

A Systematic Review of Serious Games Relating to Cognitive Impairment and Dementia

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ABSTRACT: *Assessment, diagnosis, and cognitive stimulation of patients with different stages of cognitive impairment, including mild cognitive impairment (MCI) and Alzheimer's disease, has become a growing area of research. Recently, there has been an increase in interest in applying serious games for older people with neurodegenerative diseases. The present systematic review aims to investigate and classify serious games for detecting cognitive impairment in the elderly. In this review, searches focused on studies conducted between 2014 and 2021, of which twenty-four studies met the inclusion criteria. In this regard, we identified a few categories for the collective classification of serious games. We chose taxonomy of five classes to classify serious games dedicated to cognitive training and diagnosis among seniors: cognitive skills, objectives, game elements, motivation, and validation. We conclude that gamified techniques prove to be a valuable complement to traditional treatments because of the increased patient engagement.*

Subject Categories and Descriptors: [I.2.1 Applications and Expert Systems] Games [J.3 Medical information systems] H.1.2 Human information processing

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1. Introduction

With the aging population and increasing numbers of people affected, and the lack of medical treatment, there is an increasing need to develop methods to prevent dementia. Thus, the most recent recommendations focus on the importance of non-pharmacological intervention strategies, including cognitive rehabilitation, cognitive training, gamification, serious game/ virtual environments (Bojan et al., 2021). They propose ways to make the lifestyle more cognitively and socially rich (Fondation Médéric Alzheimer 2015). The use of virtual reality (VR) in the medical field is one of the most significant technological development in recent years. Briefly, VR is an application that allows users to navigate and interact in real-time with a three-dimensional computer-generated environment ((Pallavicini et al., 2019), (Tarnanas, Laskaris, et al., 2015)). However, VR appears to be a promising way to help the clinician assess cognitive function.

Discussions have focused on the importance of integrating VR into traditional assessment tests for early detection and familiarisation of older people with the technology to establish adaptive, accurate, low-cost, and easy-to-administer tests (Zygoris & Tsolaki, 2015); (Banville et al., 2017)). Cognitive training focuses on a series of continuous, repetitive, annoying tasks, which often leads to the disengagement of participants. Integrating a gamification layer to cognitive training addresses this issue to engage and motivate participants for medium to long-term adherence. The gamification aims to use game mechanics (competition, narrative, leaderboards, graphics, and other game design elements) to

motivate users to achieve their goals and objectives and inject some fun into boring activities in addition to generating motivational and cognitive benefits (Phan Tran et al., 2016). Recently, serious games, gamification, and virtual environments can be effective tools for screening for cognitive impairment and dementia ((Tost et al., 2014); (Neto et al., 2016); (H. M. Lau et al., 2017); (Gielis et al., 2017); (Zygouris et al., 2020) ; (Gutenschwager et al. 2020)).

In the present study, we conducted research on serious games for cognitive screening and stimulation with the primary objective of investigating how older people with mild cognitive impairment engage with serious games and consider them as part of a training process to improve their cognitive abilities.

This paper aims to answer the following two main questions: 1). What are the benefits of integrating serious games into the neuropsychological assessment process of cognitive functions? 2). What game mechanisms are included to promote therapeutic engagement of seniors with mild Alzheimer's disease or dementia?

2. Methodology

In this review, research articles were searched and selected from established databases such as ACM, IEEE, SpringerLink, ScienceDirect, Sage, Scopus, JMIR, SAGE, Pubmed (Medline), and Google Scholar. Searches were limited to studies from 2014 to 2021 using keywords such as serious games and assessment, serious games and cognitive screening, serious games for training, games for early diagnosis, mental health, gamification, and games for cognitive stimulation, gamification and cognitive assessment, and serious game for diagnosis.

Table 1 below presents 24 research results for serious games used to stimulate and assess cognitive abilities. Papers selected were reviewed to ensure that they met the following criteria: 1. Design and develop at least one serious game. 2. Focus on cognitive stimulation and diagnosis in older people. 3. Implementation of cognitive assessments during or after the serious game design process.

3. Serious Games For Cognitive Training And Diagnosis

Cognitive training consists of continuous, repetitive, boring tasks, which often lead to participants' disengagement. Integrating a playful approach (the serious game) into traditional assessment tests and cognitive training addresses this problem in order to engage and motivate participants for medium to long-term adherence. Designing a game able to stimulate the cognitive functions of disoriented and Alzheimer's patients requires incorporating both a cognitive dimension and a game aspect (Aleven et al., 2010).

