

Review

Effect of 3D Virtual Reality on Functional and cognitive abilities among patients with Alzheimer's disease: A Meta-Analysis

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Abstract: Alzheimer's disease (AD) is a progressive neurodegenerative disorder characterized by decline in cognitive and functional abilities and reduced independence in activities of daily living. Despite advances in pharmacological treatment, effective non-pharmacological interventions remain important for improving patient outcomes. Virtual reality (VR) is an emerging rehabilitation approach that provides interactive environments to support cognitive and functional performance. This meta-analysis aimed to evaluate the effects of VR-based rehabilitation on cognitive function and functional mobility in individuals with mild to moderate AD. A systematic search of PubMed, MEDLINE, CINAHL, PEDro, Scopus, Web of Science, Cochrane CENTRAL, Google Scholar, and ProQuest was conducted for randomized controlled trials published between 2016 and 2024. Eligible studies were assessed using the Cochrane Risk of Bias tool, and pooled effects were calculated using standardized mean differences (SMDs) with 95% confidence intervals (CIs) in Review Manager. Six randomized controlled trials were included. Four studies involving 72 participants demonstrated a significant improvement in cognitive function with VR compared with conventional rehabilitation (SMD = 0.86, 95% CI 0.36–1.36; $I^2 = 0\%$; $P = 0.0007$). Two studies involving 96 participants found no significant effect on functional mobility (SMD = -0.19, 95% CI -0.63–0.25; $I^2 = 74\%$; $P = 0.65$). VR-based rehabilitation may improve cognitive function in individuals with mild to moderate AD, while evidence for functional mobility remains limited and heterogeneous.

Keywords: Alzheimer's disease, Virtual reality, cognition, physical therapy, rehabilitation, videogames, functional mobility

1. Introduction

The most common cause of dementia is Alzheimer disease (AD) an advanced progressive degenerative neurological condition, accounting for approximately 60 percent to 80 percent across all dementia cases [1] [2]. The most serious effects of AD is the loss of autobiographical memory, which is a form of personal memory, an important component of human cognition that involves life experiences and practices that are the foundation of self-awareness [3]. At the global level, in 2021, about 55 million individuals had dementia; by 2030, that figure will rise to 78 million, and by 2050 it will reach 139 million according to the World Health Organization (WHO) [4]. Consistent with global epidemiological trends, the prevalence of AD continues to increase at the regional level. An estimated 6.2 million US individual aged >65 years living with AD in 2020, a number likely to reach 13.8 million by 2060 [5]. Similarly, in Europe, the prevalence of AD is estimated at 5.05%, with a notably higher incidence in women (7.13%) as compared to men (3.31%) [6]. Moreover, Asia alone has a higher

prevalence of dementia patients than both America and Europe. A study conducted in tertiary care centers in Karachi showed that 63% of dementia patients had AD [7].

Progressive neuronal loss is a hallmark of AD, and the creation of neurofibrillary tangles and the deposition of amyloid plaques are two of the diseases defining neuropathological characteristics. As the diseases progress, memory impairment becomes more noticeable and evolves into global cognitive decline, affecting orientation, language, judgment, perceptual skills and ability to perform purposeful and coordinated movement. Together, these cognitive and motor impairments contribute toward a substantial decrease in overall activity of daily living [8]. Progression of AD typically occurs in three stages; mild, moderate and severe, each stage marked by increasing levels of cognitive, functional, and behavioral deterioration. In the mild stage, people may have trouble with attention and forget recent events, feel confused at times and need some help with daily tasks. During the moderate stage, memory problems become more serious and individuals may get confused about time and place and have difficulty in understanding. They begin to rely on others for personal care. In the severe stage, speech becomes unclear, people may not recognize close family members and they lose control over bladder and bowel functions, needing full support for daily care [8]. Beside cognitive decline, individuals with AD often exhibit motor control decline such as reduced balance, altered gait, decreased coordination, which compromised their mobility [9]. These impairments significantly reduce quality of life [10].

