Immersive Virtual Reality in Cognitive Rehabilitation: A systematic Review

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SYSTEMATIC REVIEW

IMMERSIVE VIRTUAL REALITY IN COGNITIVE REHABILITATION: A SYSTEMATIC REVIEW

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Abstract

Background: Virtual Reality (VR) is a new technology used more and more in clinical trial.

Aim: The aim of this study is to investigate the effects of immersive VR as a rehabilitation approach of cognitive functions.

Method and Material: A systematic literature review was conducted in the electronic databases of PubMed, Cochrane, OTseeker and PsycINFO for articles published until August 2021. The main search terms were “immersive virtual reality,” and “cognitive rehabilitation”. The research was strictly limited in immersive technologies and adult patients suffering from neurological disorder or a traumatic injury or elderly with cognitive decline, and no reviews are included. Totally, 16 citations reviewed.

Results: All intervention studies reported improvements either in cognitive functions or in stress management and relaxation. In particular, most of the studies demonstrated improvement in attention (N=6) but also in executive functions (N=3), in memory (N=5) and in navigation skills (N=1). Regarding safety and feasibility, most of the participants in the studies completed successfully the tasks and did not report stimulation sickness.

Conclusions: The available limited data indicate that immersive VR environments can a) be feasible and safe and b) have a positive impact in cognitive functions in the dynamic process of rehabilitation. Further research is warranted in large-scale longitudinal clinical trials in various patients’ groups in order to compare the effects of immersive and non-immersive VR interventions. Future studies should further investigate the long-term impact on cognitive functions in interventions using immersive VR.

Keywords: Immersive, virtual reality, rehabilitation, cognitive functions.

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INTRODUCTION

Even though virtual reality (VR) is a technology applied since 1980 in space and military (NASA - Virtual Interface Environment Workstation, 1980; Thomas A. Furness - Visually Coupled Airborne Systems Simulator, 1982), their use in medical rehabilitation is emerging in the last decade. Regarding, the field of clinical neuropsychology, VR has been used as a tool for the assessment (and rehabilitation of various cognitive functions, such as executive functions, memory, attention and visuospatial abilities, that have been degraded due to various neurological conditions and brain damage 2-5.

Researchers claim that VR intervention methods have several advantages compared to traditional, face to face and paper-and-pencil methods. More specifically, VR provides safe and engaging environment simulating the real world, and therefore high ecological validity. Their performance tracking is accurate, detailed, automated, and can record data which a human eye would not report eliminating the loss of important data due to the limitations of subjective observation. Furthermore, health care professionals thanks to VR systems own a great level flexibility and control over the tasks and they can offer personalization on the therapeutic protocols.

The VR technology can be presented in fully immersive, semi-immersive and non-immersive virtual spaces. High levels of immersion may provide a high sense of presence in the virtual world affecting both the physical and emotional reaction to the input from the VR system. The impact of immersion in rehabilitation using VR technologies needs to be assessed.

Immersive VR constitutes of a real-time three-dimensional virtual world where the user maintains a first-person view of the VR environment with which they interact, in a embodied experience, whilst in non-immersive or semi-immersive VR the "mirror" view can be used in a non-embodied experience with "mirror" view of the user, or with the use of two-dimensional (2D) graphics. The VR rehabilitation scenarios have been performed to either 2D or 3D graphics. A 3D environment is perceived to be more realistic and with higher sense of presence than a 2D environment.

Spatial presence refers to "the sense of being in an environment". Higher levels of immersion have been linked to side effects as dizziness, nausea, discomfort, eye fatigue, disorientation or motion-sickness which is referred as VR sickness. However, these symptoms have been reported to only 5% of the participants in a VR environment.

The type of graphics can affect the participants' perception of the task and intentions. 2D and 3D VR-systems lead to different presence experiences and to different cortical activation patterns. In particular, presence experiences associated with activity of a fronto-parietal network, which is modulated by the Dorsolateral Prefrontal Cortex (DLPFC). Fully immersive 3D enriched-environment requires allocation of more brain and sensory resources for cognitive/motor tasks than 2D. However, the study of Lledó et al. suggest that 2D VR environments may be a more efficient for post-stroke patients in rehabilitation of upper limb, mainly because of the accuracy in order to effectuate optimal kinematic trajectories.

