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Disability and Rehabilitation: Assistive Technology

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/iidt20

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To cite this article: Verity Longley, Jordan Wilkey & Carol Opdebeeck (23 Sep 2024): Outcome measurement of cognitive impairment and dementia in serious digital games: a scoping review, Disability and Rehabilitation: Assistive Technology, DOI: 10.1080/17483107.2024.2405894

To link to this article: https://doi.org/10.1080/17483107.2024.2405894

Published online: 23 Sep 2024.

DISABILITY AND REHABILITATION: ASSISTIVE TECHNOLOGY
https://doi.org/10.1080/17483107.2024.2405894

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REVIEW ARTICLE

Outcome measurement of cognitive impairment and dementia in serious digital games: a scoping review

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ABSTRACT

Purpose: Dementia prevalence is increasing worldwide. With the emergence of digital rehabilitation, serious digital games are a potential tool to maintain and monitor function in people living with dementia. It is unclear however whether games can measure changes in cognition. We conducted a scoping review to identify the types of outcomes measured in studies of serious digital games for people with dementia and cognitive impairment.

Methods: We included primary research of any design including adults with cognitive impairment arising from dementia or another health condition; reported data about use of serious digital games; and included any cognitive outcome. We searched Medline (*via* EBSCO), PsycInfo, CINAHL, Web of Science, from inception to 4th March 2024 and extracted study characteristics.

Results: We reviewed 5899 titles, including 25 full text studies. We found heterogeneity in domains and measures used: global cognition ($n=15$), specific cognitive processes ($n=13$), motor function ($n=5$), mood ($n=6$), activities of daily living ($n=5$), physiological processes ($n=4$) and quality of life ($n=2$). Use of outcome measurement tools was inconsistent; the most frequently used measures were the Montreal Cognitive Assessment ($n=8$), the Mini-Mental State Examination ($n=7$), and the Trail Making Test ($n=7$). Nine studies used in-game measures, most of which were related to game performance.

Conclusion: We found very few studies with assessment of cognition within the game. Studies of serious games for people with dementia and cognitive impairment should develop digital outcome tools based on recommendations in Core Outcome Sets, to increase consistency between studies.

ARTICLE HISTORY
Received 27 August 2023
Revised 9 September 2024
Accepted 13 September 2024

KEYWORDS
Serious games; cognition; dementia; assessment; outcome measurement; digital games

IMPLICATIONS FOR REHABILITATION

- Fewer than half of the studies we identified used in-game measures, most of which were related to game performance, indicating that digital measures of cognition *within* serious digital games is a largely unexplored research area.
- Only eight out of 25 included studies used measurements tools recommended in Core Outcome Sets for studies of people living with dementia.
- Given the heterogeneity of measures identified in this review, critical appraisal of relevant outcome measures would be the next step in determining suitable measures for use in future research.
- Following critical appraisal, exploration of digital measures of cognition is needed to determine their integration into serious games, and whether existing tests can be digitised and administered remotely whilst retaining psychometric properties.

Introduction

Dementia is one of the leading causes of disability worldwide and is a global health priority [1]. People living with dementia experience declines in cognitive function that may include memory loss, difficulty concentrating and disorientation which impact on activities of daily living [2]. Non-pharmacological interventions to maintain or slow disease progression traditionally involve cognitive rehabilitation (an individualised, goal-centred approach focused on real-world function), and cognitive training (practice of tasks or strategies focused on specific cognitive functions) [3]. In recent years, serious games as a form of cognitive rehabilitation or training have increased in use for people living with cognitive impairment and dementia [4,5].

Serious games are defined as games that have the primary purpose of learning and education rather than entertainment [6]. They target perceptual, cognitive, behavioural, affective and motivational outcomes, for example memory, attention, fine motor control and offer an opportunity to utilise technology to enhance rehabilitation [4]. Traditional rehabilitation and cognitive training often follows a repetitive process, and people may experience barriers to participation including fatigue, low motivation and lack of support [7]. Serious games can stimulate and motivate users to engage with rehabilitation further [8]. Serious games have been found to improve cognitive functions, activities of daily living and depression, alongside improved social engagement, more so than conventional rehabilitation [9,10]. Use of telerehabilitation and digital rehabilitation has increased in recent years, with the ability for games to be used both under supervision in therapy sessions and also independently at home by patients on mobile devices,

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tablets, or personal computers thus serious digital and online games are a potentially innovative field to enhance rehabilitation for people with cognitive impairment and dementia [10].