Current treatment of AD is a surgical line of action, for example, deep brain stimulation (DBS), enhances cognitive function in mild to moderate AD individuals older than 65, other than possibly having adverse effects in younger patients is the primary drawback of this treatment [11][12]. Further, pharmacological management primarily involves cholinesterase inhibitors including donepezil and rivastigmine, and NMDA receptor antagonists such as memantine, which may provide temporary stabilization of symptoms but do not reverse disease progression [8]. Consequently, non-pharmacological interventions are increasingly being emphasized as adjuncts to drug therapy. These include cognitive stimulation therapy, reminiscence therapy, aerobic and resistance exercises, and virtual reality-based rehabilitation approaches, which have shown positive effects on cognition, mood, and activity of daily life [11][13][14]. Individuals with Alzheimer's often struggle with low motivation and engagement in exercise due to cognitive and emotional barriers, such as memory problems and behavioral changes, which hinder their ability to participate in traditional exercise programs effectively [15].

There has been a paradigm shift toward neurological technological breakthroughs to solve the shortcomings of traditional Physical therapy [16]. To address these challenges, integrating enjoyable and interactive approaches such as virtual reality (VR) based activities has shown promise in enhancing participation. Existing investigations suggest that simulated 3D environment settings show an important role in cognitive rehabilitation and enhance overall well-being for persons with AD [17]. VR-based intervention can provide significant benefits for individuals with AD for example, VR-based cognitive training treatment strategies have been shown to improve mental abilities such as memory, attention, and spatial navigation [18]. As far as we are aware, no published meta-analysis has only examined how virtual reality (VR) affects cognitive function and functional abilities in individuals with Alzheimer's disease (AD). In this regard, the current meta-analysis sought to determine how VR affected patients with mild or moderate AD in terms of cognitive and functional results.

2. Materials and Methods

The current meta-analysis was carried out using the preferred Reporting Items for Meta-Analysis (PRISMA) standard [19]. Under registration number CRD420261405841, the study protocol and relevant details were recorded in PRSPERO, the internal prospective register of systematic Reviews. Ethical consent was not required for this study, as the analysis was based exclusively on data obtained from previously published studies.

Eligibility Criteria

Inclusion Criteria

The Population, Intervention, Comparison, and Outcome (PICO) approach was used to select and categorize research, which helped to develop clear inclusion criteria for relevant studies.

Population

Patients between ages of 50 and 85 must have mild to moderate AD.

Intervention

VR (immersive, semi-immersive and non-immersive) using cognitive stimulation and functional mobility rehabilitation is the intervention being studied

Comparison

Cognitive stimulation therapy, reminiscence therapy (often using photo or discuss past events), simple exercise programs (such as walking or aerobic exercises, treadmill) standard PT, conventional balance exercises and occupation therapy

Outcome

The results comprise the sit to stand evaluation, Gait and Balance Test, Time Up and Go (TUG) assessment, Montreal Cognitive Assessment (MoCA) Mini-Mental State Examination (MMSE), along with a questionnaire.

Exclusion Criteria

- The study did not include studies that were not (RCTs) randomized controlled trials.
- Studies that were not in English or did not have an English translation were excluded.
- Research undertaken prior to 2016 that failed to satisfy the criteria was omitted from the meta-analysis.

Search strategy and Selection Criteria

Between May and July of 2026, two independent researchers searched the following databases: For the available publications from 2016 and 2024, use data bases PubMed, MEDLINE, CINAHL, PEDro, Scopus, Web of Science and the Cochrane Central Register of Control Trials (CENTRAL), Google Scholar, and ProQuest. The MeSH terms "Physiotherapy exercises" or "physical therapy," no "immersive virtual reality"

or "Kinect Game," balance" "motor symptoms," and "Alzheimer's disease" or "AD" were combined with Boolean operators; various search strategies were used (Table 1). The exclusion and inclusion criteria were used to select relevant articles.

