Augmented Reality Serious Gaming for Cognitive Health

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Declaration of Authorship

I, Konstantinos Boletsis, hereby declare that this thesis and the work presented in it is entirely my own. Where I have consulted the work of others, this is always clearly stated.

Signed:

(Konstantinos Boletsis)

Date:

Summary

Cognitive impairment in the elderly can be associated with the normal ageing processes or be a symptom of early onset dementia. Even though, early detection of dementia has many benefits, cognitive impairment is still under-recognised and under-diagnosed. This lack of diagnosis often leads to confusion over behavioural changes and prevents social and medical intervention and planning.

Cognitive screening represents the initial step in a process of further assessment for cognitive impairment, leading to early diagnosis; however, it presents certain intrinsic limitations. These include culture, gender, and educational biases, long test-retest periods, "white coat" and learning effects, limited test validation and the user's potential lack of motivation.

Serious games can address those limitations and be an alternative to traditional, pen-and-paper and computerised cognitive screening tests, potentially motivating and engaging the user to regularly perform cognitive screening tasks, thus increasing the potential to recognise cognitive impairment and trigger referral for a more comprehensive, formal assessment.

The current work contributes by designing, implementing, and testing a novel, gaming approach for the cognitive screening process, utilising stimulating cognitive training. The study thoroughly describes all the design and development stages of a serious game for cognitive training and screening from its inception and its theoretical groundings to its Release Candidate version and the evaluation of its test validity, focusing on the iterative design process and the evaluation of each stage. Finally, a cognitive training game for cognitive health screening of the elderly is produced, utilising an interaction technique based on Augmented Reality (AR) and the manipulation of tangible, physical objects (cubes). The game succeeds in stimulating the cognitive function of the elderly players, presenting high concurrent validity versus the widely used Montreal Cognitive Assessment (MoCA) score.

Directions for future research in the area include the use of wearable biosensors - such as smartwatches - for cognitive health screening purposes, suggesting an ecosystem with serious games in the centre. The term "cognitive passport" is defined and discussed, as a tool for tracking personal cognitive health.

Acknowledgments

I would like to express my deepest gratitude to my supervisor, Simon McCallum, for his insightful guidance and support throughout the research period. I am also grateful for our long discussions and exchange of opinions on various pleasant and fascinating topics, outside the scope of the study, but within the scope of our coexistence. Working at the GameLab was a life-changing opportunity and experience.

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Part I

Overview

Chapter 1

Introduction

This chapter provides the problem description and motivation of the PhD study. It introduces the research questions addressed in the study, also depicting the relationship between research questions and published papers. Furthermore, the scope and structure of the dissertation are provided.

1.1 Research motivation

Cognitive impairment in the elderly can be associated with normal ageing processes, as well as the onset of early dementia [1, 13]. Best practices in dementia care emphasise the importance of early detection; however, cognitive impairment is still under-recognised and under-diagnosed [15, 20, 4, 17]. More than 50% of dementia and 80% of mild cognitive impairment (MCI) cases go unrecognised in primary care [17, 8, 3]. Early diagnosis has many benefits, providing an explanation for changes in behaviour and functioning, and allowing the person to be involved in the planning of future care [17].

Cognitive screening, i.e. the objective measurement of cognitive impairment by standard neuropsychological tests [5], represents the initial step in a process of further assessment for dementia and can help identify potential cases for assessment, thus leading to early diagnosis [1]. Currently, the cognitive assessment for the progression of cognitive impairments is mostly based on the passage of time rather than the cognitive performance of the patient over a period of time, making it difficult to track the point in time when the cognitive decline begins to takes place [1]. Consequently, the doctors of dementia patients are not getting enough data in a frequent and timely manner, in order to be able to help the patient promptly and this situation, mostly affects healthy elderly, elderly at the preclinical cognitive stage and patients of MCI, which is considered to be the transition phase between healthy ageing and dementia (Fig. 1.1) [11, 12, 14]. Furthermore, the existing pen-and-paper screening tests present certain intrinsic limitations, i.e. culture, gender, and educational biases, long test-rest periods (usually one month or more), as well as "white coat" and learning effects. Furthermore, one needs to consider the capacity of health care services, given the economic burden of increased screening [1, 6]. Computerised cognitive screening tests overcome some of the aforementioned limitations, however their weaknesses include limited validation of the tests and the user's potential lack of motivation [1, 17, 19].

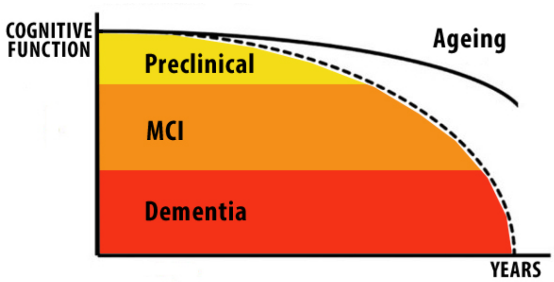


Figure 1.1: The continuum of normal ageing and Alzheimer's cognitive decline [18].

To face the new challenges that arise from an ageing society, serious games are presented as a motivating, cognitive gaming platform, aiming to delay or alleviate the cognitive decline of the elderly [1, 2]. The elderly population represents a considerable portion of digital gamers, which is predicted to increase, and serious games may represent a low-barrier, motivating, sustainable and relatively inexpensive method to improve, or at least delay, the onset of impairments in selected social, sensory-motor, and emotional functions of elderly players [16, 10, 7].

More specifically, serious games for cognitive screening may be an alternative to traditional, pen-and-paper and computerised cognitive screening tests, potentially motivating and engaging the player to regularly perform cognitive screening tasks; thus, increasing the recognition of cognitive impairment, triggering referral for a more comprehensive assessment and leading to earlier detection [1, 21]. Serious games for cognitive screening have distinct advantages; they can be economical of time and cost, provide accurate and frequent response recording free of biases and learning effects (due to dynamically updated content), be self-administered or require little training, provide a pleasant experience and reduce the psychological stress caused by the regular screening processes [1, 6]. Furthermore, cognitive screening serious games can provide an informal measurement of the player's cognitive performance through the game score. Taking as a prerequisite that the games' content consists of accredited cognitively stimulating exercises, serious games for cognitive screening can be validated against established tests used in clinical practice and provide the player with constant monitoring of his/her cognitive health, in an entertaining, motivating and engaging way [1, 9, 22]. Cognitive training exercises can assist in the games' cognitive screening process by stimulating the players' cognitive abilities, thus acquiring a representative assessment of the players' cognitive staus and performance, at the time [9, 22].

The fact that cognitive screening tests and cognitive training exercises have game-like elements (Fig. 1.2) or, at least, elements that can be gamified facilitates game designers, to implement game scenarios where cognitive training and stimulation is used for cognitive screening purposes, thus developing a

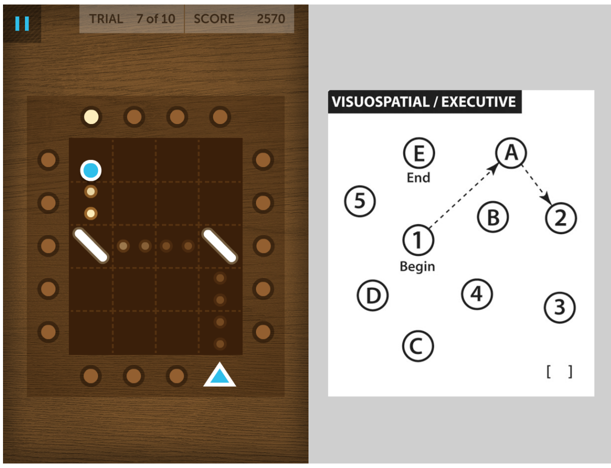


Figure 1.2: The Pinball Recall Lumosity game for cognitive training of working memory (*left*) and a visuospatial/executive "find the logical path" task from the MoCA screening test (*right*).

robust cognitive health instrument of dual nature [1, 22]. Furthermore, recent advances in technology such as Augmented Reality, wearable biosensors, hand tracking and tangible interaction, allow developers to have several new interaction methods at their disposal. New interaction techniques can stimulate and register several physical abilities of the players (e.g. motor skills and sleeping habits) during their gaming performance and provide the developer and the formal care with more cognitive-related and secondary data.

1.2 Research questions

The research objective of the current PhD study is to explore the design, development, and evaluation of serious games for cognitive screening, through the development of an original serious game, aiming to provide reliable and motivating cognitive screening for the elderly. In addition, the study is focusing on Human-Computer Interaction (HCI) and technical issues in relation to interaction methods and techniques for elderly users.

In order to accomplish the research objectives, a list of research questions (RQ) are formulated.

RQ1: *To what extent have serious games been used in the field of cognitive impairment and dementia?*

The first step towards the set research objective is the identification of the state of the art in the field of serious games for dementia and cognitive impairment. The answer to that question is aiming to affect the study's game design process, since the analysis of the state of the art can define

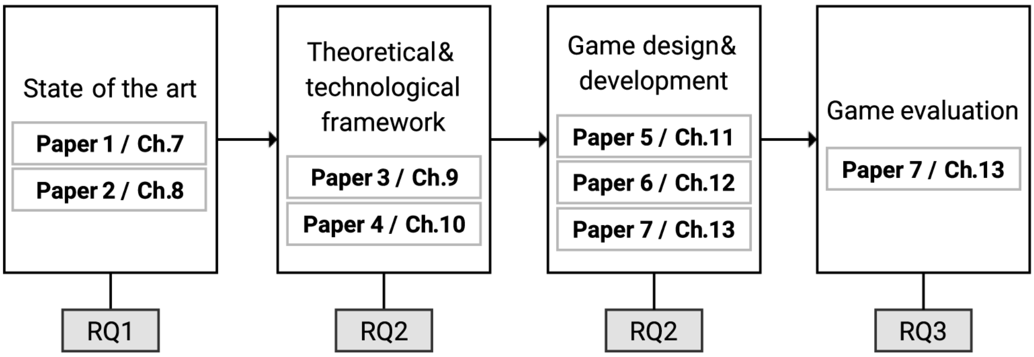


Figure 1.3: The research stages of the PhD study, the published papers, and the research questions they address.

the proper game characteristics, that the developed game should have in order to achieve the desired cognitive goals.

RQ2: *Which game design aspects and interaction methods can create an engaging, cognitive gaming experience for the elderly?*

The question focuses on the study's game design and development process and it examines the use of existing technologies (e.g. Augmented Reality, tangible interaction, wearable biosensors, et al.) for interaction and game design purposes, through theoretical frameworks, game experience studies and usability testings. The interaction technique utilised and the entertaining nature of the developed cognitive game are of high importance for its acceptability from elderly players and, therefore, for extracting all the necessary data to examine the main research question.

RQ3: *To what extent can the developed serious game be used as a cognitive screening tool for the elderly?*

The main research question assesses the outcome of the PhD study, i.e. the developed cognitive screening game. The question investigates the performance of the game with elderly players and compared to a "gold standard" screening tool, evaluating the test validity of the extracted data. The correlation and comparison between the two tools can reveal the potential of the developed game as a cognitive screening tool and guide the future direction of the project.

The above research questions are addressed by the published papers of Part II. The formation of the research questions and their interdependency can be explained by the five research phases: a) state of the art, b) theoretical and technological framework, c) game design and development, d) game evaluation, and e) future direction. Fig. 1.3 depicts the relationship between the research phases, the research questions and the published papers.

1. McCALLUM, S. & BOLETSIS, C. Dementia Games: A Literature Review of Dementia-Related Serious Games. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 15–27. Retrieved at: Chapter 7.

2. McCALLUM, S. & BOLETSIS, C. A Taxonomy of Serious Games for Dementia. In *Games for Health: Proceedings of the 3rd European conference on gaming and playful interaction in health care*. Springer Fachmedien Wiesbaden, 2013, pp. 219–232. Retrieved at: Chapter 8.

3. BOLETSIS, C. & McCALLUM, S. Connecting the Player to the Doctor: Utilising Serious Games for Cognitive Training & Screening. *DAIMI PB*, vol. 597. Department of Computer Science Aarhus University, 2015, pp. 5–8. Retrieved at: Chapter 9.

4. McCALLUM, S. & BOLETSIS, C. Augmented Reality & Gesture-based Architecture in Games for the Elderly. In *pHealth*, vol. 189 of *Studies in Health Technology and Informatics*. IOS Press, 2013, pp. 139–144. Retrieved at: Chapter 10.

5. BOLETSIS, C. & McCALLUM, S. Augmented Reality Cube Game for Cognitive Training: An Interaction Study. In *pHealth*, vol. 200 of *Studies in Health Technology and Informatics*. IOS Press, 2014, pp. 81–87. Retrieved at: Chapter 11.

6. BOLETSIS, C. & McCALLUM, S. Augmented Reality Cubes for Cognitive Gaming: Preliminary Usability and Game Experience Testing. *International Journal of Serious Games*, vol. 3(1). Serious Games Society, 2016, pp. 3–18. Retrieved at: Chapter 12.

7. BOLETSIS, C. & McCALLUM, S. Smartkuber: A Serious Game for Cognitive Health Screening of Elderly Players. *Games for Health Journal*, vol. 5(4). Mary Ann Liebert Inc. publishers, 2016. Retrieved at: Chapter 13.

1.3 Related research & publications

Further parallel research was conducted regarding related research areas of the study (smartwatches in dementia care, serious games, Augmented Reality), which - even though it does not fulfil the research objective and is outside the scope of the thesis - contributed to the acquisition of a wider knowledge of the PhD study's areas. The additional scientific publications are given below:

1. BOLETSIS, C., McCALLUM, S. & LANDMARK, B.F. The Use of Smartwatches for Health Monitoring in Home-based Dementia Care. In *Human Aspects of IT for the Aged Population*, vol. 9194 of *Lecture Notes in Computer Science*. Springer International Publishing, 2015, pp. 15–26.

2. BOLETSIS, C. & McCALLUM, S. The Cognitive Passport: Evaluating A Gaming Approach in the Fight Against Cognitive Impairment. submitted to *Games for Health Journal*, in review. Mary Ann Liebert Inc. publishers, 2016.

3. BOLETSIS, C. & McCALLUM, S. The Table Mystery: An Augmented Reality Collaborative Game for Chemistry Education. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 86–95.

1.4 Thesis outline

Part I provides an overview of the PhD study. Chapter 1 introduces the reader to the subject of the PhD study, describing the study's context and listing the related publications. Chapter 2 describes the related work on the field of the PhD study, focusing on serious games. Chapter 3 presents the flow of the research, accompanied by the summaries of the papers, as well as extra information about the research stages. The research challenges and limitations of the PhD study are described in Chapter 4. Part I concludes by providing an analysis of the study's contributions (Chapter 5) and the future work (Chapter 6). Part II presents the scientific publications of the PhD study.

1.5 Bibliography

[1] BOLETSIS, C., AND MCCALLUM, S. Connecting the player to the doctor: utilising serious games for cognitive training & screening. *DAIMI PB 597* (2015), 5–8. xiii, 3, 4, 5, 15, 31, 48, 60, 132, 134, 157, 158, 160, 162

[2] BOUCHARD, B., IMBEAULT, F., BOUZOUANE, A., AND MENELAS, B.-A. J. Developing Serious Games Specifically Adapted to People Suffering from Alzheimer. In *Proceedings of the Third international conference on Serious Games Development and Applications* (2012), SGDA '12, Springer-Verlag, pp. 243–254. 4, 14, 74, 80, 97, 106, 107, 132

[3] BOUSTANI, M., CALLAHAN, C. M., UNVERZAGT, F. W., AUSTROM, M. G., PERKINS, A. J., FULTZ, B. A., HUI, S. L., AND HENDRIE, H. C. Implementing a screening and diagnosis program for dementia in primary care. *Journal of general internal medicine 20*, 7 (2005), 572–577. 3, 132

[4] CONNOLLY, A., GAEHL, E., MARTIN, H., MORRIS, J., AND PURANDARE, N. Underdiagnosis of dementia in primary care: variations in the observed prevalence and comparisons to the expected prevalence. *Aging & Mental Health 15*, 8 (2011), 978–984. 3, 132, 158

[5] GANGULI, M., RATCLIFF, G., CHANDRA, V., SHARMA, S., GILBY, J., PANDAV, R., BELLE, S., RYAN, C., BAKER, C., SEABERG, E., AND DEKOSKY, S. A hindi version of the MMSE: The development of a cognitive screening instrument for a largely illiterate rural elderly population in India. *International Journal of Geriatric Psychiatry 10*, 5 (1995), 367–377. 3

[6] ISMAIL, Z., RAJJI, T. K., AND SHULMAN, K. I. Brief cognitive screening instruments: an update. *International Journal of Geriatric Psychiatry 25*, 2 (2010), 111–120. 3, 4, 105, 132, 158

[7] KATO, P. M. Video games in health care: Closing the gap. *Review of General Psychology 14*, 2 (2010), 113–121. 4, 12, 15, 132

[8] LOPPONEN, M., RAIHA, I., ISOAHO, R., VAHLBERG, T., AND KIVELA, S.-L. Diagnosing cognitive impairment and dementia in primary health care - a more active approach is needed. *Age and Ageing 32*, 6 (2003), 606–612. 3, 132

[9] MANERA, V., PETIT, P.-D., DERREUMAUX, A., ORVIETO, I., ROMAGNOLI, M., LYTTLE, G., DAVID, R., AND ROBERT, P. 'Kitchen and cooking', a serious game for Mild Cognitive Impairment and Alzheimer's Disease: a pilot study. *Frontiers in Aging Neuroscience 7*, 24 (2015). 4, 15, 59

[10] MCCALLUM, S. Gamification and serious games for personalized health. In *pHealth*, vol. 177 of *Studies in Health Technology and Informatics*. IOS Press, 2012, pp. 85–96. 4, 13, 15, 29, 71, 73, 76, 79, 90, 91, 93, 96, 113, 132

[11] MORRIS, J. C., AND PRICE, J. L. Pathologic correlates of nondemented aging, mild cognitive impairment, and early-stage Alzheimer's disease. *Journal of Molecular Neuroscience 17* (2001), 101–118. 3, 72

[12] MORRIS, J. C., STORANDT, M., MILLER, J., MCKEEL, D. W., PRICE, J. L., RUBIN, E. H., AND BERG, L. Mild cognitive impairment represents early-stage Alzheimer disease. *Archives of Neurology 58*, 3 (2001), 397–405. 3, 72, 104

[13] PERSSON, J., NYBERG, L., LIND, J., LARSSON, A., NILSSON, L.-G., INGVAR, M., AND BUCKNER, R. L. Structure-function correlates of cognitive decline in aging. *Cerebral Cortex 16*, 7 (2006), 907–915. 3, 103, 132, 157

[14] POZUETA, A., RODRGUEZ-RODRGUEZ, E., VAZQUEZ-HIGUERA, J., MATEO, I., SNCHEZ-JUAN, P., GONZLEZ-PEREZ, S., BERCIANO, J., AND COMBARROS, O. Detection of early Alzheimer's disease in MCI patients by the combination of MMSE and an episodic memory test. *BMC Neurology 11* (2011), 1–5. 3, 72

[15] PRINCE, M., BRYCE, R., AND FERRI, C. *World Alzheimer Report 2011: The Benefits of Early Diagnosis and Intervention*. Alzheimer's Disease International (ADI), 2011. 3, 132, 158

[16] Robert, P., Knig, A., Amieva, H., Andrieu, S., Bremond, F., Bullock, R., Ceccaldi, M., Dubois, B., Gauthier, S., Kenigsberg, P.-A., Nave, S., Orgogozo, J. M., Piano, J., Benoit, M., Touchon, J., Vellas, B., Yesavage, J., and Manera, V. Recommendations for the use of serious games in people with Alzheimer's Disease, related disorders and frailty. *Frontiers in Aging Neuroscience 6*, 54 (2014). 4, 59, 132

[17] Scanlon, L., O'Shea, E., O'Caoimh, R., and Timmons, S. Usability and validity of a battery of computerised cognitive screening tests for detecting cognitive impairment. *Gerontology Epub ahead of print* (2015). 3, 47, 54, 65, 132, 134, 158, 159, 172, 173

[18] Sperling, R. A., Aisen, P. S., Beckett, L. A., Bennett, D. A., Craft, S., Fagan, A. M., Iwatsubo, T., Jack, C. R., Kaye, J., Montine, T. J., Park, D. C., Reiman, E. M., Rowe, C. C., Siemers, E., Stern, Y., Yaffe, K., Carrillo, M. C., Thies, B., Morrison-Bogorad, M., Wagster, M. V., and Phelps, C. H. Toward defining the preclinical stages of Alzheimer's disease: recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia 7*, 3 (2011), 280–292. ix, x, 4, 104

[19] Tong, T., Guana, V., Jovanovic, A., Tran, F., Mozafari, G., Chignell, M., and Stroulia, E. Rapid deployment and evaluation of mobile serious games: A cognitive assessment case study. *Procedia Computer Science 69* (2015), 96 – 103. 3, 14, 15, 58, 158

[20] Waldemar, G., Phung, K., Burns, A., Georges, J., Hansen, F. R., Iliffe, S., Marking, C., Rikkert, M. O., Selmes, J., Stoppe, G., and Sartorius, N. Access to diagnostic evaluation and treatment for dementia in europe. *International journal of geriatric psychiatry 22*, 1 (2007), 47–54. 3, 132, 158

[21] Zucchella, C., Sinforiani, E., Tassorelli, C., Cavallini, E., Tost-Pardell, D., Grau, S., Pazzi, S., Puricelli, S., Bernini, S., Bottiroli, S., et al. Serious games for screening pre-dementia conditions: from virtuality to reality? a pilot project. *Functional neurology 29*, 3 (2014), 153–158. 4, 14, 15, 16, 58, 158

[22] Zygouris, S., Giakoumis, D., Votis, K., Doumpoulakis, S., Ntovas, K., Segkouli, S., Karagiannidis, C., Tzovaras, D., and Tsolaki, M. Can a Virtual Reality Cognitive Training Application Fulfill a Dual Role? Using the Virtual Supermarket Cognitive Training Application as a Screening Tool for Mild Cognitive Impairment. *Journal of Alzheimer's Disease 44*, 4 (2015), 1333–1347. 4, 5, 14, 15, 160

Chapter 2

Related Work

The chapter explores the main scientific topics of the thesis, i.e. serious games, serious games for cognitive health, new technologies and Augmented Reality. Its scope is to provide an overview of the study's related scientific research, in order for the reader to be able to explore and comprehend the matters discussed in the scientific publications (Part II), in a more complete and thorough way. The chapter acts as a supplementary research guide to the thesis introduction (Chapter 1) and each scientific publication's "related work" section.

2.1 Introduction

The current work is of interdisciplinary nature, examining the research spaces where the Serious Games, Cognitive Health and Augmented Reality disciplines meet (Fig. 2.1). The primary research area of the PhD study is the Serious Games domain, focusing on the scientific impact it can have for Cognitive Health processes, while attempting to maximise the impact by utilising the Augmented Reality technology.

In order to develop and deploy effective serious games, it is necessary to consider all the stakeholders (users, educators, families, researchers, developers/industries, et al.) and the whole cycle from research to market and vice-versa [22]. From a scientific point of view, this needs considering a complex mix of disciplines and technologies, which are to be developed and exploited in a target-oriented multidisciplinary approach that puts the user benefits at the centre of the process. Given their behavioural goals, serious games should provide quality contents on the target domain and their development should be strongly grounded in proper scientific foundations [22, 80].

2.2 Serious games

As the success and proliferation of video games grows, they have the potential to be more than just entertainment, just like books, movies and television. Consequently, the research community and the game industry moved towards the development of more elaborated games, incorporating both pedagogical and entertaining elements [60]. Video games can be developed for the purpose of

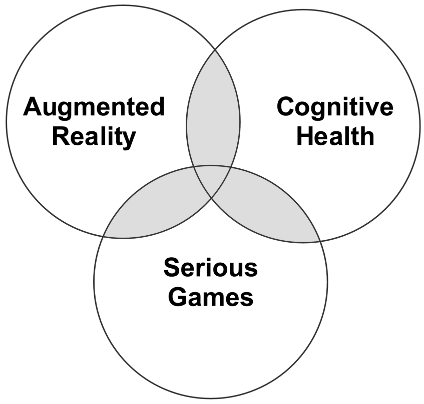


Figure 2.1: The interconnected disciplines and the research focus area of this PhD study (highlighted in grey).

changing player's attitudes and behaviours, being both an expressive and a persuasive medium [28, 10]. With a persuasive strategy in consideration, for purposes other than pure entertainment, the long existing field of "serious games" has found broad application in the video games industry (Fig. 2.2), attempting to educate, train, and inspire the players [59, 61, 79].

2.3 Serious games for health

The health domain has a history of embracing games as a means to engage patients behaviourally to improve their health outcomes. There are early reports of case studies using video games with patients experiencing diseases or physical disabilities [36, 42, 65]. Examples of video game applications in health care consist of serious games, that are designed specifically for training and education purposes, as well as commercially available off-the-shelf games that are repurposed to meet certain behavioural goals in health care [36].

In 2004, the Serious Games Initiative started the Games for Health Project, focusing on health and healthcare, recognising the special opportunities that the field offers to games [62]. More specifically, the healthcare field offered a strong research history to draw on, (previous work in cyberpsychology, Virtual Reality health, traditional medical modelling and simulation), while its large economical size (15% of the US gross domestic product) would provide the necessary opportunities for serious games to diffuse into other sectors of the economy [62]. Furthermore, games were being used in healthcare by not only researchers, but also patients (for either wellness or more therapeutic practices), since the history of video games has included - amongst others - products involving movement and exercise (although many failed commercially) [62]. Finally, in many cases of games for health, several biological markers, that prove the games' effective-

	Games for Health	Advergames	Games for training	Games for Education	Games for Science and Research	Production	Games as Work
Government & NGO	Public Health Education & Mass Casualty Response	Political Training	Employee Training	Inform Public	Data Collection / Planning	Strategic & Policy Planning	Public Policy, Opinion Research
Defense	Rehabilitation & Wellness	Recruitment & Propaganda	Soldier/Support Training	School House Education	Wargames / Planning	War Planning & Weapons Research	Command & Control
Healthcare	Cybertherapy / Exergaming	Public Health Policy & Social Awareness Campaigns	Training Games for Health Professionals	Games for Patient Education & Disease Management	Visualization & Epidemiology	Biotech Manufacturing & Design	Public Health Response Planning & Logistics
Marketing & Communications	Advertising Treatment	Advertising, Marketing with Games, Product Placement	Product Use	Product Information	Opinion Research	Machinima	Opinion Research
Education	Inform about Diseases / Risks	Social Issue Games	Train Teachers / Train Workforce Skills	Learning	Computer Science & Recruitment	P2P Learning Constructivism Documentary?	Teaching Distance Learning
Corporate	Employee Health Information & Wellness	Customer Education & Awareness	Employee Training	Continuing Education & Certification	Advertising / Visualization	Strategic Planning	Command & Control
Industry	Occupational Safety	Sales & Recruitment	Employee Training	Workforce Education	Process Optimization Simulation	Nano/Bio-tech Design	Command & Control

Figure 2.2: The Serious Games taxonomy, presenting the serious games' designed purpose (x axis) and their actual application areas (y axis) [63].

ness, can be examined and studied, providing direct and reliable measurements [62].

In order to identify the activity areas for serious games for health, the Games for Health Project, in 2007, generated a taxonomy (Fig. 8.1) based on the type of health uses the games have and the stakeholders they involve [62]. According to the taxonomy of Sawyer and the Games for Health Project [62], serious games for health can have preventative, therapeutic, or informational (i.e. assessment, education, informatics, production) uses [62, 49]. McCallum [49] in an alternative classification scheme, categorises serious games for health according to the area of health that is being affected by the game. Thus, the serious games for health field can be divided into:

- **Games for physical health**, i.e. games that promote physical exercise, fitness and health.

- **Games for cognitive health**, i.e. games that help develop the strategic and cognitive abilities of the players.

- **Games for social and emotional health**, i.e. games that actively encourage the players to link with their friends and both compete and collaborate to achieve their goals.

2.4 Serious games for cognitive health

Serious games are presented as a promising cognitive health platform (sometimes with physical characteristics, as well) to prevent or slow down the cognitive decline of players, or even to create awareness about cognitive disorders [15, 51, 52].

Following the consistent classification scheme of Sawyer [62] (Fig. 8.1), cognitive health games can be used for *preventative purposes*, i.e. played by healthy players to avoid cognitive decline, *therapeutic purposes*, i.e. played by cognitive impaired players to keep being mentally active and slow down cognitive decline, and *informational purposes*, i.e. providing the player with cognitive assessments of formal or informal measurements and educating him/her about certain cognitive disorders.

Serious games for health utilise, mainly, cognitive training and screening processes. Cognitive training games target the stimulation of the player's cognitive abilities through cognitive tasks, whereas cognitive screening games assess the player's performance in cognitive tasks. Cognitive training games constitute the majority of the serious games for cognitive health and they can serve preventative and rehabilitative purposes, as well as contribute to cognitive screening processes [83]. Even though, the retrospective and observational designs of the human studies have led to difficulty interpreting the direction of causation between cognitive function and cognitively stimulating activities, studies around the utilisation of video games for cognitive training, have produced positive indications for significant benefits on affecting memory function, attention abilities, emotional state, and, in general, improving executive functions and slowing down cognitive decline [51]. Cognitive screening games and studies on the field proliferate over the last few years and show promising results [75, 39, 82, 73, 74, 83].

Table 2.1 presents a selection of studies around serious games for cognitive health. Among the studied game titles of Table 2.1, there are repurposed commercial, off-the-shelf game titles (e.g. Brain Age, Big Brain Academy), commercial cognitive training platforms (e.g. Lumosity, Posit Science, CogniFit et al.), as well as games developed solely for academic purposes (e.g. KiMentia, MasterQuiz, GenVirtual et al.), all of which are studied as tools for cognitive interventions.

On the technological aspect, serious games for health utilise various technologies and interaction methods, ranging from the traditional PC-keyboard-mouse setup (e.g. Lumosity, CogniFit), to mobile gaming (e.g. MasterQuiz), motion sensing (e.g. Big Brain Academy, MINWii project), full-body motion tracking (e.g. KiMentia, Dual-Task Tai Chi) and Augmented Reality (e.g. GenVirtual, Eldergames).

Table 2.1: A selection of research studies on the use of serious games for cognitive health.

Game Title	Research
Brain Age	[56, 37]
Big Brain Academy	[1, 26]
Lumosity	[27, 48]
Posit Science	[5]
CogniFit	[64]
Complete Brain Workout	[67]
Eldergames	[30, 29]
SmartBrain Games	[70]
MasterQuiz	[49]
KiMentia	[17]
Dual-Task Tai Chi	[38]
MINWii project	[6, 16]
Cooking game	[33]
Kitchen and cooking	[47]
GenVirtual	[21]
Whack-a-mole game	[73, 74, 75]
Smart aging	[82]
Virtual Supermarket	[83]

2.5 Interaction & serious games for health

The popularisation of novel interaction methods, utilising *motion-sensing game controllers* (e.g. Nintendo Wiimote and Balance Board for the Nintendo Wii, Sony Move for the Sony Playstation), *full-body motion tracking* (e.g. Microsoft Kinect for the Micrsotf Xbox 360, Sony EyeToy for the Sony Playstation), *gestures/hand tracking* (e.g. Leap Motion, Pristine Eyesight), *Augmented Reality* (e.g Meta Spaceglasses, Google Glass, Vuforia SDK, Metaio), *Virtual Reality* (e.g. Oculus Rift, Sony Project Morpheus), and *wearable biosensors* (e.g. Basis Peak smartwatch, Fitbit bracelet, Microsoft Band, Apple Watch) allowed the players to move away from the desktop and from merely pushing buttons to control a game, to use gestures and physical movements as their input mechanism [71, 72, 50]. Moreover, the additional data flow and the new - secondary - information, coming from these devices introduce new ways to design effective serious games for health, or to even repurpose commercially available off-the-shelf games for the health domain [36, 50, 11].

Over the last few years, the Nintendo Wii video game console and its motion-sensing game controllers (Wiimote, Wii Balance Board) have been widely used for academic purposes. Commercially available off-the-shelf game titles, like Wii Sports (sports game simulations of bowling, boxing, baseball, et. al.) and WiiFit (exercise game) have been repurposed to fit several health studies, mostly around motor rehabilitation, energy expenditure, increase of physical activity, hand-eye coordination, cognitive training, and social/emotional interaction [44, 57, 2, 32, 66, 25, 45, 24]. The Microsoft Kinect sensor has been also utilised to address players' physical, cognitive, and psychological health and fitness, focusing on the exergaming field [35, 20, 31, 54, 43]. On the same field - and following the same technological principle of motion tracking, but only for hands/gestures - there is the free-hand interaction with devices like the Leap Motion, which has been mainly used for physiotherapeutic rehabilitation purposes, especially with stroke patients [40, 34, 78]. Virtual Reality, being an output technology, mostly, addresses the cognitive abilities of the players, engaging the player in immersive video game scenarios, having been used - amongst others - for treating early dementia and treating phobias [69, 76, 82]. In addition, wearable bionsensors can provide several health-related data, like heart rate, perspiration, and skin temperature, as well as sleeping details. Those data can be obtained unintrusively, usually by wearing a wristband or a wristwatch device, and can be used either as internal game elements or as external, secondary data, utilised for studying the game effectiveness on players' health and well-being [41].

Augmented Reality (AR) is another technology which can be used for health purposes and its utilisation contributes to the interaction design of this study's developed tool. Augmented Reality enhances the real world view - as captured by the device's camera - with digital information, in real time [53, 4, 3, 18]. AR can have advertising, entertainment, education, medical, navigational and informational applications [19]. The fact that AR can evoke the initial engagement of the player, utilising the "wow effect" and that it comes in various forms (GPS-based, markerless, marker-based) and devices (ranging from the traditional desktop PC, to mobile devices and glasses) makes it an easily-accessible and promising tool for several domains [23]. By connecting the real to the digital/gaming world, Augmented Reality - a close "relative" to Virtual Reality, utilising physically-based interaction in a non-immersive, real environment [7, 3, 81, 8, 58] - can help eliminating the need for extensive tutorials/instructions, thus reducing cognitive load and attention-switching; it can also promote continuous use and physical movement, as well as support spatial cognition and mental transformation [55, 68, 46].

AR has found its place in the "serious games for health" domain, in cases of physical rehabilitation [18], treating phobias [14], and cognitive and motor rehabilitation [21]. Tangible Augmented Reality (TAR) (i.e. the combination of an Augmented Reality system and a tangible user interface [9, 77]) is also used to preserve or train the cognitive functions of elderly players [30, 29, 21].

2.6 Conclusion

The examination of the related work in the field of serious games for cognitive health and Augmented Reality formed the direction and the nature of the current study. The literature of serious games for cognitive health allowed the discovery of the research "gaps" of the field, as presented and addressed in [51] (Chapter 7) and [52] (Chapter 8), and defined the nature of the study's developed game as for the cognitive health purposes and target group. The work on Augmented Reality and, more specifically, Tangible Augmented Reality defined the interaction technique of the game and allowed the examination of various AR implementations and modes. The related work on the available technologies, devices, and interaction methods, formed the future direction of the study with the introduction of sleep measurements by smartwatches, for cognitive screening purposes, as examined in [13]. The studies regarding serious games for cognitive screening were examined as to their potential and documented results and as to their evaluation methods, which affected the methodological approach of the "game evaluation" stage presented in [12] (Chapter 13). To sum up, the related work assisted in identifying the "best practices" in the examined fields, form the main research problems and establish the characteristics of this study and its contribution to the fields' knowledge.

2.7 Bibliography

[1] Ackerman, P. L., Kanfer, R., and Calderwood, C. Use it or lose it? Wii brain exercise practice and reading for domain knowledge. *Psychology and aging* (2010). 15

[2] Agmon, M., Perry, C. K., Phelan, E., Demiris, G., and Nguyen, H. Q. A pilot study of wii fit exergames to improve balance in older adults. *Journal of Geriatric Physical Therapy 34*, 4 (2011), 161–167. 16

[3] Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., and MacIntyre, B. Recent advances in Augmented Reality. *IEEE Computer Graphics and Applications 21*, 6 (2001), 34–47. 16

[4] Azuma, R. T. A survey of Augmented Reality. *Presence 6* (1997), 355–385. 16

[5] Barnes, D., Yaffe, K., Belfor, N., Jagust, W., DeCarli, C., Reed, B., and Kramer, J. Computer-based cognitive training for mild cognitive impairment: Results from a pilot randomized, controlled trial. *Alzheimer Disease and Associated Disorders 23* (2009), 205–210. 15, 76, 78, 96

[6] Benveniste, S., Jouvelot, P., and Péquignot, R. The MINWii project: renarcissization of patients suffering from Alzheimer's disease through video game-based music therapy. In *Proceedings of the 9th international conference on Entertainment computing* (2010), ICEC'10, Springer-Verlag, pp. 79–90. 15, 76

[7] Billinghurst, M., Clark, A., , and Lee, G. A survey of augmented reality. *Foundations and Trends Human-Computer Interaction 8*, 2-3 (2014), 73–272. 16

[8] Billinghurst, M., and Kato, H. Collaborative augmented reality. *Communications of the ACM 45*, 7 (2002), 64–70. 16

[9] Billinghurst, M., Kato, H., and Poupyrev, I. Tangible Augmented Reality. In *Proceedings of ACM SIGGRAPH Asia* (2008), pp. 1–10. 16, 34, 35, 59, 60

[10] Bogost, I. *Persuasive games: The expressive power of videogames*. MIT Press, 2007. 12, 89

[11] Boletsis, C., and McCallum, S. Connecting the player to the doctor: utilising serious games for cognitive training & screening. *DAIMI PB 597* (2015), 5–8. xiii, 3, 4, 5, 15, 31, 48, 60, 132, 134, 157, 158, 160, 162

[12] Boletsis, C., and McCallum, S. Smartkuber: A cognitive training game for cognitive health screening of elderly players. *Games for Health Journal 5*, 4 (2016). 17, 41, 44, 53, 54, 60, 61, 66

[13] Boletsis, C., and McCallum, S. The Cognitive Passport: Evaluating a gaming approach in the fight against cognitive impairment. *Games for Health Journal (in review)* (2016). 17, 61, 66

[14] Botella, C., Breton-Lpez, J., Quero, S., Baos, R., Garca-Palacios, A., Zaragoza, I., and Alcaniz, M. Treating cockroach phobia using a serious game on a mobile phone and augmented reality exposure: A single case study. *Computers in Human Behavior 27*, 1 (2011), 217 – 227. 16

[15] Bouchard, B., Imbeault, F., Bouzouane, A., and Menelas, B.-A. J. Developing Serious Games Specifically Adapted to People Suffering from Alzheimer. In *Proceedings of the Third international conference on Serious Games Development and Applications* (2012), SGDA '12, Springer-Verlag, pp. 243–254. 4, 14, 74, 80, 97, 106, 107, 132

[16] Boulay, M., Benveniste, S., Boespflug, S., Jouvelot, P., and Rigaud, A.-S. A pilot usability study of MINWii, a music therapy game for demented patients. *Technology & Health Care 19*, 4 (2011), 233–246. 15, 76, 79, 81, 96, 114

[17] Breton, Z., Zapirain, S., and Zorrilla, A. Kimentia: Kinect based tool to help cognitive stimulation for individuals with dementia. In *2012 IEEE 14th International Conference on e-Health Networking, Applications and Services* (2012), Healthcom 2012, IEEE Computer Society, pp. 325–328. 15, 74, 97, 114

[18] Burke, J., McNeill, M., Charles, D., Morrow, P., Crosbie, J., and McDonough, S. Augmented reality games for upper-limb stroke rehabilitation. In *Games and Virtual Worlds for Serious Applications (VS-GAMES), 2010 Second International Conference on* (2010), IEEE Computer Society, pp. 75–78. 16

[19] Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., and Ivkovic, M. Augmented reality technologies, systems and applications. *Multimedia Tools and Applications 51*, 1 (2011), 341–377. 16

[20] Chiang, I.-T., Tsai, J.-C., and Chen, S.-T. Using Xbox 360 Kinect Games on Enhancing Visual Performance Skills on Institutionalized Older Adults with Wheelchairs. In *Digital Game and Intelligent Toy Enhanced Learning (DIGITEL), 2012 IEEE Fourth International Conference on* (2012), pp. 263–267. 16

[21] Correa, A., de Assis, G. A., Nascimento, M. d., Ficheman, I., and Lopes, R. d. D. GenVirtual: an Augmented Reality musical game for cognitive and motor rehabilitation. In *Virtual Rehabilitation* (2007), pp. 1–6. 15, 16, 123, 135

[22] De Gloria, A., Bellotti, F., and Berta, R. Serious games for education and training. *International Journal of Serious Games 1*, 1 (2014). 11

[23] Dünser, A., Grasset, R., Seichter, H., and Billinghurst, M. Applying HCI Principles in AR Systems Design. In *2nd International Workshop on Mixed Reality User Interfaces: Specification, Authoring, Adaptation (MRUI '07)* (2007). 16

[24] Fenney, A., and Lee, T. D. Exploring spared capacity in persons with dementia: what Wii can learn. *Activities, Adaptation & Aging 34*, 4 (2010), 303–313. 16, 76, 77, 96

[25] Ferguson, G., Jelsma, D., Jelsma, J., and Smits-Engelsman, B. The efficacy of two task-orientated interventions for children with Developmental Coordination Disorder: Neuromotor Task Training and Nintendo Wii Fit training. *Research in Developmental Disabilities 34*, 9 (2013), 2449 – 2461. 16

[26] Fernández-Calvo, B., Rodríguez-Pérez, R., Contador, I., Rubio-Santorum, A., and Ramos, F. Efficacy of cognitive training programs based on new software technologies in patients with Alzheimer-type dementia. *Psicothema 23*, 1 (2011), 44–50. 15, 76, 78, 81, 96

[27] Finn, M., and McDonald, S. Computerised cognitive training for older persons with mild cognitive impairment: A pilot study using a randomised controlled trial design. *Brain Impairment 12*, 3 (2011), 187–199. 15, 76, 78, 96

[28] Fogg, B. J. *Persuasive technology: using computers to change what we think and do*. Morgan Kaufmann Publishers, 2003. 12, 89

[29] Gamberini, L., Fabregat, M., Spagnolli, A., Prontu, L., Seraglia, B., Alcaniz, M., Zimmerman, A., Rontti, T., Grant, J., Jensen, R., and Gonzales, A. Eldergames: videogames for empowering, training and monitoring elderly cognitive capabilities. *Gerontechnology 7*, 2 (2008). 15, 16, 123, 124, 135, 136, 163

[30] Gamberini, L., Martino, F., Seraglia, B., Spagnolli, A., Fabregat, M., Ibanez, F., Alcaniz, M., and Andrés, J. M. Eldergames project: an innovative mixed reality table-top solution to preserve cognitive functions in elderly people. In *Proceedings of the 2nd conference on Human System Interactions* (2009), HSI'09, IEEE Press, pp. 161–166. 15, 16, 60, 72, 107

[31] Garcia, J. A., Navarro, K. F., Schoene, D., Smith, S. T., and Pisan, Y. Exergames for the elderly: towards an embedded kinect-based clinical test of falls risk. *Stud Health Technol Inform 178* (2012), 51–57. 16