Whilst serious games are not by definition digital, those that are have an advantage of in-built outcome measurement, for example reaction time or eye movement [10]. This information can then be used to adapt the game play to meet the user's ability or to feed back to clinicians to remotely monitor symptoms. Indirect measures of cognition in games such as accuracy and error rate have been used alongside standardised questionnaires such as the Mini-Mental State Examination (MMSE) [8]. Dementia outcomes measure cognition, physical function, behavioural or psychological impact as well as quality of life, or carer impact. Understanding how these functional measures relate to performance in digital games, and whether these domains can be measured remotely within games could have implications for screening and monitoring disease progression.

Ning et al. (2020) [4] propose a conceptual model of assessment to measure the therapeutic effect of serious games for people with dementia that includes physiological signals, professional reviews, questionnaire tests, and game results. A combination of these subjective and objective measures would potentially provide a comprehensive overview of the person's state, however this model is as yet untested and lacks information on practical implementation [4].

Several systematic reviews and meta-analyses on the effectiveness of serious games for people with dementia exist [10–12], however none exist that comprehensively describe the range of outcome measures used in the literature. The recent Cochrane review of computerised cognitive training for preventing dementia in people with mild cognitive impairment notes the inconsistency of outcome measurement tools used limits conclusions about the benefits of intervention [13]. It will therefore be useful to summarise what is currently measured using digital games to inform future game development aimed at monitoring disease progression and effect of rehabilitation. It is also important to understand if measures used in research reflect outcomes valued by key stakeholders (i.e., people living with dementia and their carers) and whether they were involved in choice of outcome measures in study design phases [14]. This review therefore maps the characteristics of currently used outcome measures to identify any commonalities, as well as unknowns, of existing research.

Our objectives were:

> To identify the types of outcome measures used in serious digital games for people with dementia and other forms of cognitive impairment.
>
> To characterise and describe use of outcome measures in serious digital games for people with dementia and other forms of cognitive impairment.

Materials and methods

A scoping literature review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA-SR) Statement. The protocol was published on Research Square (https://doi.org/10.21203/rs.3.rs-2836938/v1).

Eligibility criteria

We used the SPIDER search strategy [15]. SPIDER (Sample – Phenomenon of Interest – Design of study– Evaluation – Research type) is appropriate where a review covers studies with a range of methods. We included primary research only. No restrictions were placed on publication date.

Inclusion criteria:

- Studies of adults with cognitive impairment arising from dementia or another health condition
- Studies that report data about use of serious digital games
- Studies that included any measure of cognition
- Any study design including randomised clinical trials, pre-test post-test comparisons, observational and cohort studies, case studies and evaluations
- Quantitative, qualitative, and mixed methods approaches

Exclusion criteria:

- Publications in languages other than English
- Editorials, commentaries, letters, opinion-based papers, grey literature, systematic reviews
- Research based solely on adolescents or children
- Studies of serious digital games focused on movement that included no measures of cognition

Search strategy

We searched from database inception to 4th March 2024: Medline (*via* EBSCO), PsycInfo, CINAHL, Web of Science. We developed the search strategy with input from the institution specialist librarian based on keywords including "dementia," "cognitive impairment," "serious games," "digital games," "virtual rehabilitation" (see search strategy in Table 1).

Selection process

Following database searches, results were imported into Zotero reference management software and duplicates removed. Titles

Table 1. Search terms.

Search terms
((dementia + OR + alzheimers + OR + cognitive + impairment + OR + memory + loss)+OR+(Alzheimer*)+OR+(vascular + dementia)+OR+(parkinson*)+OR+(lewy + b od*+OR + dlb)+OR+(cerebral + vascular)+OR+(frontotemporal)+OR+(aphasia + OR + aphasic + OR + people + with + aphasia)+OR+(posterior + cortical + atrop hy)+OR+(cognition + disorder + OR + MCI + OR + cognitive + impairment + OR + cognitive + dysfunction + OR + cognitively + impaired)+OR+(brain + infrac t*)+OR+(ischem*+OR + ischaem*)+OR + stroke))+
dementia OR alzheimers OR "cognitive impairment" OR "memory loss" OR alzheimer* OR "vascular dementia" OR parkinson* OR lewy bod* OR dlb OR "cerebral vascular" OR frontotemporal OR aphasia OR aphasic OR "posterior cortical atrophy" OR "cognition disorder" OR MCI OR "cognitive dysfunction" OR "cognitively impaired" OR "brain infarct" OR ischem* OR ischaem* OR stroke
AND
+((serious + games + OR + video + games + OR + digital + games)+OR+(vr + OR + virtual + reality)+OR+(online + games + OR + video + games + OR + intern et + games)+OR+(exergames + OR + exergaming + OR + active + video + games + OR + nintendo + wii + OR + xbox + kinect + OR + wii + fit)+OR+(virtual + r ehabilitation)+OR+(virtual + reha-bilitation))
"serious games" OR "video games" OR "digital games" OR vr OR "virtual reality" OR "online games" OR "internet games" OR exergam* OR "active video games" OR "nintendo wii" OR "xbox Kinect" OR "wii fit" OR "virtual rehabilitation"