There are more and more clinical trials that include VR. Most of the studies in cognitive rehabilitation, use semi or non-immersive environments, mostly due to high economic software and hardware requirements or other development complications and issue related to the technologies interfacing and the three-dimensional graphics representation of the user in virtual space. The aim of this study is to review and investigate the effects of immersive VR as a rehabilitation approach of cognitive functions. Furthermore, safety and reliability will be also examined.

METHODOLOGY

The current review was conducted and reported with guidance of with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.

Data sources and search strategy

The electronic data bases of PubMed, Scopus, Cochrane, OTseeker and PsycINFO were systematically searched from inception until August of 2021. Keywords for strategy searching were: immersive virtual reality, cognitive rehabilitation and neuropsychological rehabilitation.

For example, a sample search strategy for the PubMed database was: (((immersive virtual real*)) OR (immersiv virtual-real*)) OR (immersive VR)) AND (((neuropsychological) OR (neuro rehab*)) OR ((cogn*) OR (CR))).

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Eligibility criteria and study selection

The inclusion criteria were the following: a) studies with immersive VR technologies published in English in peer-reviewed journals, b) studies with VR technologies that measure rehabilitation in cognitive functions (memory, attention and concentration, language, executive and visuospatial function, navigation), c) adult patients with diagnosis of neurological disorder or traumatic brain injury) (d) elderly with cognitive decline. The studies with psychiatric disorders were excluded. First, all articles were evaluated by two authors according to the title, abstract, and text. Then, all those who considered potentially eligible were fully read and initially analyzed. The last machine engine research was on 30 August 2021.

Data extraction

Extracted data of the studies were organized according to PICO process: (1) author and date of publication, (2) neurological disorder (3) sample size (4) experimental intervention, (5) control interventions (7) sessions details (number, duration and frequency), (8) outcomes, (9) type of study (Table 1). Furthermore, the neuropsychological outcome measures were arranged by cognitive functions: (1) attention/concentration, (2) executive function, (3) memory, (4) visuospatial/orientation/navigation, (5) language and also stress (Table 2). Also, follow up sessions and ecological validity was also taken into account.

Quality assessment

Two authors (AD, EK) assessed the quality of the research of each RCT articles using the Physiotherapy Evidence Database (PEDro) Scale (Table 3). Total scores from 6 to 10 considered high quality, from 4-5 considered fair quality and ≤3 considered poor quality. Two authors conducted a blinded rating of the methodological quality of the studies. Different rates and unclear issues were discussed.

Level of immersion

The level of immersiveness of VR technologies that were included on the studies was assessed using the criteria of Michael Heim (1998) by the 3Is: Immersion, Interaction and Information intensity, and the classification of sense of presence (SoP) in VR can be assessed by examination both of the interfaces and technologies used (360 stereoscopic view, interaction interfaces, embodiment of the user in virtual space) and the multimedia content (real-time three-dimensional graphics, interaction mechanisms, gamification techniques and real-world physics and properties simulation).

RESULTS

The selection process is summarized according to PRISMA guidelines as a flow chart (Fig. 1). Firstly, 468 records identified through databases searching. After deleting duplicate papers, 466 were screened by the authors to assess the inclusion criteria. A total number of 223 articles assessed full-text for eligibility. Consequently, 16 studies included in qualitative synthesis. For articles meeting inclusion criteria, data on study design, participant characteristics, and intervention outcomes were extracted by two of the authors (AD and EK). Disagreements between reviewers were resolved by consensus.

There were 16 studies selected that were relevant to the aim of this review (Table 1). Most of the studies were RCTs (N=6) and five feasibility and one reliability study. There were some low-level evidences including two case studies and two non-randomized controlled trials. All studies investigated immersive VR as rehabilitation tool in persons with neurological disorders (as stroke, Traumatic Brain Injury (TBI), Alzheimer Disease (AD)) MCI and elderly.