Data Extraction

Two evaluators (FH and SPW) independently screened the literature in line with inclusion and exclusion criteria, then cross-checked the inclusion results. In cases of unclear information or missing data, the corresponding authors were contacted through email for clarification. Studies with unavailable or unreliable original data were excluded after the review. Any difference among the two assessors was determined by consulting a 3rd investigator (AMK) until the final result was achieved. Data extraction was performed using Microsoft Excel 2016. The extracted information included participant's age, stage of Alzheimer's disease, intervention details such as frequency and duration of virtual reality based therapy and outcome tool measure including the Mini-Mental State Examination (MMSE) and Montreal Cognitive Assessment (MOCA) for cognition and for balance sit to stand test and time up and go. The final study results and findings were also recorded for analysis.

Data Analysis

The statistical program RevMan 5.4.1 was used to analyze the meta-analysis data. The review's goal was to evaluate cognition and balance as outcome measures. Both the experimental and control groups were recruited for randomized controlled trials that included pre and post data. The pooled effects size (ES) estimates were evaluated using the random effects and fixed effects model. Used for both the control and experimental group, the balance and cognition total scores' 95% confidence interval (CI), mean, and standard deviation were used. The model's heterogeneity was measured using the I^2 statistic. Heterogeneity was interpreted as low when I^2 values fell between 0% and 40%, moderate between 30% and 60% substantial between 50% and 90% and significant values were between 75% and 100% [20]. When heterogeneity was mild to moderate, a fixed-effects model was employed random-effects model was employed when heterogeneity was substantial or severe. [21]. P-values below were used to classify effect sizes as minor, moderate, or large. 0.05 was regarded as statistically significant. [22].

Assessment Risk of Bias

Potential sources of bias in the included studies were evaluated, including selection bias (randomization and allocation concealment), performance bias (blinding), attrition bias (insufficient outcome data), reporting bias (selective reporting of outcomes), and other pertinent biases. [19].

3. Results

Through database searches, 1,375 records were found. After removing 623 duplicate records and 8 records identified as ineligible by the automation tools, 744 records remained for title and abstract screening. 689 of these records were eliminated since they didn't fit the requirements for eligibility. As a result, 55 reports were requested. Eleven reports could not be retrieved, leaving 44 reports for full-text assessment. 39 reports were eliminated after the full-text assessment: 10 because the intervention was inappropriate, 4 because the full text was not available in English, 19 because the relevant cognitive or functional outcomes were not reported, and 7 because the randomized controlled trial design criterion was not met. In the end, six papers were included in the meta-analysis after meeting all inclusion requirements (Figure 1). 3. *Characteristic of incorporated studies is displayed in Table 1*



Figure 1. Features of the included research on functional and cognitive outcomes

Table 1. Characteristic of incorporated studies is displayed in Table

Authors Name	Year of Publication	Age/ Gender	Sample size	Stage of AD	Intervention	Out- come tools	Conclusion
Oliveira et al.	2016	Mean age 83.24yrs, more women than men	17 participant (VR=10, Control=7)	Mild to Moderate Alzheimer's Disease	Non-immersive VR-simulating IADLs via 17-inch computer screen, 45 min/sessions/week, 6 week	MMSE, FAB, MT, IADL, CDT	Improvement in overall cognition (MMSE Mean=-1.20; SE=0.51; p=0.033); no significant change in executive functions
Yang & Kwak, 2017	2017	mean age of Experimental group 71.1 and Control group 69.9 both male and female	20(10/10)	Early stage of AD	Experimental group received computer-based cognitive training while control group received routine treatment. 12 weeks(24 sessions total) twice a week (60 minutes per session)	MMSE	Cognitive training improve cognitive outcomes in mild AD
Uğur, F. & Sertel,	2020	65-85 years both male and female	32(16/16)	Alzheimer disease mild to moderate phase	Nintendo Wii VR device for 6 weeks 1	Mmse, gait and balance tool, 5 time sit to stand	VR applications improved gait speed and balance in person with AD and can be added to routine rehabilitation programs
Xu & Wang	2020	Age ≥60, both male and female	15 participants (VR=10, Control=5)	Participant with Alzheimer's disease	Immersive VR reminiscence therapy (VR headset, 2 min exposure	MMSE, TUG	Wii Fit exercises significantly improved muscle strength, TUG, and fear of falling within the exercise group; however, between-group comparison showed significant improvement only in fear of falling (TFES)
Uğur, F. & Sertel,	2024	65-80years both male and female	32(16/16)	Alzheimer disease	Wii Fit VR training using Nintendo Wii, 30 min/sessions/week, for 6 weeks (total 12 sessions).Control Group received routine medical care.	MMSE, TUG	Wii Fit exercises significantly improved muscle strength, TUG, and fear of falling within the exercise group; however, between-group comparison showed significant improvement only in fear of falling (TFES)