and abstracts were screened by JW or CO and irrelevant studies excluded. Uncertainties were discussed with VL. Full-text versions of all studies that potentially met inclusion criteria were retrieved and each independently assessed by two team members, and any disagreements discussed. Previous recent literature reviews were scrutinised to check for any additional studies.

We extracted the following information where available using an Excel spreadsheet:

- Study information: author, title, journal, year of publication, country of origin
- Study characteristics (as applicable): design, theoretical framework, sample size, game type
- Target populations: cognitive impairment of participant, control group, age
- Outcome measures: observational tools and standardised questionnaires used in quantitative studies, themes and categories identified in qualitative studies.

As this was a scoping review, we did not make a formal assessment of study quality or risk of bias nor did we extract data about study results. We narratively synthesised the results, and grouped studies in terms of type of measure used e.g., cognition or motor function, and whether measures were taken within games.

Results

We identified 5899 titles, 563 of which were judged to have relevant abstracts. Following full text screening we included 25 studies in the review (see Figure 1).

Table 2 summarises study characteristics. Twelve studies included participants with mild cognitive impairment (MCI) [16–27]; five studies included those with MCI or Alzheimer's disease [28–32]; four studies included those with unspecified dementia or Alzheimer's disease [33–36]; and four studies included stroke survivors [37–40]. We found no studies focused on types of dementia other than Alzheimer's disease. Sample sizes were generally small, ranging from 11 [28] to 227 participants [30], with a mean of 48 (SD = 46.39).

A range of gaming platforms were used across studies: nine used tablets, mobile phones or touch screens [18,22,25,29,30,34–36,38]; two used Nintendo Wii [17,41], three used Xbox Kinect [16,20,24], and three used similar custom hand controller interfaces [21,27,33]; six used virtual reality (VR) headsets [19,23,26,32,39,40]; two used laptop computers and keyboards [28,31]; and one was unclear if run through a mobile phone or laptop [37]. Serious games were mostly played supervised by a therapist or researcher (21 studies), with the remaining two studies stating the games were played independently by participants [34,38], one