Participants

The number of participants ranged from 66 to 1 (mean=26 persons). The total number of participants was 404 (Table 1). The majority of the studies developed VR systems to train patients with traumatic brain injury (TBI). There were four VR rehabilitation systems practiced form elderly participants with cognitive decline. In addition, there are systems created aimed to train various cognitive functions for patients suffering from stroke, Alzheimer’s disease and mild cognitive impairment.

Aim of studies

The aim of the studies (Table 2) was either to test the feasibility of the VR systems or the reliability of VR systems and the reliability to train specific cognitive functions such as attention, executive functions, memory, navigation, general cognitive abilities and daily living, as well as stress relief and relaxation.
One study compared screen displays as an alternative to HMD within virtual reality (VR)-based applications to train memory and attention functions.26

**Interventions**

Some types of interventions concerned activities of the everyday life16,19,26,29,30 such as preparation of meal, interacting in a virtual store and accomplishing morning hygiene etc. Further, other scenarios included path finding and navigation19,23,24,26,28 and various kind of exercises such as card play and fishing,25 fruit ninja,22 target detection in outdoor space such as garden27 or Stroop tasks in VR Apartment and Classroom.17 One study uses scenes from nature for relaxation.21 Two studies18,20 designed simple interventions with minimal graphics such as just a black board with target and cursor or cancellation tasks, for patients with severe brain injuries on the early stages of recovery.

**Comparison**

Six out of the 15 studies22,25,26,29,30,23 included comparison group. In two studies23,29 the comparison group performed traditional, face to face training such as physical and cognitive rehabilitation or music therapy. Furthermore, in two study the experimental group was compared to non-immersive VR training,22,26 In two studies25,30 the comparison group submitted to computerized cognitive training.

**Duration of interventions**

Even though time of sessions was not included in every study, sessions lasted from two to 60 min (mean time = 30 min ca.), ranging from one to 60 sessions spread over the course of one single day to 6 months. Feasibility studies consist the shorter trials, ranging from one to 8 sessions.

**Measures**

The intervention studies (Table 2) included pre and post measures of functions by using neuropsychological assessment tools such as Mini Mental State Examination (MMSE), Digit Span, Phonemic Verbal Fluency, Dual Task, Clock, Instrumental Activity of Daily Living (IADL), Stroop Color Test, Word Test, Montreal Cognitive Assessment (MOCA), Paced Auditory Serial Addition Task (PASAT), Delis-Kaplan Executive Function System (D-KEFS), Wechsler Memory Scale , Toulouse-PiéronTrail Making or behavioral scales such as Geriatric Depression Scale (GDS), Music in Dementia Assessment Scales, State-Trait Anxiety Inventory (STAI) questionnaire. Four studies contained computerized neurocognitive function test (CNFT)25 and automated neuropsychological assessment metrics (ANAM).17 Korean version of the Consortium to Establish a Registry for Alzheimer's Disease (CERAD-K)30 and the Dutch version of the Oxford Cognitive Screen (OCS-NL).27 Additionally, two studies18,20 measured attention with kinematic analysis of movements, the performance data and observations of behavior. One study31 used custom-made hand motion tracking module and 3-dimensional positions of the hands for assessing the finger tapping as an indication for attention and response time.

The feasibility of the VR systems was measured by observations, custom-developed Likert-scale questionnaire consisting of several open-ended questions regarding the VR experience and self-reported scales such as stress arousal checklist (SAC), simulator sickness questionnaire (SSQ), ITC sense of presence inventory (ITC-SOPI) and Borg rate of perceived exertion (RPE) scale.

**Outcomes Feasibility**

Regarding safety and feasibility20,21,24,27,31 most participants (N=134 out of 142 in total) completed successfully the tasks although the cognitive abilities varied from normal to severe. All the four studies conclude that VR is a safe, feasible, usable and engaging system for cognitive rehabilitation. Most of the participants did not face stimulation sickness from the immersive environment and had no negative side-effects such as dizziness, headache, disorientation. In addition, most participants experienced positive the iVR with low stress, enjoyment and high levels of engagement and tolerated well with the technology and the equipment of HMD.

