# Integrating Virtual Reality in Cognitive Training of Older Adults Without Cognitive Impairment: A Systematic Review of Randomized Controlled Trials

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Abstract: This article aimed to analyse state-of-the-art empirical evidence of randomized controlled trials designed to assess preventive cognitive training interventions based on virtual reality for older adults without cognitive impairment, by identifying virtual reality setups and tasks, clinical outcomes and respective measurement instruments, and positive effects on outcome parameters. A systematic electronic search was performed, and six randomized controlled trials were included in the systematic review. In terms of results, the included studies pointed to significant positive impact of virtual reality-based cognitive training interventions on global cognition, memory, attention, information processing speed, walking variability, balance, muscle strength, and falls. However, further research is required to evaluate the adequacy of the virtual reality setups and tasks, to study the impact of the interventions' duration and intensity, to understand how to tailor the interventions to the characteristics and needs of the individuals, and to compare face-to-face to remote interventions.

## 1 INTRODUCTION

The increase in life expectancy and population aging have raised the prevalence of neurodegenerative diseases, which represent a major threat to human health (Constanzo *et al.*, 2020; Lanctôt *et al.*, 2023). Considering all major groups of diseases, the diseases of the nervous system have the greatest contribution to the global impact on the health of populations worldwide and are responsible for high disability rates and global burden of disease (Cicerone *et al.*, 2011).

Mild cognitive impairment, an intermediate stage between normal aging and dementia (Geda, 2012), is characterized by an objective cognitive decline in one or more cognitive domains (*e.g.*, memory, attention, information processing speed, executive functions, or language) without any significant impairment in daily activities and may be associated with a variety of underlying causes, including dementia (Geda, 2012; Constanzo *et al.*, 2020). Dementia is a major neurocognitive disorder that is characterized by a cognitive decline in one or more cognitive domains in such an extent that interferes with the individual's independence in daily activities (American Psychiatric Association, 2013). Alzheimer disease is the most common form of dementia worldwide, and estimations pointed that in 2010 it affected more than 36 million people (Prince *et al.*, 2015). Moreover, this number might double every 20 years to 66 million by 2030 and to 115 million by 2050 (Prince *et al.*, 2015; Constanzo *et al.*, 2020).

Patients with dementia constitute a burden for society, not only in terms of their quality of life and the quality of life of their relatives and caregivers, but also in terms of the costs of healthcare and social care systems (Cruz *et al.*, 2013; Chiao, Wu & Hsiao, 2015; Watson, Tatangelo & McCabe, 2019; Constanzo *et al.*, 2020). Therefore, efficient approaches to deal with the needs of an increasing number of patients are required (Constanzo *et al.*, 2020).

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Since epidemiological studies identified several modifiable risk factors for dementia (*e.g.*, diabetes, hypertension, hypercholesterolemia, depression, physical frailty, unhealthy dietary habits, smoking, excessive alcohol consumption, low education, or low social support level) (World Health Organization, 2019; Solomen *et al.*, 2021), healthier lifestyles might decrease dementia incidence and be translated into individual and societal benefit (Altomare *et al.*, 2021).

In this respect, the World Health Organization considered dementia prevention a public health priority (Solomen et al., 2021) and published, in 2019, the first guidelines for risk reduction of cognitive decline and dementia (World Health Organization, 2019). These guidelines systematize evidence-based recommendations on interventions covering multiple domains, including weight, hypertension, diabetes, alcohol and tobacco consumption, social activity, physical activity, and cognitive training (World Health Organization, 2019; Solomen et al., 2021).

In the context of this article, being cognitive training a relevant component for dementia prevention is important to study new intervention models to improve its efficiency and availability.

Traditionally, cognitive training was based on paper-and-pencil exercises. However, the technological development of the last decades promoted new ways of information exchange in all aspects of our society, including healthcare provision (Constanzo et al., 2020). Health services delivered or enhanced through information technologies offer innovative ways to provide care (Constanzo et al., 2020), and represent a viable option to support individuals with cognitive impairments and potentially reducing injury, hospitalisation, and institutionalization in residence facilities (Di Lorito et al., 2021; Di Lorito et al., 2022).