Risk of bias Summary

The risk of bias of assessment was assessed through Cochrane risk of bias of assessment (RoB 2) tool. Figures 4 and 5 show the quality assessment findings for the listed studies.

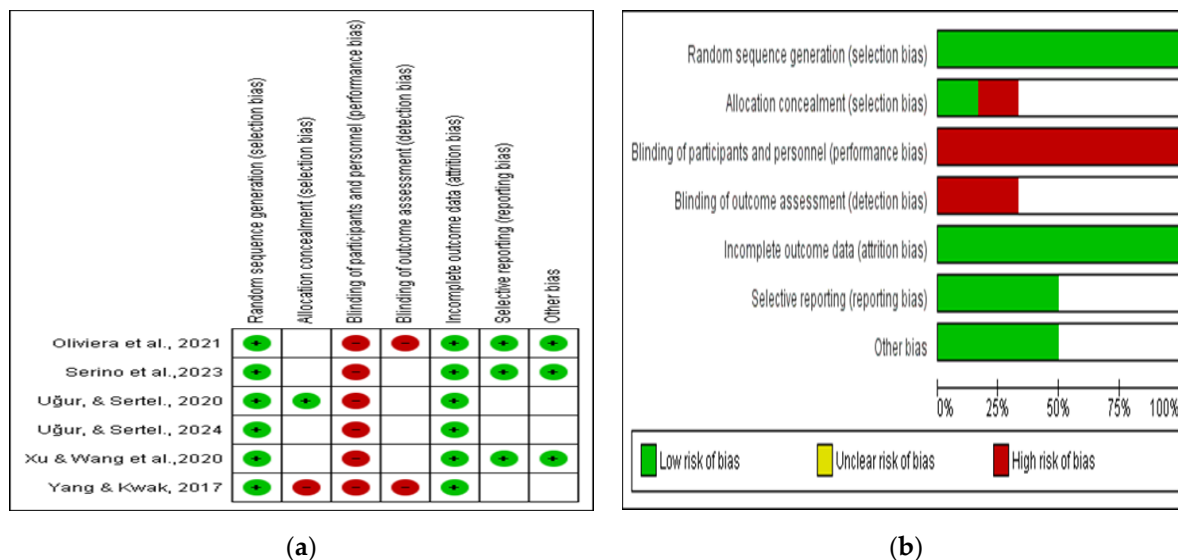


Figure 2. (a) Risk of bias summary showing the authors judgments for each bias domain. (b) Risk of bias graph displaying the proportion of included papers that the review authors scored for each risk of bias domain.