**Improvements of cognitive functions**

All intervention studies reported improvements either in cognitive functions or in stress management and relaxation (Table 2). In particular, most of the studies (N=6) demonstrated improvement in attention.18,19,20,25,26,27 Better performance was also found in executive functions (N=3),17,22,29 in memory (N=5)19,23,25,26,30 and in navigation skills (N=1).28 One study referred to stress relief in older adults with various kind of cognitive abilities.23 As far as the studies with comparison groups22,23,25,29,30...
when the control group performed traditional face to face cognitive training, in the one case\textsuperscript{23} there was no improvements but progressive decline of cognitive functions of participants although iVR group had improvements in memory tests, especially in long-term recall. Furthermore, in the other case\textsuperscript{29} even though both groups had significant improvements in Stroop test, only iVR group showed improvements in cognitive dual-task gait and more improvements in the TMT-B.

**Immersive vs Non-immersive**

In a study comparing iVR with computerized cognitive training\textsuperscript{25} both groups demonstrated similar improvement. In the study of Park et al.,\textsuperscript{30} in which they compared Mixed Reality with conventional computer-assisted cognitive training, even though experimental group showed significant more improvements than control group in visuospatial working memory and recall in visuospatial tasks, both groups did not improve significantly in the other cognitive domains.

Two studies\textsuperscript{22,26} compared immersive with non-immersive rehabilitation training, with mixed results. The study of Gamito et al.,\textsuperscript{30} found improvements in working memory and sustained attention for both groups, regardless of the level of immersion. The study of Huang\textsuperscript{22} the experimental group improved significant in executive functions (Stroop Test and Trail Making Test).

In advance, Huang\textsuperscript{22} supports that engaging in a more immersive environment may lead to a greater improvement of inhibitory control and task switching in older adults. Furthermore, when the participants felt located within an iVR and perceived the possibility of moving within the environment, they were more likely to improve their inhibitory control and taskswitching after experiencing presence.

**Quality of RCT’s**

Six studies of the study were RCT’s.\textsuperscript{22,23,25,26,29,30} The PEDro score for each study is reported in Table 3. The mean PEDro score of the studies included in the review was 7.2 with scores ranging from 6 to 8. In total, all included studied had high quality. The most common methodological weaknesses referred to the blinding of patients, therapists, and assessors. Furthermore, in most of the studies\textsuperscript{23,25,26,30} all patients received treatments as allocated, while two\textsuperscript{22,29} did not meet the criteria of “intention to treat”.

**DISCUSSION**

The purpose of the present study was to systematically review and investigate the effects of immersive VR as a rehabilitation approach of cognitive functions in patients suffering from neurological disorder or a traumatic injury or elderly with cognitive decline. Furthermore, we also examined safety and feasibility. Of the 16 studies included, all intervention studies reported improvements in cognitive functions and in particular, in attention, executive functions, memory and in navigation skills. Furthermore, all conclude that immersive VR is feasible, safe and usable for neurorehabilitation of patients with cognitive impairments.

More specifically, in patients with stroke it was noted significant improvement in Computerized neurological test that examined visual and auditory attention along with verbal and visual memory in comparison when cognitive training was performed in a fully immersive environment,\textsuperscript{25} in working memory and attention\textsuperscript{26} and in neglect.\textsuperscript{27} Most of the studies demonstrated improvement in attention.\textsuperscript{18,19,20,25,26} More RCTs have examined the beneficial effects of VR in elderly facing with cognitive challenges regarding executive functioning.\textsuperscript{22,29,30} Additionally, benefits were demonstrated even in navigational tasks,\textsuperscript{28} and in memory.\textsuperscript{19,23,25,26} One study referred to stress relief in older adults with various kind of cognitive abilities.\textsuperscript{21}