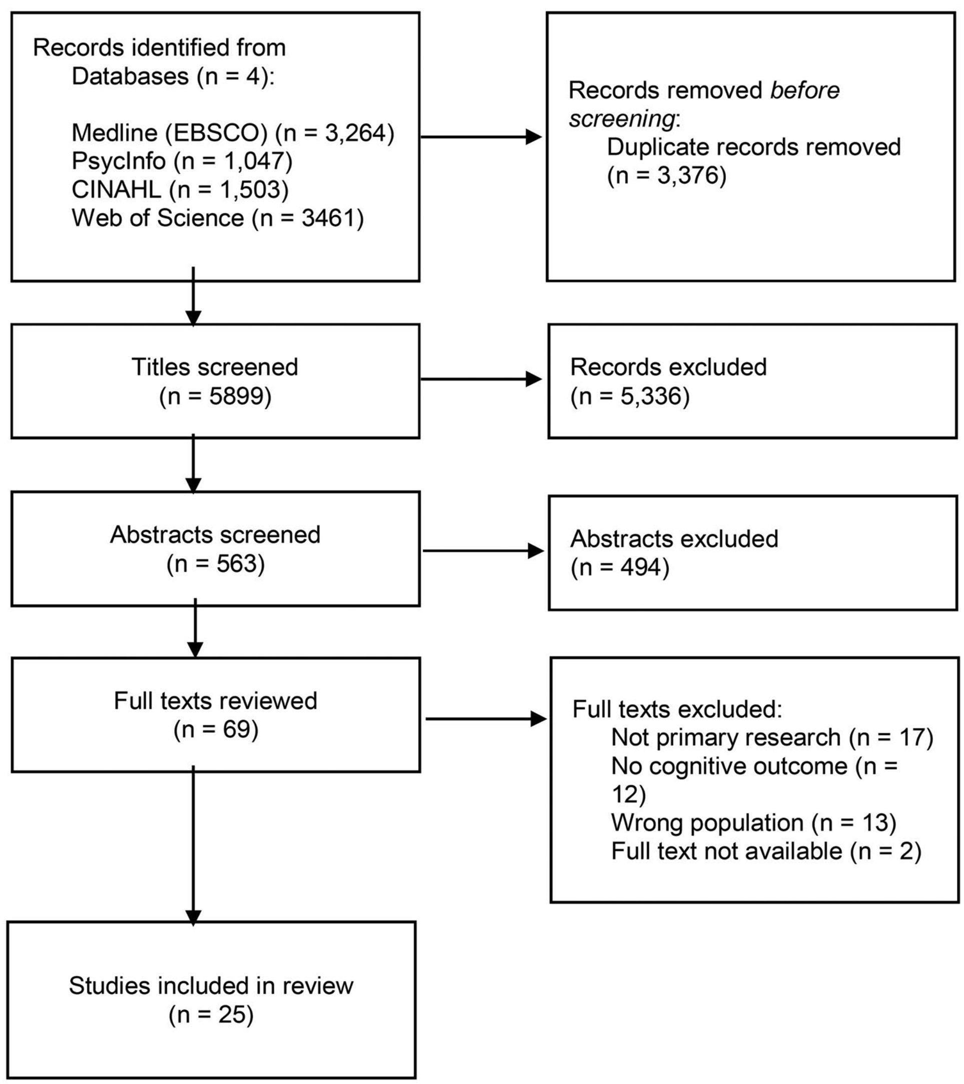

Figure 1. Flow diagram of the study selection process.

Table 2. Study characteristics. MCI = mild cognitive impairment, RCT = randomised controlled trial.

Primary Author	Study design	Location	Setting	Condition of participants	Sample Size	Mean age (years)	Maximum length of follow up (weeks)	Delivery method of intervention (virtual or in-person)	Game platform	Who delivered outcome measurement
Arshad (2021)	Quasi-experimental study	Pakistan	Hospital	MCI	18	62	6	With practitioner	Xbox Kinect	Unspecified
Arshad (2023)	RCT	Pakistan	Not reported	MCI	51	62.85 (experimental) 63.24 (control)	6	Unclear	Xbox Kinect	Unspecified
Burdea (2015)	Feasibility study	USA	Care centre	Dementia	10	63.4	8	With practitioner	Razer Hydra bimanual controller and computer	Neuropsychologist
Galante (2007)	RCT	Italy	Unclear	Probable Alzheimer's Disease or MCI	11	76	36	With practitioner	PC gaming	Neuropsychologist
Gamito (2017)	RCT	Portugal	Hospital	Stroke	20	55 (SD = 13.5)	6	With practitioner	Unclear if mobile or laptop	Therapist
Hughes (2014)	Feasibility study	USA	Church	MCI	20	77.4	24	With practitioner	Nintendo Wii	Unspecified
Iliado (2021)	Cohort study	Greece	Unclear	MCI	76	66.09 (SD = 4.73)	Immediate	With researcher	Tablet	Experimenter
Jirayucharoensak (2019)	Feasibility study	Thailand	Experiment room	MCI	119	70.9 (control)73.9 (exergame)71.7 (NFT)	10	With practitioner	Emotiv Headset with LED display and Kinect 2	Unspecified
Jung (2020)	Pilot RCT	South Korea	Rehabilitation hospital	Chronic stroke survivors with mild-to-moderatecognitive impairment	29	72.67	12	Solo	Tablet computer	Language pathologist
Li (2023)	RCT	China	Unclear	MCI, mild dementia, moderate dementia	60	70.97 (SD = 5.08) experimental condition 70.40 (SD = 4.52) control	12	With researcher	Oculus VR headset	Neurologist
Lin (2022)	Quasi-experimental study	Taiwan	Community centre	MCI	24	79.75 (SD = 4.86) intervention 77.75 (SD = 6.74) control	12	With researcher	Xavix Hot Plus (sensors and TV display)	Research assistant
Liao (2019)	RCT	Taiwan	Unclear	MCI	34	75.5 (VR group)73.1 (Combined physical and cognitive training)	12	With practitioner	Xbox Kinect	Blinded assessor
Liu (2022)	Pilot RCT	China	Unclear	Stroke	30	74.16 (SD = 7.08)	6	With therapist	Headset and sensor	Therapist
Manera (2015)	Pilot experimental study	France	Not reported	MCI, Alzheimer's disease	21	75.8 (SD = 9.1) MCI 80.3 (SD = 6.3) Alzheimer's	4	Solo and with therapist	Tablet	Clinician
Nath (2023)	Pre-post	USA	Lab	MCI	20	70.5 (SD = 9.0)	Immediate	With researcher	Tablet	Unspecified
Neto (2018)	Exploratory study	Portugal	Unclear	Cognitive impairment	51	76.5	4	With practitioner	Tablet	Unspecified
Oh (2023)	Trial	South Korea	Hospital	MCI	45	74.23 (SD = 7.50) MCI 71.45 (SD = 3.95) control	4	With therapist	VR headset	Unspecified
Park (2023)	RCT	South Korea	Rehabilitation hospital	Stroke with MCI	63	62.5 (SD = 4.7) experimental 62.0 (SD = 3.0) control 1 62.5 (SD = 4.8) control 2	8	With therapist	VR headset and controllers	Occupational therapist