Effect of VR on Cognition:

Four of the six included studies, which involved 72 individuals (32 in the control group and 40 in the experimental group), assessed cognitive outcomes among patients with mild to moderate Alzheimer's disease using the MMSE and MoCA [23][24][25][26]. Virtual reality therapies had a substantial overall impact on cognitive performance, according to the pooled analysis (SMD = 0.86[0.36-1.36], 95% CI 0.36-1.36; $I^2 = 0\%$; $P = 0.0007$) (Figure 2)

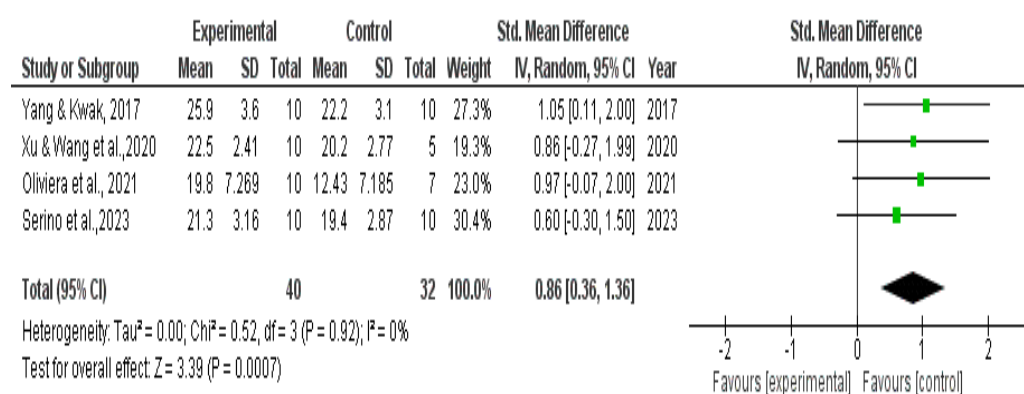


Table 3. A forest plot presenting the effects of VR based exercises on cognitive function

Effects of Virtual reality on Functional mobility

6 of studies, 2 of them used time up and Go, gait and balance and sit to stand test to evaluate the functional mobility among individual with mild to moderate AD involving 96 participants ((There were 48 participants in each of the experimental and control groups.) [27][28]. The pooled analysis demonstrated a non- significant effect of virtual reality interventions on function mobility (the pooled analysis showed no statically substantial impact (SMD, -0.19, 95%CI, 0.63, $I^2 = 74\%$ $P = 0.65$; Fig). Therefore, virtual reality interventions were not found to be significant in increasing functional mobility among patients with Alzheimer's disease (Figure 3).

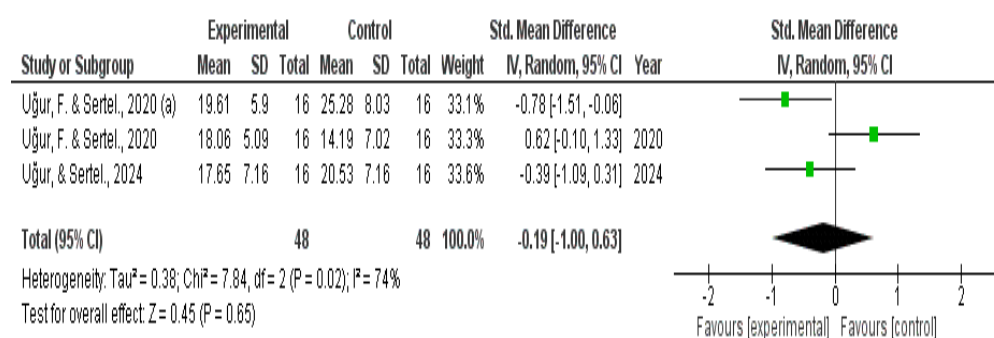


Table 4. A forest plot present the effect of VR base exercises on balance using the Berg outcomes, measured using the sit to stand and gait speed test and Timed Up and Go

Effects of Virtual reality on Functional mobility

6 of studies, 2 of them used time up and Go, gait and balance and sit to stand test to evaluate the functional mobility among individual with mild to moderate AD involving 96 participants ((There were 48 participants in each of the experimental and control groups.) [27][28]. The pooled analysis demonstrated a non-significant effect of virtual reality interventions on function mobility (the pooled analysis showed no statically substantial impact (SMD, -0.19, 95%CI, 0.63, $I^2 = 74\%$ $P = 0.65$; Fig). Therefore, virtual reality interventions were not found to be significant in increasing functional mobility among patients with Alzheimer's disease (Figure).