Regarding safety and feasibility, most of the participants completed successfully the tasks and did not report any stimulation sickness, dizziness or disorientation.\textsuperscript{20,21,24,27,31} Sakhare et al.,\textsuperscript{24} having examined the feasibility of VR training in elderly noted high levels of arousal and low stress levels indicating a level of excitement and enjoiment. And even in patients with Traumatic Brain Injury the immersion was well tolerated.\textsuperscript{16-20}

Even though the available data is still limited, VR could promote neurorehabilitation in different pathologies, such as stroke. MCI, dementia and TBI. In recent years, more and more studies, support that VR interventions provoke neuroplasticity, by promoting the activation of different neuronal connections, such as the fronto-parietal network\textsuperscript{10} and by activating cortical reorganization.\textsuperscript{32-34} Hence, VR technology is leading to improvements in motor, cognitive and psychological functions. Immer-

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sive VR seems to be a promising tool in cognitive rehabilitation both for patients and for therapist as it can provide a feasible, safe, accurate, flexible and enjoyable training environment. Further research is warranted in large-scale longitudinal clinical trials in various patients’ groups in order to investigate the long-term impact on cognitive functions in interventions using immersive VR. Longitudinal studies on cognitive VR interventions would provide better evidence of the VR efficacy on rehabilitation. Studies should also include follow-up to report the maintenance of cognitive improvements. Furthermore, immersive VR intervention could be combined with quantitative techniques such as EEG, eye-tracking, heart-rate etc. to provide useful tracks about psychophysiological responses. Additionally, we suggest more studies comparing different levels of immersion as the results are still mixed. Lastly, VR rehabilitation applications could be examined as telerehabilitation systems, to ensure accessibility and long-term improvements in the everyday life of the patients.

Acknowledgments

This review has been conducted in the framework of “REAT – Virtual Reality applications in medical rehabilitation” project, led by National and Kapodistrian University of Athens and co-funded by “RESEARCH - CREATE - INNOVATE« program, ESPA 2014-2020, and the European Union

REFERENCES

8. Roettl J, Terlutter R. The same video game in 2D, 3D or virtual reality – how does technology impact game evaluation and brand placements? PLOS ONE. 2018;13(7).


Figure 1. PRISMA flow chart

Records identified through database searching (n= 465) → Additional records identified through other sources (n= 3)

Records after duplicates removed (n= 466)

Records excluded because they mainly didn’t include:
- adult patients
- patients suffering from neurological diseases
- Cognitive Rehabilitation (n= 243)

Records screened (n= 466)

Full-text articles assessed for eligibility (n= 223)

Studies included in qualitative synthesis (n= 16)

Full-text articles excluded because they mainly didn’t include:
- immersive VR (n= 62)
**TABLE 1.** Summary of the studies included.