The cognitive aspect refers to the objectives of cognitive

training, which specify how to integrate games as a tool for diagnostic and cognitive training, and how to choose games adapted to Alzheimer's patients. The game dimension of serious games facilitates the acceptance of training, both physical and cognitive, by patients and elderly people.

The game dimension defines the elements of the game that must be adapted to the desired experience in order to achieve the training objectives. Some studies have examined the effects of using game mechanisms in cognitive training.

In this section, we have presented some serious games dealing with the themes of cognitive stimulation and training, cognitive assessment, and gamification applied to the care of the elderly.

(Tost et al., 2014) have developed a serious game for the early detection of mild cognitive impairment (MCI) in the elderly. This game performs diagnostic tests organized according to daily life tasks in a 3D environment surrounded by 2D interfaces. They have integrated different accessibility features (automatic navigation, avatar, assisted selection, and feedback mechanism) to make them usable by older people.

(Tong et al., 2014) have developed a cognitive assessment tool to detect mental changes such as delirium. Provided a mobile touch interface suitable for older people, focuses on executive functions.

(Manera et al., 2015) developed a serious game for older people with mild cognitive impairment or Alzheimer's disease, based on step-by-step preparation of cooking recipes, targeting executive functions, planning abilities, object recognition (gnosis), and praxis activity (abilities to perform gestures spontaneously).

(Rodriguez-Fortiz et al., 2016) have created a serious game that aims to train attention, memory, planning, and reasoning which helps to delay cognitive decline in the elderly. The game uses scenarios based on everyday activities (cooking, street, supermarket...), and promotes the use of an interactive 3D environment developed with WebGL to make the scenarios more realistic for the players in order to stimulate the cognitive abilities of the elderly. VIRTRA-EL allows the evaluation of user interaction through error detection. It promotes and encourages group activities and communication between seniors and their caregivers.

(Mora et al., 2016) created a gamified tool inspired by the cooperative crowdsourcing approach to preventing cognitive impairment in healthy older people or in the early stages of dementia, aiming to reduce the impact of intellectual impairment in daily activities. They used self-determination theory (SDT) to create an intrinsically motivating activity in three categories: competence, autonomy, and relationship. In addition, the tool includes 42 cogni-

tive stimulation exercises, designed by neuropsychologists, covering six intellectual functions (memory, attention, executive function, orientation, gnostic, praxis).

(Costa et al., 2017) have developed a serious game for neurocognitive stimulation and assessment. Aiming at analyzing cognitive impairments in the elderly and stimulating the neurocognitive process of the players, whose main objective is to reduce the impact of lack of ecological validity and low motivation of the players through scenarios that are close to the daily reality. It is structured in four scenarios simulating familiar real-world environments, developed in a three-dimensional interactive environment. In addition, the game includes a DDA (Dynamic Difficulty Adjustment) system that adapts the game difficulty to the cognitive ability of the user, based on the performance results of the players.

(Yun et al., 2020) designed a cognitive training game for patients with cognitive impairment aimed at improving attention and working memory. The VR interface system included an HTC Vive head-mounted display and a custom-developed hand motion tracking module for estimating hand pose and three-dimensional hand positions in the workspace.

We conclude that many studies aim to reduce the impact of low participant motivation by using scenarios closer to everyday reality, based on activities of daily living, to create an environment familiar to the elderly, which can be considered a promising approach for cognitive training. In addition, integrating the most appropriate game mechanics for older people, the avatar helps the player to accomplish the tasks in which they would be intrinsically interested. The use of game features (points, scores, badges, etc.) is redeemable when the player moves to the next level, which is used in many games to satisfy extrinsic motivation. Following these guidelines in the literature, we help to select games elements to classify serious games designed for cognitive training and diagnosis for seniors.

4. Game Mechanisms to Promote Therapeutic Engagement of the Elderly

Games are complex systems composed of various parts, characters, and mechanisms. Most senior games focus on interfaces and usability and lack motivation and engagement for long-term adherence. Game design dedicated to training and or cognitive diagnosis needs to follow a theoretical framework for effective and enjoyable gameplay.