[32] Graves, L. E., Ridgers, N. D., Williams, K., Stratton, G., and Atkinson, G. T. The physiological cost and enjoyment of Wii Fit in adolescents, young adults, and older adults. *Journal of physical activity & health 7*, 3 (2010), 393–401. 16

[33] Imbeault, F., Bouchard, B., and Bouzouane, A. Serious games in cognitive training for Alzheimer's patients. In *Proceedings of the 2011 IEEE 1st International Conference on Serious Games and Applications for Health* (2011), SEGAH '11, IEEE Computer Society, pp. 1–8. 15, 74, 97

[34] Iosa, M., Morone, G., Fusco, A., Castagnoli, M., Fusco, F. R., Pratesi, L., and Paolucci, S. Leap motion controlled videogame-based therapy for rehabilitation of elderly patients with subacute stroke: a feasibility pilot study. *Topics in Stroke Rehabilitation Advanced Articles* (2015). 16

[35] Kamel Boulos, M. N. Xbox 360 kinect exergames for health. *Games for Health: Research, Development, and Clinical Applications 1*, 5 (2012), 326–330. 16

[36] Kato, P. M. Video games in health care: Closing the gap. *Review of General Psychology 14*, 2 (2010), 113–121. 4, 12, 15, 132

[37] Kawashima, R., Okita, K., Yamazaki, R., Tajima, N., Yoshida, H., Taira, M., Iwata, K., Sasaki, T., Maeyama, K., Usui, N., and Sugimoto, K. Reading aloud and arithmetic calculation improve frontal function of people with dementia. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 60*, 3 (2005), 380–384. 15, 74, 97

[38] KAYAMA, H., OKAMOTO, K., NISHIGUCHI, S., NAGAI, K., YAMADA, M., AND AOYAMA, T. Concept software based on Kinect for assessing dual-task ability of elderly people. *Games for Health Journal 1*, 5 (2012), 348–352. 15, 114

[39] KAZMI, S., UGAIL, H., LESK, V., AND PALMER, I. Interactive digital serious games for the assessment, rehabilitation, and prediction of dementia. *International Journal of Computer Games Technology 2014* (2014), 12:12–12:12. 14, 58, 59

[40] KHADEMI, M., MOUSAVI HONDORI, H., MCKENZIE, A., DODAKIAN, L., LOPES, C. V., AND CRAMER, S. C. Free-hand interaction with leap motion controller for stroke rehabilitation. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems* (2014), CHI EA '14, ACM, pp. 1663–1668. 16

[41] KO, P.-R. T., KIENTZ, J. A., CHOE, E. K., KAY, M., LANDIS, C., AND WATSON, N. Consumer sleep technologies: A review of the landscape. *Journal of clinical sleep medicine* (2015). 16

[42] KRICHEVETS, A. N., SIROTKINA, E. B., YEVSEVICHEVA, I. V., AND ZELDIN, L. M. Computer games as a means of movement rehabilitation. *Disability and Rehabilitation 17*, 2 (1995), 100–105. 12

[43] LANGE, B., KOENIG, S., MCCONNELL, E., CHANG, C., JUANG, R., SUMA, E., BOLAS, M., AND RIZZO, A. Interactive game-based rehabilitation using the Microsoft Kinect. In *Virtual Reality Short Papers and Posters (VRW), 2012 IEEE* (2012), pp. 171–172. 16

[44] LEBLANC, A. G., CHAPUT, J.-P., MCFARLANE, A., COLLEY, R. C., THIVEL, D., BIDDLE, S. J. H., MADDISON, R., LEATHERDALE, S. T., AND TREMBLAY, M. S. Active video games and health indicators in children and youth: A systematic review. *PLoS ONE 8*, 6 (2013), e65351. 16

[45] LEGOUVERNEUR, G., PINO, M., BOULAY, M., AND RIGAUD, A. Wii sports, a usability study with MCI and Alzheimer's patients. *Alzheimer's & dementia : the journal of the Alzheimer's Association 7* (2011), S500–S501. 16, 76, 77, 80, 96, 114

[46] LIU, C., HUOT, S., DIEHL, J., MACKAY, W., AND BEAUDOUIN-LAFON, M. Evaluating the benefits of real-time feedback in mobile Augmented Reality with hand-held devices. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems* (2012), CHI '12, ACM, pp. 2973–2976. 16, 114

[47] MANERA, V., PETIT, P.-D., DERREUMAUX, A., ORVIETO, I., ROMAGNOLI, M., LYTTLE, G., DAVID, R., AND ROBERT, P. 'Kitchen and cooking', a serious game for Mild Cognitive Impairment and Alzheimer's Disease: a pilot study. *Frontiers in Aging Neuroscience 7*, 24 (2015). 4, 15, 59

[48] MAYAS, J., PARMENTIER, F. B. R., ANDRS, P., AND BALLESTEROS, S. Plasticity of attentional functions in older adults after non-action video game training: A randomized controlled trial. *PLoS ONE 9*, 3 (2014), e92269. 15

[49] MCCALLUM, S. Gamification and serious games for personalized health. In *pHealth*, vol. 177 of *Studies in Health Technology and Informatics*. IOS Press, 2012, pp. 85–96. 4, 13, 15, 29, 71, 73, 76, 79, 90, 91, 93, 96, 113, 132

[50] MCCALLUM, S., AND BOLETSIS, C. Augmented Reality & gesture-based architecture in games for the elderly. In *pHealth*, vol. 189 of *Studies in Health Technology and Informatics*. IOS Press, 2013, pp. 139–144. ix, 15, 31, 33, 34, 35, 122, 124, 134, 137, 160, 163

[51] MCCALLUM, S., AND BOLETSIS, C. Dementia games: A literature review of dementia-related serious games. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 15–27. 14, 17, 27, 28, 29, 58, 59, 61, 91, 95, 97, 106, 122, 160

[52] MCCALLUM, S., AND BOLETSIS, C. A taxonomy of serious games for dementia. In *Games for Health*. Springer Fachmedien Wiesbaden, 2013, pp. 219–232. 14, 17, 27, 29, 58, 59, 61, 160

[53] MILGRAM, P., TAKEMURA, H., UTSUMI, A., AND KISHINO, F. Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum. In *Proceedings of the SPIE Conference on Telemanipulator and Telepresence Technologies* (Boston, Massachusetts, USA, 1995), vol. 2351 of *Proceedings of SPIE*, pp. 282–292. 16, 66

[54] MUOZ, J., HENAO, O., LPEZ, J. F., AND VILLADA, J. F. Bki: Brain kinect interface, a new hybrid bci for rehabilitation. In *Games for Health*. Springer Fachmedien Wiesbaden, 2013, pp. 233–245. 16

[55] NEUMANN, U., AND MAJOROS, A. Cognitive, performance, and systems issues for augmented reality applications in manufacturing and maintenance. In *Proceedings of the Virtual Reality Annual International Symposium* (1998), VRAIS '98, IEEE, pp. 4–11. 16, 114

[56] NOUCHI, R., TAKI, Y., TAKEUCHI, H., HASHIZUME, H., AKITSUKI, Y., SHIGEMUNE, Y., SEKIGUCHI, A., KOTOZAKI, Y., TSUKIURA, T., YOMOGIDA, Y., AND KAWASHIMA, R. Brain training game improves executive functions and processing speed in the elderly: A randomized controlled trial. *PLoS ONE 7*, 1 (01 2012), e29676. 15

[57] PADALA, K. P., PADALA, P. R., MALLOY, T. R., GESKE, J. A., DUBBERT, P. M., DENNIS, R. A., GARNER, K. K., BOPP, M. M., BURKE, W. J., AND SULLIVAN, D. H. Wii-Fit for improving gait and balance in an assisted

living facility: a pilot study. *Journal of Aging Research 2012* (2012), 1–6. 16, 76, 77, 80, 96

[58] PIUMSOMBOON, T., CLARK, A., AND BILLINGHURST, M. Physically-based Interaction for Tabletop Augmented Reality Using a Depth-sensing Camera for Environment Mapping. In *Proc. Image and Vision Computing New Zealand (IVCNZ-2011)* (2011), pp. 161–166. 16

[59] PRENSKY, M. Digital game-based learning. *Computers in Entertainment 1* (2003), 21–21. 12, 89

[60] REGO, P., MOREIRA, P., AND REIS, L. Serious games for rehabilitation: A survey and a classification towards a taxonomy. In *Information Systems and Technologies (CISTI), 2010 5th Iberian Conference on* (2010). 11

[61] SAWYER, B. *Serious Games: Improving Public Policy through Game-Based Learning and Simulation*. Foresight and Governance Project, Woodrow Wilson International Center for Scholars Publication, 2002. 12, 89

[62] SAWYER, B. From cells to cell processors: The integration of health and video games. *IEEE Computer Graphics and Applications 28*, 6 (2008), 83–85. x, 12, 13, 14, 29, 89, 90, 91, 93, 94

[63] SAWYER, B., AND SMITH, P. Serious games taxonomy. In *Slides from the Serious Games Summit at the Game Developers Conference* (2008). ix, 13

[64] SHATIL, E., KORCZYN, A., PERETZ, C., BREZNITZ, S., AHARONSON, V., AND GILADI, N. P2-406: Improving cognitive performance in elderly subjects using computerized cognitive training. *Alzheimer's & Dementia: The Journal of the Alzheimer's Association 4* (2008), 492. 15

[65] SJER, J. Video games as physiotherapy. *The Medical Journal of Australia 1*, 9 (1983), 401–402. 12

[66] STAIANO, A. E., AND CALVERT, S. L. Exergames for physical education courses: Physical, social, and cognitive benefits. *Child Development Perspectives 5*, 2 (2011), 93–98. 16

[67] STAVROS, Z., FOTINI, K., AND MAGDA, T. Computer based cognitive training for patients with mild cognitive impairment (MCI). In *Proceedings of the 3rd International Conference on PErvasive Technologies Related to Assistive Environments* (2010), PETRA '10, ACM, pp. 21:1–21:3. 15, 76, 79, 96

[68] TANG, A., OWEN, C., BIOCCA, F., AND MOU, W. Comparative effectiveness of Augmented Reality in object assembly. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2003), CHI '03, pp. 73–80. 16, 107, 114, 115, 149

[69] Tarnanas, I., Schlee, W., Tsolaki, M., Müri, R., Mosimann, U., and Nef, T. Ecological validity of virtual reality daily living activities screening for early dementia: longitudinal study. *JMIR Serious Games 1*, 1 (2013). 16

[70] Tarraga, L., Boada, M., Modinos, G., Espinosa, A., Diego, S., Morera, A., Guitart, M., Balcells, J., Lopez, O. L., and Becker, J. T. A randomised pilot study to assess the efficacy of an interactive, multimedia tool of cognitive stimulation in Alzheimer's disease. *Journal of Neurology, Neurosurgery & Psychiatry 77*, 10 (2006), 1116–1121. 15, 76, 79, 81, 96

[71] Theng, Y.-L., Dahlan, A. B., Akmal, M. L., and Myint, T. Z. An exploratory study on senior citizens' perceptions of the Nintendo Wii: the case of Singapore. In *Proceedings of the 3rd International Convention on Rehabilitation Engineering & Assistive Technology* (2009), i-CREATe '09, ACM, pp. 10:1–10:5. 15, 114

[72] Theng, Y.-L., Teo, P., and Truc, P. Investigating sociability and affective responses of elderly users through digitally-mediated exercises: a case of the Nintendo Wii. In *Human-Computer Interaction*, vol. 332 of *IFIP Advances in Information and Communication Technology*. Springer Berlin Heidelberg, 2010, pp. 152–162. 15, 114

[73] Tong, T., and Chignell, M. Developing a serious game for cognitive assessment: Choosing settings and measuring performance. In *Proceedings of the Second International Symposium of Chinese CHI* (2014), Chinese CHI '14, pp. 70–79. 14, 15, 58

[74] Tong, T., Chignell, M., Lam, P., Tierney, M. C., and Lee, J. Designing serious games for cognitive assessment of the elderly. *Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care 3*, 1 (2014), 28–35. 14, 15, 58

[75] Tong, T., Guana, V., Jovanovic, A., Tran, F., Mozafari, G., Chignell, M., and Stroulia, E. Rapid deployment and evaluation of mobile serious games: A cognitive assessment case study. *Procedia Computer Science 69* (2015), 96 – 103. 3, 14, 15, 58, 158

[76] Trigo Algar, A. R. Serious games for overcoming phobias: The benefits of game elements. Master's thesis, University of Skövde - School of Humanities and Informatics, 2014. 16

[77] Ulbricht, C., and Schmalstieg, D. Tangible Augmented Reality for computer games. In *Proceedings of the Third IASTED International Conference on Visualization, Imaging and Image Processing* (2003), pp. 950–954. 16, 59, 66

[78] VOGIATZAKI, E., GRAVEZAS, Y., DALEZIOS, N., BISWAS, D., CRANNY, A., ORTMANN, S., LANGENDORFER, P., LAMPRINOS, I., GIANNAKOPOULOU, G., ACHNER, J., KLEMKE, J., AND JOST, H. Telemedicine system for game-based rehabilitation of stroke patients in the FP7- "Stroke-Back" project. In *Networks and Communications (EuCNC), 2014 European Conference on* (2014), pp. 1–5. 16

[79] WALZ, S. P. Pervasive Persuasive: A Rhetorical Design Approach to a Location-Based Spell-Casting Game for Tourists. In *Situated Play, Proceedings of DiGRA 2007 Conference* (2007), pp. 489–497. 12, 89

[80] WINN, B. The design, play, and experience framework. *Handbook of research on effective electronic gaming in education 3* (2008), 1010–1024. 11

[81] ZHOU, F., DUH, H. B.-L., AND BILLINGHURST, M. Trends in augmented reality tracking, interaction and display: A review of ten years of ismar. In *Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality* (2008), ISMAR '08, IEEE Computer Society, pp. 193–202. 16, 60

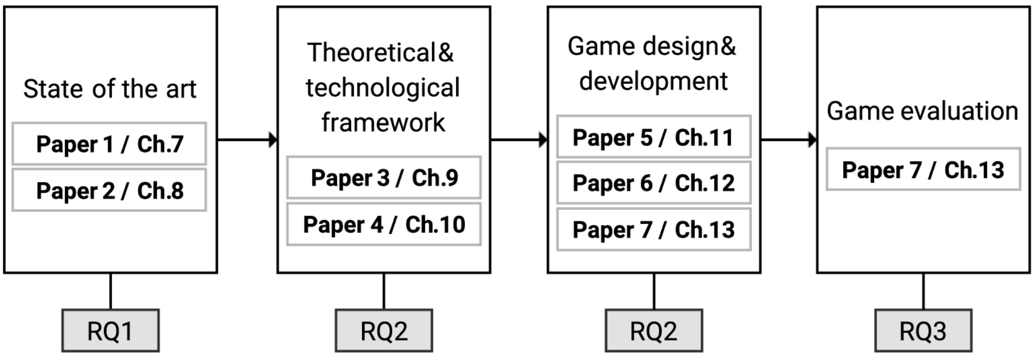
[82] ZUCCHELLA, C., SINFORIANI, E., TASSORELLI, C., CAVALLINI, E., TOST-PARDELL, D., GRAU, S., PAZZI, S., PURICELLI, S., BERNINI, S., BOTTIROLI, S., ET AL. Serious games for screening pre-dementia conditions: from virtuality to reality? a pilot project. *Functional neurology 29*, 3 (2014), 153–158. 4, 14, 15, 16, 58, 158

[83] ZYGOURIS, S., GIAKOUMIS, D., VOTIS, K., DOUMPOULAKIS, S., NTOVAS, K., SEGKOULI, S., KARAGIANNIDIS, C., TZOVARAS, D., AND TSOLAKI, M. Can a Virtual Reality Cognitive Training Application Fulfill a Dual Role? Using the Virtual Supermarket Cognitive Training Application as a Screening Tool for Mild Cognitive Impairment. *Journal of Alzheimer's Disease 44*, 4 (2015), 1333–1347. 4, 5, 14, 15, 160

Chapter 3

Summary of Papers & Research Flow

This chapter presents the flow of the PhD study following the order of the research stages and summarising the related publications. The sections of this chapter and the papers they address are portrayed in the following figure.



3.1 State of the art

The first step towards the set research objective is the establishment of the theoretical background of the study and the identification of the state of the art in the field of serious games for dementia and cognitive impairment. The study of the state of the art in the research field of serious games for cognitive impairment contributes a) to the in-depth knowledge acquisition of the research subject, b) to the identification of all the research gaps in the examined field, c) to the identification of the "best practises" (studies with similar research goals and promising results), and d) to the formation of the current study's characteristics, by addressing the identified research gaps and by building upon the best practises. The examination of the state of the art is the first step towards the set research objective and answers to the research question RQ1, utilising a literature review of dementia-related serious games [17] (Chapter 7) and a taxonomy of serious games for dementia [18] (Chapter 8).

At this stage, the dementia spectrum (mild cognitive impairment, Alzheimer's disease and other dementias) is chosen as the health field of the state-of-the-art examination, since it is important to identify how cognitive impairment is treated in various stages of the dementia spectrum, how these stages affect the game interventions, what is the effect that serious games have on patients and what is their overall social impact.

3.1.1 Literature review

Publication [17] (Chapter 7) presents a literature review of studies on serious games related to dementia and cognitive impairment, that are supported by evaluation tests on dementia, MCI (Mild Cognitive Impairment) and AD (Alzheimer's Disease) patients, with published and peer-reviewed results.

The motivation for this review (Section 7.2) comes from the fact that the dementia-related subfield of serious games for health is uncharted, while, at the same time, there is a proliferation of cognitive training, exercise and social games, some of them being originally serious games and some of them being repurposed entertainment games. The goal of the review is for the dementia stakeholders and the public to acquire a clearer picture of health purposes that each game serves and the scientific contribution of the game-related studies.

After a rigorous filtering process of the literature (Section 7.3), where only studies with a documented, peer-reviewed, and published effect on dementia-related health issues were included in the review, 15 studies of 12 game titles were presented. At first, the game titles which are used as intervention tools in these 15 studies, are analysed as to their content, distribution, gaming platforms and the input methods they have (Table 7.1). That way, the readers can obtain several, additional information about the identity of those games and their health uses.

The game titles' analysis, even though it is not a prerequisite for the literature review, is of great significance for examining the 15 studies in depth, addressing not only experimental and methodological issues, but game interaction and design/development issues as well, which are of use for game designers/developers and for the next stages of the PhD study.

Subsequently, the 15 studies are presented and analysed based on several attributes, such as: the main objective of the study, the targeted health area, the type of the study, the size of the sample (N), the participants' health state and the duration of the study (Table 7.2).

The review leads to several observations and conclusions (discussed in depth in Section 7.5).

- Dementia games do have an effect on cognitive impaired people. If that effect is long-lasting and/or transferable to the daily activities is a matter of further scientific investigation.
- Even though many games were developed for entertainment purposes, they are repurposed and being used for health reasons (usually after technical or conceptual modification), acquiring the characteristics of serious games. Nevertheless, repurposing entertainment games can cause several interaction-related problems to cognitive impaired players.

- Many dementia-related serious games use physical exercise, in combination with cognitive training, to address cognitive decline and they show promising results.

- The social/emotional function of dementia games is less emphasised and studied, although video game competition - usually within a sports cause - showed an intrinsic (emotional) motivation and a significant fun factor.

These observations highlight the need for physical stimulation and game competition, within a cognitive training context, in order for the researcher to develop a gaming tool which could potentially be more effective in dealing with cognitive impairment.

In order to be able to make even more robust observations for the whole field of dementia-related games, identifying its gaps, problems and limitations, further organisation of the field is necessary.

3.1.2 Taxonomy

Publication [18] (Chapter 8) presents a generic taxonomy of "serious games for dementia" (SG4D), based on the health functions and the health purposes they serve. Following a top-down approach, the proposed taxonomy of serious games for dementia is built upon the taxonomies of serious games for health from Sawyer [23] and McCallum [15]. To assess the practical value and validity of the proposed taxonomy, its application to existing systems is examined. In essence, the focus of [18] (Chapter 8) is placed on exploring whether the existing serious games for dementia can be validly classified, based on the proposed taxonomic characters. To this end, the studies of the dementia-related serious games' review (Chapter 7, [17]) are utilised.

The motivation for proposing the "serious games for dementia" taxonomy is to establish a classification scheme within which the position and, thus properties, of games relative to one another can be understood, and to act as a foundation for constructing a "serious games for dementia" field knowledge base. More specifically, since serious games for dementia target specific types, stages or symptoms of the dementia disease and they also fulfil various purposes, their classification is of great significance for having a clear understanding of how the games and their properties are related to one another.

Schematically, the proposed taxonomy of serious games for dementia is presented in Fig. 3.1. The broadest taxonomic category (game category) of the proposed taxonomy is associated with the dementia-related health function that the SG4D affect. Each of these dementia-related health functions/game categories serves a variety of health purposes. From a gaming point of view, this taxonomic category is referred as the "game type". The core of the proposed taxonomy is two-dimensional, based on the aforementioned two intrinsic game-related characteristics (game categories and game types), however the identification of the "serious games for dementia" health user groups/players

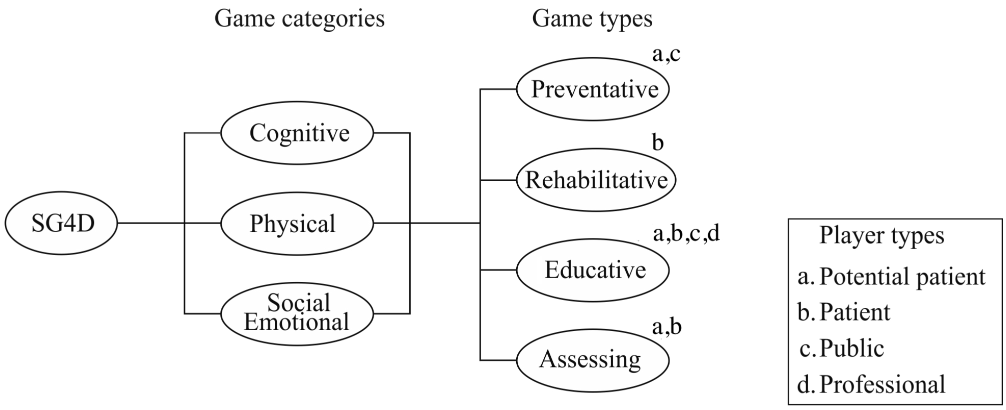


Figure 3.1: The taxonomy of serious games for dementia (SG4D).

is a useful representation of how the games are connected with society and the disease itself.

After applying the proposed taxonomical system on the existing research-supported dementia game titles (fully presented in Table 8.2), some interesting conclusions about the form of the "serious games for dementia" field can be reached (as discussed in Section 8.5.3):

- The majority of the existed dementia-related game titles are focusing on the cognitive and physical categories, serving preventative and rehabilitative purposes.
- The social-emotional function of the SG4D is mostly operating as a secondary element, coming from the multiplayer function of the games.
- The educative type of games presents a small number of titles, presumably because of the difficulty to clearly define and cover the varied nature of the dementia disease within an educational game
- The most important observation is the complete lack of assessment games, even though there are already several dementia-related screening tools that could be gamified in order to keep track of the player's cognitive status and keep him/her motivated.

Therefore, the taxonomy led to a series of observations, which provided a more clear overview of the research field and contributed to the identification of its major problems and potentials. Both publications contributed to the familiarisation with the researched area and to the extraction of all the necessary elements (e.g. more beneficial interaction method, game content, health function and use of the developed game), which would ensure that the following game design process would follow the best practises and would produce promising results.

3.2 Theoretical & technological framework

The establishment of the theoretical and technological framework of the study sets the groundings for the following game design and development stage and partially answers to the research question RQ2, from a theoretical point of view, through the description of the nature and aim of the study [4] (Chapter 9), as well as its technological identity [16] (Chapter 10).

The theoretical framework of the study embodies the findings of the previous stage, utilising the theoretical background to provide a general representation of relationships between the study's elements (i.e. cognitive training, cognitive screening, serious games, Augmented Reality, et al.) and, consequently, defining more clearly the research objective, approach and direction. The technological framework acts supplementarily to the theoretical one and is of great significance for the next phase and the following game design, development, and testing stages, since it constitutes the foundation on which all the gaming aspects of the study will be based, through several iterative processes, redesigns, changes and fixes.

3.2.1 Theoretical framework

Publication [4] (Chapter 9) discusses the ultimate goal of the study which is the connection of the elderly players to the formal care, utilising a gaming tool that will mediate the process. The paper is a "bridge" between the theoretical background of Section 3.1 and the technical, game design and development stage that will follow. Its aim is to clarify the nature of the study and to present its main characteristics: the research area, the problem description, the research problem and the general direction that the study will take. For that reason, the main part of the publication is also covered in the introductory Chapter 1.

Based on the findings of the state-of-the-art stage, the current study is decided to focus on the *cognitive* function of the players, serving *preventative* and *assessing* purposes and covering the preclinical and early MCI stages of cognitive impairment (Fig. 1.1), where the users can have subjective memory complaints, however present normal performance of activities of daily living (ADL) and normal general cognitive function, and where there is no need for formal and/or informal care. Therefore, as a first step, it is necessary to analyse the main processes behind the aforementioned cognitive health purposes, i.e. cognitive training and cognitive screening, by identifying their limitations (Sections 9.2 & 9.3). This process defines the research problem area and point towards the main research hypothesis of the publication: cognitive games (i.e. games for cognitive training and screening) can address the limitations of the cognitive training and screening processes and potentially be a tool for cognitive health, providing cognitive exercise and self-monitoring (Table 3.1).

Then, a cognitive game system that can target the research objective is theoretically described as to its *architecture*, *interaction technique*, *content* and *intrinsic objective*, in Section 9.4. The architecture of the system consists of a wearable and

Table 3.1: A summary of the cognitive screening and training limitations and how cognitive games can address them.

	Limitations	**Cognitive games' solutions**
Cognitive screening	culture, gender, and educational bias	dynamically generated, updated content
	learning effect	dynamically generated, updated content
	psychologically stressful	entertaining game experience
	target specific stages of cognitive impairment	various sets of exercises/games
	economic burden of screening/automated screening	fewer and more targeted medical examinations
Cognitive training	low-quality game design, too "serious" - less fun	entertainment is an important target, inclusion of game professionals
	no perceptual/interaction needs of cognitive impaired patients	examination/use of current interaction technologies/techniques
	no link between non-clinical and clinical settings	correlation of game score and real cognitive status, connecting player to the doctor

mobile system, based on the use of Augmented Reality and on manipulating the in-game elements using hand movements (e.g. using Augmented Reality cubes / markers to manipulate in-game elements.). The new interaction techniques available (e.g. gestures/hand tracking, Augmented Reality, biosensors, et al.) can reduce the cognitive load of in-game instructions, stimulate and register the physical abilities of the players, and provide the developer and the formal care with useful data. Especially, the Augmented Reality technology has been shown that it can improve task performance and can relieve mental workload on assembly tasks.

As to the content of the proposed cognitive game system, it is based on a set of cognitive mini-games, targeting the visuospatial, memory, attention, problem solving and logical reasoning cognitive functions, amongst others. In general, the functionality of the content allows the cognitive training exercises to coexist with the cognitive screening ones, developing a healthcare instrument of dual nature.

The intrinsic objective of the game system focuses on the correlation of the game score with the cognitive status of the player and its use as an informal measurement of the player's cognitive performance. The vision of the project is a system where gaming is used as a motivational and engaging way of cognitive self-monitoring and, if indications of cognitive decline appear, the player would be notified by an in-game message to reach out for formal care and treatment on time, practising a preventative strategy that is beneficial for the person's health and the welfare system's financial status.

After the theoretical description of the system, its practical implementation takes place. The following publication describes the technological framework, which acts as a starting base of the development process.

3.2.2 Technological framework

Publication [16] (Chapter 10) presents and describes the main technological points which will be implemented into the developed gaming system and which will be the objects of further iterative interaction, usability and programming evaluation. The paper thoroughly describes the core architecture and functionality of the study's technological framework and it also introduces the proposed hardware of the system.

At first, the target group of the system is clearly defined, i.e. the elderly population, and the technological issues which the target group faces are described, in order to be further addressed (Section 10.1). Those issues, mostly, originate from the fact that the current gaming technologies produce systems designed for the typical user, without taking into consideration the special needs of the elderly population. Therefore, there are several interaction problems related to the mainstream game controllers and the excessive cognitive burden coming from the in-game content. The aforementioned problems are recognised and verified by the literature on suggested design guidelines for suitable interaction techniques for the elderly (Section 10.1).

Following these guidelines and recommendations, the publication is describing the core architecture of a proposed gaming system and investigates the hypothesis that the utilisation of the Augmented Reality technology and the players' gestures/motor skills can theoretically address the interaction and cognitive limitations that the current gaming systems present, as fas as elderly players are concerned. On the one hand, Augmented Reality could help eliminating the need for extensive tutorials/instructions, thus reducing cognitive load and attention-switching, and be beneficial for mental processes, spatial cognition and mental transformation. On the other hand, the utilisation of the player's motor skills, apart from the benefits of physical exercise, can create a user-friendlier interaction technique, where the individual's dexterity differences are respected and do not constitute an interaction obstacle.

At that stage, the core architecture of the proposed gaming system is described (Section 10.2) with the elements of mobility and, potentially, wearability in mind (Fig 3.2). As a proof-of-concept of the core architecture, a case

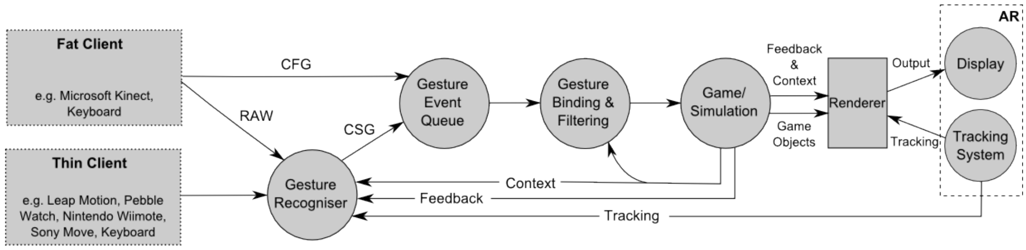


Figure 3.2: The core architecture of the gaming system, as described in [16].

study is presented (Section 10.3), where an implementation of the architecture is described as a wearable and mobile system, utilising commercial hardware. The set up of the system consists of Augmented Reality glasses (e.g. Google's project Glass, Vuzix's Smart Glasses M100, Meta Spaceglasses) for output purposes and a gesture sensing device (e.g. Leap Motion) as an input mechanism. Clearly, the proposed hardware is used to better describe the proof-of-concept of the gaming system and not to limit it. The hardware of the overall gaming system would follow the logic of the described architecture, based on the mobility element and would be determined during the course of the development stage, upon technical performance, suitability, and availability criteria.

The proposed architecture, its theoretical establishment, and technical description can help in developing interaction techniques that affect many stakeholders related with health care and gaming. Game developers and researchers are able to reproduce and explore this technical framework, adjusting its elements to better suit their targeted serious gaming purposes. The elderly players could benefit from an appropriate (for their motor and cognitive skills) interaction technique , which - if utilised appropriately - can lead to high-quality game experience and better alignment between serious games and the desired behavioural target.

The described technical elements, as well as the core architecture itself, are to be further developed, tested and evaluated during the next stages of the study.

3.3 Game design & development

This part of the study concludes the answer to the research question RQ2 which commenced with the theoretical and technological framework of Section 3.2.

The current stage examines the design and development process of the gaming system that will be further utilised as a cognitive training and screening tool. At first, the interaction is designed and studied with regular and elderly users. The interaction of the system focuses on the manipulation of tangible objects, i.e. cubes, and the use of the Augmented Reality technology (i.e. Tangible Augmented Reality [1]). Following an iterative design process, the interaction of the system is adjusted and studied with elderly users, at the Beta version of the game. Furthermore, the game content is added and evaluated. The Release Candidate (RC) version presents the latest version of the game as formed through the findings of the previous development stages and the necessary adjustments.

3.3.1 Alpha version & interaction

Publication [3] (Chapter 11) presents the Alpha version of the game system, focusing on its interaction technique and studying the integration and implementation of Augmented Reality and tangible objects as interaction components.

The interaction technique of a game system, which targets elderly players for cognitive stimulation purposes is of great significance for the scope of this PhD study. The reason is twofold: a) it has been shown that elderly users have specific interaction needs, which should be taken into consideration during the design process [16, 8, 9, 10, 13] and b) present cognitive game platforms and software have overlooked the effect that the interaction technique can have on the user experience, thus on the players' emotional response and on the targeted cognitive functions.

Recent advances in technology (e.g. gestures/hand tracking, Augmented Reality, biosensors, high-fidelity virtual reality et al.) form several new interaction methods, which can be used to explore the design of more robust and efficient, personalised cognitive training experiences. The current study presents the design of the cognitive Augmented Reality (AR) cube system, i.e. an Augmented Reality cognitive training game, utilising tangible objects (i.e. cubes) as input tools.

The interaction technique implemented in the described first stage (Section 11.4) is based on the Tangible Augmented Reality technology [1] and it features the player sitting in an office, playing the game on a tablet PC by manipulating AR cubes, which are placed on the actual desktop, using both hands. The system consists of 9 cubes of 3,5 cm/edge, a tablet PC and a base stand. The integration of AR glasses in the designed interaction technique would be an ideal solution, however the available options were at an early development stage, at the time of the study (late 2013). Therefore, the "magnifying glass" metaphor was implemented, i.e. an adjustable arm desktop base stand supporting a tablet PC, which the players can adjust to have clear view of the desktop, where they would interact with the cubes using both hands.

A pilot study was conducted in order to study the interaction with the AR cubes, as well as with the "magnifying glass" base stand (Section 11.5). The study was exploratory in nature, looking for interaction problems, specific user behaviours and it was based on direct observation of the player's movements by two AR experts and a semi-structured, informal interview at the end of each gaming session. The participants were categorised according to their AR experience during the demographics' collection, in order to examine the effect of the implemented interaction in different kind of users. Novice AR users were considered to have never used AR before, moderate AR users rarely use AR

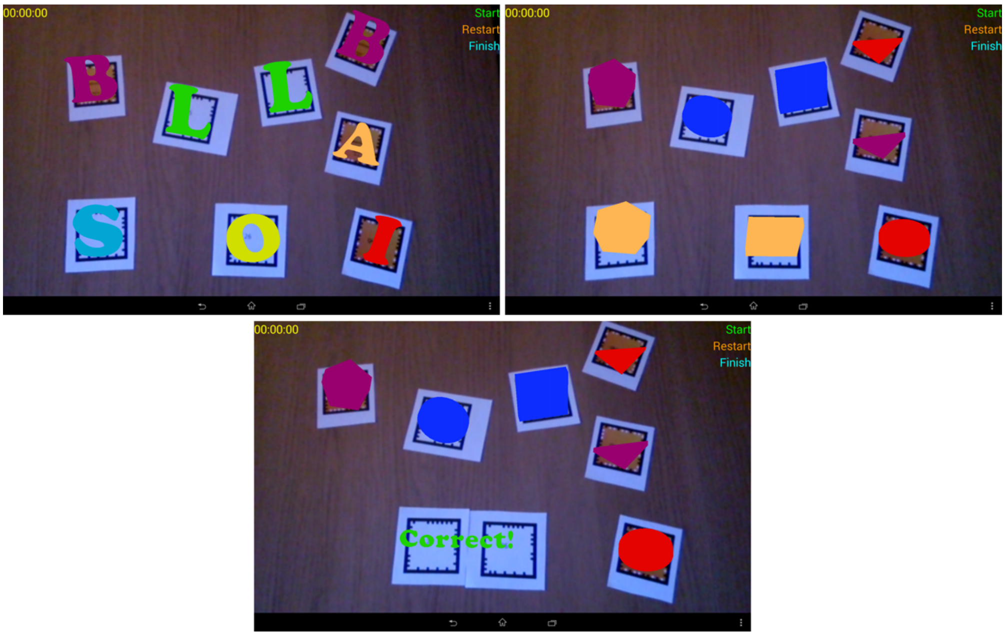


Figure 3.3: The word game (*upper left*), the speed/shape-matching game (*upper right*), and a success message (*lower*), during the game testing stage.

applications and experienced AR users were considered to use AR frequently or even develop AR applications. Five adults were recruited (two experienced AR users, one moderate AR user and two novice users) as participants and were asked to game-test the two AR mini-games of the system (a word creation game and a speed/shape-matching game, Fig. 3.3), that were specifically designed for the study. The participants had 4 sessions of playing the two games, within a week. Each session consisted of a different level of both games, with the same difficulty (the difficulty level was always static in both games and at the "moderate" stage according to informal pretesting), and lasted approximately 10 minutes.

The novice users were the main focus of the study, since the players of this category were unaware of the AR technology, therefore a different level of objectivity could be introduced to the results of the pilot study. The study led to the discovery of several AR technology-related limitations (Section 11.5.1), like the marker occlusion problem, AR lagging, losing depth perception, and dealing with limited 3D AR gaming space. However, the fast adjustment of the users to the introduced interaction technique revealed some positive signs that AR cubes, combined with the "magnifying glass" interface metaphor, can be used for cognitive training games. There are, indeed, many technical issues to be dealt with, thus an iterative design process is followed and an improved and technically updated version of the interaction technique is evaluated with the Beta version of the game.

Figure 3.4: Mockups of the CogARC menu design (*up*) and the mini-games design (*down*).

3.3.2 Beta version, interaction & game content

Publication [5] (Chapter 12) features the Beta version of the game system, presenting the game's usability, game design, and technical requirements, adding the game content, implementing and optimising the interaction technique presented at the Alpha version, and evaluating the overall game experience with elderly players.

The study of the Beta version of the game, namely Cognitive Augmented Reality Cubes (CogARC), describes the quality assurance process of the cognitive training and screening serious game, which utilises the Tangible Augmented Reality interaction described in the previous section. Firstly, the system requirements, which will guide the design and development processes of the current and the future versions of the game, are defined and presented in Table 3.2 (further analysed in Section 12.2.1). The requirements originate from the facts that: 1) the game should be an entertaining game that could train and stimulate the cognitive abilities of the players for screening purposes, 2) the target group are elderly players, and that 3) the game should adopt the positive characteristics of the widely-used screening tests and address the negative ones.

CogARC was designed based on the Alpha version of the game and the widely-used screening instruments. A mini-game architecture was followed in order to address a spectrum of cognitive abilities.

Table 3.2: The usability, game design, and technical requirements for the CogARC system.

Nr	Requirements	Field
1.	Interface elements (e.g. menus) should be easy to understand.	Usability
2.	The necessary information should be communicated across the expected range of user sensory ability (highlighting/differentiating elements, maximising legibility, et al.).	Usability
3.	The system should be simple to use, easy to learn and used individually by the player.	Usability
4.	The interface actions and elements should be consistent, protecting the users from errors.	Usability
5.	The screen layout, colours and interaction components should be appealing to the player.	Usability
6.	The system should capture an instance of the player's cognitive status, addressing a wide range of cognitive and motor skills.	Game design
7.	The system content should record the player's cognitive performance on a frequent/iterative basis.	Game design
8.	The game content should be automatically or randomly generated in every gaming session.	Game design
9.	The game should engage and entertain the player over time by utilising the appropriate game mechanics.	Game design
10.	Cross-platform (mostly Android, iOS) gaming should be supported.	Technology

At the Beta version of the game, the game content was added (Section 12.2.5). The scoring computation formula for the mini-games was uniform and it was related to the successful completion of the cognitive task and also inversely related to the level-completion time, therefore the player's game objective was to complete the cognitive tasks of the mini-game levels correctly and as fast as possible, to score more points. Leaderboards were also implemented to utilise the Competition game mechanic. Furthermore, the game mechanics of Challenges, Feedback and Rewards were also utilised, by using points (Reward), leaderboards (Competition), cognitively stimulating cognitive tasks as game levels (Challenges) and messages about the player's performance (Feedback). The levels of the mini-games were randomly generated to address and minimise the learning effects (i.e. improved game performance due to the player's "learning" and memorising the game solutions, and not because of actual better performance on the game tasks). The difficulty level of the game tasks was uniform and at a moderate degree for all the mini-game levels, in order for the system to be able to establish a player-specific scoring baseline and detect changes in scores over time, for screening purposes.

The user interface (UI) design of CogARC was specifically designed for elderly players and was based on the principles of simplicity and intuitiveness, while the interaction technique remained the same as the Alpha version's (Section 11.4).

The total cognitive abilities that are addressed in the CogARC game and are thoroughly discussed in Section 12.2.6 are: Perception, Attention, Visual and Spatial Processing, Language Processing, and the following Executive functions: Flexibility, Response Inhibition, Problem Solving, Decision Making, and Working Memory. A detailed description of the game content and the addressed cognitive abilities are presented in Sections 12.2.5 and 12.2.6.

The AR-specific interaction issues which were discovered during the interaction study of the Alpha version are addressed here. The marker occlusion problem was addressed by developing a custom multimarker setup: multiple markers (one frame marker/side) were fixed to every cube. The issues of lagging was technically addressed by moving to the Unity development platform and to the Vuforia Unity extension. The issues of the limited 3D gaming space as defined by the small screen size (10 inches), and of the loss of the player's depth perception were addressed by giving the players the opportunity to have an open trial session in order to get accustomed with the system's interaction technique and the game content.

A usability and game experience testing was conducted as part of the game's quality assurance process (described in Section 12.3). The testing was focused on investigating the game experience that CogARC offered (using the in-Game Experience Questionnaire [11, 12, 14]), the usability of the system (using the System Usability Scale [7]), as well as on documenting the players' specific remarks (using open, semi-structured interviews). The goal of the usability and game experience testing was to identify any usability problems, collect qualitative and quantitative data and determine the players' satisfaction with CogARC.

A mixed methodological approach was followed for the usability and game experience testing of CogARC, utilising both qualitative and quantitative methods. The focus of the testing was on qualitative observations related to usability and game content issues. The quantitative methods, i.e. the in-Game Experience Questionnaire (iGEQ) and the System Usability Scale (SUS) surveys, were used to support the qualitative analysis and lead the discussion during the interviews. A convenience sample of five older adults (n = 5, mean age: 67.6, SD: 5.77) participated in the testing. Included participants had to be:

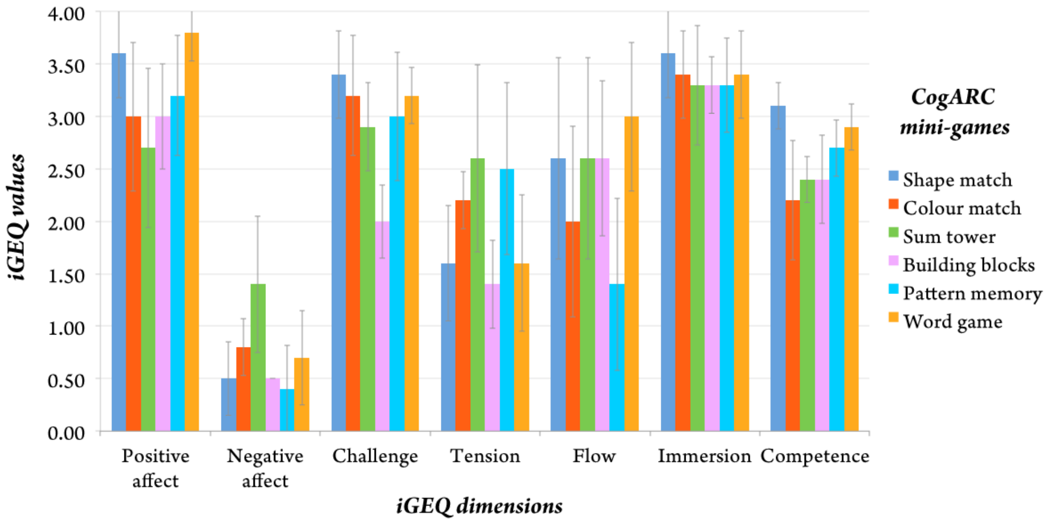


Figure 3.5: Mean iGEQ scores (with standard deviation bars) across the seven dimensions of Game Experience, for the mini-games of the CogARC game.