4. Discussion

The purpose of this review was to evaluate how virtual reality and traditional therapies affected on functional mobility and cognition among individuals with Alzheimer's disease (AD). The findings suggest that VR can considerably enhance cognitive performance among older adult with mild to moderate AD, supporting its potential as a valuable non-pharmacological rehabilitation approach. However, no significant improvements were found in functional mobility and balance. These findings may be related to the small number of available researches, limited sample sizes, and differences in intervention methods and outcome measure. Stronger data about the impact of virtual reality on physical function and mobility in individuals with Alzheimer's disease will require additional high-quality randomized controlled trials.

These findings are consistent with previous evidence. A current meta-analysis and systematic review by (Santos et al, 2025) reported that VR interventions have positively impact cognitive function among individuals with AD, particularly in global cognition, although the authors emphasized the limited quantity of high randomized controlled trials (RCTs) [29]. Similarly, Ren et al 2024 found that VR-based rehabilitation significantly improved cognitive outcomes among individual with mild cognitive impairment and dementia, supporting the use of VR as an adjunctive therapeutic strategy[28]. However, no significant improvements were observed in functional mobility and balance. This finding differs from the result of Ren et al., 2024, who reported significant improvements in balance and motor function following VR-based rehabilitation in individuals with mild cognitive impairment and dementia. This discrepancy might be qualified to the smaller amount of included researches, limited sample size, difference in VR protocols, and variations in outcome measure in the present review. Therefore, further quality RCTs are required to clarify the effectiveness of VR on physical function among individuals with Alzheimer's disease.

This meta-analysis incorporated a small number of researches with small sample sizes, reducing the generalizability of findings. There was methodological heterogeneity in intervention protocols and outcome measures, particularly for functional mobility outcomes. Furthermore, many studies demonstrated a high risk of bias, especially regarding lack of long-term follow-up data, particularly with relation to participant blinding and outcome assessment.

Future research should conduct large, high quality RCTs with standard virtual reality outcome measures and intervention protocols. Studies should incorporate appropriate blinding procedures and long term follow up to determine the sustained impact of VR on cognition and balance among older adults with mild to moderate AD.

5.5. Conclusions

This meta-analysis concluded that the available evidence suggests a possible cognitive benefit, whereas evidence for functional mobility remains insufficient and heterogeneous.

6. Patents

Not applicable.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: title; Table S1: title; Video S1: title.

Author Contributions: Conceptualization, SPW and FH; methodology, SPW and FH; software, SPW; validation, SPW, FH and MAK; formal analysis, SPW; investigation, SPW; resources, SPW, FH and MAK; data curation, SPW; writing—original draft preparation, SPW; writing—review and editing, FH and MAK; visualization, SPW; supervision, FH; project administration, SPW; funding acquisition, FH. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement:

Not applicable, as this study was a systematic review and meta-analysis of previously published studies and did not involve the recruitment or direct participation of human subjects.

Informed Consent Statement:

Not Applicable

Data Availability Statement: In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Please refer to suggested Data Availability Statements in section “MDPI Research Data Policies” at <https://www.mdpi.com/ethics>. If the study did not report any data, you might add “Not applicable” here.

Acknowledgments: Not applicable

Conflicts of Interest: All authors report no relationships that could be construed as conflicts of interest.

Appendix A

The appendix is an optional section that can contain details and data supplemental to the main text—for example, explanations of experimental details that would disrupt the flow of the main text but nonetheless remain crucial to understanding and reproducing the research shown; figures of replicates for experiments of which representative data is shown in the main text can be added here if brief, or as Supplementary data. Mathematical proofs of results not central to the paper can be added as an appendix.

Appendix B

All appendix sections must be cited in the main text. In the appendices, Figures, Tables, etc. should be labeled starting with “A”—e.g., Figure A1, Figure A2, etc.

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