The MDA (Hunicke, LeBlanc, and Zubek, 2004) is a framework for game design based on three dimensions: Mechanics (M), Dynamics (D), and Aesthetics (A). (Bouchard et al., 2012) suggested a guideline consisting of four aspects: the choice of the game challenge, the design of interactions, and the implementation of artificial intelli-

gence, and ending with the production of visual and auditory aids. (Klauser et al. 2012) classified serious games for older people into six of the most common categories for classifying games in general (genre, audience, platform, potential benefit, input method, and single- vs. multi-user modes). (Connolly et al., 2009) proposed taxonomy of four categories of learning outcomes: cognitive, motor, affective, and communicative. (Hao & Miao, 2015) presented a classification of 21 dimensions grouped into three categories: cognitive, gameplay, and game structure. (Schell, 2008) grouped all game elements into four categories: aesthetics, stories, mechanics, and technology.

From the literature, we chose a taxonomy of 28 dimensions divided into five categories to classify serious games designed for cognitive training and diagnosis for seniors: cognitive skills, goals, gaming elements, motivation, validation. Table 2 below shows the game mechanisms used for cognitive training and screening.

5. Discussion

Cognitive diagnosis and training are two crucial prevention programs aimed at early detection of cognitive decline. Our review identified 24 relevant studies, covering 28 elements of game design most suitable for older people, used to promote therapeutic engagement of older people in a cognitive training process. Of the 24 studies reviewed, 16 focused on cognitive assessment and/or diagnosis. Several reasons that researchers have identified for using gamification in cognitive training. Some of these include increasing long-term and short-term engagement in a task and reducing the impact of lack in ecological validity. However, there are more clinical reasons, such as stimulate the brain and making the task more interactive to enhance the effect of cognitive training. Several studies aimed to reduce test anxiety and optimize the performance of groups that traditionally dislike being tested, especially electronically, such as the elderly. Hiding the test behind an innovative interface and game allows the target audience to feel more comfortable.

We saw several games designed to train and test people with dementia. Overall, these games appear to be engaging and more immersive for players, in some cases even increasing the time spent training.

Serious games have seen that they can have a short-term effect, as initial contact always brings high motivation; however, the aims of rehabilitation and stimulation for older people rely on long-term support (Liu et al., 2017). Increasing participants' motivation was a common objective of several studies in this review. Many studies aim to reduce the impact of low motivation of participants by using scenarios that are closer to everyday reality, based on activities of daily life to create an environment known by seniors, which can be considered a promising approach for cognitive training (Vallejo et al., 2017).

Therefore, integrating the most appropriate game mechan-

ics for older people, the avatar helps the player to accomplish the tasks in which the player would be intrinsically interested, of which 6 of 24 studies comprise it. Points, scores, and badges are redeemable once the player moves on to the next level, which is used in many games to satisfy extrinsic motivation. In 8 out of 24 studies involving the narrative process, giving a narrative aspect to the discourse helps increase patient adherence to achieve their therapeutic goals. The three-dimensional (3D) game interface uses more than 2D, with four studies using a combination of 2D and 3D. Mini-games presented in the form of puzzles used by one of 24 studies. 14 out of 24 studies divided the game into mini-games and levels, where the games include different stages which the player must complete to progress. Seven games used positive feedback, where the game rewards good play with points, badges, and congratulatory messages.

Thus, we found that memory, attention, and executive functions, such as problem-solving and general decision-making, were common targets of cognitive assessment and training.

Regarding validation, we found heterogeneous standards

for validating gamified tasks. Indeed, many games used a comparison with neuropsychological tests, other studies used a comparison with non-gamified tests, and others used a behavioral questionnaire to assess performance on gamified training tasks. In addition, the sample sizes were small in almost all the studies reviewed.

In conclusion, this article presents an overview of the classification of serious games that have been extracted from different sources. In this review, 24 studies of serious games for cognitive stimulation and diagnosis were classified into 28 dimensions grouped under five categories. Overall, the evaluation of the serious games studied revealed that they can be more engaging and effective than traditional training tools for MCI. Nevertheless, a more in-depth clinical evaluation needs to be carried out before using them as a diagnostic or rehabilitation tool.

Thus, the integration of game mechanics is proving to be a valuable adjunct to traditional treatments due to the increase in patient engagement. For future research, detailed studies need to determine the appropriate classification of serious games for cognitive stimulation in the elderly. Thus, to understand the interactions between game mechanisms and cognitive processes.