- *≥60 years old:* according to the World Health Organisation's definition of an older person and the United Nations agreed cutoff [25],
- *independently performing activities of daily living (ADL), not diagnosed with any kind of dementia:* this criterion defines the target group of healthy elderly participants, who are not severely affected by mental health disorders,
- *familiar with technology (i.e. using or having used laptop, tablet PC, smartphone, et al.) and video games (i.e. playing or having played video games before):* this criterion minimised the risk of the results of testing being affected by technology-use and video-gaming biases, which can be present in game studies when participants are asked to use systems that they have no experience or interest in.
- *novice AR users:* the novice users were the main focus of the study, to introduce a different level of objectivity to the results of the testing.

The iGEQ questionnaires resulted in the values of Fig. 3.5, and the SUS reached the score of 70.5, indicating a usability score right above the borderline. The interviews' remarks and the results of the measures (discussed in detail in Section 12.4) verified the loss of the depth perception from all the players to some extent, discovered the issue of the players' mixed perception of the reality-virtuality space, and revealed interaction and content issues regarding three mini-games (Section 12.3.4).

The outcomes of the testing would form the Release Candidate version of the game. Redefining the role of the utilised AR technology in the Reality-Virtuality

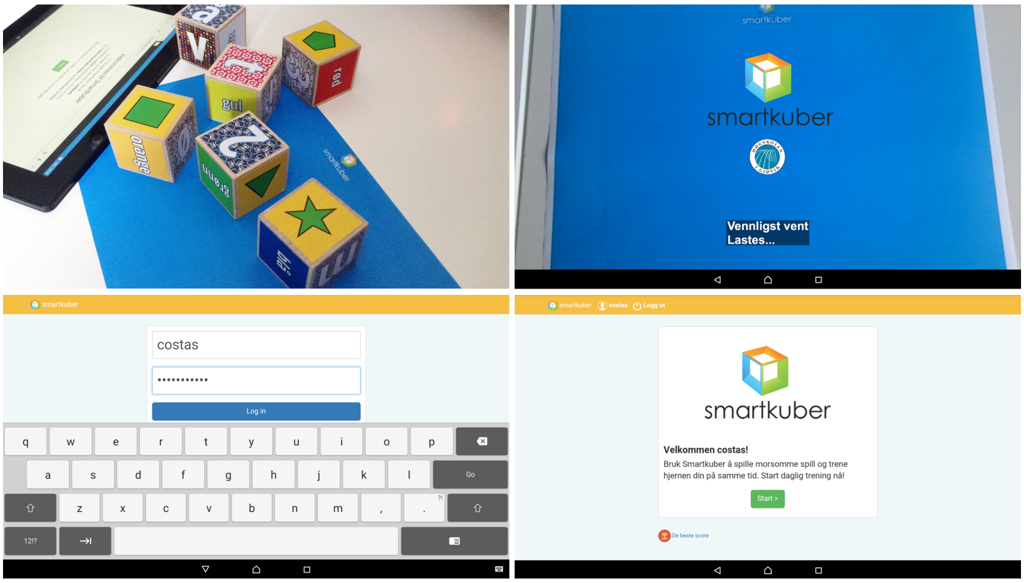


Figure 3.6: The Smartkuber setup (*upper left*), the Smartkuber loading screen (*upper right*) followed by the login screen (*lower left*) and the Smartkuber main menu (*lower right*).

spectrum and redesigning the game content are among the issues that would be addressed at the next stage.

3.3.3 Release Candidate version & game experience

Publication [6] (Chapter 13) presents the Release Candidate version of the game system, where major revisions took place, according to the testing's findings of Chapter 12. The new version of the game is utilised in a study, which aims to quantitatively evaluate the elderly players' game experience, as well as investigate the use of the serious game for its construct, criterion (concurrent and predictive), and content validity, assessing its relationship with the MoCA screening test [21].

For the Release Candidate version of the game, the changes mentioned above were implemented and resulted in the new game, namely Smartkuber. The system requirements remained the same as the ones described in Section 12.2.1.

The new elements and changes from the Beta version (CogARC) to the Release Candidate version (Smartkuber) are described in Section 13.2 and summarised below:

- The Tangible Augmented Reality implementation - so far - was borrowing elements from Mediated Reality. Smartkuber "moves" the game interaction technology towards the Reality spectrum on the Reality-Virtuality Continuum [19]. Therefore, Smartkuber places the main part of the interaction and the game content at the real world, and Augmented Reality

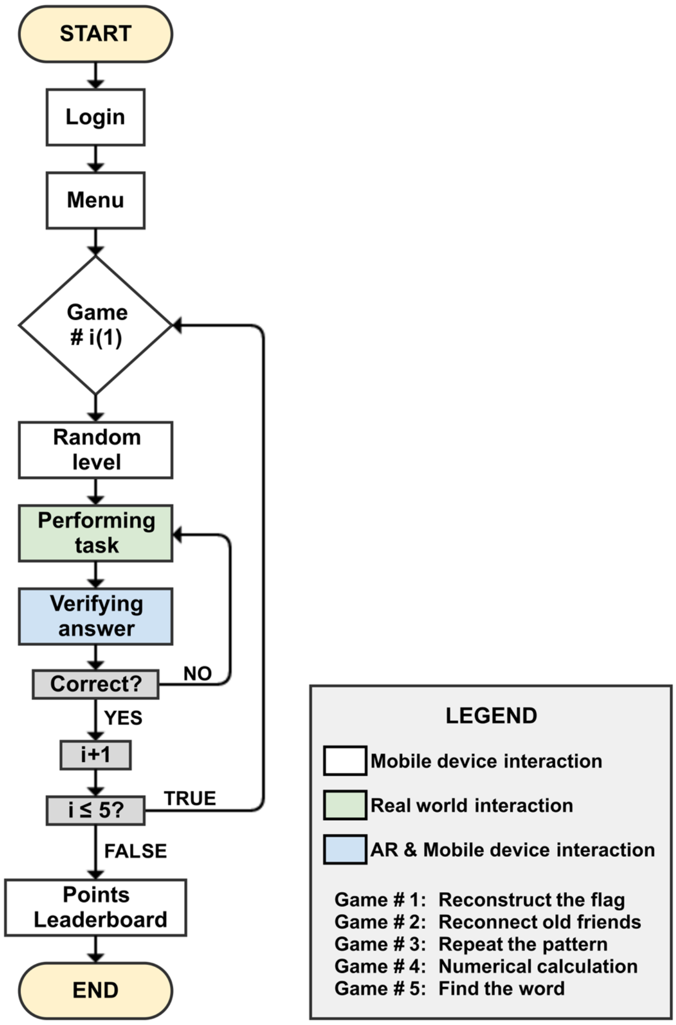


Figure 3.7: The flowchart of a full gaming session with Smartkuber.

is utilised solely for real-world recognition and for verifying the correct, real-world game tasks.

- The interaction technique and its components were altered. Smartkuber utilises 6 (instead of 10) cubes of 4.4 cm/edge with game content on every side (e.g. letters, numbers, colours, faces, shapes) and there is no tablet base stand (Fig. 3.6). A board is also used for the player to place the cubes on, so as to create a uniform background for Augmented Reality content verification purposes. The interaction technique of Smartkuber features the player using a tablet device to load the game tasks and then manipulating the cubes to perform those tasks. The game tasks are performed by placing the cubes together, one next to the other (horizontally).

- Smartkuber follows a linear gameplay. The linear mode of the game levels was found to be preferred than the free play during the testing of the game's Beta version (Fig. 3.7). The randomisation of the game levels was again implemented, for addressing and, potentially, minimising the leaning effect.

- The game content was altered in order to implement the previous testing's findings, as well as to adjust to the linear gameplay and to stimulate even more cognitive abilities.

- The user interface was completely redesigned for aesthetic and technical purposes. Emphasis was given on designing for the elderly, ensuring the legibility of the visual information and the clean and minimalistic design with vivid colours.

- The development platform changed in order to ensure the system's robust performance and the use of lightweight content. Smartkuber was developed utilising the Metaio AR SDK, which was used, tested, and created positive impressions during a previous study (see [2]). The game is logging the player's ID, scores and timings per mini-game and cross-platform gaming is still supported.

- The scoring function for the mini-games was uniform and it was related to the successful completion of the cognitive task and also inversely related to the level-completion time, as in the Beta version.

- The game mechanics of Challenges, Reward, Competition, and Feedback were also utilised. The players earn points for completing the levels (Reward) and Competition is implemented with the use of a main leaderboard, where the total score of each player (from all the sessions) is displayed in the ranking. The Challenges originate from the goal of the successfully performing the cognitive tasks and the players get various Feedback from their gaming performance, e.g. success messages for the completion of the cognitive tasks, et al. (Fig. 3.9).

- In order to be able to document the players' performance over time, a new login system was implemented and each player was given a unique username/ID and a password (Fig. 3.6).

To evaluate the game experience that Smartkuber offers, a game experience study was conducted utilising the in-Game Experience Questionnaire (iGEQ) [11, 12, 14]. Thirteen elderly players (n = 13, mean age: 68.69, SD: 7.24, male/female: 8/5) completed 244 Smartkuber gaming sessions over a period of 6 weeks (mean number of sessions/player: 18.77, SD: 2.68). Between weeks 4 and 6, the iGEQ was administered to quantitatively document the elderly players' game experience. The iGEQ mean values are presented in Fig. 3.8.

The game experience study of Smartkuber provided significant feedback regarding the elderly players' experience, which is discussed in Section 13.3. The measurements revealed a high level of players' cognitive involvement with

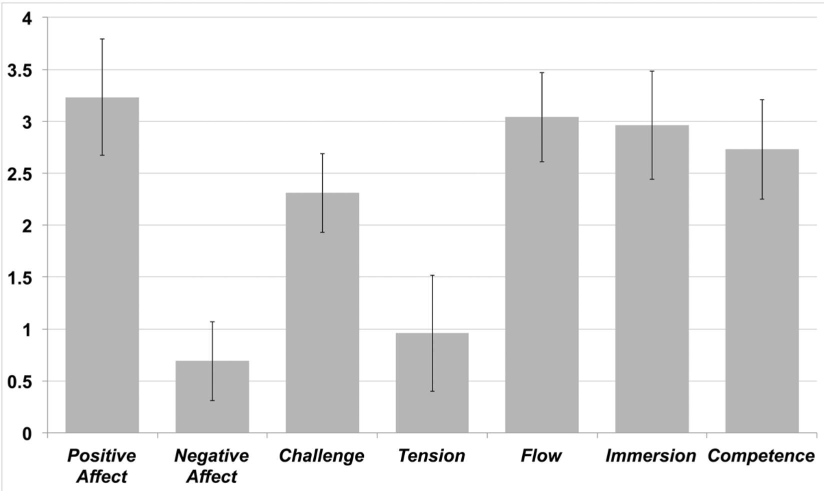


Figure 3.8: The iGEQ mean scores (with standard deviation bars) across the seven dimensions of Game Experience, for the Smartkuber game.

Smartkuber. They also showed that the players felt skilful enough while playing Smartkuber, though the difficulty level may have needed further tweaking to challenge the players more. Finally, the high values of the players' positive feelings, while playing, and the low values of the negative feelings, potentially highlighted the entertaining and motivating nature of Smartkuber, the suitability of the UI and the interaction technique for the elderly players.

The same study also explored the test validity of Smartkuber, which is described in the following section.

3.4 Game evaluation

As mentioned before, publication [6] (Chapter 13) presents a correlational study to investigate the use of the Smartkuber serious game for its construct, criterion (concurrent and predictive), and content validity, assessing its relationship with the MoCA screening test. At this stage, the research question RQ3 is addressed.

For examining the concurrent validity the correlation between the Smartkuber scores and the MoCA scores was calculated (using the Pearson correlation). The predictive ability is assessed by the linear regression, which modelled the relationship between the MoCA scores and the Smartkuber scores, focusing on the prediction of the MoCA score using the Smartkuber score. Content validity was assessed by the individual Smartkuber mini-games scores with the MoCA scores (Pearson correlation), as well as the calculation of a learning-effect-related measurement, namely Delta score, i.e. the score difference between the mean total score of the 20% last sessions minus the mean total score of the 20% first sessions of each player. Paired samples T-test was used to evaluate the significance of the Delta score.

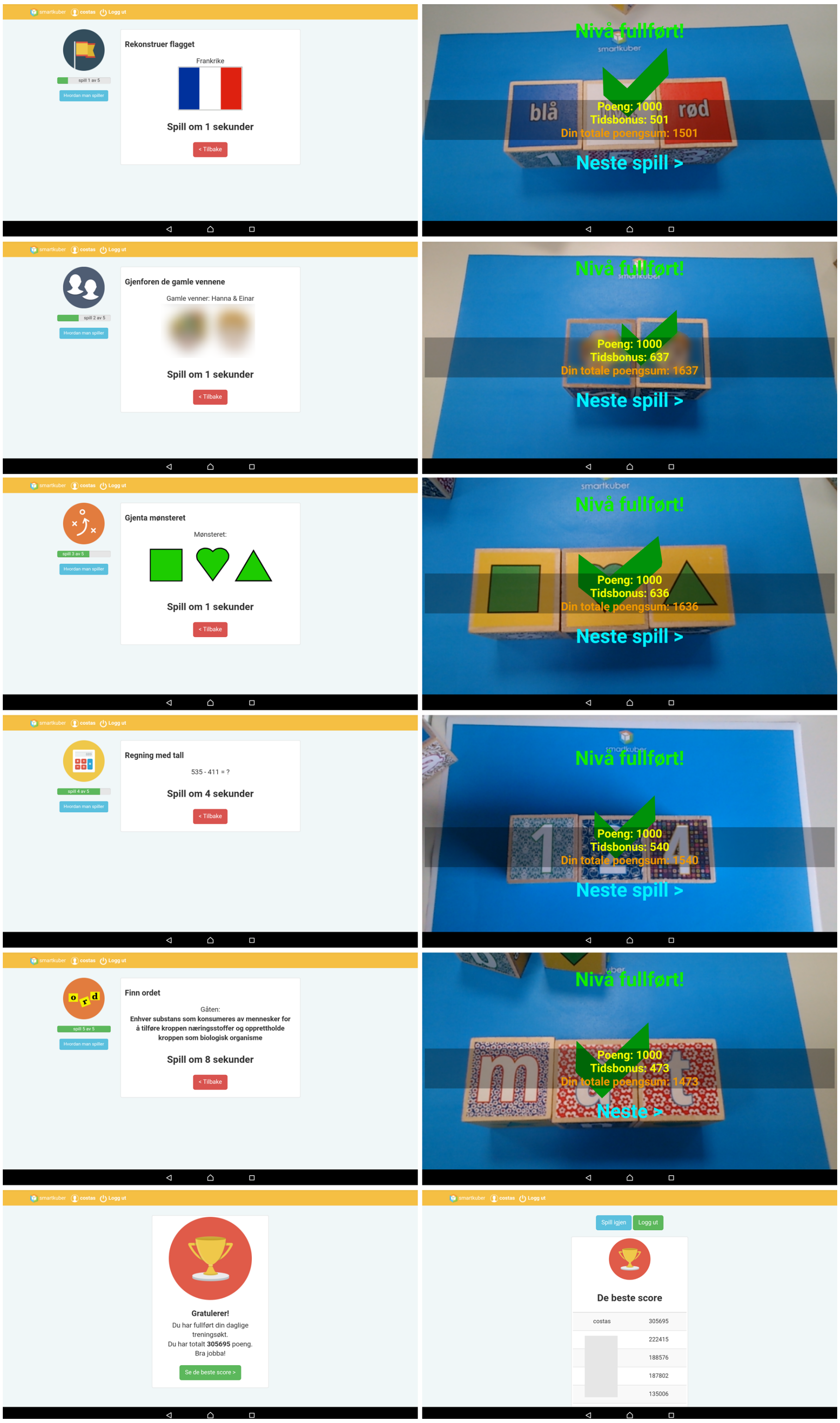


Figure 3.9: The 5 mini-game levels of a Smartkuber gaming session (tablet PC view), their solutions (AR view), and the endgame screen - leaderboard (tablet PC view). Identifiable information and copyrighted material (under the fair use policy for research purposes) are redacted or blurred out.

Table 3.3: Correlations between the Smartkuber mini-games and MoCA total scores.

	Smartkuber					
MoCA	#1: Reconstruct the flag	#2: Reconnect old friends	#3: Repeat the pattern	#4: Numerical calculation	#5: Find the word	Total score
Visuospatial	0.74**	0.73**	0.64*	0.54	0.49	0.63*
Naming	0.52	0.68*	0.82**	0.68*	0.79**	0.75**
Attention	0.54	0.64*	0.68*	0.56*	0.61*	0.64*
Language	0.61*	0.65*	0.52	0.67*	0.50	0.60*
Abstraction	0.34	0.47	0.61*	0.43	0.32	0.45
Del. recall	0.18	0.15	0.11	0.08	-0.04	0.08
Orientation	0.57*	0.68**	0.71**	0.79**	0.87**	0.78**
Total score	0.76**	0.85**	0.83**	0.79**	0.70**	**0.81****

* $p < 0.05$
** $p < 0.01$

A sample of thirteen older adults (n = 13) was recruited between July and November 2015. The inclusion citeria were similar to the CogARC's testing (as described in Section 3.3.2) suggested that the participants had to be: ≥60 years old, independently performing activities of daily living (ADL), not diagnosed with any kind of dementia (to fit in the study's target group), familiar with technology and video games (to minimise the technology-use and video-gaming biases, which can be present in game studies when participants are asked to use systems that have no experience or interest in).

Demographic data were collected at the initial stage of the study. Then, the participants received technical assistance on installing and running the game on their personal tablet PC devices. The Montreal Cognitive Assessment test (MoCA) [21] was administered prior to playing the game, scored by a trained rater, blind to the interpretation of the results and the diagnosis. The game was tested under realistic conditions, therefore the participants were allowed to take Smartkuber with them and play it at their own place of will (e.g. home, office, et al.), for as many sessions as they wanted, within a period of 6 weeks. Between weeks 4 and 6, the in-Game Experience Questionnaire (iGEQ) was administered to quantitatively document the participants' game experience, as described in Section 3.3.3.

As mentioned above and as presented in Section 13.3, 13 participants (mean age: 68.69, SD: 7.24, male/female: 8/5) were recruited for the correlational study. Regarding experience with technology, all the participants (n = 13) were using a laptop or desktop PC and at least one mobile device (tablet, smartphone, or e-reader), while 69.2% of them (n = 9) were also using a second mobile device.

All participants successfully completed the two-month period playing the game at an open and free rate. The statistical results were the following:

- 244 gaming sessions (mean number of sessions/player: 18.77, SD: 2.68) were recorded from the 13 participants.
- The 244 Smartkuber sessions resulted in a mean total score of 3564.70 (SD: 294.60).
- The Smartkuber mini-games' scores demonstrated a high level of internal consistency (Cronbach's alpha = 0.84).
- All participants successfully finished the MoCA test with a mean score of 26.85 (SD: 2.20).
- The correlational study revealed a high, significant correlation between the Smartkuber mean total scores and the MoCA total scores (r[11] = 0.81, p = 0.001) and it also demonstrated a high statistical power of 0.95. The correlation between the Smartkuber mean mini-games/total scores and the MoCA subtests/total scores are described in Table 3.3.
- Smartkuber mean total scores (β = 0.007, p = 0.001) were significant predictors of MoCA scores, explaining 62.1% of MoCA total score variance, when controlling for age, education, gender, frequency of technology use and video gaming (S = 1.35, F[1,12] = 20.70 with p = 0.001).
- The Delta score differences were not statistically significant ($p > 0.05$) for any of the players.
- The correlation between the Delta score and the MoCA score of every player was also examined, however no correlation was found.

The correlational study provided important insights on the utilisation of the Smartkuber cognitive training game as a cognitive health screening tool for elderly players. The Smartkuber scores - both totally and individually - revealed significant correlations and high concurrent validity with the MoCA scores, while demonstrating a high value of internal consistency. The significant correlation between the Smartkuber total scores and the MoCA scores likely reflects the cognitive demand of the tasks, addressing the visuoperceptual, attention, working memory, language, motor and inhibitory response skills of the players and suggesting they tapped into the cognitive domains screened by the MoCA test. The lack of significant correlation for the MoCA Delayed recall may reflect that the Smartkuber tasks test delayed recall through visual memory (e.g. flags, faces, shapes) rather than verbal memory, as in MoCA (using 5 words), utilising different and potentially competing cognitive processing centres [24, 22, 20]. Adding textual elements to the mini-games' memory tasks may address the issue. Regression results indicated that Smartkuber total scores were significantly predictive of MoCA total scores after adjusting for demographics. The

Table 3.4: The theoretical framework of [4] with the cognitive screening and training limitations and how cognitive games can address them, adding the points that the developed game managed to implement.

	Limitations	Cognitive games' solutions	Smartkuber
Cognitive screening	culture, gender, and educational bias	dynamically generated, updated content	✓
	learning effect	dynamically generated, updated content	✓
	psychologically stressful	entertaining game experience	✓
	target specific stages of cognitive impairment	various sets of exercises/games	✓
	economic burden of screening/automated screening	fewer and more targeted medical examinations	long-term goal
Cognitive training	low-quality game design, too "serious" - less fun	entertainment is an important target, inclusion of game professionals	✓
	no perceptual/ interaction needs of cognitive impaired patients	examination/use of current interaction technologies/techniques	✓
	no link between non-clinical and clinical settings	correlation of game score and real cognitive status, connecting player to the doctor	✓ + future work needed

Delta scores showed no significant difference in scoring between the first and the last players' sessions and all the players managed to demonstrate steady game performances. Therefore, the results revealed no learning effects during the Smartkuber game sessions, implying that the iterative gameplay of the cognitive screening game instrument did not rely on or affect the players' short-term memory.

3.5 Conclusion

In Smartkuber, cognitive training exercises were used to stimulate the cognitive skills of the players for cognitive screening purposes. The theoretical framework of Sections 3.2.1 and 9.5 had suggested that cognitive games can address and, potentially, solve the limitations of the cognitive screening and training processes, always on a theoretical basis. Table 3.4 presents the points which the Smartkuber cognitive screening game managed to confirm. The elderly players did not present any signs of learning effects and new levels of same difficulty were constantly added. The game content consisted of simple cognitive tasks and, even though, the language of the game was Norwegian (to facilitate the target group), translations can be made and integrated without affecting the functionality of the content. The game managed to offer an entertaining experience (according to the iGEQ values) and managed to stimulate a wide spectrum of cognitive skills (Table 3.3). The Tangible Augmented Reality technology, the use of cubes and the adjustments made to minimise the technical issues managed to offer a seamless gaming experience, allowing the players to focus on the tasks. Finally, the game demonstrated high concurrent validity and satisfying levels of predictive and content validity, versus the widely-used MoCA test, showing promising potential and that after further work on examining the game's relationship with other widely-used cognitive screening tools (e.g. MMSE, CogState. et al.) and with larger sample sizes, the Smartkuber game could be a useful cognitive screening tool that connects the player to the doctor. The game activity managed to align well with the intended behavioural goal, i.e. increase the frequency of cognitive screening through gaming. The 13 participants of the final study of Smartkuber played for 244 gaming sessions, suggesting a mean number of sessions/player of 18.77 (SD: 2.68), in a 6-week period. When the gaming frequency is combined with the high positive iGEQ values (Fig. 3.8), encouraging conclusions can be drawn about the effect of gaming on cognitive screening processes. As for the game design process, the main game mechanics utilised were those of Challenges, Reward, Competition, and Feedback. Especially the Competition mechanic and the use of leaderboards created a fun and entertaining environment with the elderly discussing and comparing their performances (coming from informal observations and meetings). The intrinsic motivation, coming from the sense of belonging to the "community" that plays the game, as well as from the players always wanting to perform better at the cognitive tasks, blends well with the extrinsic motivations of points, rewards, and rankings. The rewards and "status" someone gains through playing together with others, help him/her track the progress and connect with others.

However, the PhD study faced several research challenges and presents certain limitations, which are discussed in the next chapter.

3.6 Bibliography

[1] BILLINGHURST, M., KATO, H., AND POUPYREV, I. Tangible Augmented Reality. In *Proceedings of ACM SIGGRAPH Asia* (2008), pp. 1–10. 16, 34, 35, 59, 60

[2] BOLETSIS, C., AND MCCALLUM, S. The Table Mystery: An Augmented Reality collaborative game for chemistry education. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 86–95. 43, 54

[3] BOLETSIS, C., AND MCCALLUM, S. Augmented Reality cube game for cognitive training: An interaction study. *Studies in Health Technology and Informatics 200* (2014), 81–87. 35, 60, 61, 132, 133, 135, 136, 137, 138, 148, 149, 160, 161, 162, 163

[4] BOLETSIS, C., AND MCCALLUM, S. Connecting the player to the doctor: utilising serious games for cognitive training & screening. *DAIMI PB 597* (2015), 5–8. xiii, 3, 4, 5, 15, 31, 48, 60, 132, 134, 157, 158, 160, 162

[5] BOLETSIS, C., AND MCCALLUM, S. Augmented Reality cubes for cognitive gaming: Preliminary usability and game experience testing. *Internation Journal of Serious Games 3*, 1 (2016), 3–18. 37, 53, 54, 60, 61, 66, 160, 161, 163, 165, 169

[6] BOLETSIS, C., AND MCCALLUM, S. Smartkuber: A cognitive training game for cognitive health screening of elderly players. *Games for Health Journal 5*, 4 (2016). 17, 41, 44, 53, 54, 60, 61, 66

[7] BROOKE, J. SUS-A quick and dirty usability scale. In *Usability Evaluation In Industry*. Taylor & Francis, 1996, pp. 189–194. 39, 144

[8] GERLING, K., AND MASUCH, M. When gaming is not suitable for everyone: playtesting Wii games with frail elderly. In *Proceeding of the 1st Workshop on Game Accessibility: Xtreme Interaction Design (FDG 2011)* (Bordeaux, France, 2011). 35, 114

[9] GREGOR, P., NEWELL, A. F., AND ZAJICEK, M. Designing for dynamic diversity: interfaces for older people. In *Proceedings of the fifth international ACM conference on Assistive technologies* (2002), ASSETS '02, pp. 151–156. 35, 80, 134

[10] HELLER, R., JORGE, J., AND GUEDJ, R. EC/NSF workshop on universal accessibility of ubiquitous computing: providing for the elderly event report. In *Proceedings of the 2001 EC/NSF workshop on Universal accessibility of ubiquitous computing: providing for the elderly* (2001), WUAUC '01, ACM, pp. 1–10. 35, 80, 106, 107, 114

[11] IJSSELSTEIJN, W., DE KORT, Y., AND POELS, K. The game experience questionnaire: Development of a self-report measure to assess the psychological impact of digital games. manuscript in preparation. *FUGA technical report Deliverable 3.3* (2013). 39, 43, 55, 144

[12] IJSSELSTEIJN, W., DE KORT, Y., POELS, K., JURGELIONIS, A., AND BELLOTTI, F. Characterising and measuring user experiences in digital games. In *International conference on advances in computer entertainment technology* (2007), vol. 2, p. 27. 39, 43

[13] IJSSELSTEIJN, W., NAP, H. H., DE KORT, Y., AND POELS, K. Digital game design for elderly users. In *Proceedings of the 2007 conference on Future Play* (2007), Future Play '07, pp. 17–22. 35, 113, 114, 134, 135, 149

[14] IJSSELSTEIJN, W., VAN DEN HOOGEN, W., KLIMMT, C., DE KORT, Y., LINDLEY, C., MATHIAK, K., POELS, K., RAVAJA, N., TURPEINEN, M., AND VORDERER, P. Measuring the experience of digital game enjoyment. In *Proceedings of Measuring Behavior* (2008), pp. 88–89. 39, 43, 169

[15] MCCALLUM, S. Gamification and serious games for personalized health. In *pHealth*, vol. 177 of *Studies in Health Technology and Informatics*. IOS Press, 2012, pp. 85–96. 4, 13, 15, 29, 71, 73, 76, 79, 90, 91, 93, 96, 113, 132

[16] MCCALLUM, S., AND BOLETSIS, C. Augmented Reality & gesture-based architecture in games for the elderly. In *pHealth*, vol. 189 of *Studies in Health Technology and Informatics*. IOS Press, 2013, pp. 139–144. ix, 15, 31, 33, 34, 35, 122, 124, 134, 137, 160, 163

[17] MCCALLUM, S., AND BOLETSIS, C. Dementia games: A literature review of dementia-related serious games. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 15–27. 14, 17, 27, 28, 29, 58, 59, 61, 91, 95, 97, 106, 122, 160

[18] MCCALLUM, S., AND BOLETSIS, C. A taxonomy of serious games for dementia. In *Games for Health*. Springer Fachmedien Wiesbaden, 2013, pp. 219–232. 14, 17, 27, 29, 58, 59, 61, 160

[19] MILGRAM, P., AND KISHINO, F. A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems 77*, 12 (1994), 1321–1329. 41, 148

[20] MOREY, C. C., AND COWAN, N. When do visual and verbal memories conflict? the importance of working-memory load and retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition 31*, 4 (2005), 703–713. 47, 172

[21] NASREDDINE, Z. S., PHILLIPS, N. A., BEDIRIAN, V., CHARBONNEAU, S., WHITEHEAD, V., COLLIN, I., CUMMINGS, J. L., AND CHERTKOW, H. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society 53*, 4 (2005), 695–699. 41, 46, 54, 65, 105, 134, 158, 159, 162, 167

[22] ROTHMAYR, C., BAUMANN, O., ENDESTAD, T., RUTSCHMANN, R. M., MAGNUSSEN, S., AND GREENLEE, M. W. Dissociation of neural correlates of verbal and non-verbal visual working memory with different delays. *Behavioral and Brain Functions 3* (2007), 56. 47, 172

[23] SAWYER, B. From cells to cell processors: The integration of health and video games. *IEEE Computer Graphics and Applications 28*, 6 (2008), 83–85. x, 12, 13, 14, 29, 89, 90, 91, 93, 94

[24] SCANLON, L., O'SHEA, E., O'CAOIMH, R., AND TIMMONS, S. Usability and validity of a battery of computerised cognitive screening tests for detecting cognitive impairment. *Gerontology Epub ahead of print* (2015). 3, 47, 54, 65, 132, 134, 158, 159, 172, 173

[25] WORLD HEALTH ORGANIZATION. Definition of an older or elderly person. http://www.who.int/healthinfo/survey/ageingdefnolder/ (Last visited: January 5th, 2016). 40

Chapter 4

Research Challenges & Limitations

During the course of the study, several research challenges have arisen, which defined the limitations of this study. The documentation of the study limitations and the challenges portrays, in a realistic way, the logic behind several scientific, methodological, technical, and practical decisions that took place during the study. Those decisions shaped the nature of the study and their documentation is necessary for scientific rigour and integrity purposes.

4.1 Sample size

The publications of [2] (Chapters 12) and [3] (Chapters 13) are limited by a small sample size of 5 and 13 elderly participants respectively. In publication [2] (Chapter 12), the 5 participants are recruited for a preliminary usability and game experience testing, where in [3] (Chapter 13), the study is based on the participants conducting iterative sessions. However, the results coming from the correlational Smartkuber study [3] (Chapter 13), managed to demonstrate a high statistical power, with n = 13. Naturally, the studies would have benefited from a larger sample size for reasons of additional scientific robustness and significance. The formal collaboration between institutions and/or organisations for research purposes could address this issue.

4.2 Technology and game-related inclusion criteria

The participants' inclusion criteria for the studies in [2] (Chapter 12) and [3] (Chapter 13) contain the requirements that the included participants should be familiar with technology (i.e. using or having used laptop, tablet PC, smartphone, et al.) and video games (i.e. playing or having played video games before). These criteria were added to address the technology-use and video-gaming biases, which can be present in game studies when participants are asked to use systems that have no experience or interest in; however, it may as well be considered that they restrict the target population of the screening process and they limit the generalisation of the studies' results.

4.3 Age vs. health target group

In this study's efforts to address the issue of delaying the onset of the dementia disease, there were two options for the targeted cognitive stage: the preclinical or the Mild Cognitive Impairment (MCI) stages (Fig 1.1). However, MCI is conceptualised as a transitional state between normal ageing and dementia [8]. MCI is not an established diagnosis, but a concept for which different criteria have been proposed, and also modified over time. In most studies, MCI is defined as memory impairment, with other cognitive domains relatively spared [8]. The difficulty of solidly defining MCI is creating a research challenge when it comes to choose and define the study's target group and the study participants' inclusion criteria, as well as, analyse the future intervention results in a scientific, robust way. To address this challenge, the current study covers the preclinical and early MCI stages of cognitive function, as affected by ageing. These stages address the issue of delaying the onset of dementia and, at the same time, their definitions are clear, targeting elderly people who present normal activities of daily living and minor memory complaints - if any.

4.4 Augmented Reality development platform

At the initial stages, the study was designed to use Augmented Reality (AR) glasses for the developed gaming system. Upon availability (by that time), the Meta Spaceglasses (AR glasses) were chosen and the Unity game development engine would have been the SDK for the gaming system. However, the Meta Spaceglasses were not released on time. The development, process, however, went on with the Vuforia plugin for the Unity engine, to discover several technical issues in the study of [2] (Chapter 12). The Vuforia Unity plugin was proven to be resource-demanding and, therefore, it was necessary to be replaced. The Metaio SDK, which was successfully used in a previous study of ours (see [1]), was chosen for the development of the beta version. The choice of the appropriate software development kit (SDK) and development platform may have direct effect on the methodology and the timeframe of the study.

4.5 Other challenges and limitations

- In the study of [3] (Chapter 13), the Montreal Cognitive Assessment (MoCA) test is used as the standard for formal cognitive assessment, since MoCA is a validated, widely-used, screening tool, used to distinguish mild cognitive impairment (MCI) from normal ageing and which has been found to demonstrate high test-retest reliability and internal consistency [9, 7, 10]. A limitation of the study (as also stated in Section 13.4) is that the MoCA test, while being a widely-used and reliable screening instrument, presents certain weaknesses (e.g lack of specificity in populations with cardiovascular diseases and risk factors) and may not be the optimal standard - by itself - by which to determine the game's construct validity [5].

- The use of the In-Game Experience Questionnaire (iGEQ) - as well as of its full version, i.e. the Game Experience Questionnaire (GEQ) [4] - provides valuable information about the game experience on an internal level, favouring internal comparison between mini-games and the different versions of the game [6]. The fact that there are not validated iGEQ thresholds for cognitive screening games, which interpret the iGEQ values and characterise the game experience, does not facilitate comparisons with other cognitive screening games, thus affecting the generalisability of the iGEQ results.

4.6 Bibliography

[1] BOLETSIS, C., AND MCCALLUM, S. The Table Mystery: An Augmented Reality collaborative game for chemistry education. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 86–95. 43, 54

[2] BOLETSIS, C., AND MCCALLUM, S. Augmented Reality cubes for cognitive gaming: Preliminary usability and game experience testing. *Internation Journal of Serious Games 3*, 1 (2016), 3–18. 37, 53, 54, 60, 61, 66, 160, 161, 163, 165, 169

[3] BOLETSIS, C., AND MCCALLUM, S. Smartkuber: A cognitive training game for cognitive health screening of elderly players. *Games for Health Journal 5*, 4 (2016). 17, 41, 44, 53, 54, 60, 61, 66

[4] IJSSELSTEIJN, W., DE KORT, Y., AND POELS, K. The game experience questionnaire: Development of a self-report measure to assess the psychological impact of digital games. manuscript in preparation. *FUGA technical report Deliverable 3.3* (2013). 39, 43, 55, 144

[5] MCLENNAN, S., MATHIAS, J., BRENNAN, L., AND STEWART, S. Validity of the montreal cognitive assessment (moca) as a screening test for mild cognitive impairment (mci) in a cardiovascular population. *Journal of Geriatric Psychiatry and Neurology 24*, 1 (2011), 33–38. 55, 173

[6] NACKE, L., AND LINDLEY, C. Boredom, immersion, flow: A pilot study investigating player experience. In *IADIS International Conference Gaming 2008: Design for engaging experience and social interaction* (2008), IADIS Press. 55

[7] NASREDDINE, Z. S., PHILLIPS, N. A., BEDIRIAN, V., CHARBONNEAU, S., WHITEHEAD, V., COLLIN, I., CUMMINGS, J. L., AND CHERTKOW, H. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society 53*, 4 (2005), 695–699. 41, 46, 54, 65, 105, 134, 158, 159, 162, 167

[8] NORDLUND, A., ROLSTAD, S., HELLSTRM, P., SJGREN, M., HANSEN, S., AND WALLIN, A. The Goteborg MCI study: mild cognitive impairment is a heterogeneous condition. *Journal of Neurology, Neurosurgery & Psychiatry 76*, 11 (2005), 1485–1490. 54

[9] SCANLON, L., O'SHEA, E., O'CAOIMH, R., AND TIMMONS, S. Usability and validity of a battery of computerised cognitive screening tests for detecting cognitive impairment. *Gerontology Epub ahead of print* (2015). 3, 47, 54, 65, 132, 134, 158, 159, 172, 173

[10] SMITH, T., GILDEH, N., HOLMES, C., ET AL. The montreal cognitive assessment: validity and utility in a memory clinic setting. *Canadian Journal of Psychiatry 52*, 5 (2007), 329. 54, 158

Chapter 5

Analysis of Contributions

The main contributions of this PhD study are placed in its interdisciplinary research area i.e. the overlapping research space of serious games, cognitive health and Augmented Reality (Fig. 2.1). The contributions concern the developed approach for cognitive screening, the mapping of the research field, the implementation of Tangible Augmented Reality in games for the elderly, a methodological tool for game analysis, and, the introduction of the Cognitive Passport.

5.1 A new approach for cognitive screening

The PhD study contributes by developing a new approach for cognitive screening, utilising serious gaming. The developed serious game (namely Smartkuber) is basing its functionality and performance on cognitive training mini-games and Augmented Reality and tangible interaction.

The "pillars" of the new gaming approach for cognitive screening are the following:

- *Content:* cognitive training mini-games addressing a wide range of cognitive abilities
- *Interaction technique:* Tangible Augmented Reality (for task verification purposes)
- *Gaming environment:* mixed (physical and digital)
- *Game mechanics:* challenges, competition, feedback, rewards
- *Intended health behaviour change:* increase frequency of cognitive screening
- *Target audience:* elderly adults (≥60 years old)
- *Targeted goal:* document cognitive decline, connect player to physician for timely assessment
- *Evaluation method:* concurrent validity - correlational study against the MoCA test

Over the last year, there is a proliferation of serious games for cognitive screening of the elderly [21, 8, 25, 19, 20]. However, the role of serious games in the cognitive screening process is still uncertain, due to the lack of accompanying studies that examine the actual test validity of the developed games, focusing on the whole range of cognitive abilities, including the intended target group, i.e. elderly players, and addressing game design issues that intrinsically arise from the intended health function and behavioural change (e.g. suitable interaction, game mechanics, et al.).

The new approach presented in this thesis sets three main goals: 1) the stimulation of a wide range of cognitive abilities, which will ensure a more reliable cognitive screening process, 2) the entertaining and engaging nature of the developed game, and 3) the thorough evaluation of the produced tool, examining its test validity against accredited cognitive screening tools, currently used in healthcare.

The game content and its mini-game structure, the choice of the Tangible Augmented Reality technology, and the perceptual change between the physical and the digital world are choices that favour the first goal and address attention, memory, visuospatial processing, motor skills and executive functions. The analysis of the game content as to the game experience it offers, the player interviews, the conduct of usability and feasibility studies, and the iterative game design process, define a player-centric approach which ensures the achievement of the second goal. The evaluation of the game under real conditions (the player chooses when to play, at his/her own place of will) and against an accredited cognitive screening tool, like the MoCA, can lead to valuable and robust results about the game's concurrent, and ultimately, test validity.

Computer scientists and, more specifically, serious game designers and developers can benefit from having a complete methodological and technical approach for the development of serious games for cognitive screening, which can be used as a guide for the development of more effective serious games for cognitive screening or can be even enhanced and "built" upon.

5.2 Mapping the research field of serious games for cognitive health

The cognitive impairment and dementia-related subfield of serious games for health has been uncharted, while, at the same time, there was a proliferation of cognitive training, exercise and social games, some of them being originally serious games and some of them being repurposed entertainment games. The publications [13] (Chapter 7) and [14] (Chapter 8) are identifying the state of the art in the field of serious games for dementia and cognitive impairment.

Serious game researchers can benefit from the literature review, which thoroughly documents the games and the related studies of the field, identifying the games' main characteristics (including health function and purpose they serve), the research "gaps" and highlighting the best practices. The review's results can be used by researchers to extract meaningful conclusions about the impact that physical and cognitive games can have on cognitive-impaired players. These conclusions can further shape the design process of a serious game for cognitive health. Readers can also benefit by having a list of commercial - among others - game titles, which have been studied and have documented results.

Manera et al. [12] utilise the literature review of [13] (Chapter 7) to retrieve the health function that the reviewed physical and cognitive games serve and to identify the problems that arose by the use of serious games with their target group of MCI and Alzheimer's patients. Then, they use the extracted traits to define the health-related characteristics of their game, namely "Kitchen and Cooking", which eventually is used for rehabilitation of people with MCI, Alzheimer's disease (AD), and related disorders.

Robert et al. [17] use the literature review to perform a participant-based SWOT analysis of employing serious game with patients with Alzheimer's disease and related disorders (ADRD), in order to provide practical recommendations for the development and use of serious games in these populations. The literature review of [13] (Chapter 7) led to the identification of a threat for serious games, entitled "Lack of feasibility and efficacy studies" by the authors.

Furthermore, in the same study (i.e. [17]), the literature review was used from the authors and the participants to answer the following question, in a questionnaire focused on the use of serious games in people with ADRD: "-SG (Serious Games) for whom? i.e., what should be the target population for SG?". The literature review led to the formation of the following answers: "AD (dementia stage), MCI, people with frailty, family caregivers and health professionals", which consequently led to a series of practical recommendations for the development and use of serious games in the study's populations.

Kazmi et al. [8] utilise the mapping of the field of [13] (Chapter 7) and [14] (Chapter 8) to "build" upon the presented and reviewed games by suggesting and implementing the expansion of the review to computer-based tests and simulations. According to the authors' future research statement, they will build upon the discovered premises from their review and attempt to produce a mobile phone-based 3D virtual interactive environment, monitoring user response times and behaviour.