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Population</th>
<th>Intervention</th>
<th>Comparison</th>
<th>Duration</th>
<th>Outcomes</th>
<th>Study Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cho &amp; Lee, 2019</td>
<td>N=42 (EG=21, CG=21)</td>
<td>Stroke</td>
<td>VR (fishing, cards) + Computerized cognitive exercise (REHACOM)</td>
<td>Computerized cognitive exercise</td>
<td>4 weeks (5/week, for 30’)</td>
<td>Attention, memory, performance of daily living improved in both groups</td>
<td>RCT</td>
</tr>
<tr>
<td>Gamito at al., 2014</td>
<td>N=17 (EG=8, CG=9)</td>
<td>Stroke</td>
<td>HMD VR with 9 tasks of everyday life (such as morning hygiene and breakfast, find the way to minimarket, find a virtual character, a door number etc)</td>
<td>Desktop screen-based VR</td>
<td>12 sessions (1/week)</td>
<td>Improved working memory and sustained attention regardless of the VR device</td>
<td>RCT</td>
</tr>
<tr>
<td>Huang, 2019</td>
<td>N=32 (EG=16, CG=17)</td>
<td>Elderly</td>
<td>Immersive Fruit Ninja VR</td>
<td>Non immersive Fruit Ninja (Kinect)</td>
<td>8 sessions (within 4 weeks)</td>
<td>EG= significant effect on the Stroop Test and Trail Making Test. The feeling of presence could contribute to older adults’ cognitive improvement, and (b) the impacts of immersive exergame training on executive functions vary across individual domains</td>
<td>RCT</td>
</tr>
<tr>
<td>Optale et al., 2010</td>
<td>N=36 (EG=18, CG=18)</td>
<td>Elderly</td>
<td>VR training in path finding and in focused attention</td>
<td>Face to-face training sessions using music therapy</td>
<td>6 months (3 months (3 auditory and 3 VR sessions every 2 weeks) + 3 months (1 auditory and 1 VR session per week)</td>
<td>EG=improvements in memory tests, especially in long- term recall. CG=no improvements but progressive decline</td>
<td>RCT</td>
</tr>
<tr>
<td>Park et al., 2019</td>
<td>N=21 (EG=11, CG=10)</td>
<td>MCI</td>
<td>MR-based cognitive training based on everyday tasks such as home setting, caring for a grandchild</td>
<td>Same activities conventional computer-assisted cognitive training, using Comcog</td>
<td>18 sessions (3/week for 30’)</td>
<td>EG= significant more improvements visuospatial working memory but no to other cognitive domain either for EG or CG</td>
<td>RCT</td>
</tr>
<tr>
<td>Authors</td>
<td>Year</td>
<td>Sample Size</td>
<td>Condition</td>
<td>Intervention</td>
<td>Duration</td>
<td>Results</td>
<td>Study Design</td>
</tr>
<tr>
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<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>Liao et al., 2019</td>
<td>N=34</td>
<td>MCI</td>
<td>VR-based cognitive training (VR) like metro, kitchen chef, store clerk, football, tai chi</td>
<td>Traditional cognitive training (CPC)</td>
<td>12 weeks</td>
<td>Both groups= significant improvements in the SCWT and single-task and motor dual-task gait performance measures. VR group= showed improvements in cognitive dual-task gait, more improvements in the TMT-B and DTC of cadence with borderline significances.</td>
<td>RCT</td>
</tr>
<tr>
<td>Appel et al., 2020</td>
<td>EG=66</td>
<td>Elderly</td>
<td>VR nature scenes for relaxation and stress relief</td>
<td></td>
<td>1 session</td>
<td>Feasible and safe to expose older adults with various levels of cognitive decline in VR</td>
<td>Feasibility, non-randomized</td>
</tr>
<tr>
<td>Huygelier et al., 2020</td>
<td>EG=7</td>
<td>Stroke</td>
<td>VR outdoor space: vegetable garden, lake and forest</td>
<td></td>
<td>6 sessions</td>
<td>It is promising to us immersive VR for neglect rehabilitation.</td>
<td>Feasibility, non-randomized</td>
</tr>
<tr>
<td>Larson et al., 2011</td>
<td>EG=18</td>
<td>TBI</td>
<td>3D cancellation exercises in both visual and haptic (tactile) stimuli</td>
<td></td>
<td>12 block protocol over 2 days</td>
<td>Within-subjects’ comparisons of target acquisition time during treatment showed that a treatment condition that included haptic cues produced improved performance compared to a condition in which such cues were not provided.</td>
<td>Feasibility, Non-randomized</td>
</tr>
<tr>
<td>Sakhare et al., 2019</td>
<td>EG= 40</td>
<td>Elderly</td>
<td>Navigating in a VR park while cycling stationary bike</td>
<td></td>
<td>1 session</td>
<td>Feasible and enjoyable in both younger and older adults</td>
<td>Feasibility, non-randomized</td>
</tr>
<tr>
<td>Yun et al., 2020</td>
<td>EG=11</td>
<td>MCI</td>
<td>Virtual harvest and cook games to improve various cognitive domains</td>
<td></td>
<td>1 session</td>
<td>VR cognitive training system is feasible and usable in patients with MCI</td>
<td>Feasibility, Non-randomized</td>
</tr>
<tr>
<td>Authors</td>
<td>EG</td>
<td>Group (ICD-10)</td>
<td>Intervention</td>
<td>Outcomes</td>
<td>Study Design</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Christiansen et al., 1998</td>
<td>30</td>
<td>TBI</td>
<td>VR Kitchen, meal preparation with multiple steps</td>
<td>2 times the task (30 steps) within 7-10 days</td>
<td>Reliability, Non-randomized</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dahdah et al., 2017</td>
<td>15</td>
<td>TBI</td>
<td>VR version of the Stroop in VR Apartment and Classroom</td>
<td>8 sessions (30-60' response time on the word-reading condition of VR Stroop and non-significantly reduced response time on the interference condition. Non-significant improvements in accuracy and inhibition were demonstrated on the color-naming condition of VR Stroop. Significantly improved accuracy under time pressure was found for the ANAM, after VR intervention</td>
<td>Non-randomized</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dvorkin et al., 2013</td>
<td>21</td>
<td>TBI</td>
<td>Visuo-haptic VR, with one target and cursor</td>
<td>2 days (3 conditions - no haptic feedback, a break-through force, and haptic nudge- in 12, 4-minute blocks)</td>
<td>Non-randomized</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamito et al., 2011</td>
<td>1</td>
<td>TBI</td>
<td>9 tasks of everyday life (such as morning hygiene and breakfast, find the way to minimarket, find a virtual character, a door number etc)</td>
<td>10 online VR sessions Improvement in working memory and attention</td>
<td>Case Study</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White&amp;Moussavi, 2016</td>
<td>EG=1</td>
<td>AD</td>
<td>Navigate to targets in a symmetric, landmark-less virtual building.</td>
<td>--</td>
<td>7 weeks</td>
<td>Learned to perfectly navigate, skill at navigating while driving improved noticeably and that he enjoyed cognitive improvement in his daily life at home.</td>
<td>Case Study</td>
</tr>
</tbody>
</table>