A diverse range of new services focused on patients with cognitive impairment have been developed (Di Lorito *et al.*, 2022), including resources for the patients and caregivers (Torkamani, 2014; Gately, Trudeau & Moo, 2019), assistive technologies (Howard *et al.*, 2021), and cognitive training interventions (Orrel *et al.*, 2017; Di Lorito *et al.*, 2021). In terms of cognitive training, computerised programmes, supported on different types of interaction devices, be it computers, handheld devices, or virtual reality (*i.e.*, computer-based technology that allows user to interact with multisensory simulated environment) (Sabbagh *et al.*, 2020), are increasingly being used (Livingston *et al.*, 2020). Specifically, virtual reality allows interactions comparable to experience a real-life setting (Diaz-Orueta, Blanco-Campal, Lamar, Libon & Burke, 2015).

Several reviews have analysed the use of virtual reality by patients with mild cognitive impairment (Kim, Jung & Lee, 2022; Tam *et al.*, 2022; Yu, Li & Lai, 2023), Parkinson (Marotta *et al.*, 2022), Alzheimer (Clay *et al.*, 2020), or other neurological conditions (Dascal *et al.*, 2017; Bevilacqua *et al.*, 2019; Montana, Tuena, Serino, Cipresso & Riva, 2019). However, to our knowledge, there are no published reviews analysing the impact of cognitive training based on virtual reality on older adults without cognitive impairment.

Therefore, this systematic review of the literature aimed to gather updated empirical evidence on preventive cognitive training interventions based on virtual reality for older adults without cognitive impairment. Its objectives were to identify i) virtual reality setups and tasks, ii) clinical outcomes and respective measurement instruments, and iii) positive effects on outcome parameters.

# 2 METHODS

This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher *et al.*, 2010). A review protocol was defined with explicit descriptions of the methods to be used and the steps to be taken (Xiao & Watson, 2019): i) search strategies; ii) inclusion and exclusion criteria; iii) screening procedures; and iv) synthesis and reporting.

## 2.1 Search Strategies

The following databases were searched: i) PubMed; ii) Scopus; and iii) Web of Science. Eligible studies were required to be published in English language. In turn, there were no limits to the date of publication of the studies.

Boolean queries were prepared to include all the articles that have their titles, abstract or keywords conform with the following Boolean expression: (Computer OR “Virtual Reality” OR “Serious Games” OR Web-based OR Mobile) AND (Cognitive AND (Training OR Rehabilitation) AND (“randomized controlled trial” OR RCT).

## 2.2 Inclusion and Exclusion Criteria

The inclusion criteria were: i) full English articles; ii) articles published in peer-reviewed scientific journals; iii) articles reporting randomized controlled trials; and iv) articles reporting evidence of the application of virtual reality to support cognitive training of older adults without cognitive impairment.

The exclusion criteria were: i) articles not reporting randomized controlled trials; ii) articles reporting the use of technologies other than virtual reality (*e.g.*, augmented reality) to support cognitive training; iii) articles reporting the application of cognitive training to populations other than older adults without cognitive impairment (*e.g.*, older adults with mild cognitive impairment or Parkinson); iv) articles not reporting primary studies (*e.g.*, editorials, surveys or reviews); v) articles without abstracts or authors' identification; and vi) articles whose full texts were not available. Moreover, articles reporting on studies already covered by other included references were also excluded: when two articles reported on the same study in different venues the less mature one was excluded.

### 2.3 Screening Procedures

All retrieved references were imported to a spreadsheet Excel and checked for duplicates. Then, the titles and abstracts of all references were screened according to the predefined review inclusion and exclusion criteria. Full texts of potentially relevant articles were retrieved and independently screened by two randomly chosen authors, to verify if the inclusion and exclusion criteria were meet. If a consensus could not be reached between the two authors, a third author was consulted.

