# Chapter 1

# Virtual Reality in the Assessment and Rehabilitation of the Elderly Population with Physical and Cognitive Impairment

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## Abstract

Virtual reality (VR)-based technologies, such as navigation in virtual environment for the screening of cognitive deficits, motor skill re-learning for balance control, VR-based tasks, exergaming, serious games for physiotherapy, have been widely used to deal with aging- and frailty-related function deficits in the elderly. In the study, we screen OVID Medline and PubMed databases and extract 38 and 8 documents involved the application of VR in aging and frail individuals respectively. These documents showed that VR-based technologies were verified to be safe and efficient to screen, prevent and treat or rehabilitate the physical and cognitive deficits in the elderly with or without physical frailty. Cognitive frailty contains physical frailty and potential reversible cognitive impairment. Therefore, Cognitive frailty may be a new field of VR application.

## Introduction

Virtual reality (VR), as a valuable Information and Communications Technology tool, is a way for human to interact with computer-generated quasi-naturalistic real-life virtual environment (VE) by real-time visual, auditory, tactile and kinesthetic perceptual sensations feedback. The advanced interactive communication interface is available for user in egocentric or allocentric situation by using devices, such as joysticks, gloves, surface; and for stimuli presentation in REs by using devices such as screens, 3D-head-mounted displays (HMDs), audio headsets and speakers. The interaction elicits the participant's interpersonal immediate behaviors and responses, and gives an immediate feedback to observers. The interaction technique of VR includes non-immersive, semi-immersive and fully-immersive three types [1]. The use of newer consoles, such as the Nintendo Wii™ and Microsoft Kinect™ platforms, decreases costs, increases sophistication of VR systems, and facilitates quick adaption in greatrics.

The common physiological characteristic of aging is a gradual loss of physical (including sensory and motor) and cognitive performance. The individual difference of aging process could result from genetic and environmental factors. The major goal of geriatrics is to extend the healthy life span with independent function. Frailty is a

potentially correctable syndrome with accumulated deficits and reduced physiological reserve in many biological systems [2]. The prevalence of frailty and cognitive impairment increases significantly as age increases, frailty from 3.2% at 65 to 16.3% at 80 and 23.1% at 91 years of age [3], and cognitive impairment from 5.9% in those aged 60-64 years to 31.3% in those aged 75-79 years and 44.1% in those aged ≥80 years [4]. There is a preclinical stage precede of decade years the clinical onset of mild cognitive impairment (MCI) or dementia. Objective cognitive deficits in one or multiple cognitive domains can be detected in MCI, but without deficits in daily life ability. Co-occurrence of physical frailty and MCI was referred as cognitive frailty [5]. Reversible cognitive frailty is an ideal target for promoting healthy ageing preveting and elderly dependency [6-8]. Beyond this stage, serious physical and cognitive deficits occurred in patients with MCI and dementia. The limitation of clinical neuropysiological assessment and interventional efficacy in cognitive impairment, causes a growing interest in finding new tools to solve the challenges of medical practice.

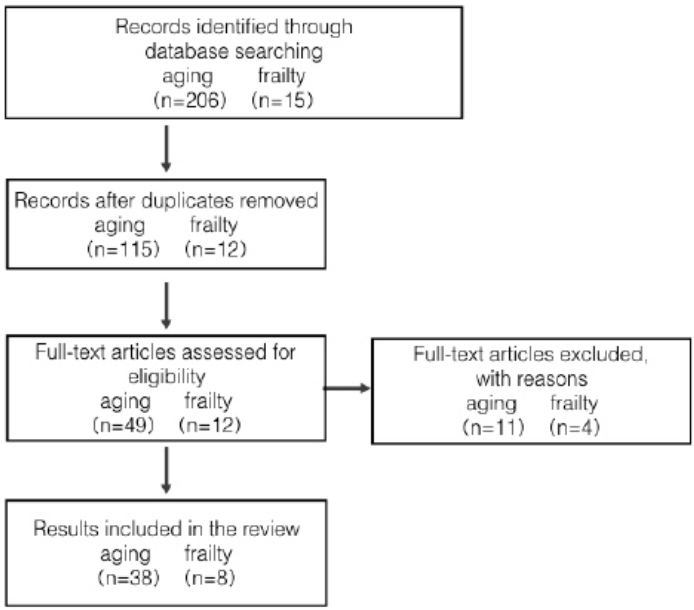
According to neural plasticity theories after interaction between brain and enriched environments, motor relearning and cognitive rehabilitation is to enable patients to overcome balance functional, cognitive and emotional deficits due to physical and cognitive impairment, and to