(*Continued*)

Table 2. Continued.

Primary Author	Study design	Location	Setting	Condition of participants	Sample Size	Mean age (years)	Maximum length of follow up (weeks)	Delivery method of intervention (virtual or in-person)	Game platform	Who delivered outcome measurement
Ríos Rincón (2022)	Feasibility study	Canada	Supportive living facility and community organization	Dementia	20	78.3	8	Solo	Web-based mobile phone games	Research assistant
Tarnanas (2015)	Cohort study	Greece	Not reported	Alzheimer's diseaseMCI	227	70.06 (SD = 13.32) control72.63 (SD = 10.05) MCI 76.59 (SD = 10.58) Alzheimer's	12	With practitioner	Mobile phone augmented reality	Unspecified
Tziraki (2017)	Proof of concept	Israel	Dementia day centre for people with dementia, own home for control	Dementia	38	Not reported	10	With practitioner	Tablet	Unspecified
Thapa (2020)	RCT	South Korea	Healthcare centre	MCI	100	72.5	8	With practitioner	Oculus VR headset (Oculus quest headset) and two wireless hand controllers, one for each hand	Neuropsychologist
Valladres-Rodriguez (2017)	Experimental	Spain	Participant's home	MCI and Alzheimer's disease	16	75 (SD = 6.08) MCI 68.3 (SD = 8.88) Control 75.8 (SD = 5.36) Alzheimer's	Immediate	With researcher	Unity 3D run on PC	Unspecified
Vallejo (2017)	Cohort study	Switzerland	Not reported	Alzheimer's disease	38	74.6 (SD = 5.9) Control 77.8 (SD = 6.2) Alzheimer's	Immediate	With practitioner	Unity 3D (run on touch screen interface)	Unspecified
Zhu (2023)	Quasi-experimental	Taiwan	Unclear	Cognitive frailty/MCI	69	72.77 (SD = 6.13)	8	With researcher	Computer and sensor	Unspecified

used a mix of supervised and independent game play [29] and one was unclear [24].

Follow-up length ranged from four weeks to six months, with two studies describing a one-off experiment with measurement post-game play [25,31]. Eleven studies collected data within the game (see Table 3) [18,19,25,26,29–33,35,36], five of which collected additional psychometric outcomes [25,26,31–33]. Studies were not all clear about how outcome measures were collected. Eleven studies collected psychometric outcomes assessed by a neuropsychologist, clinician or research assistant [20,21,23,28,32–34,37–40], seven did not specify who collected outcome data [16,17,22,24,26,27,31], and seven were not applicable due to only using automated in-game measures. Studies were also unclear about how psychometric data was collected (i.e., if using pen and paper-based assessments, or if in-person or remotely), with only two studies specifying use of computerised cognitive assessments [17,19].

Studies used limited stakeholder involvement or Patient and Public Involvement and Engagement in research design. Four studies [31,32,34,35] involved clinical stakeholders, people living with dementia, carers and/or healthy older adults in their game design. Only one study included stakeholder involvement in outcome measurement design: Valladares-Rodriguez et al. (2017) [29] present a study of gamification of a cognitive test, and involved older adults in the design and validation process.

Measures of cognition

Fifteen studies used standardised outcome measures of global cognition, most commonly the Montreal Cognitive Assessment (MoCA) ($n = 8$) [16,22,24,25,27,32,34,39] or Mini-Mental State Examination (MMSE) ($n = 7$) [16,23,24,26,32,38,40]. Other measures included the Computer Assessment of Memory and Cognitive Impairment (CAMCI) [17], Cognitive Self-Report Questionnaire (CSRQ) [17], Short Portable Mental Status Questionnaire (SPSMQ) [21], the National Centre for Geriatrics and Gerontology Functional Assessment Tool [23], Cognitive Abilities Screening Instrument [32] and Raven's Coloured Progressive Matrices, which is a general intelligence test [28].