### 2.4 Synthesis and Reporting

In addition to general inclusion and exclusion criteria, the included studies were assessed against the Physiotherapy Evidence Database (PEDro) scale, which is considered a reliable and effective scale for the evaluation of randomized controlled trials (De Morton, 2009).

Moreover, tabular and narrative syntheses were prepared to systematize the virtual reality setups and tasks, and the experimental characteristics of the studies: i) studies' type (i.e., feasibility or efficacy); ii) participants' characteristics (i.e., number, mean age, and where they live); iii) duration of the studies; iv) outcomes and respective measurement instruments; vi) delivery forms (i.e., individual versus group intervention, and face-to-face versus remote interventions); and vii) compliance and attrition (i.e., number of dropouts versus the number of participants that completed the interventions.

Finally, the authors systematize the significant impacts of the cognitive training interventions on clinical outcomes that were reported by the included studies.

## 3 RESULTS

### 3.1 Selection of the Studies

The electronic literature search was performed in June 2023 and 2999 references were retrieved. Then, 913 references were removed because they were duplicated, did not report primary studies (*e.g.*, editorials), or did not have abstracts or the identification of the respective authors.

During the title and abstract screening, 2078 references were excluded. Some excluded references were focused on cognitive training supported on computerized solutions other than virtual reality or despite reporting the use of virtual reality the respective research studies did not target older adults without cognitive impairment.

After the full-text analysis, two articles were removed, one because reported a research protocol and the other because the mean age of the participants was 44 years old.

Therefore, the final list of the retrieved articles contained six studies (Eggenberger, Schumacher, Angst, Theil & de Brui, 2015; Mirelman *et al.*, 2016; Htut, Hiengkaew, Jalayondeja & Vongsirinavarat, 2018; Boller, Ouellet & Belleville, 2021; Kwan *et al.*, 2021; Zukowski, Shaikh, Haggard & Hamel, 2022) that were included in this systematic review.

### 3.2 Quality Assurance

The PEDro scale comprises 11 items: eligibility criteria, randomization, concealment, baseline, blinding of subjects, therapists and assessors, subjects' retention, intention to treat analysis, between-group comparison, and measures of variability. For each study, when an item was verified, a point was added up to its total score. As the result of the application of the PEDro scale, one study was classified as excellent, four as good, and one as fair.

### 3.3 Virtual Reality Setups and Tasks

In terms of virtual reality setups (Table 1) fully immersive environments and semi-immersive environments were equally distributed (*i.e.*, three articles each). In turn, in what concerns the tasks performed by the participants, all tasks comprised simultaneously cognitive training and physical exercise.

## 3.4 Experimental Characteristics of the Studies

Three of the included studies (Boller *et al.*, 2021; Kwan *et al.*, 2021; Zukowski *et al.*, 2022) aimed to assess the feasibility of virtual reality cognitive training interventions. The remainder studies (Eggenberger *et al.*, 2015; Mirelman *et al.*, 2016; Htut *et al.*, 2018) were efficacy studies.

Table 2 present the experimental characteristic of the studies. The number of participants varied from 17 (Kwan *et al.*, 2021) to 302 (Mirelman *et al.*, 2016), and their mean age varied from 67.3 (Boller *et al.*, 2021) to 78.9 (Eggenberger *et al.*, 2015) years old. In four of the studies (Eggenberger *et al.*, 2015; Boller *et al.*, 2021; Kwan *et al.*, 2021; Zukowski *et al.*, 2022) the participants were older adults living independently in the community, while in two studies (Mirelman *et al.*, 2016; Htut *et al.*, 2018) the participants were older adults living in residence facilities. One study (Mirelman *et al.*, 2016) included older adults without cognitive impairments and older adults with Parkinson disease that were taking antiparkinsonian medication. The remainder studies only included participants without cognitive impairments, although (Boller *et al.*, 2021) considered older adults with subjective memory complaints, but, in terms of inclusion criteria neuropsychological were performed to determine whether the participants were cognitively intact.