achieve social adjustment and better quality of life. VR-based innovation offers new chances to the assessment and rehabilitation of frailty and cognitive impairment due a better approximation to the real word with less cost and in less time, as well as higher levels of immersion. VR-based tasks, exergaming, serious games ((SG), defined, as seen, as games that do not have the entertainment as a primary goal and can contribute to a specific purpose), or activities allow their applications in diagnosis and rehabilitation of aged population with frailty, age-related cognitive impairment, mild cognitive impairment (MCI) and dementia. Mild-moderate stage dementia is the right time to introduce in VR items. The VR applications include motor re-learning for postural control and balance, navigation and orientation, face recognition, cognitive functionality, and other instrumental activities of daily living (IADL) for different domain of cognitive impairment, and cognitive behavioural therapy for patients with frailty and age-related cognitive impairment [9,10].

## Materials and Methods

The goal of the paper is to summarize developed VR techniques in the applications of aging, frailty that are mainly associated with diagnosis or assessment, and prevention or treatment. We performed literature searches by way of a review which includes OVID Medline and Pub-

Med databases from 2007 to July 2017. The search queries included: VR or virtual enviroment, aging, frailty, behavioral or cognitive impairment, memory performance, subjective memory decline (impair¬ment), diagnosis or assessment and prevention or treatment. We obtained following results from the review: I) VR techniques for assessment and treatment of aging-related physical and cognitive impairment (n = 206); II) VR techniques for assessment and treatment of frailty (n = 15); Inclusion criteria: Articles that deal with VR techinques related to the diagnosis and treatment of aging, frailty. Exclusion criteria: Articles that do not deal with the diagnosis and treatment of above disorders even if VR techniques are used. All titles and abstracts of the articles selected were evaluated by two reviewers to determine if they met the inclusion criteria. The disagreements were solved by coordinated review. After critical reading of the documents, the total number included in the review was 46 documents (Figure. 1). The quality grades and scientific evidence level have been classified according to the criteria proposed by Hannes and Macaitis [11].




## VR in the Assessment of the Elderly Population with Physical and Cognitive Impairment

TThe rapid development of VR techniques make them are feasible and effective to be used by older adults in function assessment and treatment of health-related domains, such as posture balance, cognitive function and physical

activity [12-14]. The main applications of VR techniques for the assessment of function deficits of health-related domains in elderly population were showed in Table 1. The most prominent cognitive deficit of brain aging is reduced spatial learning and memory performances resulted from the structure alterations of hippocampus and a shift from using the hippocampus toward the caudate nucleus during navigation [15]. Both hippocampus and striatum play different roles in spatial learning and memory. Hippocampal place cells that generate allocentric neural computation and space representation, are sensitive to geometric information. Local landmarks affect striatum-dependent learning. Aging causes hippocampus–related spatial learning and memory deficits [16]. After manipulation the geometry and local landmarks of a virtual environment, older adults showed striatum-dependent activity changes. The behavior and medial-temporal lobe activity of older adults mainly were affected by local landmarks. VR-based tasks improve the assessment of spatial memory in humans. A virtual water maze with a reversal learning protocol further was demonstrated to detect early age-related spatial learning and memory deficits [17]. Moreover, mental disorders such as depression and anxiety, and personality traits also add vulnerabilities for both spatial performance and hippocampal functioning. Leon et al. carried out a study to assess the effect of aging and gender on naviga-

tional skills in a virtual memory task [18]. They found that age and gender are important factors influencing spatial orientation skills. Females showed a more noticeable poor performance in spatial memory than males and 65-74 year-old males showed that spatial memory becomes less accurate in comparison with 45-54 year-old group. VR-based 3D virtual enviroment navigation learning and 2D Hidden Maze Tasks showed convergent validity for assessment of sptial memory [19]. Elderly men reached peak performance more rapidly than elderly women during VE navigation and on the 2D Hidden Maze Tasks. Prospective memory means complex cognitive functions, referred to as the ability to remember to fulfil intentions at some predefined point in the future. VR-based ride in a virtual town is a more realistic and ecological assessment in age-related prospective memory and correlation with other cognitive functions than traditional laboratory tasks [20]. Aging resulted in a decline on the recall of prospective and retrospective components of intentions, regardless of the nature of the intention and whatever the strength of the link of two components. When the link is weak, older subjects showed more pronounced decline in the recall of retrospective components. The decline in binding involved in different cognitive functions depending on the nature of intentions, such as working memory, executive functioning, episodic memory as well as in processing speed, also contributes to the decline of prospective memory. Everyday memory is embedded within daily activities and