5.3 Tangible Augmented Reality in games for the elderly

Tangible Augmented Reality (TAR) is a concept which describes the combination of an Augmented Reality system and a tangible user interface [1, 22]. The current studies on Augmented Reality mainly focus on table-top environments with complex installations, where marker-based tracking is, usually, utilised to perform simple tasks [22, 23, 16, 10]. A basic problem of TAR is that the 3D imagery in a tangible setting can be problematic, as it is dependent on a physical display surface [24].

When it comes to game studies, the TAR utilisation is targeted mainly on the augmentation of board games with 3D graphics or the implementation of simple gaming tasks, which focus more on the demonstration and testing of the new interaction method, than the game itself [1, 11, 10, 15].

TAR is also used with elderly users [9, 7, 11], however it presents two main limitations: 1) as mentioned before, TAR systems require special complex installations, thus acquiring a "static" use environment, and 2) the complex design of the system often increases the cognitive load on the user [24].

In this PhD study and, more specifically in [2, 4, 5] (Chapters 11, 12, 13), the Tangible Augmented Reality technology is implemented and studied, using cubes as interaction components. The basic requirements regarding TAR's use suggested that it should not add extra cognitive load on elderly users and it should support realistic gameplay conditions, thus it should not require heavy installations and it should adapt to the player's game environment.

At first, in [3] (Chapter 10), the TAR interaction is theoretically described and, in [2] (Chapter 11), a prototype is implemented, which is tested as to the performance of the new interaction method with regular users. The results of that interaction study supported the implementation of the first version of the TAR interaction method, which was utilised in the developed game that is described in [4] (Chapter 12). The TAR technique was tested with elderly users and several interaction and technical issues were discovered, the main ones being: the marker occlusion problem when interacting with the tangible objects and the low computational performance of the system when sudden moves and fast interaction was taking place.

The discovered issues affected the whole game experience and, thus they were addressed in [5] (Chapter 13), where the TAR interaction was "moved" closer to Reality on the Reality-Virtuality spectrum (as described in [18]), "sacrificing" the short-lasting "wow factor" for a seamless and stressful Augmented Reality experience for the elderly. Therefore, the interaction was taking place on the real world and the game objects were real-world objects, however TAR was utilised for the task verification process by recognising, interpreting, and augmenting the real-world player's answers.

The contribution of the PhD study in this field is, firstly, the identification and documentation of potential TAR's issues in gaming for the age group of the elderly. The redefinition of the AR role in the implemented TAR interaction, that took place in [5] (Chapter 13), is a significant part of the overall study, which serious games and Augmented Reality researchers and developers can utilise to facilitate the interaction for elderly users.

5.4 Other contributions

Other contributions include:

- The development of a new methodological approach for game analysis, consisting of the in-Game Experience Questionnaire (iGEQ), the System Usability Scale (SUS), and an open interview, is presented in [4] (Chapter 12). The described mixed methodological approach can be useful to game design and developers at the game testing stages, for discovering various issues related to the game content, the system usability, the game environment, and the player's emotional response to the game, in a quick and reliable way. iGEQ can provide valuable insight on the player's game experience, while SUS evaluates the system's usability, both providing quantitative results. Those results can seed the open interview, thus discussing issues that may not have been discovered solely by using qualitative means.

- A full set of design suggestions for the development of cognitive screening serious games for the elderly can be extracted from Section 12.2.1 and Table 12.1, where the CogARC's usability, game design, and technical requirements are presented. The CogARC requirements is an outcome of the related literature and research on the field, the state-of-the-art analysis of [13] (Chapter 7) and [14] (Chapter 8), the prototype development and interaction study of [2] (Chapter 11), and many informal testings. The requirements are evaluated through the preliminary usability and game experience testing of [4] (Chapter 12), as well as the game experience study of [5] (Chapter 13). Game designers and researchers of the field can benefit from the application of these suggestions, for the development of cognitive screening serious games for the elderly.

- The current work contributes by presenting and studying a possible use for the cognitive screening game, as future work (Section 6.3). Publication [6] utilises Smartkuber and addresses the future direction of the project, suggesting the notion of the Cognitive Passport: a user profile with game data, smartwatch data etc. which can serve cognitive screening purposes. The feasibility study of the publication examines the validity of the suggested approach with serious games for cognitive screening being in the centre of a smart devices' ecosystem, along with smartwatches and smart tangible objects (cubes). The extracted data concern cognitive game score, sleep duration and stages, and motor skills, respectively. The feasibility study of the publication ensures that the Cognitive Passport approach and the use of Smartkuber as its main component is worth of further investigation and the publication presents all the technical details for the setup of the system and its reproducibility. The described future work can inspire and influence the researchers of the field to implement, utilise, and further study Smartkuber and the Cognitive Passport.

5.5 Bibliography

[1] BILLINGHURST, M., KATO, H., AND POUPYREV, I. Tangible Augmented Reality. In *Proceedings of ACM SIGGRAPH Asia* (2008), pp. 1–10. 16, 34, 35, 59, 60

[2] BOLETSIS, C., AND MCCALLUM, S. Augmented Reality cube game for cognitive training: An interaction study. *Studies in Health Technology and Informatics 200* (2014), 81–87. 35, 60, 61, 132, 133, 135, 136, 137, 138, 148, 149, 160, 161, 162, 163

[3] BOLETSIS, C., AND MCCALLUM, S. Connecting the player to the doctor: utilising serious games for cognitive training & screening. *DAIMI PB 597* (2015), 5–8. xiii, 3, 4, 5, 15, 31, 48, 60, 132, 134, 157, 158, 160, 162

[4] BOLETSIS, C., AND MCCALLUM, S. Augmented Reality cubes for cognitive gaming: Preliminary usability and game experience testing. *International Journal of Serious Games 3*, 1 (2016), 3–18. 37, 53, 54, 60, 61, 66, 160, 161, 163, 165, 169

[5] BOLETSIS, C., AND MCCALLUM, S. Smartkuber: A cognitive training game for cognitive health screening of elderly players. *Games for Health Journal 5*, 4 (2016). 17, 41, 44, 53, 54, 60, 61, 66

[6] BOLETSIS, C., AND MCCALLUM, S. The Cognitive Passport: Evaluating a gaming approach in the fight against cognitive impairment. *Games for Health Journal (in review)* (2016). 17, 61, 66

[7] GAMBERINI, L., MARTINO, F., SERAGLIA, B., SPAGNOLLI, A., FABREGAT, M., IBANEZ, F., ALCANIZ, M., AND ANDRÉS, J. M. Eldergames project: an innovative mixed reality table-top solution to preserve cognitive functions in elderly people. In *Proceedings of the 2nd conference on Human System Interactions* (2009), HSI'09, IEEE Press, pp. 161–166. 15, 16, 60, 72, 107

[8] KAZMI, S., UGAIL, H., LESK, V., AND PALMER, I. Interactive digital serious games for the assessment, rehabilitation, and prediction of dementia. *International Journal of Computer Games Technology 2014* (2014), 12:12–12:12. 14, 58, 59

[9] KERN, D., STRINGER, M., FITZPATRICK, G., AND SCHMIDT, A. Curball–a prototype tangible game for inter-generational play. In *Proceedings of the 15th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises* (2006), pp. 412–418. 60

[10] LEE, W., WOO, W., AND LEE, J. Tarboard: Tangible Augmented Reality system for table-top game environment. In *2nd International Workshop on Pervasive Gaming Applications, PerGames* (2005), vol. 5, pp. 2–1. 59, 60, 66

[11] Leitner, J., Haller, M., Yun, K., Woo, W., Sugimoto, M., and Inami, M. Incretable, a mixed reality tabletop game experience. In *Proceedings of the 2008 International Conference on Advances in Computer Entertainment Technology* (2008), pp. 9–16. 60

[12] Manera, V., Petit, P.-D., Derreumaux, A., Orvieto, I., Romagnoli, M., Lyttle, G., David, R., and Robert, P. 'Kitchen and cooking', a serious game for Mild Cognitive Impairment and Alzheimer's Disease: a pilot study. *Frontiers in Aging Neuroscience 7*, 24 (2015). 4, 15, 59

[13] McCallum, S., and Boletsis, C. Dementia games: A literature review of dementia-related serious games. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 15–27. 14, 17, 27, 28, 29, 58, 59, 61, 91, 95, 97, 106, 122, 160

[14] McCallum, S., and Boletsis, C. A taxonomy of serious games for dementia. In *Games for Health*. Springer Fachmedien Wiesbaden, 2013, pp. 219–232. 14, 17, 27, 29, 58, 59, 61, 160

[15] Nilsen, T., and Looser, J. Tankwar Tabletop War Gaming in Augmented Reality. In *2nd International Workshop on Pervasive Gaming Applications* (2005), vol. 5, Citeseer. 60

[16] Regenbrecht, H. T., and Wagner, M. T. Interaction in a collaborative augmented reality environment. In *CHI '02 Extended Abstracts on Human Factors in Computing Systems* (2002), pp. 504–505. 59, 66

[17] Robert, P., Knig, A., Amieva, H., Andrieu, S., Bremond, F., Bullock, R., Ceccaldi, M., Dubois, B., Gauthier, S., Kenigsberg, P.-A., Nave, S., Orgogozo, J. M., Piano, J., Benoit, M., Touchon, J., Vellas, B., Yesavage, J., and Manera, V. Recommendations for the use of serious games in people with Alzheimer's Disease, related disorders and frailty. *Frontiers in Aging Neuroscience 6*, 54 (2014). 4, 59, 132

[18] Schnabel, M. A., Wang, X., Seichter, H., and Kvan, T. From virtuality to reality and back. In *Proceedings of the International Association of Societies of Design Research* (2007), pp. 1–15. 60, 148

[19] Tong, T., and Chignell, M. Developing a serious game for cognitive assessment: Choosing settings and measuring performance. In *Proceedings of the Second International Symposium of Chinese CHI* (2014), Chinese CHI '14, pp. 70–79. 14, 15, 58

[20] Tong, T., Chignell, M., Lam, P., Tierney, M. C., and Lee, J. Designing serious games for cognitive assessment of the elderly. *Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care 3*, 1 (2014), 28–35. 14, 15, 58

[21] TONG, T., GUANA, V., JOVANOVIC, A., TRAN, F., MOZAFARI, G., CHIGNELL, M., AND STROULIA, E. Rapid deployment and evaluation of mobile serious games: A cognitive assessment case study. *Procedia Computer Science 69* (2015), 96 – 103. 3, 14, 15, 58, 158

[22] ULBRICHT, C., AND SCHMALSTIEG, D. Tangible Augmented Reality for computer games. In *Proceedings of the Third IASTED International Conference on Visualization, Imaging and Image Processing* (2003), pp. 950–954. 16, 59, 66

[23] WALDNER, M., HAUBER, J., ZAUNER, J., HALLER, M., AND BILLINGHURST, M. Tangible tiles: Design and evaluation of a tangible user interface in a collaborative tabletop setup. In *Proceedings of the 18th Australia Conference on Computer-Human Interaction: Design: Activities, Artefacts and Environments* (2006), pp. 151–158. 59, 66

[24] ZHOU, F., DUH, H. B.-L., AND BILLINGHURST, M. Trends in augmented reality tracking, interaction and display: A review of ten years of ismar. In *Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality* (2008), ISMAR '08, IEEE Computer Society, pp. 193–202. 16, 60

[25] ZUCCHELLA, C., SINFORIANI, E., TASSORELLI, C., CAVALLINI, E., TOST-PARDELL, D., GRAU, S., PAZZI, S., PURICELLI, S., BERNINI, S., BOTTIROLI, S., ET AL. Serious games for screening pre-dementia conditions: from virtuality to reality? a pilot project. *Functional neurology 29*, 3 (2014), 153–158. 4, 14, 15, 16, 58, 158

Chapter 6

Future Work

The promising results coming from the developed approach for cognitive training and screening create a large area for future work. The future work can take place in the areas of game development and evaluation for the existed game, as well as the use of supplementary devices for enhancing the gaming system and potentially producing more robust cognitive screening results. The chapter serves as a basis for discussions regarding these possibilities.

6.1 Game development, discriminant and construct validity

As suggested in Section 3.4, the game needs certain improvements that could strengthen - even more - its correlation with the MoCA score. Adjustments to the level of difficulty for the mini-games and adding textual elements to the mini-games' memory tasks to test the players' delayed recall abilities through verbal memory, should be made to establish an even more stimulating cognitive experience.

Furthermore, the game's relationship with other widely-used cognitive screening tools (e.g. MMSE, CogState. et al.) should be assessed, in order to further establish the game's construct validity. Finally, it is of great significance that the new game would be tested on a larger sample of elderly players, in order to acquire greater statistical power.

Smartkuber scores were well-correlated with the MoCA scores and, as stated before, the MoCA test is a screening tool that reliably distinguishes normal ageing from mild cognitive impairment (MCI) [9, 7]. Examining if the Smartkuber scores can also align with the MoCA scores for the identification of each player's cognitive status would ensure the game's discriminant validity, thus empowering its performance as a cognitive screening tool.

6.2 Investigate the use of Augmented Reality glasses

Augmented Reality glasses could improve the Tangible Augmented Reality (TAR) experience, which usually features complex installations, marker-based tracking, and, even, cumbersome head mounted displays [10, 11, 8, 5]. Since the use of AR glasses was not possible during the course of the PhD study (see Section 4.4), its future integration in the Smartkuber interaction, replacing the functionality of the tablet PC, would provide the opportunity to examine an alternative interaction technique, which could potentially affect the gaming experience and the cognitive stimulation of the players. Furthermore, the use of AR glasses would facilitate the comparison between the two different interaction techniques and uses of AR and game content that took place in the CogARC paper [1] (Chapter 12) and the Smartkuber paper [2] (Chapter 13), potentially revealing the effect of the Tangible Augmented Reality interaction on cognitive tasks and gaming experience, when tweaking the position of AR in the Reality-Virtuality Continuum [6] (provided that the interaction in both cases is the same and there are not any technical difficulties that affect performance).

6.3 Examine the "Cognitive Passport" framework

During the Smartkuber study of [2] (Chapter 13), the 244 cognitive game sessions, conducted over a period of 6 weeks, provided a large amount of data, which mapped each player's cognitive game performance over the period of the study.

Theoretically, the storage of cognitive game scores over time and the enhancement of the extracted cognitive game data with one of the most strongly correlated indicator of cognitive decline, i.e. sleep duration, would allow the creation of a more robust and complete user profile of cognitive-related information. Smartwatches have been found to be able to provide reliable sleep measurement tools [4]. Another indicator of cognitive decline is the deterioration of motor skills. Motor skills are stimulated through the Smartkuber game, however future work is necessary in order to extract objective motor skills measurements (e.g. accelerometers in the game's cubes to log hand tremors et al.).

Publication [3] addresses the future direction of the project, suggesting the notion of the Cognitive Passport: a user profile with game data, smartwatch data etc. which can serve cognitive screening purposes (Fig. 6.1). The feasibility study of the publication examines the validity of the suggested approach with serious games for cognitive screening being in the centre of a smart devices' ecosystem, along with smartwatches and smart tangible objects (cubes). The Cognitive Passport Ecosystem (CoPE) utilises Smartkuber, as the main component, the Basis Peak smartwatch for measuring sleep duration, and tangible objects as game interaction components to further record motor skills.

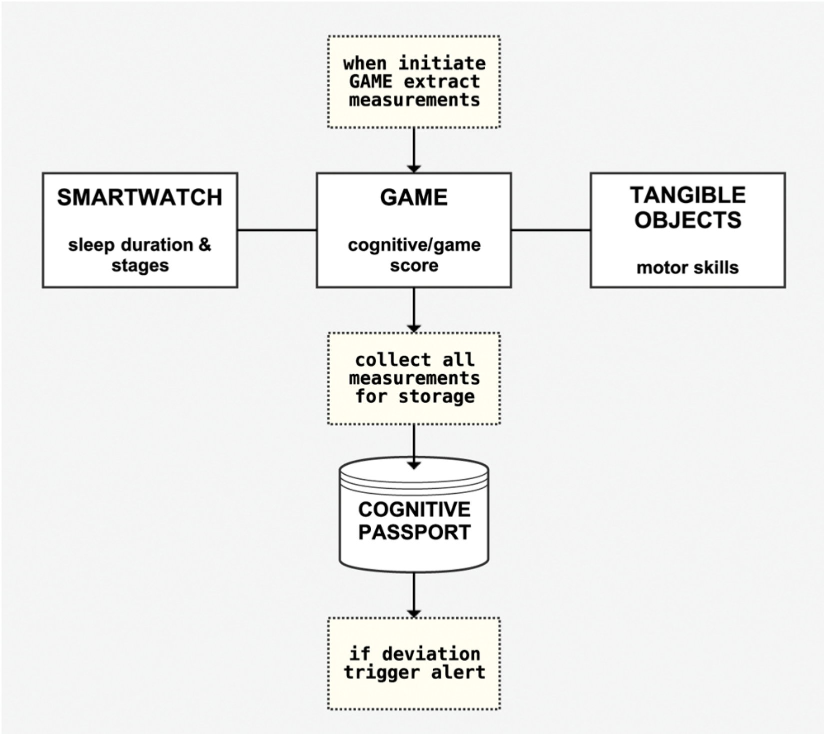


Figure 6.1: The Cognitive Passport and its Ecosystem.

The approach of the Cognitive Passport can be further developed and disseminated by conducting longitudinal studies where the Cognitive Passport Ecosystem would be used for a large period of time, thus creating the users' cognitive profile over time. That profile can later be compared with the formal, traditional cognitive assessment measurements that took place over the same period of time and evaluate its reliability and validity.

6.4 Bibliography

[1] Boletsis, C., and McCallum, S. Augmented Reality cubes for cognitive gaming: Preliminary usability and game experience testing. *International Journal of Serious Games 3*, 1 (2016), 3–18. 37, 53, 54, 60, 61, 66, 160, 161, 163, 165, 169

[2] Boletsis, C., and McCallum, S. Smartkuber: A cognitive training game for cognitive health screening of elderly players. *Games for Health Journal 5*, 4 (2016). 17, 41, 44, 53, 54, 60, 61, 66

[3] Boletsis, C., and McCallum, S. The Cognitive Passport: Evaluating a gaming approach in the fight against cognitive impairment. *Games for Health Journal (in review)* (2016). 17, 61, 66

[4] Boletsis, C., McCallum, S., and Landmark, B. The use of smartwatches for health monitoring in home-based dementia care. In *Human Aspects of IT for the Aged Population. Design for Everyday Life*, vol. 9194 of *Lecture Notes in Computer Science*. Springer International Publishing, 2015, pp. 15–26. 66

[5] Lee, W., Woo, W., and Lee, J. Tarboard: Tangible Augmented Reality system for table-top game environment. In *2nd International Workshop on Pervasive Gaming Applications, PerGames* (2005), vol. 5, pp. 2–1. 59, 60, 66

[6] Milgram, P., Takemura, H., Utsumi, A., and Kishino, F. Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum. In *Proceedings of the SPIE Conference on Telemanipulator and Telepresence Technologies* (Boston, Massachusetts, USA, 1995), vol. 2351 of *Proceedings of SPIE*, pp. 282–292. 16, 66

[7] Nasreddine, Z. S., Phillips, N. A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J. L., and Chertkow, H. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society 53*, 4 (2005), 695–699. 41, 46, 54, 65, 105, 134, 158, 159, 162, 167

[8] Regenbrecht, H. T., and Wagner, M. T. Interaction in a collaborative augmented reality environment. In *CHI '02 Extended Abstracts on Human Factors in Computing Systems* (2002), pp. 504–505. 59, 66

[9] Scanlon, L., O'Shea, E., O'Caoimh, R., and Timmons, S. Usability and validity of a battery of computerised cognitive screening tests for detecting cognitive impairment. *Gerontology Epub ahead of print* (2015). 3, 47, 54, 65, 132, 134, 158, 159, 172, 173

[10] Ulbricht, C., and Schmalstieg, D. Tangible Augmented Reality for computer games. In *Proceedings of the Third IASTED International Conference on Visualization, Imaging and Image Processing* (2003), pp. 950–954. 16, 59, 66

[11] Waldner, M., Hauber, J., Zauner, J., Haller, M., and Billinghurst, M. Tangible tiles: Design and evaluation of a tangible user interface in a collaborative tabletop setup. In *Proceedings of the 18th Australia Conference on Computer-Human Interaction: Design: Activities, Artefacts and Environments* (2006), pp. 151–158. 59, 66

Part II

Scientific Publications

Chapter 7

Dementia Games: A Literature Review of Dementia - Related Serious Games

Simon McCallum, Costas Boletsis

In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 15–27.

Abstract

Serious games find wide application in the health domain, occupying their own place in the video game industry (games for health). Currently, there is a proliferation of cognitive training, exercise and social games, targeting one of the most dangerous disease of the era: dementia, as well as its various symptoms and stages like Mild Cognitive Impairment (MCI) and Alzheimer's disease (AD). However, the dementia-related gaming field is still uncharted. In this literature review, we list studies on serious games related to dementia, that are supported by evaluation tests on dementia, MCI and AD patients with published, peer-reviewed results. This review discusses the effects that games, which include Wii Fit, Wii Sports, Big Brain Academy, Lumosity, SmartBrain Games, MasterQuiz, MINDs et al., have on dementia-related conditions. The review leads us to the conclusions that, firstly, even though many games were developed for entertainment purposes, they are being used for health reasons (usually after technical or conceptual modification), acquiring the characteristics of serious games and, secondly, dementia games do have an effect on cognitive impaired people. If that effect is longlasting and/or transferable to the daily activities is a matter of further scientific investigation.

7.1 Introduction

Dementia is one of the most significant problems facing social welfare systems [41, 31]. There are an estimated 35.6 million people with dementia worldwide. This number will nearly double every 20 years, to an estimated 65.7 million in 2030, and 115.4 million in 2050 [1].

The most common symptom or characteristic of dementia is impaired memory but it also results in impairments in thinking, communication, orientation, and coping with everyday tasks. Other symptoms are personality changes, anxiety, depression, suspiciousness, delusions and compulsive behaviours [41].

Dementia presents with various causes/types, the most common being Alzheimer's disease (AD) [34, 16, 10]. One of the early symptoms of AD is Mild Cognitive Impairment (MCI), a dementia-related heterogeneous clinical entity which is associated with the transition phase from healthy ageing to dementia [35, 36, 44]. The progression from MCI to dementia appears to be time dependent, occurring primarily within the initial 18 months [8].

There have been a large number of studies documenting the use of serious video games with respect to cognitive, physical, and social abilities of the players [18, 27, 52, 30, 45, 33, 25, 32, 17]. Consequently, serious games find wide application in the health domain, occupying their own place in the video game industry: games for health.

Over the last few years, several video games, focused on various aspects and stages of dementia, have been developed. The main idea behind these games is to delay the health decline. The secondary objective is to both improve the living standards for these groups of users, by helping them to maintain their autonomy and their social relationships, and promote a relaxed state of mind [3]. Even though dementia is characterised as a cognitive impairment, both physical and social activities have been shown to delay cognitive decline and restore cognitive function [26, 23], particularly when combined with cognitive activities.

7.2 The motivation for a dementia-related games literature review

There are several serious games addressing various aspects of the dementia disease. Some of these games are specifically designed for addressing dementia-related issues (i.e. dementia, AD, and MCI et al.) and some others - even though they were developed with other purposes in mind (e.g. entertainment) - were found to offer better gaming experiences for patients and therefore have been adopted as serious gaming.

There is, currently, a proliferation of cognitive training, exercise and social games and yet the dementia subfield of games for health is uncharted. This review offers an overview of dementia-related serious games, supported by experimental studies. The intention of this review is to be useful for the many stakeholders related to the dementia disease. Doctors, caretakers and the public are interested in which games are available for fighting dementia and, generally, in acquiring a clearer picture of the preventative, rehabilitative and/or informative purposes that each game serves, in order to play them or suggestem them to patients. Moreover, game developers in the dementia-related field can utilise the following review as a guide, providing insight into the success or failure of specific game concepts, thus contributing to the development of more suitable, effective and high quality dementia games. Lastly, this review provides healthcare researchers with an overview of a selected part of the gaming field related to dementia, as well as the studies that evaluate these games, assisting them in their academic work, related either to games for health or tools fighting dementia.

7.3 Methodology

The methodology for developing the dementia games literature review can be summarized in two stages: 1) Scan the games which have been associated with general health and filter those to extract the dementia-related game titles. 2) Narrow these games down to the ones that present a documented, peer-reviewed, and published effect on dementia-related health issues. The motivation for the second stage is that we are dealing with a sensitive and serious health issue and the reviewed game titles have to be accompanied by credibility and validity.

The review of dementia games, presented in this study is research-driven and it focuses on various research studies of games related to dementia. Within the scope of this study, we examined publications evaluating the efficacy of serious games for dementia-related conditions. For a publication to pass stage 2, it has to be peer-reviewed, published and to examine the efficacy of a video game on dementia, MCI or Alzheimer's disease patients. We include a "games to be considered" section (Section 7.4.1), which includes games with promising potential but that lack studies supporting their effectiveness on players.

The reviewed publications were collected during November and December 2012 via a library database search, Google Scholar and Web of Knowledge search tools, scanning through academic databases including IEEE Xplore, ACM Digital Library, ScienceDirect, and Springer Link. The keywords used were ["dementia" or "mild cognitive impairment" or "Alzheimer"] and ["serious games" or "video games"]. Furthermore, the Google search engine was used to find commercially available cognitive training game titles.

7.4 Literature review of dementia-related serious games

The literature review of dementia-related serious games is presented in this chapter. Table 7.1 presents the games that are associated with the current literature review. A short description of each game is given and information about their distribution, their gaming platforms and the input methods they have. The "health game category" field utilises the categorisation scheme of McCallum [31], categorising games according to the health area they affect. McCallum in [31] categorizes games for health in: *games for physical health*, which promote physical fitness, *games for cognitive health*, which target cognitive improvement and stimulation, and *games for social/emotional health*, which encourage the players to link with their friends and enable the development of a sense of community.

In Table 7.2 the publications are presented and analysed based on several attributes. These are: the main objective of the study, the targeted health area, the type of the study, the size of the sample (N), the participants' health state and the duration of the study. The key findings of each publication are summarised in the last column of the table.

7.4.1 Dementia-related games to be considered

In this section, supplementarily to the literature review, we are going to cover those dementia-related games, which present promising potential, however they have not been evaluated by studies, testing their effectiveness on dementia-related patients.

The brain training game *Brain Age* by Nintendo [38] was developed based on the previous findings of the study of Kawashima et al. [24], which examined the effect of reading aloud and arithmetic calculation on elderly people diagnosed with dementia. Kawashima's team measured their cognitive status before and after a 6-months training with two widely used tests to diagnose dementia: the Mini-Mental State Examination (MMSE) and the Frontal Assessment Battery (FAB). People in the training group improved their FAB score, maintained their MMSE score and became more communicative and independent.

KiMentia is a Kinect-based Windows application, developed to help cognitive stimulation for individuals with dementia and presented in the study of Breton et al. [7]. The tool focuses on therapeutic aspects of both cognitive and physical stimulation by allowing the player to perform mental activities and physical exercise at the same time. Five experts (two physiotherapists and three psychologists) took part in a simple personal interview about the satisfaction coming from the use of Kimentia and the survey reported positive results.

Using the paradigm of a serious game as a therapeutic tool for dementia, the *eMotiva project* introduces a collection of cognitive games for dementia, attempting to stimulate different cognitive processes such as memory or attention, trying to keep the patient motivated at all times [3, 9].

Another serious game, specifically designed for treating dementia / Alzheimer patients is an *untitled cooking game*, proposed by Imbeault and Bouchard et al. [5, 21] where a prototype has been developed, taking advantage of artificial intelligence techniques to create an accessible tool for cognitive training and allowing in-game estimation of the patient's cognitive performance.

A recent development in the dementia gaming area is the educational game *Into D'mentia* by Ijsfontein. The game consists of a physical, interactive space where the world of a person with dementia is visualized using Virtual Reality and players are able to experience the limitations and obstacles that a dementia patient faces on his/her daily life [22]. The game uses a simulation platform and it takes place inside a specifically customised truck. The goal of the game is to stimulate empathy for people with dementia and to raise awareness for the difficulties faced by these people.

Table 7.1: The games of the dementia games' review.

Game Title	Game description	Platform	Distribution	Health game category	Input method	Related studies
WiiFit	An exercise game for the Wii console, with more than 40 activities and exercises, including strength training, aerobics, yoga and balance games [40].	Nintendo Wii	Commercial	Physical	Wiimote & movement	[42]
Wii Sports	A sports game by Nintendo, which is actually a collection of five sports simulations: tennis, baseball, bowling, golf, and boxing [39]	Nintendo Wii	Commercial	Physical	Wiimote & movement	[28, 13, 51, 50]
Big Brain Academy	A puzzle video game by Nintendo, testing the player's mental acuity in a five-category quiz: thinking, memorization, computation, analysis, and identification [37].	Nintendo Wii, Nintendo DS	Commercial	Cognitive	Wiimote & movement (Wii), Controller (DS)	[14]
Lumosity	An online brain training platform using personalized training to harness brain's neuroplasticity [29].	Computer, Mobile	Commercial	Cognitive	Type & click (Computer), Tap (Mobile)	[15, 11]
Posit Science	Cognitive training gaming software that effectively address cognitive issues related to healthy aging as well as a broad range of other conditions [43].	Computer	Commercial	Cognitive	Type & click	[2, 46]
Complete Brain Workout	A collection of braining training games by Oak Systems, with 40 activities to stimulate and exercise the brain in an entertaining way [12].	Computer	Commercial	Cognitive	Type & click	[48]
SmartBrain Games	A collection of brain training games by Educamigos, for youngsters, adults or seniors, to exercise the intellectual skills and to prevent their loss in a practical and entertaining manner [47].	Computer	Commercial	Cognitive	Type & click	[49]
MasterQuiz	A tablet-based reminiscence game for mild dementia patients. The core of the game is a quiz with an image displayed on the left and text-based answers on the right [31].	Tablet PC	Academic	Cognitive	Tap	[31]
Xavix Hot Plus	A collection of twenty-four physical/sport games, offering rehabilitation support to the elderly [53].	XaviXPORT console	Commercial	Physical	Controller & movement	[53]
MinWii (MINDs)	A serious video game targeting Alzheimer and demented patients, working as a simple music therapy tool, which allows the player to improvise or play predefined songs on a virtual keyboard [4].	Computer	Academic	Emotional	Wiimote & movement	[6]

Table 7.2: The literature review of dementia-related games

Game & Study	Targeted health area	Study type	N	Subjects' health state	Duration of study*	Objective of study	Key findings
WiiFit [42]	Gait & balance	Randomised pilot study	22	AD (mild)	5 sessions per week for 8 weeks	Determine the effects on balance and gait of a Wii Fit program compared to a walking program.	Wii Fit resulted in significant improvements in balance and gait comparable to those in the robust monitored walking program.
Wii Sports [28]	Motor skills & cognition	Usability study	N/A	AD (mild-to-moderate), MCI, healthy	1 introductory and 4 test sessions, 1 session per week	Determine the ability of older adults with cognitive impairment to learn to play Wii Sports games and to control their movements with the Wiimote.	There was improvement in performance measures for most of the participants and a number of usability problems for people with cognitive deficits.
Wii Sports [13]	Motor skills	N/A	3	Dementia	9-week training session & 5-6 month follow-up retention test	Probe the capacity of persons with dementia to learn motor tasks.	The patients demonstrated improvement in bowling scores and memory for procedural components of game participation that persisted up to 6 months.
Wii Sports [51]	Attention to task & positive affect	Multiple baseline study	2	MCI	3-4 sessions per week for 10 weeks, 3 follow-up sessions	Examine effects of Wii bowling on attention to task and positive affect of older adult women with MCI, compared to a television viewing phase.	Participants showed higher attention to task and high-level demonstration of positive affect while engaged in the interactive video game as compared to baseline.
Wii Sports [50]	Positive affect & motor skills	Pilot study	10	Dementia	100 gaming hours in 6 months	Investigate whether computer games such as Nintendo Wii Sports would support demented elderly, living in special housing, to enjoy moving physically and have fun.	Wii managed to bridge the gap between the various physical abilities of the players and the patients enjoyed the feeling of being more physically active, in the appropriate technological setting.

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Big Brain Academy [14]	Cognition & behaviour	Randomised controlled trial	45	AD (mild)	12 weeks	Assess the efficacy of the Big Brain Academy compared to the Integrated Psychostimulation Program (IPP).	The group that played the game showed signicantly slower rates of cognitive decline and significantly greater decrease in depressive symptoms, compared to the group using PPI and the control group.
Lumosity [15]	Cognition & mood	Pilot randomised controlled trial	25	MCI	30 sessions in an average of 11,43 weeks	Investigate the effects of cognitive training on memory functioning and whether the effects of training would generalise to nontrained neuropsychological measures.	Participants were able to improve their performance across a range of tasks with training, but there were no significant effects of training on self-reported everyday memory functioning or mood.
Lumosity [11]	Cognition & physical exercise & psychology	N/A	78	MCI	12 weeks	Study the success of engaging patients with MCI in regular physical, social and cognitive activities by making the activities fun and easily accessible.	High activity completion rates were recorded and responses from participants have been overwhelmingly positive.
Posit Science [2]	Auditory processing speed & accuracy	Pilot randomised controlled trial	47	MCI	5 sessions per week for 6 weeks	Compare the effects of a formal computer-based, cognitive training program with more passive computer-based activities in older adults with MCI.	The results showed that intensive computer-based cognitive training is feasible in at least a subgroup of people with MCI.
Posit Science [46]	Neural substrates of response	Randomised pilot experiment	12	MCI	5 sessions per week, total of 24 sessions	Examining the influence of the software on memory ability and brain function in MCI patients by implementing exercises on processing speed and accuracy in auditory processing.	Cognitive training positively affected memory ability and memory-related left hippocampal function, even though the small number of participants did not lead to statistically signicant conclusions.

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Complete Brain Workout [48]	Cognition	N/A	59	MCI	1 session per week for 6 months	Investigate the effectiveness of a computer based training on visual spatial abilities, visual attention, executive function and visual memory, in MCI patients.	Computer cognitive training helped the experimental group to improve attention abilities and the improvement was generalized in verbal memory and in ADL as well.
SmartBrain Games [49]	Cognition	Single-blind randomised pilot study	46	AD (mild)	24 weeks	To determine the usefulness of an interactive multimedia internet-based system (IMIS) for the cognitive stimulation of Alzheimers disease, compared to an integrated psychostimulation program (IPP) and cholinesterase inhibitors (ChEIs).	Although both the IPP and IMIS improved cognition in patients with Alzheimers disease, the IMIS program provided an improvement above and beyond that seen with IPP alone, which lasted for 24 weeks.
MasterQuiz [31]	Memory	Pilot usability study	N/A	Dementia (mild)	6 design cycles	Assess the level of independence of dementia patients while playing.	It was possible for the majority of the users to independently play a game on a mobile device and there were no problems with the user interface on the device.
Xavix Hot Plus [53]	Cognition	Interventional study	9	Dementia (mild-to-moderate)	1 session per week for 10 weeks	Improve residents cognitive function indirectly by enhancing motivation using enjoyable video-sports games in a group setting.	The result showed that the general cognitive function, the visuospatial and constructive function were improved and there was an overall behavioural improvement and, more specically, improvement over the sociability of the participants.
MinWii (MINDs) [6]	Behaviour, motor skills & memory	Pilot usability study	7	AD (mild-to-moderately severe)	1 training & 4 testing sessions, once per week in a period of 3 months	Stimulating the cognitive and physical abilities of the players and aiming to improve the patients' self-esteem by setting feasible goals in a high-rewarding game.	MINWii was found to foster positive interaction with the caregivers, elicit powerful reminiscence with even the most severely impaired patients, and the patients' physical disabilities did not prevent the proper use of the Wiimote Pistol.

**The gaming sessions and hours are presented on a "per participant" basis*

Figure 7.1: A brain training game about recognising cities, from SmartBrain Games.

7.5 Discussion

Reviewing these studies shows notable findings. Firstly, an interesting point for dementia games is that many games, that are developed for entertaining purposes, are being used for health reasons. Some examples are the Nintendo's titles: Wii Fit, Wii Sports, and Big Brain Academy. These games are designed with a "typical user" in mind [19, 20]. Even though, these games cannot fully fulfill the perceptual and interaction needs of people suffering from dementia-related diseases, they are widely used amongst the elderly and cognitive impaired patients [5].

In our literature review, we examined studies showing that physical games can positively affect several health areas of the players. Padala et al. in [42] used a relatively large number of participants (N=22) and had a high number and frequency of gaming sessions (5 sessions per week for 8 weeks / participant), showing that the dementia patients could benefit from WiiFit in acquiring better balance and gait, compared to a walking program. Since dementia heavily affects cognition there are attempts to address cognitive decline through physical games. The interventional 10-week study of Yamaguchi et al. [53], using the Xavix Hot Plus game managed to show that a certain improvement in general cognitive function is possible for mild-to-moderate dementia sufferers. The studies of Weybright et al. [51] and Tobiasson et al. [50] - despite being small in participants' size - they present an adequate duration of study, therefore their positive results, regarding the positive affect that Wii Sports causes to MCI and dementia sufferers, are an indication of the emotional benefits coming from the game. However, it would be useful to take into consideration that the cognitive impairment of dementia patients may sometimes stand in the way of playing a video game. Legouverneur et al. [28] found a number of usability problems, mostly controller-related, when dementia patients played Wii Sports.

The studies related to the dominant game category within the dementia field

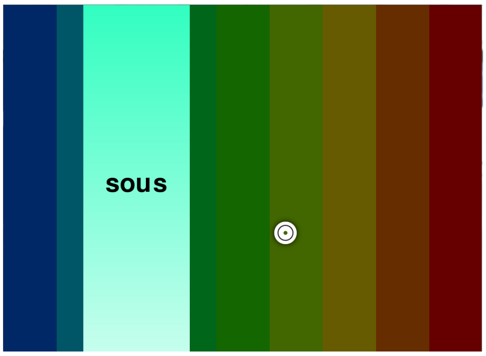

Figure 7.2: The improvisation mode of the MinWii (MINDs) game, where players are invited to improvise, playing music by pointing at a virtual keyboard.

- i.e. the cognitive games - present promising results. More specifically, Big Brain Academy [14] performed better than the Integrated Psychostimulation Program (IPP) in slowing down the cognitive decline of the participants (N=45) in a 12-week study. Another study that stands out - and which agrees with the previous finding to some extent - is the one related with the SmartBrain Games (Fig. 7.1) [49]. The study showed that the effect on cognitive improvement coming from playing the game exceeds the one coming from the Integrated Psychostimulation Program (IPP). Another notable finding is that this effect lasted for 24 weeks.

The current literature review of dementia games reveals a high concentration of game titles around the cognitive and physical functions of the players. However, the social/emotional function is less emphasised. MinWii (Fig. 7.2) is the only game in this study, having a direct, primary behavioural goal (improve patients' self-image), which was studied by Boulay et al. [6] and was found to foster positive interaction. The studies [11, 14, 50, 51, 53] showed that the games examined had positive results to the social/emotional state of the player - as side effects - affecting behaviour, depression, mood and sociability.

7.6 Conclusion & Future Work

Our work presents an overview of serious games for dementia and the relative studies on their efficacy. The main point that runs through our literature review is that dementia games do have an effect on cognitive impaired patients. Determining if that effect is longlasting and/or transferable to the daily activities is a matter of further scientific investigation.

During the course of this literature review, we analysed various health areas, health purposes, as well as engaged with various stakeholders, related to the dementia games' field. As a result of these interactions, we are developing a taxonomy of serious games for dementia, which will be presented in future publications.