One of the feasibility studies (Zukowski *et al.*, 2022) consisted in a single training session. The other two feasibility studies had a duration of two weeks (Boller *et al.*, 2021) and eight weeks (Kwan *et al.*, 2021). The longest efficacy study (Eggenberger *et al.*, 2015) was conducted during six months and the other two efficacy studies were conducted during eight (Htut *et al.*, 2018) and six weeks (Mirelman *et al.*, 2016).

Table 1: Virtual reality setups and tasks.

| Authors, Year | Immersive Level | Virtual Reality setups | Tasks |
|---|---|---|---|
| Eggenberger *et al.*, 2015 | Semi-immersive | Treadmill positioned with a large screen and a pressure sensitive platform | Dancing, treadmill walking, or treadmill walking with simultaneous verbal memory training |
| Mirelman *et al.*, 2016 | Semi-immersive | Treadmill positioned with a large screen and a Kinect | Real life challenges such as obstacles, multiple pathways, and distracters that require continued adjustments of steps |
| Htut *et al.*, 2018 | Semi-immersive | X-box 360 | Games of X-box 360 such as Light Raise (stepping forward, backward, or sideward) or Virtual Smash (moving upper and lower limbs with slightly bending trunk to crush the box on the left, right, and front) |
| Boller *et al.*, 2021 | Full-immersive | Head-mounted display, wireless position sensors and, handheld controllers | Virtual shop and virtual car ride |
| Kwan *et al.*, 2021 | Full-immersive | Head-mounted display, wireless handheld controllers, and an under-desk ergometer with adjustable cycling resistance | Travel in the virtual world through cycling on an ergometer while simultaneously participating in cognitively demanding daily living tasks (*e.g.*, find a bus stop, reporting lost items or bird watching) |
| Zukowski *et al.*, 2022 | Semi-immersive | Treadmill positioned with a large screen | Treadmill walking |

Table 2: Experimental characteristics of the studies (participants, outcomes, and respective measurement instruments).

| Authors, Year | Number of participants (mean age) | Outcomes | Instruments |
|---|---|---|---|
| Eggenberger *et al.*, 2015 | 89 (78.9) | Memory | Executive Control Task, Paired-Associates Learning Task, and Logical Memory subtest (Story Recall) and Digit Forward and Backward tasks from Wechsler Memory Scale-Revised |
| | | Attention | Age Concentration Test (A and B) |
| | | Information processing speed | Trail Making Test (A and B), and Digit Symbol Substitution Task from Wechsler Adult Intelligence Scale |
| | | Training enjoyment | Physical Activity Enjoyment Scale |
| Mirelman *et al.*, 2016 | 302 (73.8) | Attention | NeuroTrax |
| | | Executive function | NeuroTrax |
| | | Falls | Incident rate of falls during the 6 months after the end of training |
| | | Walking speed | Electronic instrument |
| | | Walking variability | Electronic instrument |
| | | Balance | Short Physical Performance Battery |
| | | Daily activities and community participation | Physical Activity Scale for the Elderly |
| | | Quality of life | Short Form 36 Health Survey Questionnaire |
| Htut *et al.*, 2018 | 84 (75.8) | Global cognition | MoCA and Timed Up and Go test Cognition |
| | | Balance | Berg Balance Scale and Timed Up-and-Go |
| | | Muscle strength | 5 Times Sit to Stand and Handgrip Strength |
| | | Falls | Fall Efficacy Scale International |
| | | Exercise effort perception | Borg CR-10 scale |
| | | Training enjoyment | Questionnaire |
| Boller *et al.*, 2021 | 40 (67.3) | Memory | Word Recall Task, and Multifactorial Memory Questionnaire |
| Kwan *et al.*, 2021 | 17 (74.0) | Global cognition | Montreal Cognitive Assessment |
| | | Physical frailty level | Fried Frailty Phenotype scale |
| | | Walking speed | Timed Up-and-Go |
| | | Feasibility (*i.e.*, adherence, adverse outcomes, and successful learning) | Intervention attendance rate of completers, intervention completion rate, level of engagement in ergometer cycling, Virtual Reality Sickness Questionnaire, and trend in completion time |
| Zukowski *et al.*, 2022 | 60 (71.6) | Global cognition | Montreal Cognitive Assessment |
| | | Attention | Trail Making Test (A and B), and Stroop Colour-Word Test |
| | | Information processing speed | Wechsler Adult Intelligence Scale |
| | | Walking speed | 10-meter Walk Test, and Timed Up-and-Go |
| | | Mobility | Timed Up-and-Go |
| | | Balance | Four Square Step Test |
| | | Lower extremity strength | 30-second Sit-to-Stand Test |
| | | Visual acuity | Snellen Test |
| | | Daily activities and community participation | Physical Activity Scale for the Elderly, Activities-specific Balance Confidence Scale |

