conclusion, added value of VR-based rehabilitation?

- **Increase dose**
- **Increase motivation, attractiveness of the training**
- 3D and 360° countless new and well controlled environments
- Real-time feedback and monitoring (remote)
- Lower cost for additional VR-based sessions (?)
- Digital output from sensors
- Ease of eye tracking measures

b. Far space kinematics

1. **Before shift**
2. **25° Shift**

![Diagram of input layer, hidden layers, and output layer with nodes and arrows representing data flow.](image)
Conclusion

**VR in neurorehabilitation**

Effective therapy $\rightarrow$ high intensity

VR based therapy $\rightarrow$ can provide additional therapy sessions
$\rightarrow$ done in addition to standard of care, not to replace it
$\rightarrow$ in subacute and chronic stages
$\rightarrow$ in clinic or at home