could be assessed by using self-rating scales to evaluate subjective memory complaints. VR-based HOMES test was showed to be free from subjective biases with a good ecological validity [21]. HOMES test not only was used to detect similar every-like memory failures of age-related and traumatic brain injury, such as poor recall, a greater recognition benefit, high false recognitions; but also could be used to differentiate their cognitive regulation. Age-related differences were mediated by executive functioning while the traumatic brain injury patients were correlated with episodic memory. Tests based on virtual environments could are used as helpful standard tools for assessing age effects on the main aspects of episodic memory. The older individuals had less recollection of the spatiotemporal context of events than the younger with intentional encoding, but similar recollection with incidental encoding (except for verbal spatial aspect) [22]. Furthermore, older ones showed worse binding than younger individuals in all types of encoding. For the older individuals, the virtual test was sensitive to mnesic complaints and golable cognitive changes.

**Table 1:** VR techniques for assessment and treatment of age-related physical and cognitive impairments.

| Reference | Partcipants | Domains | Detection methods | Immersion type |
|---|---|---|---|---|
| Konishi et al.(2013) | Young (N = 23) and older adults (N = 29) | Spatial or response strategies (navigation t in a virtual maze) | fMRI on the Concurrent Spatial Discrimination Learning Task | Non |
| Schuck et al. (2015) | 26 older participants<br><br>22 younger participants | Spatial learning and memory (navigation t in VE) | The geometry and local landmarks in VE, computational modeling, and neuroimaging | Semi |
| Schoenfeld et al. (2014) | 90 participants (52% females, 20–80 yrs) | Spatial reversal learning memory | A virtual water maze with a reversal learning procedure | Semi |
| Leon et al. (2016 ) | 135 participants (from 45 to 74 years of age were organized in three groups: 45-54, 55-64, 65-74 years old). | navigational skills | Virtual memory task | Non |
| Tippett et al. (2009) | 24 older adults | VE navigation learning | Groton Maze Learning Test and selected traditional neuropsychological tests | Non |
| Lecouvey et al. (2017) | 35 younger<br><br>29 older | Prospective memory | To recall three event-based intentions and three time-based intentions | Semi |
| Arvind pala et al. (2014) | 15 older adults 15 younger adults with traumatic brain injury | Everyday memory | VR-based HOMES test | Semi |
| Plancher et al. (2010) | 82 young adults<br><br>78 older adults | Episodic memory and<br><br>feature binding in a VE | To drive and to memorize the VE (itinerary, elements, etc.). Episodic memory were then assessed (what, where, when, and binding) | Semi |

| | | | | |
|---|---|---|---|---|
| Sakai et al. (2017) | 285 healthy individuals (from 20 to 86 years of age) | Cognitive function | A virtual shopping test Mini–Mental State Examination | Non |
| Atkins et al. (2015) | 44 healthy Younger<br>41 healthy Older | Instrumental activities associated with a shopping trip | Virtual Reality Functional Capacity Assessment Tool | Non |
| Kizony et al. (2017) | 10 young adults<br>7 old adults | Navigation ability (cognitive-executive and motor aspects) | navigation within a simulated environment with and without a functional-cognitive task | Semi |
| Taillade et al. (2013) | 23 young healthy adults<br>24 older adults | Wayfinding performances and the executive and memory decline | VR-based wayfinding and spatial memorytasks; neuropsychological tests of executive and visuo-spatial memory functions | Full |
| Davison et al. (2017) | 40 participants | Age-related cognitive functioning | VR-based a seating arrangement task, an item location task and a virtual parking simulator Stroop colour–word test and the trail-making test | Full |
| Carelli et al. (2011) | 40 subjects | transfer survey to route represnetation ability | Paper and pencil version of eight mazes VR mazes A comprehensive neuropsychological evaluation | Non |
| Francis et al. (2015) | 12 young adults<br>11 older adults | Gait variability (visual perturbations, increased cognitive load, and narrowed step width) Gait variability Challenging walking tasks Semi<br>Gait variability (visual perturbations, increased cognitive load, and narrowed step width) | Gait variability Challenging walking tasks | Semi |
| Hutzler et al. (2017) | 60 volunteers | Balance control | Rapid Stepping Test | Non |
| Chou et al. (2009) | 16 younger adults<br>17 older adults | Optic Flow Speed and lateral Flow asymmetry on locomotion | Gait kinematics and heading direction were measured using a three-dimensional motion analysis system | Full |
| Chen et al.(2015) | 26 participants | Functional range of motion and driver' performance | VR-based simulated, dynamic driving blind spot target detection task | Full |