As can be seen in Table 2, in addition to cognitive functioning (*e.g.*, global cognition, memory, attention or information processing speed) and physical functioning (*e.g.*, walking speed and variability, balance, or muscle strength) the clinical outcomes also include daily activities and community participation (Mirelman *et al.*, 2016; Zukowski *et al.*, 2022), and quality of life (Mirelman *et al.*, 2016). Moreover, two studies also measured nonclinical outcomes, such as training enjoyment (Eggenberger *et al.*, 2015) or feasibility (Kwan *et al.*, 2021).

In two studies (Eggenberger *et al.*, 2015; Boller *et al.*, 2021) the cognitive training was delivered in small groups (*i.e.*, six participants (Eggenberger *et al.*, 2015) and four or five participants (Boller *et al.*, 2021)). All the other studies considered individual interventions. Moreover, none of the included studies implemented remote interventions, which means that all the interventions were face-to-face.

Concerning compliance and attrition, globally, 474 participants completed all the interventions and assessments. Dropouts due to health issues or personal reasons were reported in five studies (Eggenberger *et al.*, 2015; Mirelman *et al.*, 2016; Boller *et al.*, 2021; Kwan *et al.*, 2021; Zukowski *et al.*, 2022), and its rate ranged from 3% of the single session study reported by Zukowski *et al.* (2022) to 47%, the dropout rate reported by Eggenberger *et al.* (2015). In what respects the remainder study (*i.e.*, (Htut *et al.*, 2018)) it is unclear if all participants completed all the interventions and assessments.

## 3.5 Clinical Outcomes

In terms of clinical outcomes, the preventive cognitive training interventions based on virtual reality had significant positive impacts on cognitive and physical functioning.

Three studies (Eggenberger *et al.*, 2015; Htut *et al.*, 2018; Kwan *et al.*, 2021) reported significant impacts on cognitive functioning: i) Htut *et al.* (2018) reported that the scores of Montreal Cognitive Assessment of the virtual reality group were significantly greater that the controls, and the average time of the Timed Up and Go test Cognition from the virtual reality group significantly decreased when compared to controls; ii) Kwan *et al.* (2021) reported a significantly larger improvement in global cognition for the virtual reality group when compared to control group; and iii) Eggenberger *et al.* (2015) reported a significant performance improvement in the intervention groups of the information processing speed.

In turn, two studies (Mirelman *et al.*, 2016; Htut *et al.*, 2018) reported significant impacts on physical functioning: i) walking variability - Mirelman *et al.* (2016) reported that walking variability during obstacle negotiation was significantly lower in the virtual reality group; ii) balance - Mirelman *et al.* (2016) reported that the scores on the Short Physical Performance Battery improved significantly in the virtual reality group, while Htut *et al.* (2018) reported that the scores on the Berg Balance Scale and the Timed Up and Go performance time after exercise of the intervention groups were better than the controls; iii) muscle strength - Htut *et al.* (2018) reported a significant increase in the left and right handgrip strength after the virtual reality exercises; and iv) falls - Mirelman *et al.* (2016) reported that incident rate of falls was significantly lower in the virtual reality group while Htut *et al.* (2018) reported a significant decrease in Fall Efficacy Scale International scores after exercise.

Moreover, Mirelman *et al.* (2016) reported that quality of life was better in the virtual reality group, even at the 6-month follow-up.