Year	Author	Name of game	Game genre	Participants
2014	(Tost et al., 2014)	SmartAging	Screening tool	1000 (>= 50 years)
	(Merilampi et al., 2014)	Cat vs Mouse/ modified Trail Making Test	Cognitive training	16 (>= 90 years)
	(Tong et al., 2014)	whack-a-mole game	Assessment /Diagnosis	24 persons
2015	(Kim et al., 2015)	Smart Harmony	Cognitive training	28 (>= 65 years)
	(Manera et al., 2015)	Kitchen and cooking	Assessment /Training	21 (>= 60 years)
	(Tarnanas, Papagiannopoulos, et al., 2015)	Virtual action planning museum (VAP-M)	Assessment /Diagnosis	50 (>= 72 years)
2016	(Rodriguez-Fortiz et al., 2016)	VIRTRA-EL	Assessment / training	—
	(Mora et al., 2016)	PNH (Preventive Neuro Health)	Cognitive training	—
	(Boletsis & McCallum, 2016a)	CogARC (Cognitive Augmented Reality Cubes)	Training/ Diagnosis	5 (>= 60 years)
	(Phan Tran et al., 2016)	Serious Game using an interactive system	Cognitive training	30 persons
	(Neto et al., 2016)	Cow Milking Game	Training / Diagnosis	106 (>= 55 years)
	(Boletsis & McCallum, 2016b)	Smartkuber	Screening tool	13 (>= 68 years)
2017	(Vallejo et al., 2017)s	The 3D virtual Memory Island	Assessment /Diagnosis	38 (>= 74 years)
	(Costa et al., 2017)	SynapseToLife	Training / Assessment	—
	(Liu et al., 2017)	Game-based measures system	Screening tool	10 (>= 62 years)
	(Hongmei Chi et al., 2017)	Smart Thinker	Cognitive training	59 (>= 55 years)
	(Savulich et al., 2017)	Memory Game	Cognitive training	42 (>= 75 years)
	(Djabelkhir et al., 2017)	CCS and CCE	WarCAT and Lock Picking	19 (>= 60 years)

2018	(Leduc-McNiven et al., 2018)	WarCAT and Lock Picking	Screening tool (MCI assessment)	—
	(Valladares-Rodriguez et al., 2018)	Panoramix	Assessment/screening tool (MCI et AD)	16 (>= 68 years)
2020	(Yun et al., 2020)	Harvest and cook game	Cognitive assessment tool	27 (>= 60 years)
	(Kock Pedersen et al., 2020)	Skill Lab	Cognitive assessment tool	30 (>= 50 years)
	(Zygouris et al., 2020)	Virtual Supermarket Test	Screening tool (MCI assessment)	95 (>= 65 years)
2021	(S.-Y. J. Lau & Agius, 2021)	A-go! (An immersive serious game)	Cognitive training	—

Table 2. Game mechanics applied in a cognitive training/screening tool

Game mechanics	Dimension		Games	Number
Cognitive skills	Executive functions	Decision making	SmartAging, Kitchen and cooking, VAP-M, VIRTRA-EL, PNH, CogARC, Cow Milking Game, Smartkuber, the 3D virtual Memory Island, Game-based measures system, CCS and CCE, Panoramix, Harvest and cook game	14
		Problem solving	Cat vs Mouse, Kitchen and cooking, VAP-M, VIRTRA-EL, CogARC, Cow Milking Game, Smartkuber, The 3D virtual Memory Island, WarCAT, Lock Picking, Panoramix, Skill Lab	13
		Response inhibition	WHACK-A-MOLE, VAP-M, CogARC, Smartkuber, the 3D virtual Memory Island, Panoramix, Harvest and cook game, Skill Lab	9
		Flexibility	Smart Harmony, PNH, CogARC, Smartkuber, The 3D virtual Memory Island	5
	Visual and Spatial processing		SmartAging, Smart Harmony, VAP-M, VIRTRA-EL, CogARC, Cow Milking Game, Smartkuber, the 3D virtual Memory Island, Game-based measures system, Memory Game, Panoramix, Harvest and cook game, Skill Lab	13
	Attention processing		Smart Harmony, SmartAging, Kitchen and cooking, VIRTRA-EL, PNH, CogARC, Serious Game using an interactive system, Cow Milking Game, Smartkuber, the 3D virtual Memory Island, SynapseToLife, Game-based measures system, Smart Thinker, Lock Picking, WarCAT, Panoramix, Harvest and cook game	16
	Memory		SmartAging, Cat vs Mouse, WHACK-A-MOLE, Smart Harmony, VAP-M, VIRTRA-EL, PNH, CogARC, Serious Game using an interactive system, Cow Milking Game, Smartkuber, the 3D virtual Memory Island, SynapseToLife, Game-based measures system, Smart Thinker, Memory Game, CCS and CCE, Lock Picking, WarCAT, Panoramix, Harvest and cook game, Skill Lab	21
Goals	Clair goal		SmartAging, Cat vs Mouse, Kitchen and cooking, PNH, CogARC, Cow Milking Game, Smartkuber, The 3D virtual Memory Island, SynapseToLife, Game-based measures system, Memory Game, CCS and CCE, Virtual Supermarket Test	13
	Avatar		SmartAging, VIRTRA-EL, PNH, Serious Game using an interactive system, A-go!	5
	Points		Cat vs Mouse, VIRTRA-EL, PNH, CogARC, Smartkuber, Panoramix	6