7.7 Bibliography

[1] ALZHEIMER'S DISEASE INTERNATIONAL. Dementia statistics. alz.co.uk/research/statistics (Last visited: December 26th, 2014). 71

[2] BARNES, D., YAFFE, K., BELFOR, N., JAGUST, W., DECARLI, C., REED, B., AND KRAMER, J. Computer-based cognitive training for mild cognitive impairment: Results from a pilot randomized, controlled trial. *Alzheimer Disease and Associated Disorders 23* (2009), 205–210. 15, 76, 78, 96

[3] BAYO-MONTON, J. L., FERNANDEZ-LLATAS, C., GARCA-GOMEZ, J.-M., AND TRAVER, V. Serious games for dementia illness detection and motivation: the eMotiva experience. In *3rd Workshop on Technology for Healthcare and Healthy Lifestyle* (2011). 72, 74, 97

[4] BENVENISTE, S., JOUVELOT, P., AND PÉQUIGNOT, R. The MINWii project: renarcissization of patients suffering from Alzheimer's disease through video game-based music therapy. In *Proceedings of the 9th international conference on Entertainment computing* (2010), ICEC'10, Springer-Verlag, pp. 79–90. 15, 76

[5] BOUCHARD, B., IMBEAULT, F., BOUZOUANE, A., AND MENELAS, B.-A. J. Developing Serious Games Specifically Adapted to People Suffering from Alzheimer. In *Proceedings of the Third international conference on Serious Games Development and Applications* (2012), SGDA '12, Springer-Verlag, pp. 243–254. 4, 14, 74, 80, 97, 106, 107, 132

[6] BOULAY, M., BENVENISTE, S., BOESPFLUG, S., JOUVELOT, P., AND RIGAUD, A.-S. A pilot usability study of MINWii, a music therapy game for demented patients. *Technology & Health Care 19*, 4 (2011), 233–246. 15, 76, 79, 81, 96, 114

[7] BRETON, Z., ZAPIRAIN, S., AND ZORRILLA, A. Kimentia: Kinect based tool to help cognitive stimulation for individuals with dementia. In *2012 IEEE 14th International Conference on e-Health Networking, Applications and Services* (2012), Healthcom 2012, IEEE Computer Society, pp. 325–328. 15, 74, 97, 114

[8] BUSSE, A., ANGERMEYER, M. C., AND RIEDEL-HELLER, S. G. Progression of mild cognitive impairment to dementia: a challenge to current thinking. *The British Journal of Psychiatry 189*, 5 (2006), 399–404. 72, 104

[9] CALZON, A. B. S., FERNANDEZ-LLATAS, C., NARANJO, J. C., AND MENEU, T. Personalized motivation in dementia management through detection of behavior patterns. In *The Fourth International Conference on eHealth, Telemedicine, and Social Medicine* (2012), eTELEMED 2012, Xpert Publishing Services, pp. 203–208. 74, 97

[10] CHIU, M. J., CHEN, T. F., YIP, P. K., HUA, M. S., AND TANG, L. Y. Behavioral and psychologic symptoms in different types of dementia. *Journal of the Formosan Medical Association 105*, 7 (2006), 556–562. 72

[11] CLEVERLEY, M., WALKER, Z., AND DANNHAUSER, T. Engaging patients at high risk of dementia in multimodal cognitive health promoting activities: the ThinkingFit study. *Alzheimer's & Dementia 8* (2012), P220 – P221. 76, 78, 81, 96

[12] COMPLETE BRAIN WORKOUT. Oak Games PC and Facebook Developers. goo.gl/uSDG2c (Last visited: April 5th, 2013). 76

[13] FENNEY, A., AND LEE, T. D. Exploring spared capacity in persons with dementia: what Wii can learn. *Activities, Adaptation & Aging 34*, 4 (2010), 303–313. 16, 76, 77, 96

[14] FERNÁNDEZ-CALVO, B., RODRÍGUEZ-PÉREZ, R., CONTADOR, I., RUBIO-SANTORUM, A., AND RAMOS, F. Efficacy of cognitive training programs based on new software technologies in patients with Alzheimer-type dementia. *Psicothema 23*, 1 (2011), 44–50. 15, 76, 78, 81, 96

[15] FINN, M., AND MCDONALD, S. Computerised cognitive training for older persons with mild cognitive impairment: A pilot study using a randomised controlled trial design. *Brain Impairment 12*, 3 (2011), 187–199. 15, 76, 78, 96

[16] FRIEDLAND, R. P., BUDINGER, T. F., GANZ, E., YANO, Y., MATHIS, C. A., KOSS, B., OBER, B. A., HUESMAN, R. H., AND DERENZO, S. E. Regional cerebral metabolic alterations in dementia of the Alzheimer type: positron emission tomography with [18F]fluorodeoxyglucose. *Journal of computer assisted tomography 7*, 4 (1983), 590–598. 72

[17] GAMBERINI, L., MARTINO, F., SERAGLIA, B., SPAGNOLLI, A., FABREGAT, M., IBANEZ, F., ALCANIZ, M., AND ANDRÉS, J. M. Eldergames project: an innovative mixed reality table-top solution to preserve cognitive functions in elderly people. In *Proceedings of the 2nd conference on Human System Interactions* (2009), HSI'09, IEEE Press, pp. 161–166. 15, 16, 60, 72, 107

[18] GREEN, C. S., AND BAVELIER, D. *Digital Media: Transformations in Human Communication*. Peter Lang Publishing, 2006, ch. The cognitive neuroscience of video games. 72

[19] GREGOR, P., NEWELL, A. F., AND ZAJICEK, M. Designing for dynamic diversity: interfaces for older people. In *Proceedings of the fifth international ACM conference on Assistive technologies* (2002), ASSETS '02, pp. 151–156. 35, 80, 134

[20] HELLER, R., JORGE, J., AND GUEDJ, R. EC/NSF workshop on universal accessibility of ubiquitous computing: providing for the elderly event report. In *Proceedings of the 2001 EC/NSF workshop on Universal accessibility of ubiquitous computing: providing for the elderly* (2001), WUAUC '01, ACM, pp. 1–10. 35, 80, 106, 107, 114

[21] IMBEAULT, F., BOUCHARD, B., AND BOUZOUANE, A. Serious games in cognitive training for Alzheimer's patients. In *Proceedings of the 2011 IEEE 1st International Conference on Serious Games and Applications for Health* (2011), SEGAH '11, IEEE Computer Society, pp. 1–8. 15, 74, 97

[22] INTO D'MENTIA. Into D'mentia. intodmentia.com (Last visited: April 5th, 2013). 74, 97

[23] KARP, A., PAILLARD-BORG, S., HUI-XIN, W., SILVERSTEIN, M., WINBLAD, B., AND FRATIGLIONI, L. Mental, physical and social components in leisure activities equally contribute to decrease dementia risk. *Dementia and geriatric cognitive disorders 21*, 2 (2006), 65–73. 72

[24] KAWASHIMA, R., OKITA, K., YAMAZAKI, R., TAJIMA, N., YOSHIDA, H., TAIRA, M., IWATA, K., SASAKI, T., MAEYAMA, K., USUI, N., AND SUGIMOTO, K. Reading aloud and arithmetic calculation improve frontal function of people with dementia. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 60*, 3 (2005), 380–384. 15, 74, 97

[25] KEYANI, P., HSIEH, G., MUTLU, B., EASTERDAY, M., AND FORLIZZI, J. Dancealong: supporting positive social exchange and exercise for the elderly through dance. In *CHI '05 extended abstracts on Human factors in computing systems* (2005), CHI EA '05, ACM, pp. 1541–1544. 72

[26] KRAMER, A. F., AND ERICKSON, K. I. Capitalizing on cortical plasticity: influence of physical activity on cognition and brain function. *Trends in Cognitive Sciences 11*, 8 (2007), 342–348. 72

[27] LAGER, A., AND BREMBERG, S. *Health Effects of Video and Computer Game Playing - A Systematic Review of Scientific Studies*. National Swedish Public Health Institute, 2005. 72

[28] LEGOUVERNEUR, G., PINO, M., BOULAY, M., AND RIGAUD, A. Wii sports, a usability study with MCI and Alzheimer's patients. *Alzheimer's & dementia : the journal of the Alzheimer's Association 7* (2011), S500–S501. 16, 76, 77, 80, 96, 114

[29] LUMOSITY. Brain Games & Brain Training. lumosity.com (Last visited: April 4th, 2013). 76

[30] MAHNCKE, H. W., CONNOR, B. B., APPELMAN, J., AHSANUDDIN, O. N., HARDY, J. L., WOOD, R. A., JOYCE, N. M., BONISKE, T., ATKINS, S. M.,

AND MERZENICH, M. M. Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. *Proceedings of the National Academy of Sciences of the United States of America 103*, 33 (2006), 12523–12528. 72

[31] MCCALLUM, S. Gamification and serious games for personalized health. In *pHealth*, vol. 177 of *Studies in Health Technology and Informatics*. IOS Press, 2012, pp. 85–96. 4, 13, 15, 29, 71, 73, 76, 79, 90, 91, 93, 96, 113, 132

[32] MELLECKER, R. R., AND COSHOTT, R. Perspectives on exergaming. *International Journal of Computer Science in Sport 10* (2011), 93–95. 72

[33] MIKKONEN, M., VÄYRYNEN, S., IKONEN, V., AND HEIKKILÄ, M. O. User and concept studies as tools in developing mobile communication services for the elderly. *Personal Ubiquitous Computing 6*, 2 (2002), 113–124. 72

[34] MIRRA, S. S., N., H. M., AND TERRY, R. D. Making the diagnosis of alzheimer's disease. a primer for practicing pathologists. *Archives of pathology & laboratory medicine 117*, 2 (1993), 132–144. 72

[35] MORRIS, J. C., AND PRICE, J. L. Pathologic correlates of nondemented aging, mild cognitive impairment, and early-stage Alzheimer's disease. *Journal of Molecular Neuroscience 17* (2001), 101–118. 3, 72

[36] MORRIS, J. C., STORANDT, M., MILLER, J., MCKEEL, D. W., PRICE, J. L., RUBIN, E. H., AND BERG, L. Mild cognitive impairment represents early-stage Alzheimer disease. *Archives of Neurology 58*, 3 (2001), 397–405. 3, 72, 104

[37] NINTENDO.COM. Big Brain Academy - Game Info. goo.gl/gDjZdf (Last visited: April, 4th 2013). 76

[38] NINTENDO.COM. Brain Age - Game Info. goo.gl/wO200P (Last visited: April 5th, 2013). 74

[39] NINTENDO.COM. Wii Sports - Game Info. goo.gl/aIGSTT (Last visited: April 4th, 2013). 76

[40] NINTENDO.COM. WiiFit - Game Info. goo.gl/avwAz2 (Last visited: April, 4th 2013). 76

[41] NORWEGIAN MINISTRY OF HEALTH AND CARE SERVICES. *Dementia Plan 2015: making the most of good days*. Norwegian Ministry of Health and Care Services, 2007. 71, 72, 90, 92

[42] PADALA, K. P., PADALA, P. R., MALLOY, T. R., GESKE, J. A., DUBBERT, P. M., DENNIS, R. A., GARNER, K. K., BOPP, M. M., BURKE, W. J., AND SULLIVAN, D. H. Wii-Fit for improving gait and balance in an assisted living facility: a pilot study. *Journal of Aging Research 2012* (2012), 1–6. 16, 76, 77, 80, 96

[43] Posit Science. Brain Training Software, Brain Fitness, Brain Games, BrainHQ . positscience.com (Last visited: April 4th, 2013). 76

[44] Pozueta, A., Rodrguez-Rodrguez, E., Vazquez-Higuera, J., Mateo, I., Snchez-Juan, P., Gonzlez-Perez, S., Berciano, J., and Combarros, O. Detection of early Alzheimer's disease in MCI patients by the combination of MMSE and an episodic memory test. *BMC Neurology 11* (2011), 1–5. 3, 72

[45] Roenker, D. L., Cissell, G. M., Ball, K. K., Wadley, V. G., and Edwards, J. D. Speed-of-processing and driving simulator training result in improved driving performance. *Hum Factors 45*, 2 (2003), 218–33. 72

[46] Rosen, A. C., Sugiura, L., Kramer, J. H., Whitfield-Gabrieli, S., and Gabrieli, J. D. Cognitive training changes hippocampal function in mild cognitive impairment: a pilot study. *Journal of Alzheimers disease 26* (2011), 349–357. 76, 78, 96

[47] Smartbrain Games. Smartbrain Games. smartbrain-games.com (Last visited: April 5th, 2013). 76

[48] Stavros, Z., Fotini, K., and Magda, T. Computer based cognitive training for patients with mild cognitive impairment (MCI). In *Proceedings of the 3rd International Conference on PErvasive Technologies Related to Assistive Environments* (2010), PETRA '10, ACM, pp. 21:1–21:3. 15, 76, 79, 96

[49] Tarraga, L., Boada, M., Modinos, G., Espinosa, A., Diego, S., Morera, A., Guitart, M., Balcells, J., Lopez, O. L., and Becker, J. T. A randomised pilot study to assess the efficacy of an interactive, multimedia tool of cognitive stimulation in Alzheimer's disease. *Journal of Neurology, Neurosurgery & Psychiatry 77*, 10 (2006), 1116–1121. 15, 76, 79, 81, 96

[50] Tobiasson, H. Physical action gaming and fun as a tool within elderly care: Game over or play it again and again. In *Proceedings of the International Ergonomics Association 2009 conference* (2009), IEA '09. 76, 77, 80, 81, 96

[51] Weybright, E., Dattilo, J., and Rusch, F. Effects of an interactive video game (Nintendo Wii) on older women with mild cognitive impairment. *Therapeutic Recreation Journal 44*, 4 (2010), 271–287. 76, 77, 80, 81, 96

[52] Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M. M., Morris, J. N., Rebok, G. W., Unverzagt, F. W., Stoddard, A. M., Wright, E., and ACTIVE Study Group. Long-term effects of cognitive training on everyday functional outcomes in older adults. *JAMA : the journal of the American Medical Association 296*, 23 (2006), 2805–2814. 72

[53] YAMAGUCHI, H., MAKI, Y., AND TAKAHASHI, K. Rehabilitation for dementia using enjoyable video-sports games. *International Psychogeriatrics 23* (2011), 674–676. 76, 79, 80, 81, 96

Chapter 8

A Taxonomy of Serious Games for Dementia

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In *Games for Health: Proceedings of the 3rd European conference on gaming and playful interaction in health care*. Springer Fachmedien Wiesbaden, 2013, pp. 219–232.

Abstract

Serious games for dementia (SG4D) hold their own, unique and significant space within the Games for Health domain. However, the SG4D field still has not been fully mapped out and classified. In this work, we present a generic taxonomy of serious games for dementia, based on the health functions and the health purposes they serve. Firstly, we classify dementia games based on the health function they serve, in: cognitive, physical and social-emotional games. Each of these functions serves a variety of health purposes, leading us to a second, lower level of classification in: preventative, rehabilitative, assessing and educative games. Furthermore, we provide an ex-post evaluation of the proposed taxonomy by exploring whether the existing serious games for dementia can be validly classified, based on the proposed taxonomic characters. To this end, we collect and analyse a set of dementia-related serious games (e.g. WiiSports, Big Brain Academy, Cognifit, MinWii, et al.) by performing a literature review. The results show that the taxonomical system covers a sub-field of "games for health" and indicates areas which are under-explored by current games.

8.1 Introduction

Video games can be developed for the purpose of changing player's attitudes and behaviours, being both an expressive and a persuasive medium [14, 3]. With a persuasive strategy in consideration, for purposes other than pure entertainment, the long existing field of "serious games" has found broad application in the video games industry, attempting to educate, train, and inspire the players [28, 30, 36].

One of the key areas of application of serious games is the health domain, targeting changes in health-related behaviours. Games for Health (G4H) provides opportunities for players to improved rehabilitation, disease prevention, assessment, diagnosis and education/training [15, 31].

Within the wider health area, there are areas with particularly strong game development activity. One of these is the issue of dementia. Part of the motivation for research in this area is the current and predicted increases in the cost of dementia, both to the social welfare system, and to the wider fabric of society [26, 22].

However, the serious game for dementia (SG4D) field still has not been fully mapped out and classified. Sawyer and Smith [32] imply the need for top-down game taxonomical approaches ("You can't have a serious Serious Games Taxonomy without developing a taxonomy of all games"). The fact that an all-games taxonomy, a serious games taxonomy, and a G4H taxonomy have already been presented [32], opens the way for focusing on more specific parts of the G4H domain. The SG4D field, a part of the G4H domain, contains enough games and research studies and it is mature enough for analysis as a clear and *consistent* taxonomy, which could be further utilised for obtaining *predictive* abilities over the efficacy and efficiency of SG4D.

8.1.1 Contribution & paper organisation

In this paper, we present a new taxonomical scheme for serious games for dementia and we apply it on existing systems for evaluation purposes. The contribution of this work is to:

- present a generic taxonomy of serious games for dementia, based on the health functions and the health purposes they serve.
- present an up-to-date review of dementia-related serious games (i.e. games targeting dementia, Alzheimer's disease, or Mild Cognitive Impairment), accompanied by their related research studies and classify them according to the proposed taxonomy for evaluating its validity.
- acquire an overview of the SG4D field - based on the proposed taxonomy and the literature review of dementia games thus identifying the fields problems and potentials.

The rest of the paper is organised as follows. Section 8.2 examines the related work and Section 8.3 describes the motivation behind this study. Next, Section 8.4 describes the proposed taxonomy, Section 8.5 presents the application of the proposed taxonomy to existing dementia-related game titles and discusses the observations that came out of the application of the taxonomy. The paper concludes in Section 8.6.

8.2 Related Work

The work of Sawyer and Smith on serious games' taxonomies [31, 32], under the Serious Games Initiative and Games for Health Project, is of significant value

	Personal	Professional Practice	Research / Academia	Public Health
Preventative	Health Assets: PERMA, Exergaming, Stress, Nutrition	Patient Communication	Data Collection	Public Health Policy & Social Awareness Campaigns
Therapeutic	PT/OT Sensorimotor Rehabitainment Disease Management	Pain Distraction CyberPsychology Disease Management	Virtual Humans	First Responders
Assessment	Self-Ranking	Measurement	Inducement	Interface/Visualization
Education & Training	First Aid, Patient Education Health Literacy	Skills / Training	Recruitment	Management Sims
Informatics	Personal Health Record (PHR)	Electronic Medical Record (EMR)	Visualization	Epidemiology
Production	Personal Data Collection Quantified Self	Biotech Manufacturing & Design	Biotech Manufacturing & Design	Large-scale Data Collection & Monitoring

Figure 8.1: The Games for Health taxonomy developed by the Games for Health project [31].

for the scope of this study. Sawyer and Smith in [31, 32] present a games-for-health taxonomy (Fig. 8.1) based on the type of health uses the games have and the stakeholders they involve. We also extend the work of McCallum [22], categorising the games for health according to the health area that they affect. Finally, our previous work on reviewing the existed dementia-related game titles and the research studies that accompany them [23], provides the basis for the ex-post evaluation of the proposed SG4D taxonomy. In [23], we presented a total of 12 video games targeting dementia-related health problems (dementia, Alzheimer's disease, and mild cognitive impairment), all of them supported by published, experimental studies.

8.3 The motivation for the SG4D taxonomy

The SG4D is a gaming field of high significance, due to its serious target. The variety of the SG4D game titles and the various health purposes they serve make the need for a classification scheme imperative. The motivation for proposing the SG4D taxonomy is twofold:

- to establish a classification scheme within which the position and, thus properties, of games relative to one another can be understood, and
- to act as a foundation for constructing a SG4D field knowledge base as part of the SG4D design and development process.

More specifically, since SG4D target specific types, stages or symptoms of the dementia disease and they also fulfill various purposes, their classification is of great significance for having a clear understanding of how the games and their properties are related to one another. Furthermore, a clear taxonomy on the field of serious games for dementia will stand as an assistive tool for SG4D developers by enabling them to focus on a specific, distinct research areas and target more accurately the dementia-related purpose that are trying to achieve.

Therefore, the motivation behind developing the current taxonomy further requires that it satisfies three distinct characteristics: *validity*, *consistency* and *predictive power*. The validity element allows the taxonomy to be an acceptable and accredited tool for the researchers and the game developers community. The consistency of the proposed taxonomy will offer high taxonomic resolution and comparability of game datasets [8]. Finally, the predictive power of the taxonomy, given that a game A belongs to taxon x in category y, will allow us to infer that A has a set of X properties [10].

The validity and the consistency of the proposed taxonomy will be ensured by providing an ex-post evaluation of the proposed taxonomy based on the existed game titles (in the current study) and by collaborating with expert researchers from the "games for health" field for further evaluation. The predictive power will be assessed by documenting the correlations between the dementia game traits and their effectiveness' traits, as part of future work which will be based on the current preliminary study. The process will require breaking down each game into its attributes, and extracting the various aspects of the effects on patients. Having created a finer grained matrix of potential relationships, we will be able to examine their relationship, thus creating a potential training set for providing attribute predictions for instances/new SG4D titles that enter the system.

8.4 The SG4D taxonomy

The proposed taxonomy of SG4D is built on purely dementia-related taxonomic characters. The classification of dementia games is based on the dementia-related health areas they affect and the health purposes they serve. At the end of the proposed taxonomy we identify the user groups affected by the dementia-related games to provide a clearer overview of the health impacts. Schematically, the proposed taxonomy of serious games for dementia is shown in Fig. 8.2, following a circuit-schematic approach. A serious game for dementia might perform more than one health functions and also serve more than one health purposes simultaneously.

8.4.1 Towards the SG4D taxonomy, taxonomic categories, characters and nomenclature

Dementia is a disease that affects the cognitive, physical and emotional abilities of the patients. The most common symptom of dementia is impaired memory, however it also results in impairments in thinking, communication, orientation, and coping with everyday tasks. Other symptoms are personality changes, anxiety, depression, suspiciousness, delusions and compulsive behaviours [26].

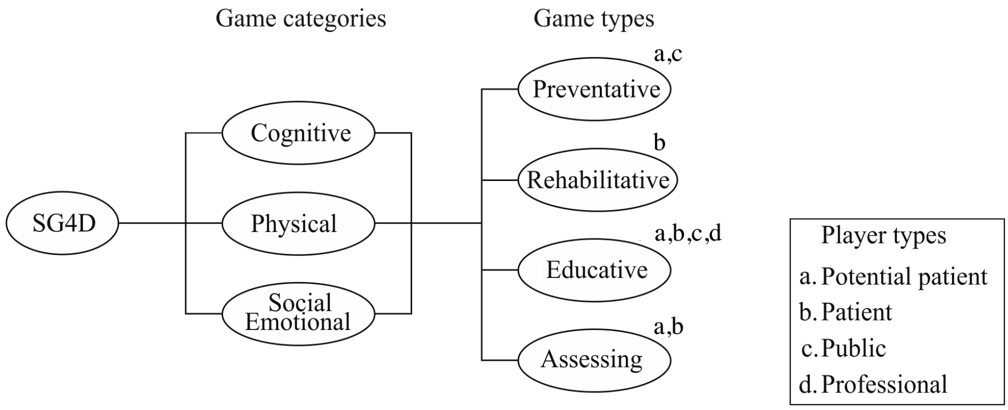

Figure 8.2: The taxonomy of serious games for dementia (SG4D).

With this in mind, and based on the categorisation of health games presented by McCallum in [22], the broadest taxonomic category of the proposed taxonomy is associated with the dementia-related health function that the SG4D affect. Therefore, the upper "layer" of the proposed taxonomy is the "game category" dividing games into *cognitive games*, i.e. games that trigger the cognitive and mental abilities of the player; *physical games*, i.e. games that are developed for physical health, promoting physical activity; and *social-emotional games*, i.e. games that encourage players to link with their friends, providing shared experiences and discussion opportunities which enable the development of a sense of community.

Each of these dementia-related health functions/game categories serves a variety of health purposes. From a gaming point of view, we refer to this taxonomic category as the "game type" based on the nomenclature on the games-for-health taxonomy of Sawyer and Smith [32] and Sawyer [31]. Consequently, the SG4D can be *preventative*, i.e. games that keep the player physically, cognitively and/or emotionally active and slow down dementia's symptoms; *rehabilitative*, games that have therapeutic functionality and restore player's/patient's health; *assessing*, i.e. games that provide direct and accredited health data to the player about his/her health status; and *educative*, i.e. games that educate the player about the dementia disease, raise awareness or train the player to cope with dementia-related situations, thus containing informational and/or training aspects.

The core of the proposed taxonomy is two-dimensional, based on the aforementioned two intrinsic game-related characteristics (game categories and game types), however the identification of the SG4D health user groups/ players is a useful representation of how the SG4D are connected with society and the disease itself. Therefore, Fig. 8.2 includes the "player types" categorisation, as an extra layer of significant dementia-related information, on top of the proposed taxonomical scheme. This categorisation is analysed further in Section 8.4.2.

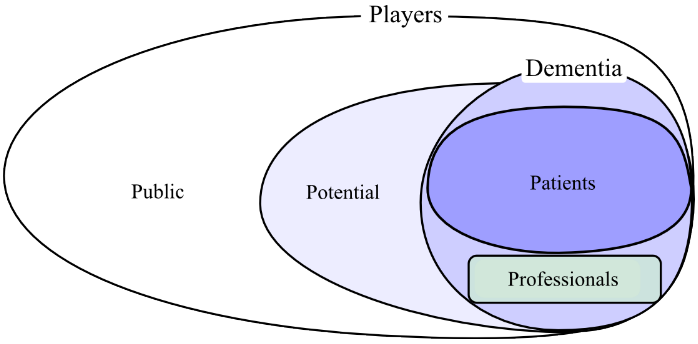

Figure 8.3: The proposed player types and their relationship with the dementia disease.

8.4.2 Dementia-related health user groups

In our attempt to classify the SG4D based on dementia-related criteria, the need of identifying the health user groups that are affected by SG4D has emerged, in order to explore a more user-centric focused approach for the proposed taxonomy. The health user groups are categorised based on their relationship with the dementia disease and they are presented as the “player types” of SG4D.

There are four player types:
- *potential patients:* people who have not had a dementia-related diagnosis but their health status is at a critical point,
- *patients:* people who have been diagnosed with some type of dementia,
- *public:* meaning the part of the population who does not have a first hand relationship with dementia, and
- *professionals*, i.e. people who are not patients themselves but whose lives are directly affected by dementia in a professional way (e.g. academic researchers, professional practitioners, public health workers and caregivers).

The relationship of each player type with the dementia disease is visualised in Fig. 8.3. This diagram emphasises the distinction between the first hand experiences (patients and professionals) and second hand experiences (general public and potential patients).

The categorisation of the player types derives from the generic categorisation of healthcare stakeholders, presented by Sawyer and Smith in [32] and Sawyer in [31] (Fig. 8.1), having undergone a number of adjustments to fit the dementia-oriented nature of the study.

8.5 Applying the proposed taxonomy

To assess the practical value and validity of the proposed taxonomy, we turn our attention to its application to existing systems. In essence, we are interested in exploring whether the existing serious games for dementia can be validly classified, based on the proposed taxonomic characters. To this end, firstly, we collected and analysed a set of dementia-related serious games by performing a literature review [23]. The methodology for developing the dementia games literature review can be summarised in two stages:

1. Scan the games which have been associated with general health and filter those to extract the dementia-related game titles.

2. Narrow these games down to the ones that present a documented, peer-reviewed, and published effect on dementia-related health issues.

The motivation for the second stage is that we are dealing with a sensitive and serious health issue and the reviewed game titles have to be accompanied by credibility and validity. For a publication to pass stage 2, it has to be peer-reviewed, published and to examine the efficacy of a video game on dementia, MCI or Alzheimer's disease patients. We include a "games to be considered" section (Section 8.5.1), which includes games with promising potential but that lack studies supporting their effectiveness on players [23].

The reviewed publications were collected during November and December 2012 via a library database search, Google Scholar and Web of Knowledge search tools, scanning through academic databases including IEEE Xplore, ACM Digital Library, ScienceDirect, and Springer Link. The keywords used were ["dementia" or "mild cognitive impairment" or "Alzheimer"] and ["serious games" or "video games"]. Furthermore, the Google search engine was used to find commercially available cognitive training game titles.

Table 7.1 presents the games that are associated with the dementia games literature review. It contains a short description of each game, general information, as well as the supported gaming platforms and input methods. The final column presents all the related research studies [23].

Table 8.1: The games of the dementia games' review.

Game Title	Game description	Platform	Distribution	Input method	Dementia-related studies
Big Brain Academy	A puzzle video game by Nintendo, testing the player's mental acuity in a five-category quiz: thinking, memorization, computation, analysis, and identification.	Nintendo Wii, Nintendo DS	Commercial	Wiimote & movement (Wii), Controller (DS)	[12]
Complete Brain Workout	A collection of braining training games by Oak Systems, with 40 activities to stimulate and exercise the brain in an entertaining way.	Computer	Commercial	Type & click	[33]
Lumosity	An online brain training platform using personalized training to harness brain's neuroplasticity.	Computer, Mobile	Commercial	Type & click (Computer), Tap (Mobile)	[13, 9]
MasterQuiz	A tablet-based reminiscence game for mild dementia patients. The core of the game is a quiz with an image displayed on the left and text-based answers on the right.	Tablet PC	Academic	Tap	[22]
MinWii (MINDs)	A serious video game targeting Alzheimer and demented patients, working as a simple music therapy tool, which allows the player to improvise or play predefined songs on a virtual keyboard.	Computer	Academic	Wiimote & movement	[5]
Posit Science	Cognitive training gaming software that effectively address cognitive issues related to healthy aging as well as a broad range of other conditions.	Computer	Commercial	Type & click	[1, 29]
SmartBrain Games	A collection of brain training games by Educamigos, for youngsters, adults or seniors, to exercise the intellectual skills and to prevent their loss in a practical and entertaining manner.	Computer	Commercial	Type & click	[34]
Wii Sports	A sports game by Nintendo, which is actually a collection of five sports simulations: tennis, baseball, bowling, golf, and boxing.	Nintendo Wii	Commercial	Wiimote & movement	[19, 11, 37, 35]
WiiFit	An exercise game for the Wii console, with more than 40 activities and exercises, including strength training, aerobics, yoga and balance games.	Nintendo Wii	Commercial	Wiimote & movement	[27]
Xavix Hot Plus	A collection of twenty-four physical/sport games, offering rehabilitation support to the elderly.	XaviXPORT console	Commercial	Controller & movement	[38]

8.5.1 Dementia-related games to be considered

Supplementary to the literature review, we covered those dementia-related games, which present promising potential, however they have not been evaluated by studies, testing their effectiveness on dementia-related patients [23].

The brain training game *Brain Age* by Nintendo was developed based on the previous findings of the study of Kawashima et al. [18], which examined the effect of reading aloud and arithmetic calculation on elderly people diagnosed with dementia.

KiMentia is a Kinect-based Windows application, developed to help cognitive stimulation for individuals with dementia and presented in the study of Breton et al. [6]. The tool focuses on therapeutic aspects of both cognitive and physical stimulation by allowing the player to perform mental activities and physical exercise at the same time.

Using the paradigm of a serious game as a therapeutic tool for dementia, the *eMotiva project* introduces a collection of cognitive games for dementia, attempting to stimulate different cognitive processes such as memory or attention, trying to keep the patient motivated at all times [2, 7].

Another serious game, specifically designed for treating dementia / Alzheimer patients is an *untitled cooking game*, proposed by Imbeault and Bouchard et al. [4, 16] where a prototype has been developed, taking advantage of artificial intelligence techniques to create an accessible tool for cognitive training and allowing in-game estimation of the patient's cognitive performance.

A recent development in the dementia gaming area is the educational game *Into D′mentia* by Ijsfontein. The game consists of a physical, interactive space where the world of a person with dementia is visualized using Virtual Reality and players are able to experience the limitations and obstacles that a dementia patient faces on his/her daily life [17]. The game uses a simulation platform and it takes place inside a specifically customised truck. The goal of the game is to stimulate empathy for people with dementia and to raise awareness for the difficulties faced by these people.

8.5.2 Categorising the selected games

Table 8.2 presents the application of the core proposed taxonomy (Fig. 8.2) on the games described in Table 7.1. The player types categorisation (Fig. 8.2 and Section 8.4.2) can be consistently applied to the classified games of Table 8.2, according to their types (e.g. the game Brain Age, being of preventative nature, can be played by potential patients and the public).

8.5.3 Observations made from applying the proposed taxonomy

After applying the proposed taxonomical system on the existing research-supported dementia game titles, we can reach some interesting conclusions about the form

Table 8.2: Applying the proposed taxonomy.

Game types → Game categories ↓	**Preventative**	**Rehabilitative**	**Educative**	**Assessing**
Cognitive	- Brain Age - Big Brain Academy - Lumosity - Posit Science - CogniFit - Complete Brain Workout - SmartBrain Games	- MasterQuiz - MinWii - Cooking game - eMotiva	- Into D'mentia	N/A
Physical	- WiiFit - Wii Sports	- MinWii - eMotiva	- Into D'mentia	N/A
Social/ Emotional	- WiiFit - Wii Sports - Big Brain Academy	- eMotiva	- Into D'mentia	N/A

of the SG4D field, as well as about the performance of the proposed taxonomy. At first glance, it is obvious that the majority of the existed dementia-related game titles are focusing on the cognitive and physical categories, serving preventative and rehabilitative purposes. The social-emotional function of the SG4D is mostly operating as a secondary element, coming from the multiplayer function of the games.

The educative type of games presents a small number of titles, presumably because of the difficulty to clearly define and cover the varied nature of the dementia disease within an educational game. However, there are informational and training programs and games that are currently being developed, and this space will hopefully fill out over time [20].

The most important observation is the complete lack of assessment games. The fact that there are no games in this category could mean that it is unnecessary and out of the scope of the proposed taxonomy. However, this type of game is being developed and there are already several dementia-related screening tools, like the Mini Mental State Examination [21], Montreal Cognitive Assessment [24], Neurotrack [25] et al., that could be gamified in order to keep track of the player's cognitive status and keep him/her motivated. Consequently, we consider this game type to emerge in the near future and we consider its inclusion to the proposed taxonomical system necessary for the system to be complete and up-to-date.

8.6 Conclusion & future work

The proposed taxonomy is able to give us an overview of the current SG4D field, classifying the dementia-related game titles according to dementia-related criteria. Having based the current study on previous knowledge, helped us to create a complete taxonomical system that focuses further inside the "games for health" field.

As future work, the proposed taxonomy will be evaluated by expert researchers of the field, with the goal of creating a collaborative, updated and validated tool, creating a synergy between game developers and dementia professionals. The ultimate goal - as described in Section 8.3 - is to develop a SG4D taxonomy with predictive power, aiming to provide attribute predictions for each new game title that is introduced.

8.7 Bibliography

[1] Barnes, D., Yaffe, K., Belfor, N., Jagust, W., DeCarli, C., Reed, B., and Kramer, J. Computer-based cognitive training for mild cognitive impairment: Results from a pilot randomized, controlled trial. *Alzheimer Disease and Associated Disorders 23* (2009), 205–210. 15, 76, 78, 96

[2] Bayo-Monton, J. L., Fernandez-Llatas, C., Garca-Gomez, J.-M., and Traver, V. Serious games for dementia illness detection and motivation: the eMotiva experience. In *3rd Workshop on Technology for Healthcare and Healthy Lifestyle* (2011). 72, 74, 97

[3] Bogost, I. *Persuasive games: The expressive power of videogames*. MIT Press, 2007. 12, 89

[4] Bouchard, B., Imbeault, F., Bouzouane, A., and Menelas, B.-A. J. Developing Serious Games Specifically Adapted to People Suffering from Alzheimer. In *Proceedings of the Third international conference on Serious Games Development and Applications* (2012), SGDA '12, Springer-Verlag, pp. 243–254. 4, 14, 74, 80, 97, 106, 107, 132

[5] Boulay, M., Benveniste, S., Boespflug, S., Jouvelot, P., and Rigaud, A.-S. A pilot usability study of MINWii, a music therapy game for demented patients. *Technology & Health Care 19*, 4 (2011), 233–246. 15, 76, 79, 81, 96, 114

[6] Breton, Z., Zapirain, S., and Zorrilla, A. Kimentia: Kinect based tool to help cognitive stimulation for individuals with dementia. In *2012*

IEEE 14th International Conference on e-Health Networking, Applications and Services (2012), Healthcom 2012, IEEE Computer Society, pp. 325–328. 15, 74, 97, 114

[7] Calzon, A. B. S., Fernandez-Llatas, C., Naranjo, J. C., and Meneu, T. Personalized motivation in dementia management through detection of behavior patterns. In *The Fourth International Conference on eHealth, Telemedicine, and Social Medicine* (2012), eTELEMED 2012, Xpert Publishing Services, pp. 203–208. 74, 97

[8] Charles, D. Taxonomic Consistency - Algae, Academy of Natural Sciences of Drexel University. goo.gl/YO1jyF (Last visited: May, 15th 2013). 92

[9] Cleverley, M., Walker, Z., and Dannhauser, T. Engaging patients at high risk of dementia in multimodal cognitive health promoting activities: the ThinkingFit study. *Alzheimer's & Dementia 8* (2012), P220 – P221. 76, 78, 81, 96

[10] Dasgupta, S. A hierarchical taxonomic system for computer architectures. *Computer 23*, 3 (1990), 64–74. 92

[11] Fenney, A., and Lee, T. D. Exploring spared capacity in persons with dementia: what Wii can learn. *Activities, Adaptation & Aging 34*, 4 (2010), 303–313. 16, 76, 77, 96

[12] Fernández-Calvo, B., Rodríguez-Pérez, R., Contador, I., Rubio-Santorum, A., and Ramos, F. Efficacy of cognitive training programs based on new software technologies in patients with Alzheimer-type dementia. *Psicothema 23*, 1 (2011), 44–50. 15, 76, 78, 81, 96

[13] Finn, M., and McDonald, S. Computerised cognitive training for older persons with mild cognitive impairment: A pilot study using a randomised controlled trial design. *Brain Impairment 12*, 3 (2011), 187–199. 15, 76, 78, 96

[14] Fogg, B. J. *Persuasive technology: using computers to change what we think and do*. Morgan Kaufmann Publishers, 2003. 12, 89

[15] Göbel, S. Cloud-based games for health: serious games and social media as multimedia technologies for healthcare. In *Proceedings of the 1st ACM multimedia international workshop on Cloud-based multimedia applications and services for e-health* (2012), CMBAS-EH '12, ACM, pp. 1–2. 89

[16] Imbeault, F., Bouchard, B., and Bouzouane, A. Serious games in cognitive training for Alzheimer's patients. In *Proceedings of the 2011 IEEE 1st International Conference on Serious Games and Applications for Health* (2011), SEGAH '11, IEEE Computer Society, pp. 1–8. 15, 74, 97

[17] Into D'mentia. Into D'mentia. intodmentia.com (Last visited: April 5th, 2013). 74, 97

[18] Kawashima, R., Okita, K., Yamazaki, R., Tajima, N., Yoshida, H., Taira, M., Iwata, K., Sasaki, T., Maeyama, K., Usui, N., and Sugimoto, K. Reading aloud and arithmetic calculation improve frontal function of people with dementia. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 60*, 3 (2005), 380–384. 15, 74, 97

[19] Legouverneur, G., Pino, M., Boulay, M., and Rigaud, A. Wii sports, a usability study with MCI and Alzheimer's patients. *Alzheimer's & dementia : the journal of the Alzheimer's Association 7* (2011), S500–S501. 16, 76, 77, 80, 96, 114

[20] Lever, A. M. BBC News - Initiative helps dementia carers train in empathy. goo.gl/nDdis0 (Last visited: May, 15th 2013). 98

[21] Lurlowicz, L., and Wallace, M. The Mini Mental State Examination (MMSE), The Hartford Institute for Geriatric Nursing. goo.gl/wdMqGt (Last visited: May, 15th 2013). 98

[22] McCallum, S. Gamification and serious games for personalized health. In *pHealth*, vol. 177 of *Studies in Health Technology and Informatics*. IOS Press, 2012, pp. 85–96. 4, 13, 15, 29, 71, 73, 76, 79, 90, 91, 93, 96, 113, 132

[23] McCallum, S., and Boletsis, C. Dementia games: A literature review of dementia-related serious games. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 15–27. 14, 17, 27, 28, 29, 58, 59, 61, 91, 95, 97, 106, 122, 160

[24] Nasreddine, Z. The Montreal Cognitive Assessment (MoCA). mocatest.org (Last visited: December, 20th 2015). 98

[25] Neurotrack. Transforming the diagnosis and treatment of Alzheimer's. neurotrack.com (Last visited: May, 15th 2013). 98

[26] Norwegian Ministry of Health and Care Services. *Dementia Plan 2015: making the most of good days*. Norwegian Ministry of Health and Care Services, 2007. 71, 72, 90, 92

[27] Padala, K. P., Padala, P. R., Malloy, T. R., Geske, J. A., Dubbert, P. M., Dennis, R. A., Garner, K. K., Bopp, M. M., Burke, W. J., and Sullivan, D. H. Wii-Fit for improving gait and balance in an assisted living facility: a pilot study. *Journal of Aging Research 2012* (2012), 1–6. 16, 76, 77, 80, 96

[28] Prensky, M. Digital game-based learning. *Computers in Entertainment 1* (2003), 21–21. 12, 89

[29] Rosen, A. C., Sugiura, L., Kramer, J. H., Whitfield-Gabrieli, S., and Gabrieli, J. D. Cognitive training changes hippocampal function in mild cognitive impairment: a pilot study. *Journal of Alzheimers disease 26* (2011), 349–357. 76, 78, 96

[30] Sawyer, B. *Serious Games: Improving Public Policy through Game-Based Learning and Simulation*. Foresight and Governance Project, Woodrow Wilson International Center for Scholars Publication, 2002. 12, 89

[31] Sawyer, B. From cells to cell processors: The integration of health and video games. *IEEE Computer Graphics and Applications 28*, 6 (2008), 83–85. x, 12, 13, 14, 29, 89, 90, 91, 93, 94

[32] Sawyer, B., and Smith, P. Serious Games Taxonomy - Digitalmill. goo.gl/EHcWvy (Last visited: May, 15th 2013). 90, 91, 93, 94

[33] Stavros, Z., Fotini, K., and Magda, T. Computer based cognitive training for patients with mild cognitive impairment (MCI). In *Proceedings of the 3rd International Conference on PErvasive Technologies Related to Assistive Environments* (2010), PETRA '10, ACM, pp. 21:1–21:3. 15, 76, 79, 96

[34] Tarraga, L., Boada, M., Modinos, G., Espinosa, A., Diego, S., Morera, A., Guitart, M., Balcells, J., Lopez, O. L., and Becker, J. T. A randomised pilot study to assess the efficacy of an interactive, multimedia tool of cognitive stimulation in Alzheimer's disease. *Journal of Neurology, Neurosurgery & Psychiatry 77*, 10 (2006), 1116–1121. 15, 76, 79, 81, 96

[35] Tobiasson, H. Physical action gaming and fun as a tool within elderly care: Game over or play it again and again. In *Proceedings of the International Ergonomics Association 2009 conference* (2009), IEA '09. 76, 77, 80, 81, 96

[36] Walz, S. P. Pervasive Persuasive: A Rhetorical Design Approach to a Location-Based Spell-Casting Game for Tourists. In *Situated Play, Proceedings of DiGRA 2007 Conference* (2007), pp. 489–497. 12, 89

[37] Weybright, E., Dattilo, J., and Rusch, F. Effects of an interactive video game (Nintendo Wii) on older women with mild cognitive impairment. *Therapeutic Recreation Journal 44*, 4 (2010), 271–287. 76, 77, 80, 81, 96

[38] Yamaguchi, H., Maki, Y., and Takahashi, K. Rehabilitation for dementia using enjoyable video-sports games. *International Psychogeriatrics 23* (2011), 674–676. 76, 79, 80, 81, 96

Chapter 9

Connecting the Player to the Doctor: Utilising Serious Games for Cognitive Training & Screening

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Abstract

In this paper, we discuss the limitations of common cognitive training and cognitive screening methods, and examine how serious games could address some of these issues. We propose a cognitive game system, supporting self-care of cognitive health, in non-clinical settings, which can also function as a connection between the players/patients and their mental health clinician.

9.1 Introduction

Older adults often present symptoms of associated memory impairment, both for declarative and episodic memories. These symptoms can be caused by normal aging processes, but also indicate the potential development of Alzheimer's disease (AD) - the most common form of dementia [16]. Although current Alzheimer's treatments cannot stop Alzheimer's from progressing, they can temporarily slow the worsening of dementia symptoms and improve quality of life for those with Alzheimer's and their caregivers. Today, there is a worldwide effort to find better ways to treat the disease, delay its onset, and prevent it from developing [9].

Dementia is a devastating disease for the patient, their carers, and family. The cost of dementia care is also starting to have a significant impact on the healthcare systems of many countries [12]. Despite the increasing costs, and potentially because of the cost of front line care, there are limited resources available to support research into early detection and monitoring of pre-clinical patients. As a result of this, the cognitive assessment for the progression of cognitive impairments is mostly based on the passage of time rather than the

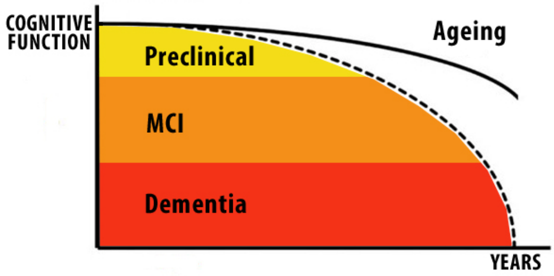

Figure 9.1: The continuum of normal ageing and Alzheimer's cognitive decline [19].

cognitive performance of the patient over a specific period of time, making it difficult to track the point in time when the cognitive decline begins to takes place. Consequently, doctors treating dementia do not have the right kind of data at the right time in order to be able to help the patient most effectively. This situation, mostly affects the patients at preclinical stages and those of Mild Cognitive Impairment (MCI), which is considered to be the transition phase between healthy ageing and dementia [14] (Fig. 9.1). The progression from MCI to dementia appears to be time dependent - occurring primarily within the initial 18 months [3] - and the doctor could treat the patient more effectively with access to timely monitoring, since initiating treatment early may have significant and clinically meaningful advantages in the course of the dementia disease, for example in early clinical trials with donepezil shows potential to delay the onset of Alzheimer's dementia [8]. *Cognitive training* has shown promise as a preventative treatment in the premorbid stage. Clinicians encourage older adults to engage in self-care for cognitive health, through everyday cognitively stimulating activities in non-clinical settings (e.g. patients' homes, senior centres et al.) [21]. Another preventative approach is the identification of patient's cognitive status by *cognitive screening* in clinical settings (i.e. hospitals, memory clinics etc.).