Two studies used standardised measures that were completed by caregivers rather than through self-report or observation, the Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE) [31], and the Neuropsychiatric Inventory, which evaluates behavioural aspects of dementia [28].

Studies used further tests of specific cognitive processes, most commonly of attention, memory, or verbal fluency. Twelve studies used specific attention tests. The Trail Making Test (A and/or B) of visual attention was used in seven studies [16,20,21,23,24,33,34] and the digit symbol substitution test of visuospatial attention and executive function was used in two studies [23,39]. Other tests of attention used were the Neuropsychological Assessment Battery (Attention Module) [33], digit cancellation test [28], the Toulouse-Pieron Test [37], the Stroop test [20,25] and a study-specific tracking task [17].

Seven studies used specific memory tests. Two studies used the digit span test [38,39]. Other standardised tests used were the Hopkins Verbal Learning Test Revised [33], Brief Visuospatial Memory Test [33], Bisyllabic Word Repetition Test [28], Corsi's Block Tapping Test [28], Wechsler Memory Scale [37], Rey Complex Figure test [37], Alzheimer's Disease Assessment Scale Word Recall Task [25], the California Verbal Learning Test (CVLT) [31] and the Memory Alteration Test (MAT) [31].

Four studies included measures of semantic or phonemic verbal fluency [16,24,28,39]. One study included a specific measure of executive function using the Neuropsychological Assessment Battery

Table 3. Studies that included in-game measures.

Primary Author	In game measure 1	In game measure 2	In game measure 3	In game measure 4	In game measure 5	In game measure 6
Burdea (2015)	Degree of flexion/ extension of the index in each hand	Game total score	Arm reach			
Iliado (2021)	Average game play duration	Error rate	EEG			
Jirayucharoensak (2019)	Rapid Visual information Processing (RVP)	Pattern Delayed Matching to Sample (DMS)	Pattern Recognition Memory (PRM)	Spatial Span Length (SSP)	EEG	
Li (2023)	Task independence	Accuracy	Task completion rate			
Manera (2015)	Time spent on activities	Total playing time	Game improvement score			
Oh (2023)	Number of items picked up	Number of errors	Number of times they used hints in each session	Total performance time	Task accuracy	
Tarnanas (2015)	Accuracy	Omissions, repetition and perseverations of incorrect order while performing the subroutines	Total time to complete the game, total time to complete subroutines execution; and time of execution through acceleration data, such as "fast hand pointing gestures," per subroutine completion.	(1) Total time to complete the navigation route; (2) Gait frequency at interactive events (3) Gait parameters such as stride length, distance, and variability of stride	Reaction times	Timed response performance data
Tziraki (2017)	Speed of successful completion	Task completion rate				
Valladres-Rodriguez (2017)	Failures, guesses, omissions					
Vallejo (2017)	Time on task					

(Executive Functioning Module) [33]. One study included a test of visual perception, the Motor-Free Visual Perception Test [40].

Only one study [19] appeared to run a direct standardised cognitive test within the game system, using the Cambridge Neuropsychological Test Automated Battery. They implemented individual sub-tests of spatial working memory, rapid visual processing (sustained attention), pattern delayed matching to sample (short term visual memory and visual recognition memory), pattern recognition memory and spatial span length (working memory and attention span). Hughes et al. (2017) [15] used a digital cognitive outcome measure (CAMCI), but this was not administered within the game system itself. See Table 4 for summary of outcome measures used.

Measures of motor function

Eight studies included outcome measures of motor and physical function, all using different measures, three of which were standardised measures: the Senior Functional Test and timed unipedal stance test [21], and Manual Function Test [38]. Three studies used study-specific gait performance tests [20], timed six metre walk test [17] and measures of gait speed, mobility and handgrip strength [23]. Galante et al. (2007) [28] measured constructional apraxia and ideomotor apraxia of the upper limb. One study measured arm reach, flexion and extension of index fingers during game play [33].

Measures of ADL

Five studies measured activities of daily living, using a range of standardised outcome measures: the modified Barthel Index [39,40], Instrumental Activities of Daily Living Scale [21], The Timed Instrumental Activities of Daily Living [17], Lawton Instrumental Activities of Daily Living (IADL) Scale [28].