Aging related cognitive dysfunction, such as attention, memory, and executive functions causes many difficulties in everyday life. A virtual shopping test (VST) had been showed to be useful for assessing general cognitive decline in healthy older individuals [23]. Based similar VR shopping trip, Atkins et al. [24] developed a Virtual Reality Functional Capacity Assessment Tool (VRFCAT). The tool was verified to be reliable to assess complete instrumental activities related to VR shopping trip in healthy aging and preclinical MCI/AD. Strong age-related differences in performance assessment of functional capacity were observed, including total completion time, total errors, and total forced progressions. VRFCAT performance was strong associated with cognitive performance across all participants. Thus, VRFCAT can be used to measure functional change in primary prevention and preclinical AD/MCI trials. Aging might cause decline of navigation skills, including cognitive-executive and motor aspects, which are required for performance of functional complex tasks. In a VE with mall, participants performed the Virtual Multiple Errands Test when they navigated in VE accompanying with or without shopping tasks [25]. The results showed that older adults was less efficient and slower than younger individuals to perform the Virtual Multiple Errands Test . Both groups walked slower in the VR-based mall, but there were no difference in gait parameters. Age-related wayfinding difficulties associated with executive and memory decline was verified in a realistic

VE [26]. The objective evaluation of wayfinding performances in VE could find the additional deficit of cognitive aging. VR technology is an ideal substitution of self-reported questionnaires, which strongly underestimated the wayfinding difficulties in older adults. Executive function involves in inhibition, working memory, cognitive flexibility, reasoning, problem solving and planning abilities in cognitive process. Immersive virtual reality (IVR) tasks including a seating arrangement task, an item location task in the virtual chemistry lab environment, and the parking simulator task, were showed to be more sensitive and ecologically valid, in predicting age-related cognitive decline when compared to the traditional neuropsychological measures, including the Stroop colour–word test and the trail-making test [27], although few participants experienced a minor degree of motion sickness. The transfer from survey (map-like) to route representations is high cognitive demanding, and sensitive to cognitive decline, such as excutive functions and visuo-spatial abilities. Healthy individuals showed age-related deterioration performance to translate the map-like paths of the paper and pencil version of eight mazes into egocentric routes of equivalent VR mazes [28]. Global cognitive level, previous experience with computer and fluidity of navigation into the VR affect performance, but education level and gender do not affect performance.

Gait variability arisen from subtle age-related changes in cognitive processing and sensorimotor function is as-

sociated with fall risk in the elderly. Francis et al. investigated the effects of mediolateral visual perturbations, increased cognitive load (serial seven subtractions), and narrowed step width on gait variability in healthy old and young adults when participants walked on a treadmill while watching a speed-matched virtual hallway [29]. They found that cognitive task and walking with narrowed step width did not show any effect on gait variability in step width or step length in either group. Visual perturbations significantly increased gait variability in old adults by more than 100% in both step width and step length, but not young adults. The differences might potentially reflect subclinical balance deficits in the elderly. A Rapid Stepping Test protocol utilizing a virtual reality SeeMeTMsystem (VR-RST) is feasible and valid to assess the balance control in elderly ambulatory and independent individuals living in a community residential home [30]. Locomotion control depends on the integration of information from visual, vestibular, and somatosensory systems. Compared to young adults, locomotion in a virtual hallway was recorded and walking speed and heading direction were assessed by a three-dimensional motion analysis system, healthy older adults demonstrated a less reliance on optic flow information due to a central sensory reweighting deficit and/or age-related peripheral sensory loss in the vestibular and somatosensory systems [31]. The VR-based techniques may be useful to assess whether perception of optic flow is degraded in the fall-prone elderly and how

they use the optic flow information to guide locomotion. The functional range of motion (overall rotation used during a task) of drivers could provide comprehensive assessment of driving ability. Drivers in a creoss-sectional laboratory study performed stimulated, dynamic driving blind spot target detection task in an immersive VR system [32]. The results showed that older drivers demonstrated less functional range of motion, nearly twice less in target detection and more target detection time than the younger drivers.