In this work, we discuss cognitive training and cognitive screening, focusing on current limitations, and propose a cognitive game system, utilising Augmented Reality (AR), to address those problems. Through the proposed system, we are planning to further examine our research hypothesis that the introduction of Augmented Reality gaming can benefit the cognitive training and screening processes, being a tool for self-care of cognitive health and connecting the player to the doctor when that is necessary. In the context of this study, self-care of cognitive health takes the form of an active process of engaging individuals to take responsibility for managing aspects of their mental health and adopting behaviours that prevent cognitive decline. Through active participation in their health management, patients are empowered to have more control over their daily lives by purposely engaging in cognitively stimulating activities, self-monitoring and implementing a course of actions in a timely manner (e.g. visiting the mental health clinician) that can lessen or slow down the debilitating symptoms of cognitive decline [4].

9.2 Cognitive screening: tests & limitations

Cognitive impairment is measured objectively by standard neuropsychological (cognitive) tests. Cognitive screening represents the initial step in a process of further assessment for dementia and can help identify potential cases for assessment, thus leading to early diagnosis. Early diagnosis provides the opportunity for cognitive training and pharmacological management, if appropriate, with the hope of preserving or improving executive function, behaviour, and cognition [11]. Screening for dementia is usually accomplished by means of cognitive tests. The most widely-used are the Mini-Mental State Exam (MMSE) [5] for screening severe dementia and the Montreal Cognitive Assessment (MoCA) [15] for screening Mild Cognitive Impairment (MCI).

However, these screening tests present certain intrinsic limitations [11]. MMSE contains *culture, gender, and educational bias*. Additionally, patients with high premorbid intelligence or education show a ceiling effect, thus leading to false negatives. Great age, limited education, foreign culture, and sensory impairment can conversely produce false positives. Therefore, the MMSE score is adjusted for age and education [11]. Demographic based adjustments are common for the majority of cognitive tests, however the MoCA test is increasing in usage, as it appears to have less bias related to cultural and educational elements [11].

Almost all screening tests, as longitudinal and mostly static (pen and paper) measures of screening, they are susceptible to the *learning effect* and are considered to be *psychologically stressful*, presenting a risk of false positive results with concomitant distress and potential stigma for a person labelled with cognitive impairment. Furthermore, most of these tests *target specific stages of cognitive impairment*, not providing an objective overview of the patient's cognitive status (e.g. MMSE cannot be used to identify MCI). Finally, one needs to consider the capacity of local health care services given the *economic burden of increased screening* [11].

9.3 Cognitive training: games & limitations

Examination of the range and limits of cognitive reserve capacity (plasticity) by means of cognitive training has been suggested as a promising diagnostic strategy for the early identification of dementia, particularly Alzheimer's disease, in sub-clinical populations [6]. Furthermore, cognitive training aims to help people with early-stage dementia delay the disease's onset and make the most of their memory and cognitive functioning despite the difficulties they are experiencing, by utilising compensatory and/or restorative strategies [1]. Cognitive training shows promise in the treatment of AD, with primarily medium effect sizes for learning, memory, executive functioning, activities of daily living, general cognitive problems, depression, and self-rated general functioning [17], the retrospective and observational designs of the human studies have led to difficulty interpreting the direction of causation between cognitive function and cognitively stimulating activities [13]. To face the new challenges that arise from an ageing society, serious games are presented as a cognitive training platform to slow the cognitive decline of impaired patients.

Cognitive training games present several problems and have their own limitations. Current cognitive training games *focus mainly and directly on the serious aspects*, i.e. the stimulation of the targeted cognitive functions, at the expense of the game design. Consequently, a large number of cognitive training games are *low-quality games*, not utilising the appropriate game design and game mechanics and fail to either engage or entertain the player.

From an interaction point of view, most of the cognitive training games presented in [13] suffer from multiple important limitations since they *do not fulfil perceptual and interaction needs of cognitively impaired patients* [2]. These games are designed exclusively as entertainment or wellbeing games, with a "typical user" in mind [10], which have acquired serious games characteristics through studies that test their efficacy on a group of patients. These games may be suitable for cognitively impaired patients, but are not specifically designed and targeted for them. As a consequence, many of the current serious games for dementia do not take into consideration the fragile cognitive state of the player, thus adding extra cognitive (and possibly physical) load through complicated and non-customisable interaction techniques, complex and non-adaptive game scenarios, and cognitively dense artistic design [2].

A significant limitation that runs through most of the current cognitive training games is that there is still *a gap between non-clinical and clinical settings*, that does not allow those games to act as accredited screening and self-monitoring tools for the early identification of cognitive decline, and to connect with formal care, such as medical experts. The value to the medical profession is limited by the lack of data collection and analysis related to cognitive function and status. Game performance indicators such as game score often bear little relationship to general cognitive competence.

9.4 A proposed cognitive game system

The main idea that runs through this work is that cognitive games (i.e. games for cognitive training and screening) can potentially be a tool for self-care of cognitive health, providing cognitive exercise and self-monitoring. The proposed cognitive game system is the study object of the GameLab in Gjøvik University College and its functionality covers the preclinical and early MCI stages of cognitive impairment (Fig. 9.1), where the users can have subjective memory complaints, however present normal performance of activities of daily living

Figure 9.2: Using AR cube/markers to manipulate in-game elements.

(ADL) and normal general cognitive function, and where there is no need for formal and/or informal care.

9.4.1 Architecture

The architecture of the system consists of a wearable and mobile system, based on the use of AR and on manipulating the in-game elements using hand movements. More specifically, the system consists of a pair of AR glasses and a number of AR markers (Fig. 9.2) for "building" the AR scene and manipulating the in-game objects. We focus on AR glasses (Google, Glass, Meta Spaceglasses et al.), since glasses are an accepted way of altering our perception of the world.

9.4.2 Interaction

Recent advances in technology (e.g. gestures/hand tracking, Augmented Reality, biosensors, high-fidelity Virtual Reality et al.) allow us to have several new interaction methods at our disposal. New interaction techniques can *reduce the cognitive load of in-game instructions*, *stimulate and register the physical abilities of the players*, and *provide the developer and the formal care with secondary data*. In our study, we utilise the Augmented Reality technology in order to overcome the interaction problems, related to traditional interaction techniques [2, 10] and we hypothesise that AR can be utilised to implement a cognitively-suitable interaction technique for elderly players. AR has been shown to provide a pleasant cognitive training experience for elderly players, because of its simplicity and usability of the interface, as described in the Eldergames project (presented as a mixed-reality platform) [7]. Furthermore, AR systems improve task performance and can relieve mental workload on assembly tasks. The ability to overlay and register information on the interaction space in a spatially meaningful way allows AR to be a more effective instructional medium. However, the limitations in the current calibration techniques, display and tracking technologies (e.g. the occlusion of AR markers issue) are the biggest obstacles preventing AR from being a wide-spread medium [20]. As designers, we are planning to make use of the performance gains of AR and address its problematic areas, by

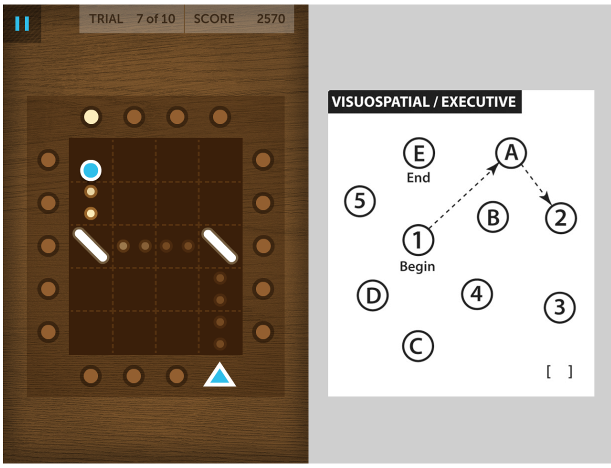

Figure 9.3: The Pinball Recall Lumosity game for cognitive training of working memory (*left*) and a visuospatial/executive "find the logical path" exercise from the MoCA screening test (*right*).

implementing an interaction technique for elderly players, which is based on assembling in-game elements by moving AR markers (such as AR cubes - Fig. 9.2) with hand movements, attempting to provide a pleasant cognitive training experience and stimulate the motor skills of the players as well. Furthermore, the collection of untrained secondary data, facilitated by the proposed interaction technique (e.g. hand movements coordinates, revealing hand tremors), provides extra data for clinical evaluation, which is potentially less effected by the learning effect of the games [18].

9.4.3 Content

Cognitive screening tests and cognitive training exercises have game-like elements or, at least, elements that can be gamified (e.g. Fig. 9.3). That alone allows us, as game designers, to *implement game scenarios where cognitive training exercises coexist with the cognitive screening ones*, developing a healthcare instrument of dual nature. The content of the proposed game is based on a set of puzzle mini-games, targeting the visuospatial, memory, attention, problem solving and logical reasoning cognitive functions amongst others. The functionality and the cognitive-related content of the games, as well as the proper interaction movements (focusing on motor skills) will be decided by the team's neuropsychologist. As examples of best practices concepts of popular and entertaining puzzle and platform games (e.g. Wooord, Threes, 2048, DragonBox), as well as gamified versions of cognitive tests' exercises, will be examined for integration and implementation purposes. *Cognitive games' content can also be dynamic*, as opposed to the static/paper version of the widely-used cognitive screening tests, thus eliminating the learning effect. In the proposed game, several levels of the mini-games will be dynamically generated and new levels will be added frequently as expansion packs or downloadable content. The dynamically generated content will be based on a validated and pre-approved set of rules for level generation, where the content will be changing but its essence and functionality will remain the same.

9.4.4 Intrinsic objective

A cognitive game can give the player an informal measurement of his/her cognitive performance through the game score. Taking as a prerequisite that the proposed game's content consists of accredited cognitive exercises (i.e. the mini-games), *the correlation of the game score with the cognitive status of the player* (as screened by the "gold standard" methods - the MoCA test in our case) could provide the player/patient a constant monitoring of his/her mental health. The vision of the project is a system where gaming is used as a motivational and engaging way of cognitive self-monitoring and, if indications of cognitive decline appear, the player will be notified by an in-game message to reach out for formal care and treatment. If the player is an already enrolled cognitively impaired patient, the doctor will have the opportunity to follow his/her performance, get notified of sudden cognitive changes, get supplementary secondary data (e.g. hand movements coordinates), as well as, choose the set of games that are suitable for the player's cognitive status and set the game score/performance thresholds. Consequently, the constant cognitive monitoring and screening of the player can provide the opportunity for formal care to assess the progression of cognitive impairments based on the cognitive performance of the patient and provide treatment only when necessary, *thus reducing the financial burden on the social welfare system*.

9.5 Conclusion

Current cognitive training and screening methods, even being of great scientific and health value, present certain limitations. With the current advances in technology we hypothesise that an optimised version of the two processes can be introduced as a tool for self-care of cognitive health: cognitive games. Cognitive games can be studied not only as a mean to surpass those limitations (Table 9.1), but to motivate the player in order to provide himself/herself and the system with objective cognitive data. If this data is interpreted and handled correctly, they potentially can reveal the cognitive changes of the player, connecting him/her with the formal care in a cognitive-timely manner.

Even though, such a project is of a long-term nature, we consider that its promising character is worth further discussion and examination.

Table 9.1: A summary of the cognitive screening and training limitations and how cognitive games can address them.

	Limitations	Cognitive games' solutions
Cognitive screening	culture, gender, and educational bias	dynamically generated, updated content
	learning effect	dynamically generated, updated content
	psychologically stressful	entertaining game experience
	target specific stages of cognitive impairment	various sets of exercises/games
	economic burden of screening/automated screening	fewer and more targeted medical examinations
Cognitive training	low-quality game design, too "serious" - less fun	entertainment is an important target, inclusion of game professionals
	no perceptual / interaction needs of CI patients	examination/use of current interaction technologies/techniques
	no link between non-clinical and clinical settings	correlation of game score and real cognitive status, connecting player to the doctor

9.6 Bibliography

[1] BAHAR-FUCHS, A., CLARE, L., AND WOODS, B. Cognitive training and cognitive rehabilitation for mild to moderate Alzheimer's disease and vascular dementia. *Cochrane Database of Systematic Reviews*, 6 (2013). 105

[2] BOUCHARD, B., IMBEAULT, F., BOUZOUANE, A., AND MENELAS, B.-A. J. Developing Serious Games Specifically Adapted to People Suffering from Alzheimer. In *Proceedings of the Third international conference on Serious Games Development and Applications* (2012), SGDA '12, Springer-Verlag, pp. 243–254. 4, 14, 74, 80, 97, 106, 107, 132

[3] BUSSE, A., ANGERMEYER, M. C., AND RIEDEL-HELLER, S. G. Progression of mild cognitive impairment to dementia: a challenge to current thinking. *The British Journal of Psychiatry 189*, 5 (2006), 399–404. 72, 104

[4] CAMERON, J., WORRALL-CARTER, L., PAGE, K., RIEGEL, B., LO, S. K., AND STEWART, S. Does cognitive impairment predict poor self-care in

patients with heart failure? *European Journal of Heart Failure 12*, 5 (2010), 508–515. 105

[5] COCKRELL, J. R., AND FOLSTEIN, M. F. Mini-Mental State Examination (MMSE). *Psychopharmacology Bulletin 24*, 4 (1988), 689–692. 105

[6] FERNANDEZ-BALLESTEROS, R., BOTELLA, J., ZAMARRON, M. D., MOLINA, M. A., CABRAS, E., SCHETTINI, R., AND TARRAGA, L. Cognitive plasticity in normal and pathological aging. *Clinical Interventions in Aging 7* (2012), 15–25. 105, 132

[7] GAMBERINI, L., MARTINO, F., SERAGLIA, B., SPAGNOLLI, A., FABREGAT, M., IBANEZ, F., ALCANIZ, M., AND ANDRÉS, J. M. Eldergames project: an innovative mixed reality table-top solution to preserve cognitive functions in elderly people. In *Proceedings of the 2nd conference on Human System Interactions* (2009), HSI'09, IEEE Press, pp. 161–166. 15, 16, 60, 72, 107

[8] GAUTHIER, S. G. Alzheimer's disease: the benefits of early treatment. *European Journal of Neurology 12* (2005), 11–16. 104

[9] GHAHGHAEI, A., BATHAIE, S., AND BAHRAMINEJAD, E. Mechanisms of the effects of crocin on aggregation and deposition of Aβ1-40 fibrils in Alzheimer's disease. *International Journal of Peptide Research and Therapeutics 18*, 4 (2012), 347–351. 103

[10] HELLER, R., JORGE, J., AND GUEDJ, R. EC/NSF workshop on universal accessibility of ubiquitous computing: providing for the elderly event report. In *Proceedings of the 2001 EC/NSF workshop on Universal accessibility of ubiquitous computing: providing for the elderly* (2001), WUAUC '01, ACM, pp. 1–10. 35, 80, 106, 107, 114

[11] ISMAIL, Z., RAJJI, T. K., AND SHULMAN, K. I. Brief cognitive screening instruments: an update. *International Journal of Geriatric Psychiatry 25*, 2 (2010), 111–120. 3, 4, 105, 132, 158

[12] KNAPP, M., COMAS-HERRERA, A., SOMANI, A., AND BANERJEE, S. *Dementia: international comparisons*. Personal Social Services Research Unit, 2007. 103

[13] MCCALLUM, S., AND BOLETSIS, C. Dementia games: A literature review of dementia-related serious games. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 15–27. 14, 17, 27, 28, 29, 58, 59, 61, 91, 95, 97, 106, 122, 160

[14] MORRIS, J. C., STORANDT, M., MILLER, J., MCKEEL, D. W., PRICE, J. L., RUBIN, E. H., AND BERG, L. Mild cognitive impairment represents early-stage Alzheimer disease. *Archives of Neurology 58*, 3 (2001), 397–405. 3, 72, 104

[15] Nasreddine, Z. S., Phillips, N. A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J. L., and Chertkow, H. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society 53*, 4 (2005), 695–699. 41, 46, 54, 65, 105, 134, 158, 159, 162, 167

[16] Persson, J., Nyberg, L., Lind, J., Larsson, A., Nilsson, L.-G., Ingvar, M., and Buckner, R. L. Structure-function correlates of cognitive decline in aging. *Cerebral Cortex 16*, 7 (2006), 907–915. 3, 103, 132, 157

[17] Sitzer, D. I., Twamley, E. W., and Jeste, D. V. Cognitive training in Alzheimer's disease: a meta-analysis of the literature. *Acta Psychiatrica Scandinavica 114*, 2 (2006), 75–90. 106

[18] Sørensen, H. T., Sabroe, S., and Olsen, J. A framework for evaluation of secondary data sources for epidemiological research. *International Journal of Epidemiology 25*, 2 (1996), 435–442. 108

[19] Sperling, R. A., Aisen, P. S., Beckett, L. A., Bennett, D. A., Craft, S., Fagan, A. M., Iwatsubo, T., Jack, C. R., Kaye, J., Montine, T. J., Park, D. C., Reiman, E. M., Rowe, C. C., Siemers, E., Stern, Y., Yaffe, K., Carrillo, M. C., Thies, B., Morrison-Bogorad, M., Wagster, M. V., and Phelps, C. H. Toward defining the preclinical stages of Alzheimer's disease: recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia 7*, 3 (2011), 280–292. ix, x, 4, 104

[20] Tang, A., Owen, C., Biocca, F., and Mou, W. Comparative effectiveness of Augmented Reality in object assembly. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2003), CHI '03, pp. 73–80. 16, 107, 114, 115, 149

[21] Williams, K., and Kemper, S. Exploring interventions to reduce cognitive decline in aging. *Journal of Psychosocial Nursing and Mental Health Services 48*, 5 (2010), 42–51. 104, 132

Chapter 10

Augmented Reality & Gesture-based Architecture in Games for the Elderly

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Abstract

Serious games for health and, more specifically, for elderly people have developed rapidly in recent years. The recent popularisation of novel interaction methods of consoles, such as the Nintendo Wii and Microsoft Kinect, have provided an opportunity for the elderly to engage in computer and video games. These interaction methods, however, still present various challenges for elderly users. To address these challenges, we propose an architecture consisted of Augmented Reality technology (as an output mechanism) combined with gestured-based devices (as an input method). The intention of this work is to provide a theoretical justification for using these technologies and to integrate them into an architecture, acting as a basis for creating more effective games for the elderly.

10.1 Introduction

Following the proliferation of game consoles and their adoption of user-friendlier interfaces and interactions, the elderly population (age of 65+ [1]) is becoming more and more interested and engaged in gaming. Video games for the elderly, apart from providing a pleasant and motivating experience, can also offer several health benefits and help prevent or treat health problems that come with age, like changes in sensory-perceptual processes, motor abilities, and cognitive processes [21, 15, 10].

The popularisation of novel interaction methods, utilising handheld devices (Wiimote for the Nintendo Wii, Move for the Sony Playstation) and motion sensing devices (Kinect for the Microsotf Xbox 360, EyeToy for the Sony Playstation), allowed the players to move away from merely pushing buttons to control a game, but to use gestures and physical movements as their input mechanism.

[1] http://www.who.int/healthinfo/survey/ageingdefnolder/en/index.html

These new interactions form the state-of-the-art interaction techniques for video games for the elderly, which are widely used in senior centres [19, 20] and are also applied in experimental games, intended for elderly people suffering from various health conditions [2, 3, 11].

However, gaming technologies produce systems designed for the typical user (male, fit, and with static-over-time abilities), without taking into consideration specific design guidelines, catering to the special needs of the elderly population [7, 9, 10].

More specifically, several studies document problems related to the current interaction techniques. Using Wii, elderly players face problems related to: the pressing of the Wiimote buttons [12, 16, 4, 5]; the movements that are needed to perform in-game actions [14]; the cognitive load related to processing the large amount of information displayed [12, 14]; and the posture necessary for interaction and the calibration issues when sitting [12, 5, 4, 16]. Using Kinect elderly players find it difficult to hold their hands still when selecting menu options [4].

Therefore, researchers have suggested design guidelines for suitable interaction techniques for the elderly. Minimizing the cognitive burden caused by in-game functions [10, 5], elderly-user-friendly controllers without unnessecary buttons [5], adaptable and flexible user interfaces that could compensate for the physical and cognitive limitations of the elderly players, and finally, an elderly-user-centered design process[5].

Following these guidelines and recommendations, we propose an architecture based on Augmented Reality(AR) and gestures, to act as a “backbone” for developing wearable and mobile interaction techniques for the elderly players. We propose a gesture-based sensing system, which supports the adaptability of the developed interaction technique to the special abilities of each individual user. AR provided a novel solution to the problem of providing the right information, at the right time, in the right place. AR also provides a feedback solution which allows gestures to be learned more easily.

The implementation of a gesture-based interaction technique will help us avoid the problems of fine dexterity required to use traditional remote controllers, but still we have to overcome individual moter skill differences in the elderly players. The element of adaptability in the proposed architecture, allows personalisation of gesture calibration. The input method includes the ability to use a set of gestures which do not need body or posture movement, and have these mapped to the normal gesture inputs. This allows sitting players to also fully interact with the games.

The choice of AR as a preferred technology for the system’s output is based on the intrinsic characteristics of AR that provide solutions to the problematic interaction areas of the current techniques. By linking input and output to the real world, AR could help eliminating the need for extensive tutorials/instructions, thus reducing cognitive load and attention-switching, and promoting continuous use and physical movement [17, 18, 13]. It could also be

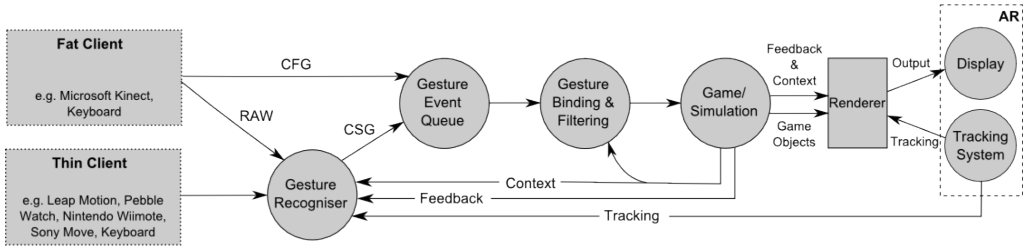

Figure 10.1: The proposed framework.

beneficial for mental processes, since it can support spatial cognition and mental transformation [18].

The combination of gestures and AR can be implemented as a wearable system, moving the player away from the confined space defined by current interaction techniques, and placing the elderly user as the "centre" of the game (Section 10.3). A thorough, technical description of the core architecture is given below (Section 10.2).

10.2 The core architecture

The overview of the proposed architecture is visualised in Fig. 10.1. Data for gesture processing is provided by either thin or fat clients. In the case of the *fat client*, gesture events are provided directly to the *gesture event queue*. The gestures from fat clients will generally be from a *context-free grammar (CFG)*, such as gestures represented in the CoGesT format [6], and can be passed directly to the gesture event queue. The *fat client* can also provide raw gesture data that need to be further processed by the *gesture recogniser*, which implements the behavioural basis for gesture recognition, using a *context-sensitive grammar (CSG)*, based on contextual information provided by the game. Gesture data, that are provided by a *thin client*, are processed by the *gesture recogniser* and pushed to *gesture event queue*.

The *gesture event queue* contains all the gesture events, which take place in an asynchronous manner, for later processing. The gesture events are popped off the event queue and edited by the *gesture binding and filtering* system, which provides the essential adaptability of the system - a useful feature for impaired users who need to alter the default gesture mapping system. At that stage the gesture patterns are customisable to the user's preferences and abilities and the gesture data can be bound to various sets of gestures. The gesture data is then bound and filtered according to the user's preferences and they are interpreted as user input to the *game* or *simulation*.

The gesture events have three main types gStart(uID, gID, Data), gUpdate(uID, gID, Data), gEnd(uID, gID, Data). These event types have a unique event ID (uID), gesture ID (gID) and a data object containing either parameter data for

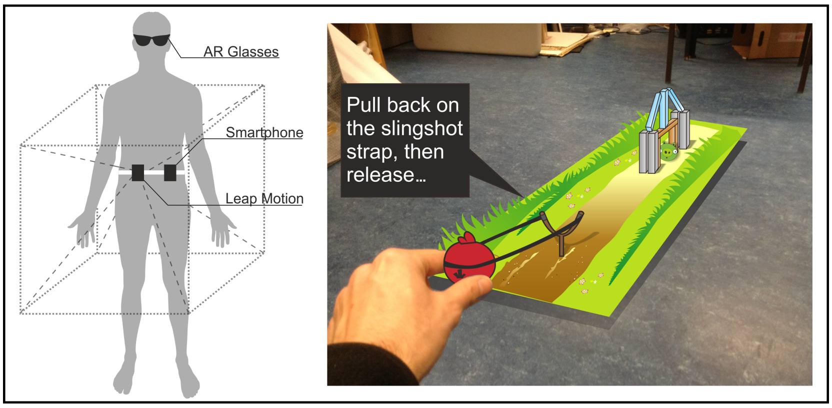

Figure 10.2: *Left side:* the placement of the devices on a silhouette figure; *Right side:* a mockup of the interaction through the view of the AR glasses, when playing a 3D Angry Birds-like game

the recognised gesture, or raw data. The additional data provided with a gesture is vital for online gestures, where the system is updating the linked activity with every gesture event update. For example "pinch to zoom" gestures need to continuously response to pinch distance change. This data can also provide feedback to the user through the AR system about the gestures that are being executed.

The *game* provides a broadcast service with *feedback* about the current state of the gestures being executed and a *context* to indicate which set of gestures are valid in the current game situation. The *rendering engine* listens to both of these. The game sends the *game objects* to the *renderer*, which - along with the tracking information acquired by the *tracking system* - visualises the output on the *AR display*.

The tracking system connected to the AR display must be able to provide very fast feedback on view orientation to the renderer. This allows the system to keep a tight link between the feedback from gestures and the real world that is being augmented. The tracking system also provides raw data to the gesture recognition system so that player interactions based on view direction can be integrated as a standard gesture input.

As an example of gesture feedback integrated into the AR system, gestures could be visualised as a glowing corona around the player's hand, informing him/her of the status of the performed gestured-based action.

10.3 Case study

The proposed architecture describes a wearable system based on the use of AR and on gesture-based input devices. More specifically, we focus on AR glasses, since glasses are an accepted way of altering our perception of the world. Usually they provide either improved focus or protection from glare, whereas AR glasses will add digital content, without blocking the perception of the real world, allowing the rest of the body to interact either with in-game elements or the physical world.

For the proposed architecture, devices like Google's project Glass or Vuzix's Smart Glasses M100 are proposed as output mechanisms. For input purposes, we propose using gesture sensing technologies like: the Pebble watch, the Microsoft's Digit project, and the Leap Motion.

As an example, a description of an interaction technique based on the proposed architecture is presented at the left side of Fig. 10.2. In this figure, we visualize the experimental use of the devices of AR glasses (like Google Project Glass), as an output device, the Leap Motion (or a Leap Motion-like device) as a gesture based input device, and a smartphone as the main processing unit. The Leap Motion creates an interaction space of 1 cubic meter in front of the users' waist, so the user can interact and manipulate the in-game elements that appear on the AR screen/glasses. The Leap Motion and the AR glasses are connected to a smartphone where the game and the devices' software are installed. The Leap Motion and the smartphone are placed on the user's belt allowing continuous movement and creating a user centric interaction space. This combination requires a belt and a pair of glasses, both of which are familiar objects for most elderly people.

The proposed architecture mainly favours video games that have to do with the manipulation of a digital object (i.e. Angry Birds, Worms, Wii Sports, Jenga et al.). Therefore, we present a mockup of a 3D Angry Birds-like game, as seen through the AR glasses view of an elderly player (Fig. 10.2). The player's view defines the position of the game terrain, the player can move around the terrain exploring the in-game objects, they can get instructions about the in-game actions that they should take and, potentially in multiplayer mode, could see the avatar of a remote opponent as the other player moves around the terrain.

10.4 Discussion

The existing literature and the experimental results suggest that an AR and gesture-based architecture for elderly video games could result in a significant improvement in player experience. Games that adopt concepts popular amongst the elderly, like Wii Bowling, could have more beneficial cognitive, physical and social effects if they were supported by an interaciton system that is more suitable to the elderly players.

The proposed architecture could help in developing interaction techniques that affect many stakeholders related with personalised health care and gaming. The elderly players would have a more personalised and entertaining gaming experience with multiple benefits (depending also on the development quality of the game played). Medical experts could also benefit, since having a safe and efficient interaction technique would increase health games' effectiveness for their elderly patients. Game developers would have the opportunity to explore new gaming concepts taking full advantage of the possibilities that new, personalised, and flexible interaction techniques could offer to a niche market. Lastly, taking into consideration the documented gaming/entertainment needs of the elderly, familiarising them with the latest emerging technologies and preparing them for the near future when technologies like Augmented Reality or gestures will be part of smart homes [1, 8], could offer a higher quality of life, a beneficial effect for the public and society, in general.

10.5 Future Work

The next stage of this project is to implement an interaction technique based on the proposed architecture, using some of the aforementioned devices, and testing it on elderly players inside a game concept. This will include an iterative, elderly-user-centered design process and a usability testing, aiming to reveal the potential problems of the proposed architecture.

10.6 Bibliography

[1] Bien, Z. Z., Park, K., Bang, W., and Stefanov, D. H. Lares: An intelligent sweet home for assisting the elderly and the handicapped. In *Cambridge Workshop Series on Universal Access and Assistive Technology (CWUAAT)* (2002). 118

[2] Boulay, M., Benveniste, S., Boespflug, S., Jouvelot, P., and Rigaud, A.-S. A pilot usability study of MINWii, a music therapy game for demented patients. *Technology & Health Care 19*, 4 (2011), 233–246. 15, 76, 79, 81, 96, 114

[3] Breton, Z., Zapirain, S., and Zorrilla, A. Kimentia: Kinect based tool to help cognitive stimulation for individuals with dementia. In *2012 IEEE 14th International Conference on e-Health Networking, Applications and Services* (2012), Healthcom 2012, IEEE Computer Society, pp. 325–328. 15, 74, 97, 114

[4] Fraile, S. H., Browne, J., Brox, E., and Evertsen, G. Suitability analysis of commercial open-source driven motion sensor devices applied to exergames for the elderly. *Ambient Assisted Living Forum Eindhoven* (2012). 114

[5] Gerling, K., and Masuch, M. When gaming is not suitable for everyone: playtesting Wii games with frail elderly. In *Proceeding of the 1st Workshop on Game Accessibility: Xtreme Interaction Design (FDG 2011)* (Bordeaux, France, 2011). 35, 114

[6] Gibbon, D., Gut, U., Hell, B., Looks, K., and Thies, R. A computational model of arm gestures in conversation. In *Proceedings of Eurospeech* (2003). 115

[7] Gregor, P., and Newell, A. F. Designing for dynamic diversity: making accessible interfaces for older people. In *Proceedings of the 2001 EC/NSF workshop on Universal accessibility of ubiquitous computing: providing for the elderly* (2001), WUAUC'01, pp. 90–92. 114

[8] Hammond, J. C., Sharkey, P. M., and Foster, G. T. Integrating Augmented Reality with home systems. In *Proceeding of the 1st International conference on disability, virtual reality and associated technologies ECDVRAT '96* (1996), pp. 57–66. 118

[9] Heller, R., Jorge, J., and Guedj, R. EC/NSF workshop on universal accessibility of ubiquitous computing: providing for the elderly event report. In *Proceedings of the 2001 EC/NSF workshop on Universal accessibility of ubiquitous computing: providing for the elderly* (2001), WUAUC '01, ACM, pp. 1–10. 35, 80, 106, 107, 114

[10] Ijsselsteijn, W., Nap, H. H., de Kort, Y., and Poels, K. Digital game design for elderly users. In *Proceedings of the 2007 conference on Future Play* (2007), Future Play '07, pp. 17–22. 35, 113, 114, 134, 135, 149

[11] Kayama, H., Okamoto, K., Nishiguchi, S., Nagai, K., Yamada, M., and Aoyama, T. Concept software based on Kinect for assessing dual-task ability of elderly people. *Games for Health Journal 1*, 5 (2012), 348–352. 15, 114

[12] Legouverneur, G., Pino, M., Boulay, M., and Rigaud, A. Wii sports, a usability study with MCI and Alzheimer's patients. *Alzheimer's & dementia : the journal of the Alzheimer's Association 7* (2011), S500–S501. 16, 76, 77, 80, 96, 114

[13] Liu, C., Huot, S., Diehl, J., Mackay, W., and Beaudouin-Lafon, M. Evaluating the benefits of real-time feedback in mobile Augmented Reality with hand-held devices. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems* (2012), CHI '12, ACM, pp. 2973–2976. 16, 114

[14] Marin, J. G., Navarro, K. F., and Lawrence, E. Serious games to improve the physical health of the elderly: A categorization scheme. In *proceedings of CENTRIC 2011, The Fourth International Conference on Advances in Human-oriented and Personalized Mechanisms, Technologies, and Services* (Barcelona, Spain, 2011). 114

[15] MCCALLUM, S. Gamification and serious games for personalized health. In *pHealth*, vol. 177 of *Studies in Health Technology and Informatics*. IOS Press, 2012, pp. 85–96. 4, 13, 15, 29, 71, 73, 76, 79, 90, 91, 93, 96, 113, 132

[16] NEUFELDT, C. Wii play with elderly people. In *International Reports on Socio-informatics. Enhancing Interaction Spaces by Social Media for the Elderly: A Workshop Report* (2009), vol. 6, pp. 50–59. 114

[17] NEUMANN, U., AND MAJOROS, A. Cognitive, performance, and systems issues for augmented reality applications in manufacturing and maintenance. In *Proceedings of the Virtual Reality Annual International Symposium* (1998), VRAIS '98, IEEE, pp. 4–11. 16, 114

[18] TANG, A., OWEN, C., BIOCCA, F., AND MOU, W. Comparative effectiveness of Augmented Reality in object assembly. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2003), CHI '03, pp. 73–80. 16, 107, 114, 115, 149

[19] THENG, Y.-L., DAHLAN, A. B., AKMAL, M. L., AND MYINT, T. Z. An exploratory study on senior citizens' perceptions of the Nintendo Wii: the case of Singapore. In *Proceedings of the 3rd International Convention on Rehabilitation Engineering & Assistive Technology* (2009), i-CREATe '09, ACM, pp. 10:1–10:5. 15, 114

[20] THENG, Y.-L., TEO, P., AND TRUC, P. Investigating sociability and affective responses of elderly users through digitally-mediated exercises: a case of the Nintendo Wii. In *Human-Computer Interaction*, vol. 332 of *IFIP Advances in Information and Communication Technology*. Springer Berlin Heidelberg, 2010, pp. 152–162. 15, 114

[21] WHITCOMB, G. R. Computer games for the elderly. *SIGCAS Computers and Society 20*, 3 (1990), 112–115. 113

Chapter 11

Augmented Reality Cube Game for Cognitive Training: An Interaction Study

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In *pHealth*, vol. 200 of *Studies in Health Technology and Informatics*. IOS Press, 2014, pp. 81–87.

Abstract

There is the potential that cognitive activity may delay cognitive decline in people with mild cognitive impairment. Games provide both cognitive challenge and motivation for repeated use, a prerequisite for long lasting effect. Recent advances in technology introduce several new interaction methods, potentially leading to more efficient, personalised cognitive gaming experiences. In this paper we present an Augmented Reality (AR) cognitive training game, utilising cubes as input tools, and we test the cube interaction with a pilot study. The results of the study were mostly positive, revealing the marker occlusion problem and that novice AR users can adjust to the developed AR environment after a small number of sessions.

11.1 Introduction

Cognitive decline is associated with risk for functional decline, nursing home placement, depression, anxiety and mortality, especially in older individuals [10]. Interventions that reliably improve cognitive function thus have the opportunity to substantially improve the health and quality of life of the elderly [10].

Studies in animals and humans suggest that non-specific cognitive stimulation reduces the risk of cognitive decline. This has led to the practice of encouraging older adults to engage in everyday cognitively stimulating activities [10]. Even though, the retrospective and observational designs of the human studies have led to difficulty interpreting the direction of causation between cognitive function and cognitively stimulating activities, studies around the utilisation of video games for cognitive training (e.g. Lumosity, Posit Science, et al.), have produced positive indications for significant benefits on affecting memory function, attention abilities, emotional state, and, in general, improving executive functions and slowing down cognitive decline [6].

However, present cognitive game platforms and software, as well as the studies that accompany them, focus mainly and directly on the "serious" aspects, i.e. the stimulation of the targeted cognitive functions, at the expense of the game design and the interaction technique can have on the user experience, thus on the players' emotional response and on the targeted cognitive functions. The majority of the cognitive games are designed for desktop PCs, gaming consoles or mobile devices (smartphones and tablets) utilising keyboard/mouse, controllers or tapping as the main input methods, using screen monitors as output devices [6, 5]. Recent advances in technology (e.g. gestures/hand tracking, augmented reality [5], biosensors, high-fidelity virtual reality et al.) allow us to have several new interaction methods at our disposal, in order to explore the design of more robust and efficient, personalised cognitive training experiences.

Designing engaging cognitive video games, addressing the motor skills and the emotional state of the players, as well as getting secondary data, supplementary to the cognitive performance (e.g. stability of hand movements, heart rate, breathing activity et al.) are potentially feasible goals that may lead to the next generation of cognitive training and assessment software. To move in that direction, we have designed a *cognitive Augmented Reality (AR) cube* system. The cognitive AR cube system is an AR cognitive training game, utilising cubes as input tools. The game is of preventative nature and is targeting, primarily, mild cognitive impaired players, players at the initial stages of mild dementia, and secondarily healthy adults. The ultimate goal of the cognitive AR cube system is to alleviate cognitive decline and to provide timely cognitive assessment information to the player, thus playing an intermediary role between the (potential) patient and the medical expert. The final product is destined to be a collection of 6 cube mini-games. During the first step however, we are studying the interaction with the cubes and Augmented Reality implementing the prototypes of 2 core cube mini-games. The interaction goal is to provide the players with a cognitively stimulating interaction technique (use of cubes, AR, etc.) which will utilise known interaction metaphors, will be portable, and will be used without the help of experts/professionals.

In this paper, we describe the development process followed (Section 11.2), analysing the components and the interaction design of the system (Section 11.3-11.4), and concluding with an interaction pilot study (Section 11.5).

11.2 Developing the cognitive AR cube system

In this study, the first stage of the project is analysed by examining the interaction technique of the AR cube system (grey highlighted box in Fig. 11.1) - utilising AR and cubes - with a pilot study of random participants with un-

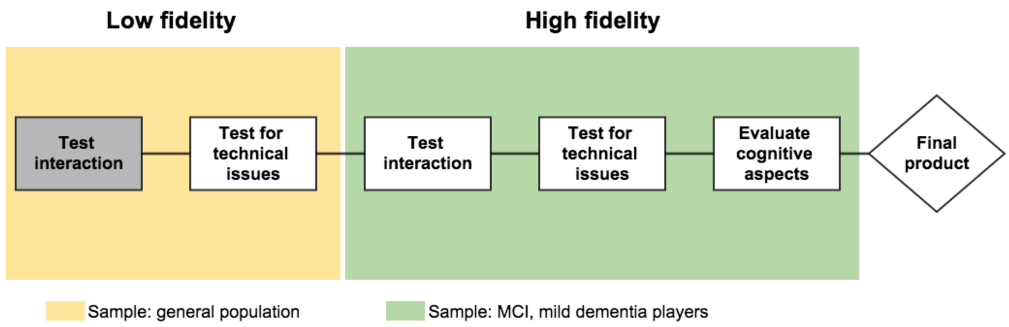

Figure 11.1: The flowchart of the cognitive AR cube system development process.

known cognitive status. However, this study stands as an important first step in the whole development process of the system. For the development of the cognitive AR cube system, we follow a rigorous design process in three parts: examining interaction, solve technical issues, and testing the game's effect on player's cognition (Fig. 11.1).

The prototyping process is broken down into two parts: the low fidelity prototyping stage and the high fidelity one. The main reason behind this distinction is to utilise the low fidelity prototype to solve the main interaction and technical issues, as experienced and suggested by a generic sample of players with unknown cognitive status. Then, the suggested changes are applied and the produced high fidelity prototype will be tested on the main target group (mild cognitive impaired or players with mild dementia), in order to recognise and highlight the unique interaction requirements of the group, if any. Naturally, each development stage described herein includes several iterative design processes until ensuring the proper system quality that will allow to move further, to the next stage. The ultimate goal of the presented design process is, in the end, to produce a robust cognitive training system that will provide us with objective cognitive perfomance-related results, which will be directly affected by the mini-games of the system and which will not reflect interaction or technical inadequacies.

11.3 Designing the interaction of the cognitive AR cube system

The use of physical objects as tools for cognitive training and assessment is well established, especially for the assessment of constructional and matching abilities, which integrate perception and motor response in a spatial context [9]. Cubes are an accredited assistive tool for occupational therapy [7], further used in a wide range of tasks, like cognitive training [4, 3], cognitive assessment [9], motor rehabilitation [3], neurodevelopmental treatment [1] and social engagement through multiplayer gaming [4]. The game element that is associated with the cube, usually originating from childhood memories, transforms them into playful, entertaining objects, appealing to a wide target audience - ranging from children to elderly players - with various health profiles [4, 11, 2].

Consequently, we consider the cube to be not only an ideal input mechanism for cognitive training, but also an assistive tool that can help address the physical/motor skills of the player, thus collecting significant data for the health benefit of the player. The cubes, also, provide a promising platform for augmentation with various gaming "skins", as shown in some of the aforementioned works and projects, providing us the opportunity to explore the area of Augmented Reality further.

Augmented Reality can be beneficial for mental processes, supporting spatial cognition and mental transformation [5]. Furthermore, it may reduce cognitive load by minimising attention-switching, promoting continuous use and physical movement [5].

Especially, in games, AR can evoke the initial engagement of the player utilising the "wow effect", coming from the visualisation of an alternative "reality", augmented with 3D artifacts. Even though, the "wow effect" is short-lasting, it provides the kick-start for engaging the users into playing the game, causing a strong initial impact by addressing to the players' visceral level of processing, which may potentially influence the overall gaming and training experience [8]. Finally, the fact that AR utilises a variety of sensors (e.g. camera, accelerometer, magnetic compass et al.) allows us to get valuable secondary data about the movements of the players, thus being able to assess the players' physical performance and evaluate the changes over time.

11.4 Designing the cognitive AR cube system

The interaction technique implemented in the described first stage features the player sitting in an office, playing the game on a tablet PC by manipulating AR cubes, which are placed on the actual desktop. The cognitive training can take place in a small space, while the whole system is quite portable; it consists of 9 cubes of 3,5 cm/edge, a tablet PC and a base stand (Fig. 11.2).

The design requirements suggested that the player should be able to use both his/her hands in order to manipulate the cubes. AR glasses would be an ideal solution, however - so far - the available options are at an early development stage. In this study, we implement the "magnifying glass" metaphor: an adjustable arm desktop base stand supporting a tablet PC (our version of "magnifying glass") which the player can adjust according to his/her position, in order to have clear view of the desktop, where he/she will interact with the cubes using both hands (Fig. 11.2).