N= Number of Participants, EG= Experimental Group, CG= Control Group, MCI= Mild Cognitive Impairment, TBI= Traumatic Brain Injury, AD= Alzheimer's Disease, VR= Virtual Reality, RCT= Randomized Control Trial
TABLE 2. Summary of the cognitive function improved in studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Population</th>
<th>Aim</th>
<th>Measures/Assessment</th>
<th>Attention &amp; Concentration</th>
<th>Executive functions</th>
<th>Memory</th>
<th>Visuospatial, Orientation, Navigation</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optale et al., 2010</td>
<td>36 (EG=18, CG=18)</td>
<td>Elderly</td>
<td>Lessen cognitive decline and improve memory functions</td>
<td>MMSE, Digit Span, Phonemic Verbal Fluency, Dual Task, Clock, IADL, GDS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Cho &amp; Lee, 2019</td>
<td>42 (EG=21, CG=21)</td>
<td>Stroke</td>
<td>Impact of cognitive function and activity of daily living</td>
<td>Computerized Neurocognitive Function Test (CNT)</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamito et al., 2014</td>
<td>17 (EG=8, CG=9)</td>
<td>Stroke</td>
<td>Compare HMD vs non-HMD VR in memory and attention rehabilitation</td>
<td>Wechsler Memory Scale, Toulouse- Piéron</td>
<td>✓</td>
<td></td>
<td>✓</td>
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<tr>
<td>Huygelier et al., 2020</td>
<td>EG=7</td>
<td>Stroke</td>
<td>Feasibility of VR rehabilitation game for neglect</td>
<td>The Dutch version of the Oxford Cognitive Screen (OCS-NL), Behavioral Inattention Test (BIT) letter cancellation task and figure copy task</td>
<td>✓</td>
<td></td>
<td>✓</td>
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<tr>
<td>Liao et al., 2019</td>
<td>34 (EG=18, CG=18)</td>
<td>MCI</td>
<td>Cognitive training on executive function and dual-task gait performance in older adults with MCI, as well as to compare VR-based cognitive training</td>
<td>Stroop Color and Word Test (SCWT)</td>
<td></td>
<td></td>
<td>✓</td>
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</table>