## VR in the Rehabilitation of the Elderly Population with Physical and Cognitive Impairment

Aging manifests the deterioration of cognitive performance and physical abilities, such as muscular strength, sensory sensitivity, and functional capacity which can be rehabilitated by VR applications (Table 2). A 3-D virtual reality kayak program, as an intervention method, could improve cognitive function, muscle strength and balance control of community-dwelling elderly [33]. Older adults increase the risk of falls due to age-related poor balance control. Balance training by using a innovative virtual-reality system (two sessions/week for 6 weeks), could significantly improve balance parameters, reduce in falls and lower the levels of fear of falling in community-dwelling older individuals with a known history of falls [34]. Some

balance parameters still showed a improvement after 9 months post-training. VR based three-dimensional video gaming technology training (60 minutes, twice a week, for 6 weeks) could significantly improve physical abilities, including static and dynamic postural balance and lower extremity strength in community-dwelling older adults [35]. VR-based three different Nintendo® Wii FIT balance interventions three times per week for 6 weeks were showed to improve dynamic balance and balance confidence by measuring of the 8-foot Up & Go test in older adults, compared to no intervention control individuals [36]. In a randomised controlled trial at five clinical centres across five countries, adults aged 60–90 years with a high risk of falls based on a history of two or more falls in the 6 months before the study and with varied motor and cognitive deficits were randomly assigned by use of computer-based allocation to receive 6 weeks of either treadmill training plus VR or treadmill training alone [37]. The results showed that the incident rate of falls was significantly lower in the treadmill training plus VR group than in the treadmill training group (incident rate ratio 0.58, 95% CI 0.36–0.96; p=0.033) 6 months after the end of training. The treadmill training plus VR did not cause serious training-related adverse events.

**Table 2:** VR techniques for treatment of age-related physical and cognitive impairments.

| Reference | Partcipants | Domains | Interventions | Immersion type |
|---|---|---|---|---|
| Park et al. (2016) | 72 elders (Kayak group n = 36, control group n =36) | Cognitive function, muscle strength and balance | A 3-D virtual reality kayak program | Full |
| Duque et al. (2013) | 60 community-dwelling older subjects | Balance, falls, and fear of falling | VR-based Balance Rehabilitation Unit | Full |
| Lee et al. (2017) | 40 participants | Postural balance and lower extremity strength | The Wii-Fit game | Semi |
| Rendon et al.(2012) | Community-dwelling adults between 60 and 95 years of age (VR group n=16, control group n=18) | dynamic balance and balance confidence | VR gaming balance training (3×/week × 6 weeks) | Semi |
| Mirelman et al. (2016) | 282 participants | reduce fall risk | Treadmill training plus VR (including real-life challenges such as obstacles, multiple pathways, and distracters that required continual adjustment of steps) Treadmill training alone | Semi |
| Anderson-Hanley et al.(2012) | 63 older adults | Executive function and fitness, brain-derived neurotrophic growth factor | exercising on a cycle ergometer using virtual environment cycle ergometer without interaction with virtual reality | Semi |
| Monteiro-Junior et al. 2016 | 19 institutionalized older persons (Wii group n=10, Control group n=9) | Congnitive function (short-term memory, working memory and semantic memory/executive function) | Wii group performed six exercises with virtual reality Contral group performed six exercises without virtual reality | Semi |
| Eggenberger et al. (2015a) | 71 completed the training at 6-month 47 were available at 1-year follow-up | Cognitive function | VR video game dancing, treadmill walking with simultane¯ous verbal memory training and treadmill walking | Semi |
| Debarnot et al. (2015) | 30 healthy elderly | Prospective memory | Theta burst stimuli | Full |

VR-enhanced exercise (exergames) facilitates the participation of older individuals and improves balance, gait and cognition. In a randomized clinical trial of 3 months of cybercycling versus traditional excise, cybercycling older adults showed a 23% relative reduction in clinical progression to MCI, and similar fitness with traditional excisers [38]. Individuals with simultaneous cognitive and physical exercise had better cognitive function than traditional excisers. In another single-blinded, randomized and control pilot study, participants did not showed an acute effect on cognition when they performed a single seccion of exergames or excercises without VR [39]. A single seccion of exergames did not improve short-term memory, working memory and semantic memory/executive function, but did verbal fluency. Eggenberger et al. designed a clinical trial to compare the differential positive effects on cognition of physical and cognitive training [40]. Their study showed that cognitive-physical training and physical multicomponent training could improve executive functions, long-term visual memory (episodic memory) and processing speed in the elderly. The improvement could be maintained at 1-year fellow-up. Advantages of the simultaneous cognitive–physical programs could counteract widespread cognitive impairments, particularly in two dimensions of executive function. Prospective memory decline is the early manifestation of normal aging. The left

Brodmann area 10 (BA10) plays a major role in prospective memory function. Debarnot et al. assessed the effects on prospective memory function of healthy aged subjects by modulating left BA10 using theta burst stimulation (TBS), including excitatory TBS, inhibitory TBS or control (vertex) TBS [41]. A reliable and ecological VR prospective memory task that included both event- and time-based retrievals was used to assess the behavioral effects. Excitatory stimulation, but not inhibitory stimulation caused significant improvement in event-based prospective memory performance.