Finally, three studies (*i.e.*, the feasibility studies (Boller *et al.*, 2021; Kwan *et al.*, 2021; Zukowski *et al.*, 2022)) did not report significant impacts in clinical outcomes, although they concluded that the use of virtual reality-based cognitive training is feasible.

# 4 DISCUSSION

Six studies published between 2015 and 2022 were included in this systematic review. This means that the interest in conducting randomized controlled trials to assess the impact of cognitive training interventions based on virtual reality on older adults without cognitive impairment is recent and did not yet attract a significant number of researchers.

A simple search in databases such as Scopus or Web of Science reveals that there are a huge number of scientific articles focused on the application of virtual reality, in general, and, in particular, to support cognitive training interventions. Therefore, the relatively small number of studies included in this systematic review could be a surprise if we were not aware that one of the inclusion criteria was the report of randomized controlled trials. In this sense, the number of articles included in this review is in line with the number of articles included in other reviews that addressed the cognitive training of older adults with cognitive impairment using virtual reality (*e.g.*, Kim *et al.* (2022) included six studies, Tam *et al.* (2022) included eight studies, Clay *et al.* (2020) included nine studies, Marotta *et al.*, (2022) included ten studies, and Dascal *et al.* (2017) included 11 studies).

Half of the studies included in this systematic review were efficacy studies (Eggenberger *et al.*, 2015; Mirelman *et al.*, 2016; Htut *et al.*, 2018) and the other half were feasibility studies (Boller *et al.*, 2021; Kwan *et al.*, 2021; Zukowski *et al.*, 2022). Surprisingly the feasibility studies were more recent, but in two of them (Boller *et al.*, 2021; Kwan *et al.*, 2021), this is justified by the fact that they reported the use of full-immersive environments (*i.e.*, more recent technologies).

The virtual reality setups of the fully immersive environments included head-mounted displays, wireless position sensors, and handheld controllers. Additionally, Kwan *et al.* (2021) also included an under-desk ergometer with adjustable cycling resistance. In turn, in terms of semi-immersive environments, Htut *et al.* (2018) reported the use of X-Box 360 games, and Eggenberger *et al.* (2015), Mirelman *et al.* (2016) and Zukowski *et al.* (2022) reported the use of treadmills positioned with large screens. Moreover, Eggenberger *et al.* (2015) also included a pressure sensitive platform, and Mirelman *et al.* (2016) a Kinect sensor.

The tasks performed by the participants include treadmill walking (Eggenberger *et al.*, 2015; Zukowski *et al.*, 2022), treadmill walking with simultaneous verbal memory training (Eggenberger *et al.*, 2015), dancing (Eggenberger *et al.*, 2015), real life challenges such as obstacles, multiple pathways, and distracters that require continued adjustments of steps (Mirelman *et al.*, 2016), virtual shop and virtual car ride (Boller *et al.*, 2021), travel in a virtual world through cycling on an ergometer while simultaneously performing cognitive tasks (Kwan *et al.*, 2021), and games of X-box 360 (Htut *et al.*, 2018) requiring the performance of physical exercises (*e.g.*, stepping forward, backward, or sideward, or moving upper and lower limbs).

Interventions were designed to be delivered face-to-face, individually (Mirelman *et al.*, 2016; Htut *et al.*, 2018; Kwan *et al.*, 2021; Zukowski *et al.*, 2022) or in small groups (Eggenberger *et al.*, 2015; Boller *et al.*, 2021). None of the interventions were designed to be delivered remotely, and, therefore, it was not possible to compare face-to-face interventions with remote interventions.

The duration of the feasibility studies varied from one session (Zukowski *et al.*, 2022) to eight weeks (Kwan *et al.*, 2021). In turn, the efficacy studies varied from six weeks (Mirelman *et al.*, 2016) and six months (Eggenberger *et al.*, 2015). However, none of the efficacy studies assessed the impact of the duration and intensity (*e.g.*, number of sessions per week) of the cognitive training interventions on clinical outcomes.