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<table>
<thead>
<tr>
<th>Study</th>
<th>Group</th>
<th>Intervention</th>
<th>Outcome Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Park et al., 2019</td>
<td>21 (EG=11, CG=10)</td>
<td>MCI</td>
<td>Effectiveness in general cognition of an MR-based cognitive training</td>
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<td></td>
<td></td>
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<td>Korean version of the Consortium to Establish a Registry for Alzheimer’s Disease (CERAD-K)</td>
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<tr>
<td>Appel et al., 2020</td>
<td>EG=66</td>
<td>Elderly</td>
<td>Provide enjoyment/relaxation and reduce anxiety and depressive symptoms.</td>
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<tr>
<td></td>
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<td></td>
<td>State-Trait Anxiety Inventory, Music in Dementia Assessment Scales, modified STAI questionnaire</td>
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<tr>
<td>Dahdah et al., 2017</td>
<td>EG=15</td>
<td>TBI</td>
<td>Whether immersive VR treatment interventions improve executive dysfunction in patients with brain injury and whether performance is stronger on a VR version of the Stroop than traditional Stroop</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Woodcock-Johnson, 3rd Edition (WJ-III), Delis-Kaplan Executive Function System (D-KEFS), Automated Neuropsychological Assessment Metrics (ANAM), Simulator Sickness Questionnaire (SSQ)</td>
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<tr>
<td>White &amp; Moussavi, 2016</td>
<td>EG=1</td>
<td>AD</td>
<td>Learn to navigate in a simple VR navigation (VRN) environment and whether training could also bring real-life cognitive benefits</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>MOCA</td>
</tr>
<tr>
<td>Gamito et al., 2011</td>
<td>EG=1</td>
<td>TBI</td>
<td>Train memory and attention</td>
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<tr>
<td></td>
<td></td>
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<td>PASAT (Paced Auditory-</td>
</tr>
<tr>
<td>Study</td>
<td>Group 1 (EG)</td>
<td>Group 2 (CG)</td>
<td>Intervention</td>
</tr>
<tr>
<td>------------------------------</td>
<td>--------------</td>
<td>--------------</td>
<td>-------------------------------------------------------------------------------</td>
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<tr>
<td>Dvorkin et al., 2013</td>
<td>EG=21</td>
<td>TBI</td>
<td>Attention training in early stages of recovery from severe TBI</td>
</tr>
<tr>
<td>Larson et al., 2011</td>
<td>EG=18</td>
<td>TBI</td>
<td>Feasibility of VR and robotics technology to improve attention in patients with severe TBI in the early stages of recovery.</td>
</tr>
<tr>
<td>Huang, 2019</td>
<td>EG=16, CG=17</td>
<td>Elderly</td>
<td>Exergaming and virtual reality (VR)-based training for executive functions in older adults</td>
</tr>
</tbody>
</table>

EG= Experimental Group, CG= Control Group, MCI= Mild Cognitive Impairment, TBI=Traumatic Brain Injury, AD=Alzheimer’s Disease, VR=Virtual Reality, MMSE= Mini Mental State Examination, MOCA= Montreal Cognitive Assessment, IADL= Instrumental Activities of Daily Living Scale, GDS= The Geriatric Depression Scale
TABLE 3. PEDro score for RCT’s included in the systematic review

<table>
<thead>
<tr>
<th>Study</th>
<th>Random allocation</th>
<th>Concealed allocation</th>
<th>Baseline comparability</th>
<th>Blinded subjects</th>
<th>Blinded therapists</th>
<th>Blinded assessors</th>
<th>Follow-up</th>
<th>“Intent to treat”</th>
<th>Between-group analysis</th>
<th>Point estimates and variability</th>
<th>Total Score PEDro Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cho &amp; Lee, 2019</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>8/10</td>
</tr>
<tr>
<td>Gamito et al., 2014</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>7/10</td>
</tr>
<tr>
<td>Huang, 2019</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
<td>7/10</td>
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<tr>
<td>Optale et al., 2010</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
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<td>Yes</td>
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<td>Park et al., 2019</td>
<td>Yes</td>
<td>No</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Liao et al., 2019</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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<td>7/10</td>
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