## VR in the Assessment and Rehabilitation of the Elderly Population with Physical and Cognitive Impairment

VR also could be used to assess and rehabilitate physical or cognitive deficits (Table 3). The ability to resolve sensory conflicts and the integrity of many postural regulating systems in central neural system (CNS), including musculoskeletal, sensory systems, neural processing and conduction of information, show a age-related decline. When immersed in a VE for 1 hour with randomly transient visual and/or surface perturbations, older adults showed to maintain upright equilibrium relied more on vision than young adults [42]. Moreover, a one-hour immersion in VE and exposure to sensory conflicts is

enough to improve balance capability in older adults by the recalibration and adaption of CNS to the changes. Simultaneous cognitive–physical training programs. VR-based video game dancing and treadmill walking with simultaneous verbal memory training displayed similarly potential with the exclusive physical exercise program to counteract age-related decline of physical functioning in the elderly persons [43]. After a 6-month training interven¬tion with these programs, gait performance was partly retained over 1 year with some attenuation in fast walking speed and gait variability. Compared to the exclusive physical exercise program, simultaneous cognitive–physical training caused a significant advantage in relative dual-task costs (as the percentage of relative loss to the single task walking perfor¬mance) of walking, but not in other gait variables.

VR is often used to test pedestrians' behavior. In a virtual reality setting, older pedestrians behaved in a less secure manner while crossing a street and looked more at their feet and less attention to the traffic [44]. The less secure behavior might result from reduced cognitive and visual abilities that cause difficulties in plan precise stepping movement. VR-based mixed physical-cognitive trainings might improve older pedestrians' safety. VR-based training can help older pedestrians make safer street-crossing decisions in two-way traffic situations., Different to

younger individuals older participants, , accepted more often to cross and had more collisions on the small-scale simulation device than on the full-scale one [45]. After two 1.5-h training sessions with the small-scale device, unlike untrained older individuals, the trained older individuals showed a significant global decrease in the percentage of accepted crossings and collisions on both simulation devices. Thus, a small scale simulation device could be a good means to improve the safety of street-crossing decisions and behaviors among older pedestrians.

Following learning in a semi-immersion virtual environment, older subjects showed poorer spatial memory than younger subjects in all tested spatial tasks including object recognition, egocentric spatial processing (direction judgement), allocentric spatial processing (proximity judgement) and cognitive mapping ability, especially in allocentric spatial processing [46]. A familiar context can enhance object recognition and egocentric spatial memory in both younger and older subjects, and reduce spatial memory deficits in older subjects. Older individuals usually have trouble in finding their way in new environments. VR-based maze could be used to assess the types of self-reported search strategies and cues [47]. The oldest old individuals were less likely to use strategies such as triangulation and distance strategies. All individuals found their way by the use of visual landmarks, but older individuals less use of geometric cues (corners). These

findings obviously were beneficial for the design more supportive environments. The event-related responses obtained by virtual reality may be a reliable method to test the environmental feasibility to age-related cognitive changes. A P3b paradigm was designed to test the best features of a target place (bathroom) to be recognized in a virtual ambient reproducing a real house [48]. Three different VEs were tested, as the bathroom was designed in the aisle, living room or bedroom. The bathroom door was identified as target stimulus and other rooms as frequent stimuli. In order to understand the better features for target room doors recognition, bathroom doors were semi-opened so that participants could see the typical furniture. All doors were illuminated in white, and only target doors were colored with a green or red spotlight. All the target stimuli evoked a significant increase in P3b amplitude on the parietal, occipital and central electrodes in electroencephalograph of young individuals, compared to frequent stimuli condition, and being irrelative with the color of the target door. However, the green and red colors, but not white in target stimuli significantly evoked larger P3b amplitude on the parietal, occipital, and central derivations from the frequent stimulus in elderly individuals. The results showed that cortical neuroplasticity in the elderly may be facillitated, and is able to compensate the age-related progressive loss of cognitive performance in elderlyindividuals.