In order to test the interaction technique, we developed the prototypes of two core mini-games. Those games were chosen because they implemented two different gaming and interaction styles, that would allow us to witness the

Figure 11.2: The cubes (left), the player's game view (middle) and playing the game during the pilot study (right).

player's performance under two different conditions. The first game is a word game, which trains logical reasoning. In the game, the player use 9 letters (displayed as 3D models on the cubes) to form as many words as possible within 5 minutes. The second game is a speed, shape-matching game, which trains response inhibition and information processing. The player should match simple shapes (cube, sphere et al.) of different colours as quickly as possible. The first game favours a more focused and calm interaction, whereas the second game favours fast movements. Each game had 4 levels. The 3D objects of the games were designed in a minimal way with plain textures.

For the development of the low fidelity prototype, the Android Vuforia AR SDK was used, and as a testing device we used a tablet PC with a moderate-sized screen and a high-resolution camera (Sony Xperia Z 10").

11.5 Studying the interaction of the cognitive AR cube system

A pilot study was conducted in order to study the interaction with the AR cubes, as well as with the "magnifying glass" base stand. The study was exploratory in nature, looking for interaction problems and specific user behaviours and it was based on direct observation of the player's movements by two AR experts and a semi-structured, informal interview at the end of each gaming session. A random sampling technique was used, in order to register five participants. The participants were asked to game-test the two AR games of the system, to minimise the experimenters' effect on them when interacting with the system. The categorisation of the players was based on their previous experience on using Augmented Reality applications. Two experienced AR users, one moderate AR user and two novice users participated in our pilot study.

The participants had 4 sessions of playing the two games, within a week. Each session consisted of a different level of both games and lasted approximately 10 minutes. At the beginning of the first session the game scenarios were given to the player and at the end of each session a semi-structured interview was conducted, asking for the player's feedback on the cubes interaction, the AR technology, as well as the game setting. The results of the study show us the benefits and the problems of the selected input/output methods.

11.5.1 Results

All 5 players completed the sessions with minor interaction complaints. The experienced players mastered the games and the AR cube interaction right away (Fig. 11.3). However, their style in the word game was featuring fast and sudden movements that led to the constant reproduction of the marker occlusion problem, i.e. the players used to grab the cube in a way that their hand obstructs the tracking of the marker, therefore the 3D model that was "linked" with the marker was not displayed, until the marker was visible again. They both highlighted the *marker occlusion problem* (although admitting they sometimes caused the problem in order to save gaming time) and one of them highlighted a common AR interaction issue, that of *lagging*, i.e. the delay (in milliseconds) between the real movement of the player's hand and its display on the screen via the AR camera capture. In general, the experienced users were more focused on playing the game and completing the task, than mastering the interaction technique. Specifically, after the first session both users mastered the system, accomplishing high scores. The players did not face problems with the "magnifying glass" metaphor, adjusting the AR view through the tablet, according to their postures.

The moderately experienced player faced the *occlusion problem*, however she managed to overcome it the fourth time it appeared (the experimenters did not provide any help about the cause of the problem to the player) by picking the cubes from their sides. The player stressed the *small screen size (10 inches), which limits the 3D gaming space*. However, after the first session, the player had mastered the system, by being able to use the 3D gaming space as defined - and limited - by the AR camera view and by being able to quickly move the cubes, picking them correctly without obscuring the display of the 3D models.

The novice users were the main focus of our study, since the players of this category were completely unaware of the AR technology, therefore a different level of objectivity can be introduced to the results of the pilot study. Both participants experienced the "wow effect" in a degree. During the first session, one of them was moving carefully and slowly, try not to affect the 3D models that were displayed on top of the cubes. The other player found it difficult to adjust to the *depth perception* when looking through the tablet screen. The former player, also, stressed that *"in the word game it was difficult and tiring to reach out the cubes"*, since he avoided to adjust the arm stand and the tablet AR view to his posture and he also *found the 3D gaming space, as defined by the AR camera view, to be limited*. The main finding related to the novice participants was that by the third session they managed to master the interaction and focus on the game, gaining high scores, get used to the depth perception and the AR view, ulti-

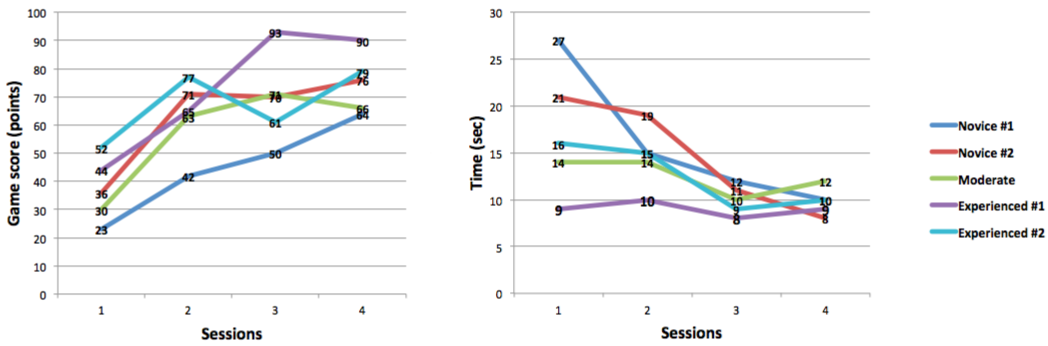

Figure 11.3: The players' performance (the players are categorized according to their AR experience) on the word game, measured by the game score (*left graph*) and on the speed/shape-matching game, measured in seconds needed to complete the level (*right graph*).

mately resembling the gaming style of the other two user groups at the same session (Fig. 11.3). The *occlusion problem* was present in every session of the players (more intense during the first session), however after the third session they were aware of the problem and they were picking the cubes properly.

11.6 Conclusions & future work

The main finding of the study was the *marker occlusion problem*, while we verified several AR technology-related limitations like AR lagging, losing depth perception, and dealing with limited 3D AR space. Another important finding was the fast adjustment of the AR novice users to the introduced interaction technique. So far, there are positive indications that AR cubes, combined with the "magnifying glass" interface metaphor, can be used for cognitive training games, however there are many technical issues to be dealt with, the occlusion problem being the major one.

In our future work, we plan to address the occlusion problem and tweak, in the degree which is possible, the aforementioned AR limitations. Furthermore, the full set of games, even in a prototype shape, will be developed, in order to evaluate interaction with longer sessions, ideally lasting about 30 minutes. Our future goal is to complete the "low fidelity" stage, as described in Fig.11.1, and to test a robust, high fidelity prototype on our target group (cognitive impaired players), also examining the feasibility of the independent use of the system by the players (without external assistance).

The authors would like to thank the Master student, Samuel Jimenez Mu for developing the games that were used in the pilot study.

11.7 Bibliography

[1] ANDERSON, J., HINOJOSA, J., AND STRAUCH, C. Integrating play in neurodevelopmental treatment. *American Journal of Occupational Therapy 41*, 7 (1987), 421–426. 123, 135

[2] BARAKOVA, E., VAN WANROOIJ, G., VAN LIMPT, R., AND MENTING, M. Using an emergent system concept in designing interactive games for autistic children. In *Proceedings of the 6th International Conference on Interaction Design and Children* (2007), IDC '07, pp. 73–76. 124, 136

[3] CORREA, A., DE ASSIS, G. A., NASCIMENTO, M. D., FICHEMAN, I., AND LOPES, R. D. D. GenVirtual: an Augmented Reality musical game for cognitive and motor rehabilitation. In *Virtual Rehabilitation* (2007), pp. 1–6. 15, 16, 123, 135

[4] GAMBERINI, L., FABREGAT, M., SPAGNOLLI, A., PRONTU, L., SERAGLIA, B., ALCANIZ, M., ZIMMERMAN, A., RONTTI, T., GRANT, J., JENSEN, R., AND GONZALES, A. Eldergames: videogames for empowering, training and monitoring elderly cognitive capabilities. *Gerontechnology 7*, 2 (2008). 15, 16, 123, 124, 135, 136, 163

[5] MCCALLUM, S., AND BOLETSIS, C. Augmented Reality & gesture-based architecture in games for the elderly. In *pHealth*, vol. 189 of *Studies in Health Technology and Informatics*. IOS Press, 2013, pp. 139–144. ix, 15, 31, 33, 34, 35, 122, 124, 134, 137, 160, 163

[6] MCCALLUM, S., AND BOLETSIS, C. Dementia games: A literature review of dementia-related serious games. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 15–27. 14, 17, 27, 28, 29, 58, 59, 61, 91, 95, 97, 106, 122, 160

[7] NEISTADT, M. A critical analysis of occupational therapy approaches for perceptual deficits in adults with brain injury. *American Journal of Occupational Therapy 44*, 4 (1990), 299–304. 123, 135

[8] NORMAN, D. *Emotional Design: Why We Love (Or Hate) Everyday Things*. Basic Books, 2004. 124

[9] SHARLIN, E., ITOH, Y., WATSON, B., KITAMURA, Y., SUTPHEN, S., AND LIU, L. Cognitive cubes: A tangible user interface for cognitive assessment. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2002), CHI '02, pp. 347–354. 123, 135, 163

[10] SMITH, G., HOUSEN, P., YAFFE, K., RUFF, R., KENNISON, R., MAHNCKE, H., AND ZELINSKI, E. A cognitive training program based on principles of

brain plasticity: results from the improvement in memory with plasticity-based adaptive cognitive training (IMPACT) study. *Journal of the American Geriatrics Society 57*, 4 (2009), 594–603. 121

[11] ZHOU, Z., CHEOK, A., AND PAN, J. 3D Story Cube: an interactive tangible user interface for storytelling with 3D graphics and audio. *Personal and Ubiquitous Computing 8*, 5 (2004), 374–376. 124, 136, 163

Chapter 12

Augmented Reality Cubes for Cognitive Gaming: Preliminary Usability and Game Experience Testing

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Abstract

Early detection is important in dementia care; however, cognitive impairment is still under-recognised and under-diagnosed. Cognitive screening and training are two important preventative treatments, which can lead to early detection of cognitive decline. In this work, the "Cognitive Augmented Reality Cubes" (CogARC) system is presented, i.e. a serious game for cognitive training and screening, utilising an interaction technique based on Augmented Reality and the manipulation of tangible, physical objects (cubes). The game is a collection of cognitive mini-games of preventative nature and is, primarily, targeting elderly players (geq60 years old). A preliminary testing was conducted focusing on the game experience that CogARC offers (utilising the In-Game Experience Questionnaire), the usability of the system (using the System Usability Scale), and the specific user observations and remarks, as documented by open, semi-structured interviews. Overall, CogARC demonstrated satisfying positive responses, however, the negative reactions indicated that there are specific problems with aspects of the interaction technique and a number of mini-games. The open interview shed more light on the specific issues of each mini-game and further interpretation of user interactions. The current study managed to provide interesting insights into the game design elements, integration of Augmented Reality, tangible interaction of the system, and on how elderly players perceive and use those interaction components.

12.1 Introduction

Older adults often present symptoms of associated memory impairment, which can be caused by normal aging processes, but also indicate the potential development of Alzheimer's disease (AD) - the most common form of dementia [45, 7]. Best practices in dementia care emphasise the importance of early detection; however, cognitive impairment is still under-recognised and underdiagnosed [46, 57, 13, 49]. More than 50% of dementia and 80% of mild cognitive impairment (MCI) cases go unrecognised in primary care [49, 37, 9]. Early diagnosis has many benefits, providing an explanation for changes in behaviour and functioning, and allowing the person to be involved in the planning of future care [49].

Cognitive screening, i.e. the objective measurement of cognitive impairment by standard neuropsychological (cognitive) tests, is an important part of preventative measures, given the benefits of earlier access to information, resources and supports [49, 7, 31, 12, 59]. Cognitive screening represents the initial step in a process of further assessment for dementia and can help identify potential cases for assessment, thus leading to early diagnosis. Early diagnosis provides the opportunity for cognitive training and pharmacological management, if appropriate, aiming to preserve or improve executive function, behaviour, and cognition [7, 31].

Cognitive training has also shown promise as a preventative treatment in the premorbid stage [7, 58]. Examination of the range and limits of cognitive reserve capacity (plasticity) by means of cognitive training has been suggested as a promising diagnostic strategy for the early identification of dementia, particularly Alzheimer's disease, in sub-clinical populations [19, 7]. Clinicians encourage older adults to engage in self-care for cognitive health, through everyday cognitively stimulating activities in non-clinical settings (e.g. patients' homes, senior centres) [7, 58].

To face the new challenges that arise from an ageing society, serious games are presented as a motivating, cognitive gaming platform, aiming to delay or alleviate the cognitive decline of the elderly [7, 8]. The elderly population represents a considerable portion of digital gamers, which is predicted to increase, and serious games may represent a low-barrier, motivating, sustainable and relatively inexpensive method to improve, or at least delay, the onset of impairments in selected social, sensory-motor, and emotional functions of elderly players [47, 38, 32]. Cognitive screening tests and cognitive training exercises have game-like elements or, at least, elements that can be gamified [44, 7]. This allows game designers to relatively easily implement game scenarios where cognitive training exercises coexist with the cognitive screening ones, developing a healthcare instrument of dual nature [7].

The next generation of cognitive training and screening games needs to be designed to address the cognitive state, motor skills and emotional state of the players. To assess cognitive state the games should collect both primary cognitive performance and secondary data including dexterity measures, stability of hand movements, heart rate, breathing activity and stress levels [6]. The "Cognitive Augmented Reality Cubes" (CogARC) system is designed and developed with this more holistic approach to cognitive assessment.

12.1.1 CogARC: a serious game for cognitive training & screening

CogARC is a serious game for cognitive training and screening, utilising an interaction technique based on Augmented Reality (AR) and the manipulation of tangible, physical objects (cubes). The game is a collection of cognitive minigames of preventative nature and is targeting elderly players (geq60 years old), mild cognitive impaired players and, secondarily, healthy adults, with an interest in gaming and/or cognitive training. The ultimate goal of CogARC is to alleviate or prevent cognitive decline. The stimulating cognitive training with CogARC is aiming to screen the cognitive abilities of the players on a frequent basis (potentially even daily), triggering referral for a more comprehensive assessment, thus playing an intermediary role between the (potential) patient and the medical expert, and leading to early treatment.

This paper presents the next step in the project's development, building on the design and testing of the interaction techniques described in [6]. In the current work, the game content has been added, the game interaction is adjusted, based on the previous study's findings, and the system is evaluated with respect to the new designs, its usability issues, and the game experience it provides to elderly players. CogARC's game design aims to provide challenging cognitive training and, at the same time, offer a pleasant gaming experience that will motivate the elderly players to exercise their cognitive skills and log their cognitive game performance (for screening purposes) more often. The interaction goal is to provide the elderly players with a cognitively stimulating and suitable interaction technique, which will utilise known interaction metaphors, will be portable and will be used without any assistance. To evaluate the design of the game content an empirical study with three assessment objectives was conducted: 1) the game experience it offers (using the in-Game Experience Questionnaire), 2) the usability and interaction (using the System Usability Scale), and 3) the personal experience of playing (having open, semi-structured interviews).

12.1.2 Contribution & paper organisation

The current work contributes to the field of serious games for health by describing the quality assurance process of a serious game for cognitive training, focusing on technological, behavioural, and motivational issues, which constitute important factors in the development and evaluation of serious games [33, 26]. Moreover, the work provides insight on the use of Augmented Reality, tangible interaction, and cognitive training games from elderly users and documents some of the problems that developers of similar serious games could face.

The rest of the paper is organised as follows. Section 12.2 describes the CogARC game design elements, focusing on the interaction technique, the game content and the gameplay. Section 12.3 presents the preliminary usability and game experience testing of CogARC. Section 12.4 discusses the results of the testing, while the paper is concluded in Section 12.5.

12.2 Game design

This section analyses the game design process for CogARC including the requirement analysis, interaction design, content, interface design, and gameplay. CogARC was developed using the Vuforia AR SDK (Unity extension) and was tested on a Sony Xperia Z 10″, which has both a good screen and rear-facing camera. A multidisciplinary team was involved in the development of the game, including both ″fun-ness″ members, focusing on the entertaining nature of the game, and ″serious-ness″ members, focusing on content validity [5, 33]. The team included three game developers and two game designers, a physician specialising in mental health and disorders, and two academics specialising in behavioural change and serious games.

12.2.1 Requirements

CogARC is designed to be an engaging tool for cognitive screening. Therefore, the elderly players should be motivated and engaged to play it on a frequent basis. To achieve this, the game environment is specifically and primarily designed for elderly players. Universal design principles that accommodate older adults [17], as well as design and usability suggestions for elderly players [30, 25], were taken into consideration when forming the usability requirements of CogARC (Table 12.1, Req. 1-5). The usability requirements address the comprehensibility and perceptibility (Table 12.1, Req. 1, 2), the learnability and simplicity (Table 12.1, Req. 3), the attractiveness (Table 12.1, Req. 4), and the operability of the system (Table 12.1, Req. 5,) for elderly players. The design focus is on creating a pleasant gaming environment that minimises negative feelings of tension, uncertainty, and confusion, which may arise from a complex system, designed for the typical user (male, fit, and with static-overtime abilities) [27, 39]. Furthermore, the system should be easily operated by the elderly player, since the game should be played without any assistance, so as to document each individual player's cognitive performance objectively, for screening purposes.

Widely used cognitive screening instruments, such as the Montreal Cognitive Assessment (MoCA) [42], the Mini-Mental State Examination (MMSE) [21], attempt to measure a representative instance of the user's cognitive status and are usually short in duration (i.e. they do not tire the user). However, these instruments are susceptible among others to "white coat" and learning effects, long test-rest periods (usually one month or more) and negative effects on the user's screening motivation [49, 7]. CogARC, being a serious game for cognitive screening, needs to include several of the main characteristics of traditional cognitive screening tools while alleviating the negative ones. Firstly, CogARC needs to provide cognitive stimulation to the player (Table 12.1, Req. 6) and capture a representative instance of the player's cognitive status, addressing a number of cognitive functions and the motor skills (since motor kills decline can be associated with cognitive decline [35]). By addressing the "learning effect" issue (Table 12.1, Req. 8), a serious game for cognitive screening, like CogARC, could be played more frequently, thus providing more timely cognitive-related data to the player. This would be particularly useful for screening purposes and in case of sudden cognitive decline (Table 12.1, Req. 7). Furthermore, a cognitive screening game can entertain and engage the player (Table 12.1, Req. 9), offering a motivating gaming experience of fun and stress-free playing, which can lead to more frequent screening through the game and better quality of cognitive-related data.

From a technical standpoint, CogARC and its next version should be playable on the players' personal tablet PC devices (Table 1, Req. 10), thus at their places of choice and not only in a controlled, gaming environment. By having the players playing CogARC at their places of choice, there is the potential to decrease biases caused by stress created by an unfamiliar environment. The following subsections present how these requirements were addressed.

12.2.2 User interface design

The user interface (UI) design of CogARC is specifically designed for elderly players and is based on the principles of simplicity and intuitiveness, providing appropriate affordances and overview, thus keeping the load on memory and cognitive processing to a minimum [30]. The menus are clear and simple in structure, with large-sized icons, text, and buttons. The game's auditory feedback is limited and text and icons are used for guiding the player, satisfying the need for sensitivity to players' decreased sensory acuity [20]. The relevant game objects (3D models used to augment the cubes) have clear elements, which are highlighted through contrast and colour settings [25]. The implementation of visual effects took place only for purposes of motivational feedback, after the successful completion of a level. The UI design of CogARC was based on the design principles for elderly players as described in [30, 25, 20, 24].

12.2.3 Interaction components

The main components of CogARC's interaction design are: a) the tangible, physical objects, which serve as input mechanisms - i.e. the cubes - and b) the Augmented Reality technology.

The use of physical objects in the cognitive health domain is well established [6, 51] and, more specifically, cubes are an accredited assistive tool for occupational therapy [43], cognitive training [23, 14], cognitive assessment [51], motor rehabilitation [14], and neurodevelopmental treatment [2]. The game element that is associated with the cube, usually originating from childhood memories,

Table 12.1: The usability, game design, and technical requirements for the CogARC system.

Nr	Requirements	Field
1.	Interface elements (e.g. menus) should be easy to understand.	Usability
2.	The necessary information should be communicated across the expected range of user sensory ability (highlighting/differentiating elements, maximising legibility, et al.).	Usability
3.	The system should be simple to use, easy to learn and used individually by the player.	Usability
4.	The interface actions and elements should be consistent, protecting the users from errors.	Usability
5.	The screen layout, colours and interaction components should be appealing to the player.	Usability
6.	The system should capture an instance of the player's cognitive status, addressing a wide range of cognitive and motor skills.	Game design
7.	The system content should record the player's cognitive performance on a frequent/iterative basis.	Game design
8.	The game content should be automatically or randomly generated in every gaming session.	Game design
9.	The game should engage and entertain the player over time by utilising the appropriate game mechanics.	Game design
10.	Cross-platform (mostly Android, iOS) gaming should be supported.	Technology

transforms them into playful, entertaining objects, appealing to a wide target audience - ranging from children to elderly players [23, 6, 60, 4]. Therefore, as part of CogARC's interaction technique, the cube is considered to be an ideal input mechanism for cognitive training and a familiar, assistive tool that can help address the physical/motor skills of the player, thus collecting additional, significant data for the health benefit of the player. Furthermore, the cubes constitute an ideal component for digital and physical augmentation with various game patterns, providing the game designers the opportunity to create various game scenarios with just a set of cubes and, at the same time, examine further

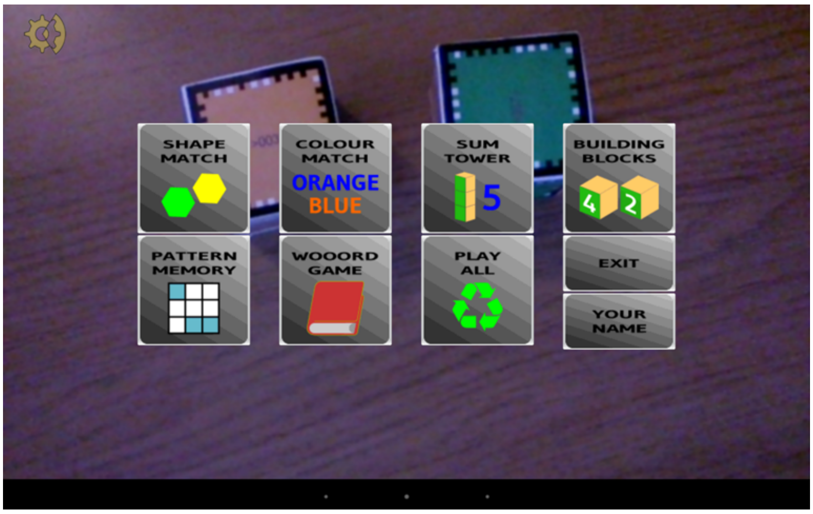

Figure 12.1: The main menu of CogARC.

the use of AR in the cognitive gaming context [6].

Augmented Reality is a technology which is strongly connected with the user's cognitive and physical functionality, since it can be beneficial for mental processes, supporting spatial cognition and mental transformation [6, 39]. As a component of CogARC's interaction technique, AR can evoke the initial engagement of the player, utilising the "wow effect" which originates from the visualisation of an extra layer of 3D artifacts on top of the real world view [6]. Moreover, AR utilises a variety of sensors to register and recognise the real world before augmenting it, thus - apart from providing the CogARC's game content by augmenting the real world view - it can also augment the real world use, by evaluating the real world tasks using accuracy and error measurements [6].

12.2.4 Interaction technique

The interaction technique of CogARC features the player sitting at a desk, playing the game on a tablet PC by manipulating the AR cubes that are placed on the actual desktop. The AR game content is projected on the cubes' view through the tablet PC camera and the player moves and matches the cubes, according to the game task. The cognitive training gaming session can take place in a small space, while the whole system is quite portable; it consists of 10 cubes of 4.4 cm/edge and with Vuforia AR frame markers on every side, a tablet PC and a base stand (Fig. 12.2). The base stand is an adjustable arm desktop base stand supporting a tablet PC (similar to commercial magnification sheet stands) which the player can adjust according to his/her position, in order to have a clear view of the desktop, where he/she will interact with the cubes using both hands. The base stand is an important component of the interaction technique since the player should be able to use both his/her hands in order to manipulate the cubes.

The interaction technique of the system was previously examined and studied in [6]. The previous study revealed a number of interaction problems, originating from AR's functionality. Most of those issues were addressed during the development of CogARC and the examination of the effect of those adjustments on the system's usability is one of the goals of the current preliminary testing.

First of all, at the previous stage, the marker occlusion problem was present, i.e. the players used to grab the cube in a way that their hand obstructed the tracking of the cube's marker, therefore the 3D model that was associated with the marker was not displayed, until the marker was visible again. To address this issue, a custom multimarker setup was developed, i.e. multiple markers (one frame marker/side) were fixed to every cube. The logic behind this adjustment is that the multimarker setup significantly increases robustness to occlusion and it is capable of keeping track of the camera and placing the 3D model at scene, even if one marker is obscured or out of the camera field, since another marker may be visible [1]. This adjustment is important since it provides the user with more freedom to move the tablet device and manipulate the cubes without having to worry about obscuring the markers and, consequently, the appearance of the 3D model.

The issues of lagging, i.e. the delay (in milliseconds) between the real movement of the player's hand and its display on the screen via the AR camera capture, was technically addressed by moving to the Unity development platform and to the Vuforia Unity extension, in order to improve the tracking performance and make it less resource-demanding. The use of the Unity platform also facilitates the export of an Android and iOS version of the game, thus addressing the requirement of cross-platform support (Table 12.1, Req. 10).

The issues of the limited 3D gaming space as defined by the small screen size (10 inches), and of the loss of the player's depth perception when looking through the tablet screen, are AR-related, hardware issues that were proven to take place during the first uses of the system [6]. To address these issues, the players were given the opportunity to have an open trial session in order to get accustomed with the system's interaction technique and the game content.

12.2.5 Game content

CogARC features 6 mini-games, which address various cognitive abilities (Section 12.2.6). The following section thoroughly describes the characteristics of the CogARC game and its mini-games. At first, the generic elements of the game, which are present in all of the mini-games, are described, concluding with the mini-games' individual characteristics (Table 12.2).

- **Players' game objectives:** Completing the cognitive tasks of the mini-game levels correctly and as fast as possible, to score more points.

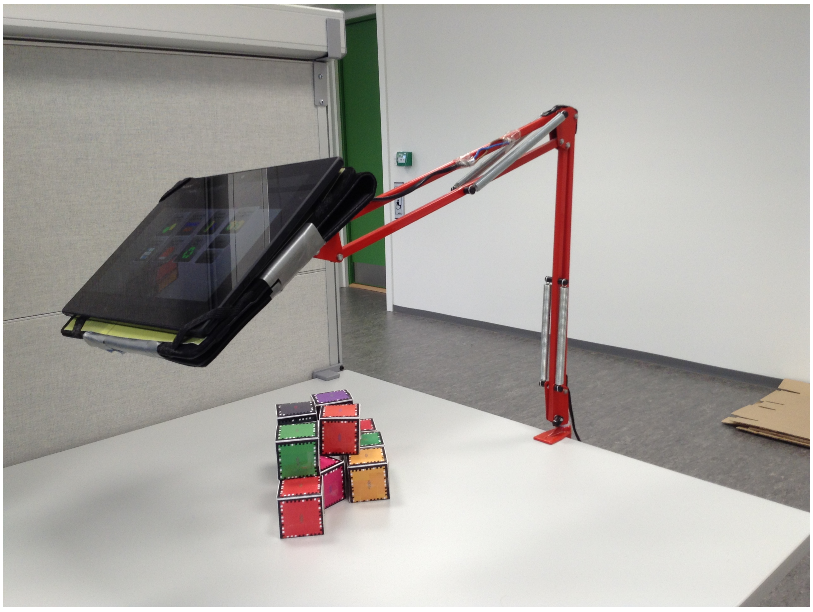

Figure 12.2: The CogARC interaction setup: the 10 cubes and the tablet PC on the base stand.

- **Game mechanics:** CogARC utilises the following game mechanics:
  - *Challenges:* the cognitive tasks should be completed to earn points.
  - *Competition:* leaderboards and score ranking are used, per mini-game.
  - *Feedback:* success messages for the completion of the cognitive tasks (Fig. 12.3), performance feedback, i.e. score per mini-game, and feedback on competition, i.e. ranking and leaderboards per mini-game, are used.
  - *Rewards:* the player earns points for completing the levels.
- **Scoring:** CogARC's scoring computation formula is identical for all the mini-games, it is related to the successful completion of the cognitive task and is also inversely related to the level-completion time; therefore the faster the player completes each level's task, the more points he/she scores. The player gets a specific amount of points when completing the level plus the time bonus. The level-completion time is calculated as the elapsed time between loading the level and successfully completing the cognitive task. The points earned are added incrementally to form the player's mini-game score and that score is displayed on the mini-game's leaderboard.
- **Level generation:** The mini-game levels are randomly generated from a database of game content. Therefore, the player comes across different game content, almost every time he/she plays a mini-game, thus addressing the "learning effect" issue.

- **Difficulty level:** The difficulty level of the game tasks is uniform and at a moderate degree for all the mini-game levels, in order for the system to be able to establish a player-specific scoring baseline and detect changes in scores over time, for screening purposes. The challenging factor of the game mostly rests on the player pursuing lower level-completion times.

- **Gameplay structure:** The gameplay structure presents two modes: the free and the linear. The player has the options either to play the mini-games freely, in any order and for as many levels as desired (i.e. the free mode) or to play all the mini-games (one level/mini-game) in a predefined sequence (i.e. the linear mode). Even though both modes favour casual gaming, they aim to engage different kinds of player types; the free mode is expected to favour a more competitive gameplay style, whereas the linear mode targets the kind of gaming that is more focused on the final cognitive health goal.

- **Game-end condition:** When each level is complete, an end screen appears, displaying the player's score, the ranking on the leaderboard and the option to move on to the next level. After the completion of the final level the player is shown his/her mini-game score, the ranking on the leaderboard and can return to the main menu.

- **Estimated playtime:** 10-15 minutes for the linear mode (i.e. one level/ mini-game).

12.2.6 Cognitive abilities

CogARC mini-games' concepts were co-designed and approved by the project's physician, aiming to cognitively stimulate the player, by directly addressing a wide range of cognitive abilities. Each mini-game focuses on specific cognitive abilities, however the total cognitive abilities that are addressed in the CogARC game are: Perception, Attention, Visual and Spatial Processing, Language Processing, and the following Executive functions: Flexibility, Response Inhibition, Problem Solving, Decision Making, and Working Memory [18]. All the mini-games are addressing the player's Motor Skills, since the game's interaction technique is based on manipulating tangible objects (cubes) for performing game tasks.

The "Shape match" mini-game (Fig. 12.3) asks from the player to recognise and interpret the visual stimuli of shapes (addressing the cognitive ability of Perception) and to sustain concentration on them (Attention) in order to identify them correctly. The constant and quick identification and matching of new shapes requires from the player to switch between mental modes (Executive function: Flexibility), as well as avoid the wrong answers (Executive function: Response Inhibition), which may be the result of high gameplay speed.

Table 12.2: The CogARC mini-games' individual characteristics.

Title	AR game content	Goal	Interaction technique	Cubes' nr.
Shape match	Shapes	Match same shapes	Place the cubes next to each other (in pairs)	10
Colour match	Coloured text	Match one word's meaning to another word's colour	Place the cubes next to each other (in pairs)	10
Sum tower	Numbers	Use the numbers to create the desired total sum	Place the cubes on top of each other	10
Building blocks	Numbers	Find the answer to simple arithmetic calculations	Place the cubes next to each other	10
Pattern memory	Coloured tiles	Memorise a 3x3 matrix pattern of coloured tiles and recreate it	Create a 3x3 matrix using the cubes	9
Word game	Letters	Form as many words as possible - out of letters - related to a given subject	Place the cubes next to each other	10

"Colour match" is a game inspired by traditional Colour Matching Tasks and the Stroop effect [52]. The game resembles the "Shape match" game and it addresses almost the same abilities, however it trains the abilities of Perception, Attention and Response Inhibition at a higher degree, focusing more on the Visual Processing ability. The player has again to recognise some visual stimuli, i.e. the text's colour, and interpret others, i.e. the text's meaning (Perception, Visual Processing). The demanding Visual Processing task requires the player's constant attention and concentration on the task (Attention), as well as his/her ability to withstand perceptive urges that could lead to errors (Executive function: Response Inhibition). The cognitive Flexibility is also necessary since the player should constantly transition from thinking about one concept (e.g. text's colour) to another (e.g. text's meaning).

The "Sum tower" and "Building blocks" mini-games are both addressing the executive functions of Problem Solving and Decision Making. "Sum tower" favours Decision Making since the player has to decide on the right numbers, which when added will lead to the solution, i.e. the desired total sum (Problem Solving). "Building blocks" is a straightforward arithmetic calculation game, on which the player is finding the solution to the problem, i.e. the arithmetic calculation. The two games differ on the address of Motor Skills, utilising a different interaction technique (Table 2), with "Building blocks" requiring the setting of

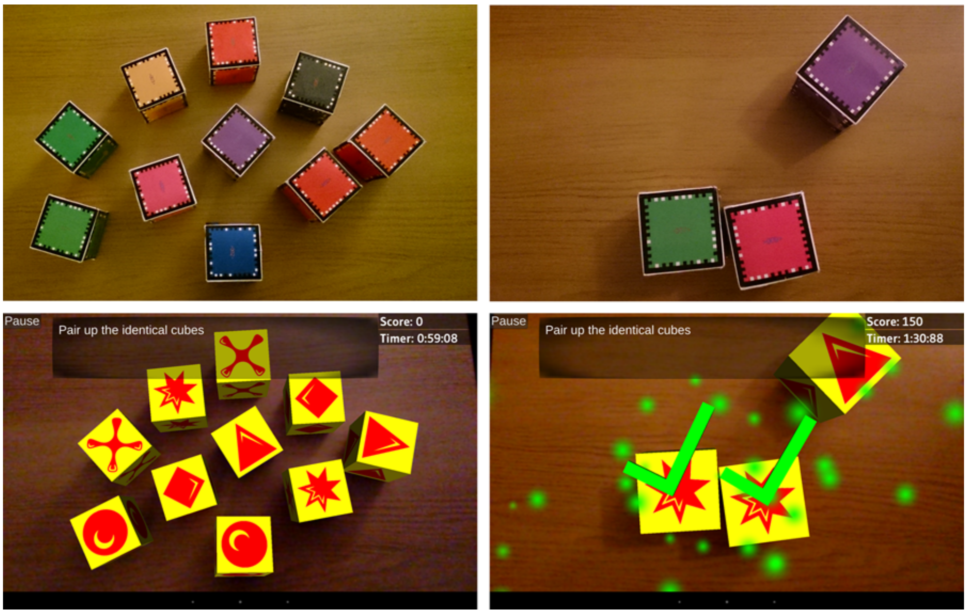

Figure 12.3: The real world view (*upper left & right*) and the augmented view, as seen on the tablet PC screen (*lower left & right*). A screenshot from "Shape match" with all the cubes on scene (*lower left*) and a success message after a correct shape match (*lower right*).

the cubes to be vertical (cubes on top of each other), instead of horizontal (cubes next to each other), which is the case with all the other mini-games.

"Pattern memory" is firstly about memorising a matrix pattern, thus targeting the Working Memory. Naturally, the player needs to sustain the concentration on the task (Attention), as well as visually process the 3x3 matrix pattern of tiles and understand the spatial relationship between the tiles (Visual and Spatial Processing), before memorising it and recreating it using the cubes.

The "Word game" is a mini-game, which targets the Language Processing and Problem Solving abilities, since the player is given a specific subject, and tries to generate possible solutions/words (using the available letters/cubes) and pick the right one. The Working Memory is also addressed since the player will train on the ability to hold and manipulate information (i.e. letters, correct words, wrong words, possible words) in real time.

12.3 Usability & game experience testing

The current work examines:

- the game experience that CogARC offers, utilising the In-Game Experience Questionnaire (iGEQ),
- the usability of the system, using the System Usability Scale (SUS), and

- the specific user experiences and remarks as documented by open, semi-structured interviews.

The goal of the usability and game experience testing is to identify any usability problems, collect qualitative and quantitative data and determine the players' satisfaction with CogARC. The collection of all the necessary information will guide the next design and development stage, focusing on the game content, the interaction technique and the implementation of the Augmented Reality technology.

12.3.1 Participants

A convenience sample of five older adults (n = 5) participated in the testing. The sample size, even though limited, was considered adequate for providing preliminary feedback on usability issues and game design/development quality, as part of a larger iterative design process. Included participants had to be ≥60 years old (according to the World Health Organisation's definition of an older person and the United Nations agreed cutoff [1]), independently performing activities of daily living (ADL), not diagnosed with any kind of dementia, familiar with technology (i.e. using or having used laptop, tablet PC, smartphone, et al.) and video games (i.e. playing or having played video games before), and finally be novice AR users. The inclusion criteria minimised the risk of the results of testing being affected by technology-use and video-gaming biases, which can be present in game studies when participants are asked to use systems that they have no experience or interest in. All participants gave informed consent to participate in the testing.

12.3.2 Methodology & procedures

A mixed methodological approach was followed for the usability and game experience testing of CogARC, utilising both qualitative and quantitative methods. The focus of the testing was on qualitative observations related to usability and game content issues. The quantitative methods (the iGEQ and SUS surveys) are used to support the qualitative analysis. Naturally, the small sample size cannot lead to statistically significant, robust, quantitative results, however the iGEQ and SUS measures can shed more light on the issues examined, providing reliable indications and seeding a discussion around CogARC's qualitative characteristics.

The data collection process took place, as follows:

1. Demographic data were collected before the start of testing.

2. The participants were given the opportunity to trial the linear gameplay mode (one level/mini-game, 10-15 minutes total playtime) followed by

[1] Definition of an older person: www.who.int/healthinfo/survey/ageingdefnolder/en/

the free play mode with any mini-game they wanted (for approximately 10 minutes).

3. The main gaming session required the players to complete two levels of each mini-game followed by filling out the iGEQ survey for that mini-game. Consequently, 6 iGEQ surveys were completed per player. All the mini-game levels were set at the same difficulty level (moderate), as stated in Section 12.2.5. The mini-games were randomly sorted and the levels of the mini-games were randomly generated (as stated in Section 12.2.5) to avoid learning effects. During the session, the leaderboard of all the mini-games were filled with 5 ”ghost” scores with the intention of increasing competitive motivation. The main game session lasted 25-30 minutes in total, and the 6 iGEQ surveys completion time was approximately 10 minutes.

4. Finally the players were asked to complete the SUS survey and participate in an open interview, mainly focusing on documenting the player's remarks and comments. The SUS survey-interview phase lasted 15-20 minutes.

12.3.3 Measures

The players' game experience was measured by filling out the In-Game Experience Questionnaire (iGEQ) [29]. The iGEQ contains 14-items, rated on a five-point intensity scale ranging from 0 (”not at all”) to 4 (”extremely”), distributed in pairs between seven dimensions of player experience: 1) Immersion (sensory and imaginative), 2) Flow, 3) Competence, 4) Tension, 5) Challenge, 6) Negative affect and 7) Positive affect [29, 28, 15, 16]. The iGEQ has been used in several gaming studies and is of sufficient quality to accurately report game-play experience [28, 15, 16, 22, 41]. The iGEQ is the shorter - but reliable - in-game version of the GEQ [29], and it was chosen so as not to tire the players when completing the full questionnaire per mini-game [56].

The usability of the system is measured using the System Usability Scale (SUS). The System Usability Scale [10] is an instrument that allows usability practitioners and researchers to measure the subjective usability of products and services. Specifically, it is a 10-item survey that can be administered quickly and easily, and it returns scores ranging from 0-100 [10, 36]. SUS has been demonstrated to be a reliable and valid instrument [3, 34], robust with a small number of participants [55], and to have the distinct advantage of being technology agnostic, meaning it can be used to evaluate a wide range of hardware and software systems [36, 11].

The iGEQ and SUS surveys can provide general information on the players' game experience and the perceived usability of the system, however they cannot directly contribute to the identification of technical, gameplay, and usability issues, which is the primary goal of the testing. For this reason, a short, open,

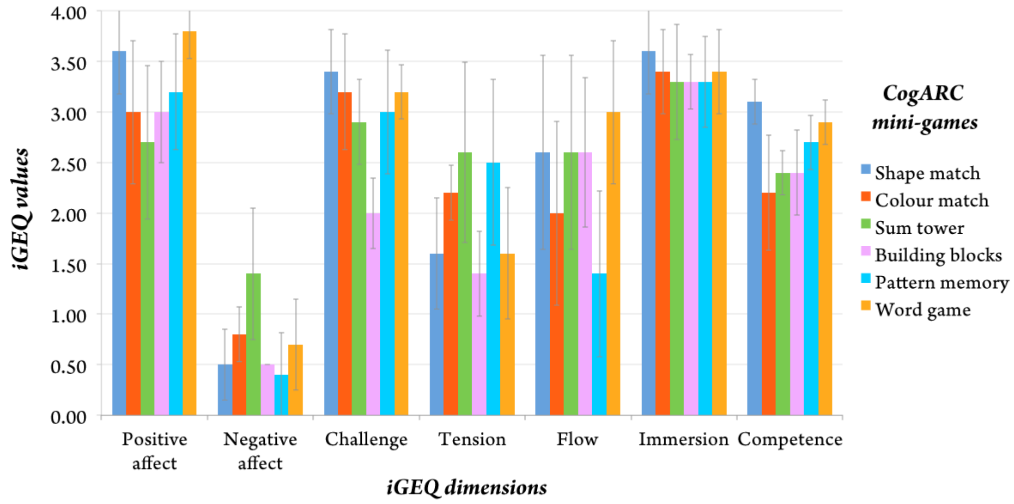

Figure 12.4: Mean iGEQ scores (with standard deviation bars) across the seven dimensions of Game Experience, for the mini-games of the CogARC game.

semi-structured interview was conducted immediately following the completion of the two surveys. During the interview, the player was asked to identify and comment on the positive and negatives points of the gaming session. The interviewer followed up with exploratory questions in order to gather more information about the issues and the game elements that affected the playability of CogARC.

12.3.4 Results

In total, 5 participants (mean age: 67.6, SD: 5.77, range: 61-75) were recruited for the usability and game experience testing. Three participants have completed tertiary education and two have completed secondary. All of the participants were using technology on an everyday basis and owned a laptop and, at least, one mobile device (smartphone, tablet, e-reader). The participants had some degree of experience with video games (three of them playing video games "rarely" and the other two "frequently") and they had never used the Augmented Reality technology before (as required by the inclusion criteria). No participant dropped out during the testing.

The iGEQ survey produced valuable results related to the players' game experience. The data collection method for each mini-game supported the analysis of each mini-game separately and provided an overview of the game experience of each mini-game. The performance of each mini-game in every dimension of the Game Experience Questionnaire scale can be seen in Fig. 12.4.

The data acquired by the SUS survey provided extra insight on the usability of the system and, especially, the use of the interaction technique and Augmented Reality. According to [3, 11, 54, 48], the average SUS score across var-

Table 12.3: The player's remarks as collected from the open interview.