Measures of mood

Seven studies used standardised measures of mood: three used the Geriatric Depression Scale (GDS) [21,28,38], one use the Beck Depression Inventory (BDI) [33], one used the Positive Affect Negative Affect Schedule (PANAS) [34] and one used the Loneliness Scale [27]. One study used the Stroke Self-Efficacy Questionnaire, which is related to confidence and mood [40].

Measures of quality of life

Two studies measured health-related quality of life; using the EQ-5D-5L [21] and the 12-Item Short Form Health Survey [40].

Physiological measures

Four studies included physiological measures; three of brain function, using electroencephalogram (EEG) [18,19,23]; one of salivary biomarkers [25]. Two of these collected data during game play [18,19].

Game performance

Nine studies collected data about game performance including: time spent on specific activities in the games [29,30,32,35,36], duration of total game play [18,26,29,30], total score [33], accuracy [26,30,32], game improvement score [29], reaction time and timed response performance [30], error rate [18], failures, guesses and omissions [26,31], task independence [32], and repetition and perseveration [30] (see Table 3).

Discussion

We identified twenty-five studies using serious digital games for people with dementia and other forms of cognitive impairment that included cognitive outcome measures. Most ($n = 15$) included general measures of cognition, and thirteen tested specific cognitive processes. Nine studies collected data within the game, mainly about game performance, and most studies were unclear of the modality of psychometric outcome (i.e., if conducted on paper or digitally), with only two studies collecting specific computer-based psychometric outcomes. There was a large amount of heterogeneity in terms of both domains assessed and outcome measures used across studies.

We found that whilst studies reported data about game performance, computerised tests of cognition were rarely used. It has been argued that computerised tests are acceptable for use with people living with dementia, with the added benefit of testing speed of cognitive processing which can potentially detect subtle changes in cognition to a high level of sensitivity [42]. Whilst multiple online digital cognitive tests exist for general populations, there are concerns about psychometric properties such as reliability and validity of these in populations with cognitive impairment [43]. Technical requirements (such as compatible software and hardware), contextual factors (such as language and test environment), and psychological factors (such as fatigue and motivation) all impact on utility of online, unsupervised cognitive tests [43]. We identified two studies that used a standardised computerised measure of cognitive processes, one separate to the game using the CAMCI [17], and one within the game, using the Cambridge Neuropsychological Test Automated Battery (CANTAB) [19]. It was unclear if the latter was administered under supervised conditions. The CANTAB has been found to have comparable performance indices in unsupervised, web-based settings as in-person, laboratory settings [44]. However, differences in reaction times when comparing settings have been thought to be the product of variations in personal computer hardware, indicting the importance of testing multiple domains when administering outcome tests remotely, unsupervised.

There are recommended core outcome measurement tools for interventions to prevent or slow progress of dementia for people living with mild cognitive impairment, developed through expert consensus, albeit pharmacological interventions [45]. Measurement of cognition is recommended *via* the MMSE or Alzheimer's Disease Assessment Scale–Cognitive Subscale (ADAS-Cog), and biological markers, measured through serial structural MRI. There are also recommended tools to measure domains of activities of daily living *via* the Disability Assessment for Dementia (DAD), global functioning *via* the Clinical Dementia Rating (CDR), neuropsychiatric symptoms *via* the Neuropsychiatric Inventory (NPI) and quality of life *via* the DEMQOL [45]. Out of these core outcomes, only seven studies included in this review used the MMSE and one used the NPI. Whilst the ADAS-Cog has been validated for remote use in some settings, it still requires a test administrator for delivery [46,47]. The repeatability of tests in a digital environment needs consideration also; the MMSE for example has been found to show retest effects in people with dementia [48]. It would be beneficial for future research to explore the remote, unsupervised digital application of these tests for integration into serious games to enhance rehabilitation and monitoring.

Table 4. Summary of outcome measures used. Note Iliadou et al. (2021); Jirayucharoensak et al. (2019); Manera et al. (2015); Tarnanas et al. (2015); Tziraki et al. (2017); Vallejo et al. (2017) are not included in this table due to only collecting within game data.