**Table 3:** VR techniques for assessment and treatment of age-related physical and cognitive impairments.

| Reference | Partcipants | Domains | Detection methods or Tasks | Immersion type |
|---|---|---|---|---|
| Merriman et al. (2016) | 48 healthy younger adults<br><br>23 older adults | Spatial memory or cognitive mapping abilities | An object recognition<br><br>task, an egocentric spatial processing task, an allocentric spatial processing<br><br>task and two pen-and-paper tests | Full or semi |
| Bugnariu et al.<br><br>(2007) | 10 young adults<br><br>10 older adults | Postural control | VE with transient visual and/or surface perturbations | Full |
| Zito et al. (2015) | 18 healthy younger adults<br><br>18 older adults | Street crossing behavior, eye and head movements | Far visual acuity, the number of safe crossings, the number of virtual crashes and the number of missed opportunities | Full |
| de Tommaso et al. (2016) | 14 young adults<br><br>14 older adults | Wayfinding in three different VE | The P3b paradigm to detect the neural activity related to the target stimulus by electroencephalograph | Full |
| Jebara et al.<br><br>(2014) | 64 young adults<br><br>64 elderly adults | Feature binding in episodic memory<br><br>Subjective sense of remembering | (1) passive condition where participants were immersed as passengers of a virtual car [no interaction, no itinerary control, (2) the subject chose the itinerary, but did not drive the car, (3) low, or (4) high navigation control (the subject just moved the car on rails or drove the car with a steering-wheel and a gas pedal on a fixed itinerary, respectively) | Semi and full |
| Maillot et al. (2017) | 20 young adults<br><br>40 older adults (20 trained and19 untrained) | pedestrian safety (street-crossing decisions and behaviors) | Street crossings using both full-scale and small-scale simulation devices | Semi and full |

| | | | | |
|---|---|---|---|---|
| Eggenberger et al. (2015b) | 71 participants (older than 70 years, live independently without cognitive impairment) | Dual-task gait performance | VR video game dancing, tread¬mill walking with simultaneous verbal memory training and treadmill walking | Semi |
| Legault et al. (2013) | 10 younger adults<br><br>10 older adults (cognitively healthy) | Perceptual-cogniti-ve processes | 3D-multiple object tracking task | Full |
| Davis et al.(2015) | 129 healthy inde-pendently living older adults (55–96 years old) | Search Strategies in wayfinding | Cognitive measures<br><br>VR place learning task<br><br>Questions of strategies and cues | Non |
| Lau et al. (2016) | 8 older adults with bilateral hearing loss | Word recognition accuracy in a dual-task experi-ment. | VR auditory, visual, mo-bility and cognitive chal-lenges for listening while walking: listening-only, walking-only and listening while walking in street intersection | Semi |

Fluent and continuous perceptual-cognitive processing is required to process complex dynamic scenes in real life. Healthy aging resulted in reduced performance in a VR-based dynamic 3D-multiple object tracking (MOT) task [49]. Perceptual-cognitive training for a complex dynamic multifocal attention motion task by 3D-MOT, significantly reduce age-related deficit. Moreover, the training benefit for older observers is the same level as that for younger healthy adults. In a longitudinal control clinical study, during VR-based Nintendo Wii FitTM training, individuals with Parkinson's disease had marked learning deficits in some games with particularly cognitive demands, such as decision-making, response inhibition, divided attention and working memory [50]. After training, patients demonstrated significant improvements in

the abilities of learning, retention and transferred to activities of daily living. Navigation (active or passive) in VE and itinerary choice were demonstrated to affect feature binding (the association between what, where, and when) in episodic memory and the subjective sense of remembering. Jebara et al. designed four modes of exploration navigation in a virtual city [51]. Participants memorized as many events, including their factual (what), spatial (where), and temporal (when) details, as possible. After these tasks, subjects required to perform immediate and delayed memory tests. The immediate and delayed feature binding showed an age-related decline. The decision of the itinerary is beneficial to improving episodic memory in aging, although it does not eliminate age-related deficits. Active navigation, such as low navigation, can also enhance episodic memory, but passive or high navigation that demands more for subjects' cognitive resources. Beyond age-related hearing loss, aging is usually accompanied with deterioration of many other domains, such as other sensory, sensorimotor and cognitive aging. To maximize the beneficial effects of hearing aid on daily life, these factors all should be considered. VR-based environment simulation for real life, such as a dual-task condition listening while walking in a virtual downtown street intersection was used to assess word recognition accuracy of people with different levels of sensory, motor, and cognitive abilities in multisensory environments [52]. The

virtual environment is useful for hearing assessment after age-related hearing loss and the objective benefits after using hearing aid in the real world.