The participants of four of the studies (Eggenberger *et al.*, 2015; Boller *et al.*, 2021; Kwan *et al.*, 2021; Zukowski *et al.*, 2022) lived independently in the community, while the participants of two of the studies (Mirelman *et al.*, 2016) lived in residence facilities.

A multiplicity of clinical outcomes and measurement instruments were considered by the included studies. Except one study (Boller *et al.*, 2021) that considered a single clinical outcome (*i.e.*, memory), the remainder studies considered multiple clinical outcomes, including cognitive and physical outcomes, quality of life, daily activities, and community participation: i) global cognition (Htut *et al.*, 2018; Kwan *et al.*, 2021; Zukowski *et al.*, 2022); ii) memory (Eggenberger *et al.*, 2015); iii) attention (Eggenberger *et al.*, 2015; Mirelman *et al.*, 2016; Zukowski *et al.*, 2022); iv) information processing speed (Eggenberger *et al.*, 2015; Zukowski *et al.*, 2022); v) executive functions (Mirelman *et al.*, 2016); vi) walking speed (Mirelman *et al.*, 2016; Kwan *et al.*, 2021; Zukowski *et al.*, 2022), vii) walking variability (Mirelman *et al.*, 2016); viii) mobility (Zukowski *et al.*, 2022); ix) balance (Mirelman *et al.*, 2016; Htut *et al.*, 2018; Zukowski *et al.*, 2022); x) muscle strength (Htut *et al.*, 2018; Zukowski *et al.*, 2022); xi) falls (Mirelman *et al.*, 2016; Htut *et al.*, 2018); xii) physical frailty level (Kwan *et al.*, 2021); xiii) visual acuity (Zukowski *et al.*, 2022), xiv) quality of life (Mirelman *et al.*, 2016); xv) daily activities; and xvi) community participation (Mirelman *et al.*, 2016; Zukowski *et al.*, 2022).

In terms of significant results, the studies pointed to positive impacts of cognitive training interventions based on virtual reality on: i) global cognition (Htut *et al.*, 2018; Kwan *et al.*, 2021); ii) memory (Eggenberger *et al.*, 2015); iii) attention (Eggenberger *et al.*, 2015); iv) information processing speed (Eggenberger *et al.*, 2015); v) walking variability (Mirelman *et al.*, 2016); vi) balance (Mirelman *et al.*, 2016; Htut *et al.*, 2018); vii) muscle strength (Htut *et al.*, 2018); and viii) falls (Mirelman *et al.*, 2016; Htut *et al.*, 2018). The application of the PEDRo scale pointed for a high confidence level of these results. In fact, according to the PEDro scale, five of the included studies were classified as excellent or good.

More long-term randomized controlled trials are needed to assess the impact of the duration and intensity of the cognitive training interventions based on virtual reality. Other evidence gaps are related to the adequacy of the virtual reality setups (*e.g.*, full semi-immersive versus full immersive environments) and the tasks to be performed by the participants, since the included studies only compared participants using or not using virtual applications. Also, is not yet fully clear how the interventions should be tailored to the specific characteristics of the participants to achieve a precision risk reduction approach (*i.e.*, tailoring the right interventions for the right people and at the right time) (Solomen *et al.*, 2021). In this respect, it should also be compared the impact of face-to-face and remote cognitive training interventions.

Like all systematic reviews, this systematic review has limitations, namely, the dependency on the keywords and the selected databases, or the fact that publications not written in English were excluded. However, the authors tried to guarantee that study selection and the data extraction were methodologically rigorous.

## 5 CONCLUSIONS

From the results of this systematic review, it is possible to conclude that preventive cognitive interventions based on virtual reality had positive impacts in the cognitive (*i.e.*, global cognition, memory, attention, and information processing speed) and physical (*i.e.*, walking variability, balance, muscle strength, and falls) functioning of older adults without cognitive impairments. However, further research studies are required to fulfil some evidence gaps, such as, adequacy of the virtual reality setups and tasks, impact of the duration and intensity of the interventions, and how to tailor the interventions to the characteristics and needs of the individual. Moreover, it is also necessary to assess the impact of remote cognitive training interventions based on virtual reality.

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