Primary Author	Outcome Measure 1	Outcome Measure 2	Outcome Measure 3	Outcome Measure 4	Outcome Measure 5	Outcome Measure 6	Outcome Measure 7	Outcome Measure 8
Arshad (2021)	MMSE	MoCA	Trail Making Test A & B	Semantic Fluency Test	Phonetic verbal fluency test			
Arshad (2023)	MMSE	MoCA	Trail Making Test A & B	Semantic Fluency Test	Phonetic verbal fluency test			
Burdea (2015)	Beck Depression Inventory	Neuropsychological Assessment Battery, Attention Module	Neuropsychological Assessment Battery, Executive Functioning Module	Hopkins Verbal Learning Test, Revised	Brief Visuospatial Memory Test	Trail Making Test		
Galante (2007)	Bisyllabic Word Repetition Test, Prose memory	Corsi's block tapping test, Digit cancellation test	Raven's Coloured Progressive Matrices	Semantic and phonemic verbal fluency, Denomination	Neuropsychiatric Inventory	Geriatric Depression Scale	Lawton Basic Activities of Daily Living and Instrumental Activities of Daily Living	Constructional apraxia and ideomotor apraxia for upper limbs
Gamito (2017)	Wechsler Memory Scale (working memory)	Toulouse-Pieron Test	Rey Complex Figure					
Hughes (2014)	Tracking task	Computerized Assessment of Mild Cognitive Impairment	The Cognitive Self-Report Questionnaire-25	The Timed Instrumental Activities of Daily Living	Time in seconds to complete a 6-meter walk			
Jung (2020)	MMSE	Digit span test	Geriatric Depression Scale	Manual function test				
Li (2023)	Cognitive Abilities Screening Instrument (CASI)	MMSE	MoCA					
Lin (2022)	Short Portable Mental Status Questionnaire	Instrumental Activities of Daily Living Scale	Senior Functional Test	Balance (timed unipedal stance test)	Geriatric Depression Scale short form	EQ-5D-5L		
Liao (2019)	Trail Making Test	Stroop test	Gait performance test					
Liu (2022)	MoCA	Trail Making Test A	Digit symbol substitution test	Digit span test	Verbal fluency test	modified Barthel index		
Nath (2023)	Stroop test	Congruent Correct-Incongruent Incorrect metric	Alzheimer's Disease Assessment Scale Word Recall Task	MoCA	Cortisol, alpha-amylase, IGF-1, and protein concentrates in saliva			
Neto (2018)	MoCA							
Oh (2023)	MMSE							
Park (2023)	Stroke self-efficacy questionnaire	MMSE	Motor-Free Visual Perception Test	modified Barthel Index	12-Item Short Form Health Survey			
Ríos Rincón (2022)	Positive affect negative affect schedule	MoCA	Trail Making Test A & B					
Thapa (2020)	MMSE	National Center for Geriatrics and Gerontology Functional Assessment Tool	Trail making Test A & B	Symbol digit substitution test	EEG	Physical function (gait speed, mobility and handgrip strength)		
Valladres-Rodriguez (2017)	California Verbal Learning Test	MMSE	Memory Alteration Test	Informant Questionnaire on Cognitive Decline in the Elderly				
Zhu (2023)	MoCA	Loneliness Scale						

Equally, researchers should consider including people living with dementia and cognitive impairment in their study design, using Patient and Public Involvement, to ensure studies measure domains such as function or quality of life; trials of treatments rarely capture outcomes of importance to the individual [49,50]. For example, studies of technology that involve people living with dementia in the design mainly focus on the user-centred design of the game or the evaluative phase of the intervention itself, rather than how the impact of the intervention will be measured or what tool will be used [51]. Interventions also need to be easily accessible and integrated into daily life for people living with dementia and cognitive impairment. This would ensure interventions and outcomes are relevant to the population they are aiming to help.

Due to this being a scoping review of outcome measures, we did not complete any critical appraisal of the studies and thus cannot comment on study quality. Now we have identified the types of outcome measures used by studies of serious digital games, the next step for future studies is to complete critical appraisal of these using the COnsensus-based Standards for the selection of health Measurement Instruments (COSMIN Standards) when deciding which outcomes to use, if recommend core outcomes cannot be implemented digitally.

This review has some limitations, including the fact we only included studies of adult participants with existing cognitive impairment. Wider exploration of outcome measurement in gaming research across all populations may prove valuable, for example Flynn et al. (2021) describe indirect and direct cognitive outcome measurement within games using studies of children between 6-12 [52]. Despite attempting to adhere to rigorous methodology, due to time and funding constraints, only one team member screened titles and abstracts using four databases so we may have missed some relevant studies. We only included published English-language peer-reviewed research for the same reason, so may have missed some relevant studies published in the grey literature or in other languages both of which may impact on reliability of results.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by an Innovation Voucher between Memory Lane Games and Manchester Metropolitan University.

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