## VR Applications in the Elderly Population with Frailty

Physical frailty is defined as a medical syndrome with multiple causes and contributors that is characterized by diminished strength, endurance, and reduced physiologic function that increases an individual's vulnerability for developing increased dependency and/or death [2]. Frailty is the middle stage between aging and adverse outcomes, such as hospital readmission, admission to a care home, a worse outcome following surgery, post-operative complications and a greater risk of falling, dementia, general morbidity and mortality [2,5]. The potential reversibility means frailty is primary target of against aging and disability. Apart from frailty phenotype and frailty index for the screening [53,54], exercise, protein-calorie supplementation, vitamin D, reduction of polypharmacy and rehabilitation for the, prevention and treatment of frailty [2,55], many technological resources were used to dealing with frailty in the elderly. Mugueta and Garcia-Zapirain systemically reviewed literature that showed many new technologies, such as internet networking, smartphones with accelerometer, gyroscope, digital compass, camera, Bluetooth, proximity sensors, GPS, microphones and

WIFI, were used widely as tools for the screening, wireless sensors of different types (motion, optic and pressure, etc.), smartphones and robots for the prevention, and the Nintendo® Wii™ console, different mobile applications such as FitBit, iFit or some other type of motion sensor or activity gauge for the treatment of frailty [56]. As a novel technology, VR plays an important role on diagnosis, prevention and treatment of frailty in the elderly (Table 4). VR-based interactive multimedia game was developed to measure grip strength [57,58] or GAITRite®-System to measure walking speed and leisure activities [59] were used to screen physical frailty according to Fried's physical frailty scale [54]. Menelas et al.[60] presented a VR game that participants keep balance on different types of flooring, including broken stone, stone powder, sand, concrete and wood. The VR training was demonstrated to enhance the balance ability and prevent falls of frail older adults. Several studies showed that VR could be used to treat frailty. Szturm et al. [61] designed three types of video game with different levels of difficulty. The frail patients performed balance training via interactive games that caused better control of dynamic balance compared to a standard physical strength and balance program. Compared to control group, both training via Geri-Fit® and the Nintendo® WiiTM indicated an improvement in the physical and muscular state of pre-frail participants [62]. VR-based muscle strength exercise program for the hip and balance control was a useful tool for improving the

reduction in physical function in elderly individuals as a supervised home-based exercise [63]. In a single-blinded randomized controlled clinical trial, VR-based exergaming balance training was more effective than conventional balance training in reducing risk and incidence of falls among the frail older adults with a history of falls [64]. Physiological Profile Assessment scores and incidence of falls were improved significantly greater after six weeks of balance training with either Wii Fit equipment than conventional balance exercise. The Wii Fit balance training has shown to reduce falls by 69% compared to the conventional exercise after 12 month follow-up on fall surveillance. A further VR-based motor skill re-learning for postural control and balance study showed that a certain level of motor skill re-learning was retained in frail patients and more training would be necessary to be able to automate the movement [65].

**Table 4:** VR techniques for assessment and intervention of patients with frailty.

| Reference | Participants | VR methods | Domain | Purpose | Immersion type |
|---|---|---|---|---|---|
| Chang et al., 2011 | 309 | Wireless sensors and artificial neural | Grip strength | diagnosis | Semi |
| Zavala et al., 2012 | 11 | WiiTM console using remote sensor | Grip strength | diagnosis | Semi |
| Dapp et al., 2013 | 3326 | GAITRite®-System | Walking speed<br>Leisure activities<br>Risk of falling | diagnosis | Semi |
| Menelas et al., 2012 | —— | KinectTM Interactive shoe | Balance | prevention | Semi |
| Szturm et al., 2011 | 30 | Pressure and motion sensors | Balance training | treatment | Semi |
| Daniel et al., 2012 | 23 | Wii Fit Nintendo®WiiTM console | Muscle strengtht | treatmen | Semi |
| Kim et al., 2013 | 32 | Virtual reality | Muscle strength<br>Balance | treatment | Full |
| Fu et al., 2015 | the Frail Older Adults with a History of Falls (n =60 ), 55 completed 12 months follow-up) | Wii Fit balance training using a Nintendo's Wii Fit® balance board<br>A conventional balance training | Balance | treatment | Semi |
| Kubicki et al., 2014 | 46 | Based on 2D virtual reality Fovea Interactive® and marker | Postural control<br>Motor skill re-learning | treatment | Non |

## Conclusion

VR-based technologies are safe, cost-effective, and allow using standardized test conditions to screen, prevent and treat age-related physical and cognitive deficits. Although most of studies contain small sample number and limited time length, these studies showed that VR–based technologies are convenient and sensitive to screen, prevent and treat single or multiple function deficits in patients with physical frailty. We speculate VR-based technologies are potential tools to screen, prevent and treat cognitive frailty. Because of the complex and heavy equipment, it still is difficult for participants to use independently and easily in home or hospital. The development of VR-related techniques with high definition and 3D displays will improve the sense of realism and provide stereoscopic perception, reducing discomfort for the user. The VR techniques integrates multi-dimension interactive cues will meet more requirements of the elderly.

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