Gaming elements	Scores	Cat vs Mouse, WHACK-A-MOLE, Smart Harmony, VAP-M, VIRTRA-EL, CogARC, Smartkuber, SynapseToLife, Smart Thinker, Memory Game,	6
	Mini-games	WarCAT, Panoramix, Skill Lab	13
	First-person perspective	Kitchen and cooking, SmartAging, VAP-M, PNH, CogARC, Smartkuber,	14
	Badges	The 3D virtual Memory Island, SynapseToLife, Smart Thinker, WarCAT, Panoramix, Skill Lab, A-go!	5
	Leaderboard	SmartAging, VIRTRA-EL, Harvest and cook game, Skill Lab, A-go! VIRTRA-EL, CogARC, WarCAT, A-go!	4
	Levels	VIRTRA-EL, PNH, Cow Milking Game, Memory Game, A-go! SmartAging, Cat vs Mouse, Kitchen and cooking, PNH, CogARC, Cow Milking Game, Smartkuber, the 3D virtual Memory Island, SynapseToLife, Game-based measures system, WarCAT, Panoramix, Harvest and cook game, A-go!	5
	Task presented as puzzles	VAP-M	14
	Narrative	Cat vs Mouse, Kitchen and cooking, VAP-M, Cow Milking Game, the 3D virtual Memory Island, Game-based measures system, Memory Game, Harvest and cook game	1
	Competition	Smart Harmony, Smartkuber, WarCAT, A-go!	8
	3D Graphics	SmartAging, Kitchen and cooking, VAP-M, VIRTRA-EL, CogARC, Serious Game using an interactive system, Cow Milking Game, Smartkuber, the 3D virtual Memory Island, SynapseToLife, Game-based measures system, Memory Game, Harvest and cook game, Skill Lab, Virtual Supermarket Test, A-go!	4
	2D Graphics	SmartAging, Cat vs Mouse, WHACK-A-MOLE, Smart Harmony, Kitchen and cooking, Smart Thinker, Skill Lab, A-go!	17
Time pressure	Cat vs Mouse, WHACK-A-MOLE, Smart Harmony, Kitchen and cooking, CogARC, Cow Milking Game, the 3D virtual Memory Island, WarCAT, Harvest and cook game, Skill Lab	8	
Motivation	Challenges	PNH, CogARC, Smartkuber, A-go!	10
	immersion	SmartAging, Kitchen and cooking, VIRTRA-EL, Serious Game using an interactive system, the 3D virtual Memory Island, SynapseToLife, Game-based measures system, Harvest and cook game, Skill Lab, Virtual Supermarket Test, A-go!	11
	Autonomy: freedom of choice	SmartAging, Smart Harmony, PNH, CogARC, Serious Game using an interactive system, Cow Milking Game, SynapseToLife, Game-based measures system, A-go!	9
	Positive feedback	WHACK-A-MOLE, Kitchen and cooking, PNH, CogARC, Smartkuber, WarCAT, A-go!	7
	Social interaction	WHACK-A-MOLE, VIRTRA-EL, Serious Game using an interactive system, CCS and CCE	4

Validation	Compared against / neuropsychological tests	SmartAging, Cat vs Mouse, WHACK-A-MOLE, Cow Milking Game, Kitchen and cooking, Smartkuber, The 3D virtual Memory Island, SynapseToLife, Game-based measures system, Smart Thinker, Memory Game, CCS and CCE, Panoramix, Skill Lab, Virtual Supermarket Test	15
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Table 2. Game mechanics applied in a cognitive training/screening tool

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