Subject	**Remark**
Interaction	The AR game content that is displayed on the cubes interferes with the real content of the cubes, i.e. the markers.
Interaction	Loss of depth perception when interacting in the real world and displaying the AR output to the tablet PC's screen.
Technology	Lagging issues from time to time, when tracking all the AR multimarkers on scene.
Interaction	The cubes constitute an entertaining and engaging interaction component.
Interaction	The "Sum tower" mini-game provided a confusing interaction technique (placing cubes on top of each other, instead of next to each other).
Game content	The "Word game" is an enjoyable mini-game with interesting challenges.
Gameplay	The linear gameplay mode is preferable than the free mode.
Game content	The "Building blocks" mini-game was not challenging.
UI graphic design	The UI presents icons of bad quality, dark colours, and low readability of text in some cases.

ious technologies is 68 out of 100 (these scaled scores are not a percentage), meaning it is at the 50th percentile. The average SUS score for CogARC was 70.5 (SD: 6.71, range: 65-80), placing its percentile ranking around 60%, according to the percentile rankings of SUS scores [48]. The SUS score of 70.5 indicates that CogARC has a higher usability score than approximately 60% of all applications tested.

The interviews that were conducted at the end of the gaming session resulted in the following qualitative results/remarks, presented in Table 12.3. The remarks were further organised and are listed according to their frequency of occurrence (top to bottom, top being the most frequently occurring remark).

12.4 Discussion

12.4.1 Usability & game experience findings

The use of the iGEQ and SUS surveys and the open interview allowed the evaluation of the gaming experience both qualitatively and quantitatively, as well as the collection and identification of all the specific issues, which affected the gaming experience and that will be further addressed.

The fact that an iGEQ survey per mini-game was used, resulted in a closer examination of the gaming experiences offered by each CogARC mini-game, as well as a more objective estimation of the CogARC Game Experience as a whole. Overall, the iGEQ demonstrated satisfying elements of Positive affect, Immersion and Challenge (Fig. 12.4). However, the values of Negative affect, Tension and Flow indicated that there are specific problems with several of the mini-games. Naturally, the iGEQ highlights the general performance of each mini-game, however it does not recognise the exact issues that affect the performance. The performance of the individual mini-games significantly affected the general Game Experience and the Usability score. The SUS score of CogARC (70.5) was just above average and denoted low perceived usability from the players. Furthermore, it suggested that the low perceived usability was directly connected with the high Negative affect and Tension values of some mini-games. The open interview shed more light on these specific issues of each mini-game and further provided a means to interpret the values of the quantitative methods.

The use of cubes as interaction components was verified by the usability and game experience study, however several AR-related, usability, interaction, and game design issues for elderly users were also discovered.

- All the players - to some extent - experienced the loss of depth perception when interacting in the real world and watching the output on the tablet's screen.

- According to the iGEQ, the "Sum tower" mini-game presented high Negative affect and Tension, whereas the "Pattern memory" mini-game scored low in Flow and high in Tension. Indeed, the players' remarks suggest that the "Sum tower" was using a confusing interaction technique (placing cubes on top of each other, instead of next to each other) and the "Pattern memory" presented technical problems (lagging), since there were many multimarkers on the screen at the same time (tracking needed more computational power), and sudden player movements were taking place, in order to solve the task as quickly as possible.

- A significant interaction issue was that the players confused the actual shape and colour of the cubes' AR markers (real world view) with the displayed 3D content of the AR marker (camera view), especially for the "Colour match" games, thus the high Tension values. Therefore, there was a mixed perception of the reality-virtuality space by the elderly players, leading to confusion.

- From a game design point of view, the players found the "Building blocks" not to be a challenging mini-game (a remark supported by the game's low Challenge value), whereas they found the "Word game" to be an entertaining game and an interesting concept (also supported by high Positive affect values).

The AR-related issues of loss of depth perception and lagging were also discovered in the previous study of [6]. Even though, the problems were addressed and moderated for the current testing, they still exist and affect the gaming experience negatively, something that can be witnessed in the Tension values of Fig. 12.4.

12.4.2 Addressing the current issues

To further address the AR-related issues, it is important to examine and change - if necessary - the position of the game's technology in the Reality-Virtuality continuum [50]. CogARC utilises the AR technology and, so far, is also borrowing elements from Mediated Reality, i.e. a more general framework for artificial modification of human perception, using devices that augment and alter sensory input. Moving the game interaction technology towards the Reality spectrum on the Milgram's Reality-Virtuality Continuum [40] could address the aforementioned AR-related issues. Therefore, placing the main part of the interaction and the game content at the real world (e.g. real colours, shapes, etc. on the cubes) and, at the same time, using the game content to trigger the AR functionality could potentially provide a more clear interaction technique, which would improve the gaming experience.

Placing the interaction space in the real world could potentially solve the depth perception issue and the interaction technique could be reinvented, using a simpler approach. The reduction of the number of cubes (i.e. less AR markers to track) on screen and "simpler" AR content could address the lagging issue. The "move" of the interaction space towards the real world in combination with fewer cubes could also address the limited interaction space problem, as described by a number of elderly players (Table 12.3).

As for the game content, the "Pattern memory" game can be removed and the "Sum tower" could merge with the "Building blocks" - being both arithmetic calculation games - to create a more challenging mini-game. The linear gameplay mode is preferable by the elderly players, as the game has a clear structure with a start and an end point, containing clearly defined levels, thus reducing the players' cognitive load from taking extra game decisions. Therefore, the linear mode could be the only mode available in the next version of the game, offering a structured and short gaming experience (of approximately 10 minutes) that would focus on iterative gameplay. Moreover, the UI would need several adjustments, with a focus on aesthetics and text readability.

12.4.3 Lessons learned

The usability and game experience testing led to several observations, which will be taken into consideration for the next stage of the game development, and which might be of use for researchers and game developers in this field.

- The quantitative methods of the iGEQ and SUS surveys were showed to be useful for providing objective and reliable indications, which may not be discovered solely by using qualitative means. Small scale usability testing may benefit from the use of quantitative measures, as a means of supporting qualitative methods and guiding the discovery of qualitative results.

- Eliminating error-prone conditions is of great significance and should be highlighted, when designing for such a heterogeneous group as the elderly [24]. This specific design principle was proved to be crucial for the CogARC testing and it can greatly affect the quality of a system designed for elderly users. System errors contribute to negative feelings of confusion, uncertainty and tension. The system design should focus on preventing errors, then recovery from errors and only as a last resort error messages that are easy to follow.

- Age-related changes in cognition should be taken into consideration when designing a system for elderly users. Augmented Reality is closely related with the user's perceptive and cognitive abilities [6, 53] and the AR implementation should be iteratively tested and tweaked until it satisfies the interaction needs of the targeted group and fulfills the targeted goal. An iterative design approach, when implementing AR for the elderly may be a challenging - yet necessary - process, according to the CogARC experience.

- Interaction issues may negatively affect the perception, cognition, and emotional state of the users, consequently having major effects on the targeted cognitive stimulation. The interaction technique of software and video games for cognitive training and screening, which target specific user groups, should be considered as an integral and important part of the developed system. Extensive and iterative usability testing may be required in order to form an appropriate interaction technique.

- Game mechanics, like Competition, Feedback, Rewards, and Challenges, have been found, so far, to motivate and entertain the elderly players. Cognitive games can be played with the explicit motivation of sharpening one's mind [30], however many elderly players enjoy challenging mental activities, such as puzzles and quizzes (e.g. the CogARC's Word mini-game), which add extrinsic motivators, social interaction and initiate enjoyable topics of conversation (e.g. by playing with friends and/or having a competition). The examination of the long-term motivation, engagement, and social interaction, which these game mechanics trigger for elderly players, is a research goal that needs further investigation.

12.5 Conclusion & further research

The current work presented a stage of the quality assurance process for the CogARC game. The preliminary usability and game experience testing managed to provide interesting insights about the game design elements, the integration of Augmented Reality, the tangible interaction of the system, and about how elderly players perceive and use those interaction components.

The outcomes of the testing will form the next version of the game (the discovered issues will be addressed as described in Section 12.4.2). The idea of moving AR towards the Reality spectrum will be implemented and further investigated, in terms of interaction and expected impact on the mini-games. The game content will also be redesigned to meet the remarks of the tester. The focus of the future work will be to design and develop a stimulating, cognitive training game that will provide a compelling game experience, validated for elderly players, to be used as a motivational, cognitive health screening tool.

12.6 Acknowledgements

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12.7 Bibliography

[1] ANAGNOSTOU, K., AND VLAMOS, P. Square ar: Using augmented reality for urban planning. In *Proceedings of the 2011 Third International Conference on Games and Virtual Worlds for Serious Applications* (2011), pp. 128–131. 138

[2] ANDERSON, J., HINOJOSA, J., AND STRAUCH, C. Integrating play in neurodevelopmental treatment. *American Journal of Occupational Therapy 41*, 7 (1987), 421–426. 123, 135

[3] BANGOR, A., KORTUM, P. T., AND MILLER, J. T. An empirical evaluation of the system usability scale. *International Journal of Human-Computer Interaction 24*, 6 (2008), 574–594. 144, 145

[4] BARAKOVA, E., VAN WANROOIJ, G., VAN LIMPT, R., AND MENTING, M. Using an emergent system concept in designing interactive games for autistic children. In *Proceedings of the 6th International Conference on Interaction Design and Children* (2007), IDC '07, pp. 73–76. 124, 136

[5] Baranowski, T., Buday, R., Thompson, D., Lyons, E. J., Lu, A. S., and Baranowski, J. Developing games for health behavior change: Getting started. *Games for Health Journal 2*, 4 (2013), 183–190. 134, 161

[6] Boletsis, C., and McCallum, S. Augmented Reality cube game for cognitive training: An interaction study. *Studies in Health Technology and Informatics 200* (2014), 81–87. 35, 60, 61, 132, 133, 135, 136, 137, 138, 148, 149, 160, 161, 162, 163

[7] Boletsis, C., and McCallum, S. Connecting the player to the doctor: utilising serious games for cognitive training & screening. *DAIMI PB 597* (2015), 5–8. xiii, 3, 4, 5, 15, 31, 48, 60, 132, 134, 157, 158, 160, 162

[8] Bouchard, B., Imbeault, F., Bouzouane, A., and Menelas, B.-A. J. Developing Serious Games Specifically Adapted to People Suffering from Alzheimer. In *Proceedings of the Third international conference on Serious Games Development and Applications* (2012), SGDA '12, Springer-Verlag, pp. 243–254. 4, 14, 74, 80, 97, 106, 107, 132

[9] Boustani, M., Callahan, C. M., Unverzagt, F. W., Austrom, M. G., Perkins, A. J., Fultz, B. A., Hui, S. L., and Hendrie, H. C. Implementing a screening and diagnosis program for dementia in primary care. *Journal of general internal medicine 20*, 7 (2005), 572–577. 3, 132

[10] Brooke, J. SUS-A quick and dirty usability scale. In *Usability Evaluation In Industry*. Taylor & Francis, 1996, pp. 189–194. 39, 144

[11] Brooke, J. SUS: A Retrospective. *Journal of Usability Studies 8*, 2 (2013), 29–40. 144, 145

[12] Clionsky, M., and Clionsky, E. Dementia screening: Saying no to the uspstf and yes to brief cognitive evaluation. *Journal of Alzheimers Disease & Parkinsonism 4* (2014), e132. 132

[13] Connolly, A., Gaehl, E., Martin, H., Morris, J., and Purandare, N. Underdiagnosis of dementia in primary care: variations in the observed prevalence and comparisons to the expected prevalence. *Aging & Mental Health 15*, 8 (2011), 978–984. 3, 132, 158

[14] Correa, A., de Assis, G. A., Nascimento, M. d., Ficheman, I., and Lopes, R. d. D. GenVirtual: an Augmented Reality musical game for cognitive and motor rehabilitation. In *Virtual Rehabilitation* (2007), pp. 1–6. 15, 16, 123, 135

[15] Drachen, A., Nacke, L. E., Yannakakis, G., and Pedersen, A. L. Correlation between heart rate, electrodermal activity and player experience in first-person shooter games. In *Proceedings of the 5th ACM SIGGRAPH Symposium on Video Games* (2010), pp. 49–54. 144

[16] Drachen, A., Nacke, L. E., Yannakakis, G., and Pedersen, A. L. *Psychophysiological Correlations with Gameplay Experience Dimensions*. 2010. 144

[17] Farage, M. A., Miller, K. W., Ajayi, F., and Hutchins, D. Design principles to accommodate older adults. *Global journal of health science 4*, 2 (2012), 2–25. 134

[18] Fernandez, A., Goldberg, E., and Michelon, P. *The Sharpbrains Guide to Brain Fitness: How to Optimize Brain Health and Performance at Any Age*. SharpBrains, 2013. 140

[19] Fernandez-Ballesteros, R., Botella, J., Zamarron, M. D., Molina, M. A., Cabras, E., Schettini, R., and Tarraga, L. Cognitive plasticity in normal and pathological aging. *Clinical Interventions in Aging 7* (2012), 15–25. 105, 132

[20] Flores, E., Tobon, G., Cavallaro, E., Cavallaro, F. I., Perry, J. C., and Keller, T. Improving patient motivation in game development for motor deficit rehabilitation. In *Proceedings of the 2008 International Conference on Advances in Computer Entertainment Technology* (2008), pp. 381–384. 135

[21] Folstein, M. F., Folstein, S. E., and McHugh, P. R. mini-mental state: a practical method for grading the cognitive state of patients for the clinician. *Journal of psychiatric research 12*, 3 (1975), 189–198. 134, 159, 162, 174

[22] Gajadhar, B. J., De Kort, Y., and IJsselsteijn, W. A. Rules of engagement: Influence of co-player presence on player involvement in digital games. *International Journal of Gaming and Computer-Mediated Simulations 1*, 3 (2009), 14–27. 144

[23] Gamberini, L., Fabregat, M., Spagnolli, A., Prontu, L., Seraglia, B., Alcaniz, M., Zimmerman, A., Rontti, T., Grant, J., Jensen, R., and Gonzales, A. Eldergames: videogames for empowering, training and monitoring elderly cognitive capabilities. *Gerontechnology 7*, 2 (2008). 15, 16, 123, 124, 135, 136, 163

[24] Gerling, K. M., Schild, J., and Masuch, M. Exergame design for elderly users: The case study of silverbalance. In *Proceedings of the 7th International Conference on Advances in Computer Entertainment Technology* (2010), pp. 66–69. 135

[25] Gerling, K. M., Schulte, F. P., and Masuch, M. Designing and evaluating digital games for frail elderly persons. In *Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology* (2011), ACE '11, pp. 62:1–62:8. 134, 135

[26] GOLD, S. C., AND WOLFE, J. The validity and effectiveness of a business game beta test. *Simulation & Gaming* (2011), 1–25. 133, 166

[27] GREGOR, P., NEWELL, A. F., AND ZAJICEK, M. Designing for dynamic diversity: interfaces for older people. In *Proceedings of the fifth international ACM conference on Assistive technologies* (2002), ASSETS '02, pp. 151–156. 35, 80, 134

[28] HERREWIJN, L., AND POELS, K. Putting brands into play. *International Journal of Advertising 32*, 1 (2013), 17–44. 144, 169

[29] IJSSELSTEIJN, W., DE KORT, Y., AND POELS, K. The game experience questionnaire: Development of a self-report measure to assess the psychological impact of digital games. manuscript in preparation. *FUGA technical report Deliverable 3.3* (2013). 39, 43, 55, 144

[30] IJSSELSTEIJN, W., NAP, H. H., DE KORT, Y., AND POELS, K. Digital game design for elderly users. In *Proceedings of the 2007 conference on Future Play* (2007), Future Play '07, pp. 17–22. 35, 113, 114, 134, 135, 149

[31] ISMAIL, Z., RAJJI, T. K., AND SHULMAN, K. I. Brief cognitive screening instruments: an update. *International Journal of Geriatric Psychiatry 25*, 2 (2010), 111–120. 3, 4, 105, 132, 158

[32] KATO, P. M. Video games in health care: Closing the gap. *Review of General Psychology 14*, 2 (2010), 113–121. 4, 12, 15, 132

[33] KATO, P. M. Evaluating efficacy and validating games for health. *Games for Health Journal 1*, 1 (2012), 74–76. 133, 134, 161, 166

[34] KIRAKOWSKI, J. The Use of Questionnaire Methods for Usability Assessment. sumi.ucc.ie/sumipapp.html (Last visited: October 25th, 2015). 144

[35] KLUGER, A., GIANUTSOS, J. G., GOLOMB, J., FERRIS, S. H., GEORGE, A. E., FRANSSEN, E., AND REISBERG, B. Patterns of motor impairment in normal aging, mild cognitive decline, and early alzheimer's disease. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences 52B*, 1 (1997), P28–P39. 135

[36] KORTUM, P., AND ACEMYAN, C. Z. How low can you go?: Is the system usability scale range restricted? *Journal of Usability Studies 9*, 1 (2013), 14–24. 144

[37] LOPPONEN, M., RAIHA, I., ISOAHO, R., VAHLBERG, T., AND KIVELA, S.-L. Diagnosing cognitive impairment and dementia in primary health care - a more active approach is needed. *Age and Ageing 32*, 6 (2003), 606–612. 3, 132

[38] McCallum, S. Gamification and serious games for personalized health. In *pHealth*, vol. 177 of *Studies in Health Technology and Informatics*. IOS Press, 2012, pp. 85–96. 4, 13, 15, 29, 71, 73, 76, 79, 90, 91, 93, 96, 113, 132

[39] McCallum, S., and Boletsis, C. Augmented Reality & gesture-based architecture in games for the elderly. In *pHealth*, vol. 189 of *Studies in Health Technology and Informatics*. IOS Press, 2013, pp. 139–144. ix, 15, 31, 33, 34, 35, 122, 124, 134, 137, 160, 163

[40] Milgram, P., and Kishino, F. A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems 77*, 12 (1994), 1321–1329. 41, 148

[41] Nacke, L. E., Grimshaw, M. N., and Lindley, C. A. More than a feeling: Measurement of sonic user experience and psychophysiology in a first-person shooter game. *Interacting with Computers 22*, 5 (2010), 336–343. 144

[42] Nasreddine, Z. S., Phillips, N. A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J. L., and Chertkow, H. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society 53*, 4 (2005), 695–699. 41, 46, 54, 65, 105, 134, 158, 159, 162, 167

[43] Neistadt, M. A critical analysis of occupational therapy approaches for perceptual deficits in adults with brain injury. *American Journal of Occupational Therapy 44*, 4 (1990), 299–304. 123, 135

[44] Ninaus, M., Pereira, G., Stefitz, R., Prada, R., Paiva, A., Neuper, C., and Wood, G. Game elements improve performance in a working memory training task. *International Journal of Serious Games 2*, 1 (2015), 3–16. 132

[45] Persson, J., Nyberg, L., Lind, J., Larsson, A., Nilsson, L.-G., Ingvar, M., and Buckner, R. L. Structure-function correlates of cognitive decline in aging. *Cerebral Cortex 16*, 7 (2006), 907–915. 3, 103, 132, 157

[46] Prince, M., Bryce, R., and Ferri, C. *World Alzheimer Report 2011: The Benefits of Early Diagnosis and Intervention*. Alzheimer's Disease International (ADI), 2011. 3, 132, 158

[47] Robert, P., Knig, A., Amieva, H., Andrieu, S., Bremond, F., Bullock, R., Ceccaldi, M., Dubois, B., Gauthier, S., Kenigsberg, P.-A., Nave, S., Orgogozo, J. M., Piano, J., Benoit, M., Touchon, J., Vellas, B., Yesavage, J., and Manera, V. Recommendations for the use of serious games in people with Alzheimer's Disease, related disorders and frailty. *Frontiers in Aging Neuroscience 6*, 54 (2014). 4, 59, 132

[48] Sauro, J. *A practical guide to the system usability scale: Background, benchmarks & best practices*. CreateSpace Independent Publishing Platform, 2011. 145, 146

[49] Scanlon, L., O'Shea, E., O'Caoimh, R., and Timmons, S. Usability and validity of a battery of computerised cognitive screening tests for detecting cognitive impairment. *Gerontology Epub ahead of print* (2015). 3, 47, 54, 65, 132, 134, 158, 159, 172, 173

[50] Schnabel, M. A., Wang, X., Seichter, H., and Kvan, T. From virtuality to reality and back. In *Proceedings of the International Association of Societies of Design Research* (2007), pp. 1–15. 60, 148

[51] Sharlin, E., Itoh, Y., Watson, B., Kitamura, Y., Sutphen, S., and Liu, L. Cognitive cubes: A tangible user interface for cognitive assessment. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2002), CHI '02, pp. 347–354. 123, 135, 163

[52] Stroop, J. R. Studies of interference in serial verbal reactions. *Journal of Experimental Psychology 18*, 6 (1935), 643–662. 141

[53] Tang, A., Owen, C., Biocca, F., and Mou, W. Comparative effectiveness of Augmented Reality in object assembly. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2003), CHI '03, pp. 73–80. 16, 107, 114, 115, 149

[54] Tullis, T., and Albert, W. *Measuring the user experience: collecting, analyzing, and presenting usability metrics*. Morgan Kaufmann Publishers Inc., 2008. 145

[55] Tullis, T. S., and Stetson, J. N. A comparison of questionnaires for assessing website usability. In *Usability Professional Association Conference* (2004), pp. 1–12. 144

[56] van den Hoogen, W. M., IJsselsteijn, W. A., and de Kort, Y. A. Exploring behavioral expressions of player experience in digital games. In *Proceedings of the workshop on Facial and Bodily Expression for Control and Adaptation of Games ECAG 2008* (2008), pp. 11–19. 144

[57] Waldemar, G., Phung, K., Burns, A., Georges, J., Hansen, F. R., Iliffe, S., Marking, C., Rikkert, M. O., Selmes, J., Stoppe, G., and Sartorius, N. Access to diagnostic evaluation and treatment for dementia in europe. *International journal of geriatric psychiatry 22*, 1 (2007), 47–54. 3, 132, 158

[58] Williams, K., and Kemper, S. Exploring interventions to reduce cognitive decline in aging. *Journal of Psychosocial Nursing and Mental Health Services 48*, 5 (2010), 42–51. 104, 132

[59] WORKMAN, B., DICKSON, F., GREEN, S., ET AL. Early dementia: optimal management in general practice. *Australian family physician 39*, 10 (2010), 722. 132

[60] ZHOU, Z., CHEOK, A., AND PAN, J. 3D Story Cube: an interactive tangible user interface for storytelling with 3D graphics and audio. *Personal and Ubiquitous Computing 8*, 5 (2004), 374–376. 124, 136, 163

Chapter 13

Smartkuber: A Serious Game for Cognitive Health Screening of Elderly Players

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Abstract

Objective: The goal of this study was to design and develop a cognitive training game for cognitive health screening of the elderly, namely Smartkuber, and evaluate its construct, criterion (concurrent and predictive), and content validity, assessing its relationship with the Montreal Cognitive Assessment (MoCA) test. Furthermore, the study aims to quantitatively evaluate the elderly players' game experience with Smartkuber.

Subjects and Methods: Thirteen older adults were enrolled in the study. The game was designed and developed by a multidisciplinary team. The study follows a mixed methodological approach, utilising the in-Game Experience Questionnaire to assess the players' game experience and a correlational study, to examine the relationship between the Smartkuber and MoCA scores. The learning effect is also examined by comparing the mean scores of the first and last game sessions of each player (Delta score).

Results: All thirteen participants (mean age: 68.69, SD: 7.24) successfully completed the study. Smartkuber demonstrated high concurrent validity with the MoCA test ($r = 0.81$, $p = 0.001$) and satisfying levels of predictive and content validity. The Delta scores showed no statistically significant differences in scoring, thus revealing the lack of learning effects during the Smartkuber game sessions.

Conclusions: The study shows that Smartkuber is a promising tool for cognitive health screening, providing an entertaining and motivating gaming experience to elderly players. Limitations of the study and future directions are discussed.

13.1 Introduction

Cognitive impairment in the elderly can be associated with normal ageing processes, or be a symptom of the onset of dementia [4, 27]. Symptomatic cognitive impairment is under-recognised and under-diagnosed, even though early detection in dementia care is of great significance and has many benefits, including providing an explanation for changes in behaviour and functioning, and allowing the person to be involved in future care planning [29, 35, 7, 31].

Cognitive screening represents the initial step in a process of further assessment for dementia and can help identify potential cases for assessment, thus leading to early diagnosis [4]. The existing pen-and-paper screening tests present certain intrinsic limitations, such as being biased by culture, gender, and educational level and having long test-rest periods (usually one month or more). They can also be too psychologically stressful to the point that the screening results can be skewed (the "white coat" effect), as well as present learning effects (i.e. improved performance on cognitive tests that occur when a person is retested on the same test, due to the previous knowledge of the test's content, and not because of actual improvement on the skills being assessed) [4, 31, 16, 18, 17, 13].1, 6-10 Furthermore, there is significant economic burden associated with increased screening [4, 16]. Computerised cognitive screening tests overcome some of the limitations mentioned above, however they still have weaknesses including limited validation of the tests and the user's potential lack of motivation [4, 31, 34].

Serious games for cognitive screening may be an alternative to traditional, pen-and-paper and computerised cognitive screening tests, potentially motivating and engaging the user to regularly perform cognitive screening tasks, thus providing more, timely cognitive-related data and facilitating the recognition of cognitive decline, triggering referral for a more comprehensive formal assessment and earlier detection of cognitive impairment [4, 38]. Cognitive screening serious games have distinct advantages; they can be economical of time and cost, provide accurate and frequent response recording free of the aforementioned biases and effects (due to dynamically updated content), be self-administered or require little training, provide a pleasant experience and reduce the psychological stress caused by the traditional screening processes [4, 16].

Cognitive screening serious games can provide an informal measurement of the player's cognitive performance through the game score. Taking as a prerequisite that the games' content consists of accredited cognitive exercises, serious games for cognitive screening can be validated against established tests used in clinical practice - like the widely-used Montreal Cognitive Assessment (MoCA) test - and provide the player with constant monitoring of his/her cognitive health, in a entertaining, motivational and engaging way [4]. The MoCA test is a brief, validated, screening tool, used to distinguish mild cognitive impairment (MCI) from normal ageing and which has been found to demonstrate high test-retest reliability and internal consistency [31, 26, 33]. It has been reported to be a useful tool for the detection of age-related early cognitive decline and early dementia, as well as being an accurate screening measurement of cognitive ability [33, 20]. Compared to the other widely-used brief cognitive measure, that is, the Mini-Mental State Examination (MMSE) [9], MoCA has been found to perform better on detecting age-related cognitive decline across the adult lifespan [11]. For our assessment, we use the lower cutpoint (e.g. 22 or 23 out of 30) as suggested by recent research [31, 26, 11].

The current work presents, examines, and evaluates a serious game for cognitive health screening of the elderly, namely Smartkuber (Table 13.1, Fig. 13.1). Smartkuber is an original mobile game, utilising an interaction technique based on Augmented Reality (AR) and the manipulation of tangible, physical objects (cubes). The game is a collection of cognitive mini-games of preventative health purpose and is designed for elderly players (60+ years old), mild cognitive im-

Table 13.1: Characteristics of a videogame for health (Smartkuber).

Characteristic	
Health topic(s)	Cognitive health screening
Short description of game idea	Elderly adults (60+ years old), mild cognitive impaired adults, all adults
Target player(s)	Individual
Guiding knowledge or behavior change, theory(-ies), models, or conceptual framework(s)	Flow Theory, Self-Regulation Theory, Self-Determination Theory
Intended health behavior changes	Increase frequency of cognitive screening
Behavioral change procedure(s) (taken from Michie inventory) or therapeutic procedure(s) used	Goal, Monitoring, Feedback, Social Comparison, Reward
Clinical or parental support needed?	No
Data shared with parent or clinician	No
Story	
Synopsis	The player goes through 5 mini-game levels: Reconstruct the flag, Reconnect old friends, Repeat the pattern, Numerical calculation, and Find the word
How the story relates to the targeted behaviour change	The mini-games address several cognitive skills, such as: Attention, Memory, Motor skills, Visual & spatial processing, Language, Executive functions: problem solving, decision making, working memory, flexibility, response inhibition

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Game components	
Players game goal / objective(s)	Complete each level as fast as possible to win more points; complete all 5 levels to conclude the gaming session
Rules	Complete each level before moving to the next one
Game mechanic(s)	Challenges, Competition, Feedback, Rewards
Procedures to generalize or transfer what's learned in the game to outside the game	Cognitive stimulation, which is utilised for cognitive training and screening purposes
Virtual environment	
Setting	5 levels of different cognitive training tasks
Avatar	
Characteristics	NA
Abilities	NA
Game platform(s) needed to play the game	Mobile device (preferably tablet PC)
Sensors used	Camera, Accelerometer, Magnetic Compass

paired players and, healthy adults, with an interest in video gaming and/or cognitive training. The ultimate goal of Smartkuber is to alleviate or prevent cognitive decline. The stimulating cognitive training exercises of Smartkuber are aiming to screen and monitor the cognitive abilities of the players on a frequent basis (potentially daily), triggering referral for a more comprehensive assessment when cognitive decline is indicated, thus playing an intermediary role between the (potential) patient and the medical expert, and leading to early treatment [4, 39]. The design of Smartkuber was informed by, and tested within, a long-term project documented in previous articles. A thorough literature review and taxonomy analysis [22, 23] resulted in the shaping of the characteristics and the theoretical description of the gaming system [4, 21], followed by an iterative development process and the examination of several interaction, game design, and game content aspects [3, 5].

This paper describes the design and development process of Smartkuber and, consequently, examines and studies the utility of the Smartkuber game as an entertaining and motivating tool for cognitive health screening of elderly players. Specifically, the study aims to 1) quantitatively evaluate the elderly players' game experience with Smartkuber, 2) investigate the use of Smartkuber for its construct, criterion (concurrent and predictive), and content validity, assessing its relationship with the MoCA test.

The paper describes the design and development process of Smartkuber and, consequently, examines and studies the utility of the Smartkuber game as an entertaining and motivating tool for cognitive health screening of elderly

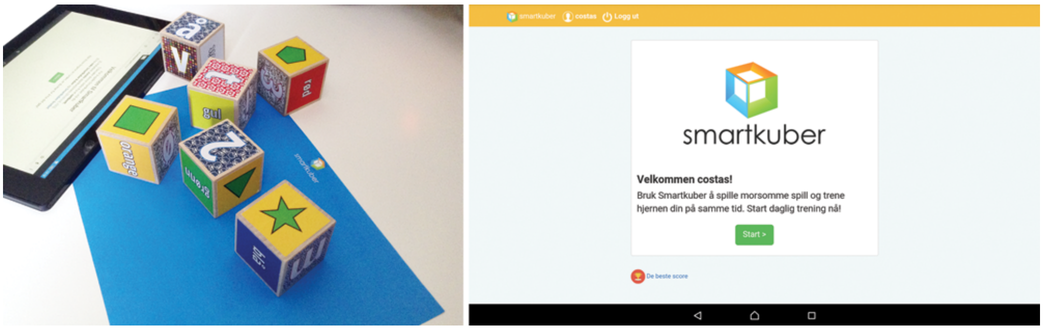

Figure 13.1: The Smartkuber setup consisted of the 6 cubes with the Smartkuber board (*left*) and the Smartkuber main menu (*right*).

players. Specifically, the study aims to 1) quantitatively evaluate the elderly players' game experience with Smartkuber, 2) investigate the use of Smartkuber for its construct, criterion (concurrent and predictive), and content validity, assessing its relationship with the MoCA test.

13.2 Subjects and methods

13.2.1 Game development process

Smartkuber went through three major development stages and several iterative processes, where early game versions were evaluated as to the implemented interaction and the game content. Previous work was focused on examining the game's interaction, its content, and its overall design [3, 5]. A multidisciplinary team was involved in the development of the game, focusing on the entertaining nature of the game ("fun-ness" members), and content validity ("serious-ness" members) [1, 19]. The team included five game developers and two game designers, a physician specialising in mental health and disorders, two academics specialising in behavioural change and serious games, and several older adults as game testers.

13.2.2 Design requirements

Smartkuber is destined to be a motivational tool for cognitive screening purposes, thus certain design requirements should be met. Firstly, the elderly players should be motivated and engaged in order to play it on a frequent basis. The game should construct an enjoyable gaming environment - specifically designed for elderly players - offering a satisfying gaming experience that supports casual, iterative and stress-free playing. Studying the Smartkuber game experience, the player motivation and engagement should be respected and, at the same time, not being controlled by performing the study in controlled environments with tech-specific equipment. The players should be able to play the

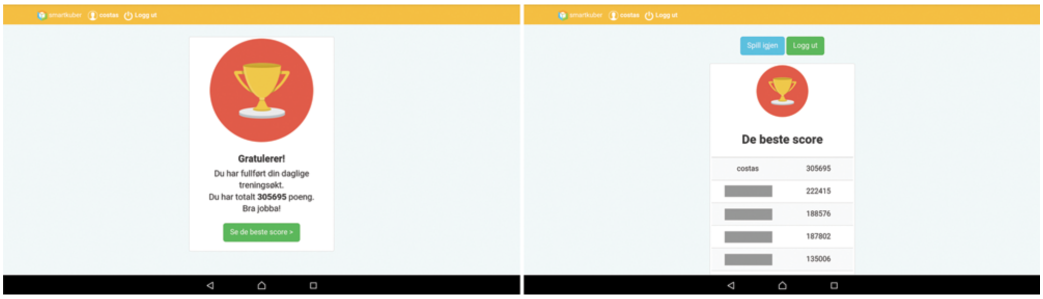

Figure 13.2: A Smartkuber's session final screen with the points display (*left*) and the Smartkuber leaderboard (*right*).

game at their own device (cross-platform support is necessary), at their places of choice, and without any assistance. That way, more realistic measurements of game experience can be achieved and more objective results from the cognitive health screening process can be obtained, since a familiar gaming environment will contribute to a more relaxed state of mind for the player [4]. The appropriate cognitive game triggers should be used, for addressing the respective cognitive abilities of the player that should be later captured and analysed for screening purposes. The stimulation of the cognitive abilities should take place on an iterative basis, therefore it is important not to tire or stress the player and, also, to address and solve the learning effect that originates from repeating the same level/task over time.

13.2.3 Game characteristics

The main characteristics of Smartkuber were defined based on the aforementioned design requirements and goals, as well as the design suggestions of the previous related studies [3]. Consequently, Smartkuber was developed to be a mobile game for tablet PCs, with a short duration of each gaming session's playtime (approximately 5-10 minutes, in compliance with the short duration of widely-used, pen-and-paper, cognitive screening instruments, such as the MoCA [26] and MMSE [9]), supporting casual gaming, targeting both tactical and logistical players (motivated by Mastery, i.e. challenge and strategy, according to the Gamer Motivation Model [36]) and focusing on frequent gaming sessions. The Smartkuber gameplay is based on the player completing the cognitive mini-game levels correctly and as fast as possible to score more points. Additionally to the intrinsic motivation of the player, always wanting to perform better, competition is utilised as an extrinsic motivation factor since the points won are displayed cumulatively on a leaderboard against other players (Fig. 13.2).

13.2.4 Interaction components

Smartkuber's interaction is based on the Tangible AR technology, that is, the combination of an Augmented Reality system and a tangible user interface [2]. Therefore, the main components of Smartkuber's interaction design are: the tangible, physical objects, which serve as input mechanisms - that is, the cubes (Fig. 13.1) - and the Augmented Reality technology, for real-world recognition and augmentation purposes. The cube - as a tangible physical object - is an accredited assistive tool for cognitive training, cognitive assessment, and motor rehabilitation, which addresses the players' cognitive and motor skills, while being a game element, which appeals to a wide target audience, from children to elderly players [3, 5, 10, 37, 32]. Augmented Reality is a technology, which is strongly connected with the users' perception, as well as their cognitive and physical functionality [3, 21]. In previous, related studies, Augmented Reality has been found to manifest technical and perceptual issues, when cubes are digitally augmented with game content [3, 5]. To overcome these issues, Smartkuber places the main part of the interaction and the game content at the real world, that is, the game content is placed physically on the cubes, and AR is utilised solely for real-world recognition and content verification purposes, that is, verifying the correct, real-world game tasks (Fig. 13.3) [5]. The AR functionality of the game is based on marker-based tracking.

13.2.5 Interaction technique

The interaction technique of Smartkuber features the player using a tablet device to see the game tasks and then "returning" to the real world to manipulate the physical cubes and perform those tasks. Afterwards, the tablet device is again used to scan the task's solution as formed by the cubes, utilising the AR technology for verifying the answer (Fig. 13.4). The cognitive screening gaming session can take place in a small space, while the whole system is quite portable; it consists of 6 cubes of 4.4 cm/edge with game content on every side (e.g. letters, numbers, colours, faces, shapes), and a board on which the cubes are placed, to create a uniform background for Augmented Reality real-world recognition purposes (Fig. 13.1).

13.2.6 Gameplay

The Smartkuber gameplay is designed so as to facilitate the stimulation of the players' cognitive abilities. The gaming session follows a linear gameplay structure (Fig. 13.4) with the player playing one level of each mini-game on a consecutive order (i.e. 5 levels in total). The order of the mini-games remains always the same, however the levels of each mini-game are chosen randomly from a "pool" of levels, in order to address the learning effect issue. The game content and its mini-game structure, the choice of the Tangible Augmented Reality technology, and the perceptual change between the physical and the digital world

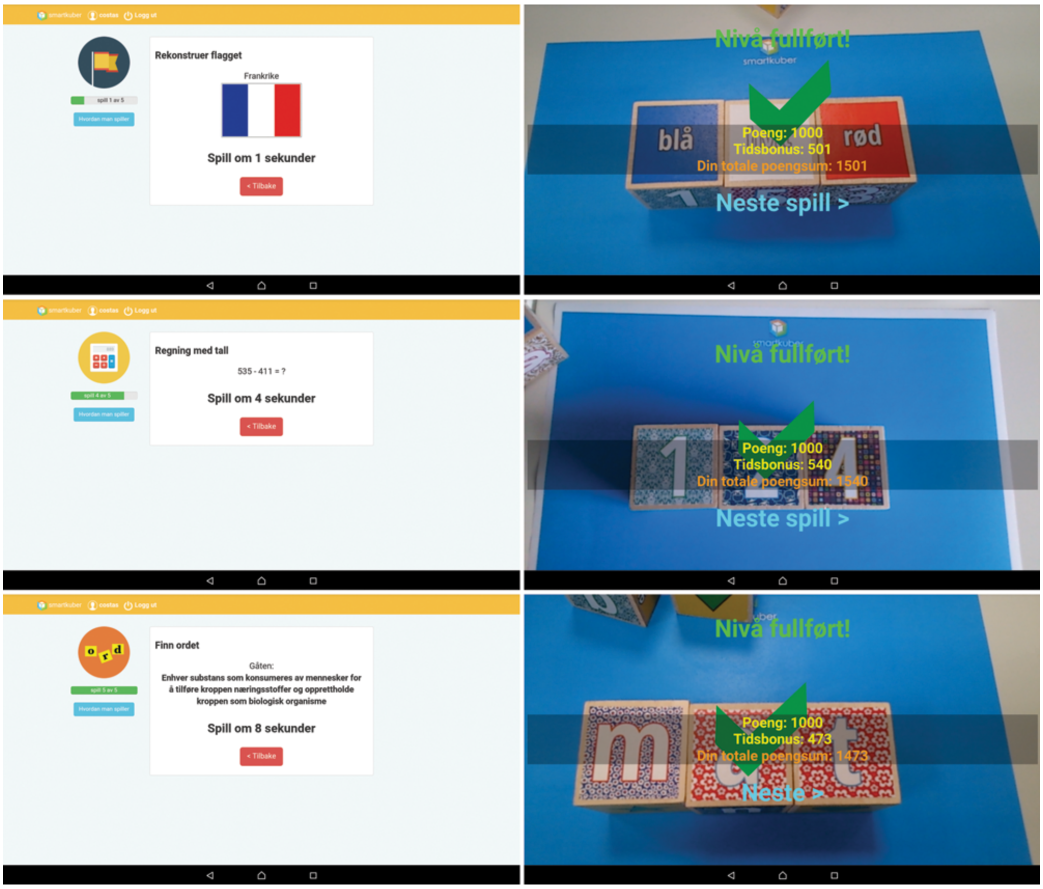

Figure 13.3: The "Reconstruct the flag", "Numerical calculation", and "Find the word" mini-games' main screens (*left*) and the success message of completing the level (*right*).

(Fig. 13.4) are choices that favour the stimulation of several cognitive abilities, such as attention, working memory, flexibility, visuospatial processing, motor skills and response inhibition. The task completion speed is factored in the gameplay (i.e. the faster the player completes each level's task, the more points he/she scores) to further stimulate the visuospatial processing, the motor skills and the response inhibition cognitive abilities of the players, for screening purposes. The difficulty of all the mini-games and levels starts at the "normal" level and is uniform, so the game can establish the baseline performance of the player, track any changes, and screen the cognitive abilities of the player.

13.2.7 User interface design

The user interface (UI) design of Smartkuber is specifically designed for elderly players and is based on the principle of simplicity and intuitiveness, providing appropriate affordances and overview, and aiming at avoiding adding extra cognitive load for the player [6]. The menus are clear and simple in structure,

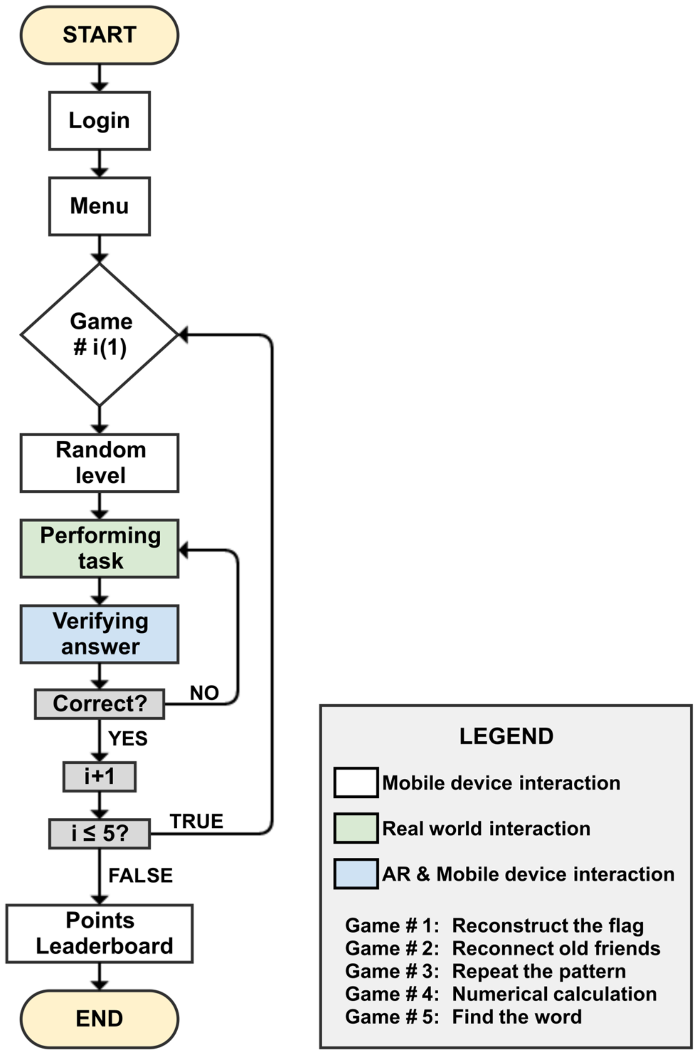

Figure 13.4: The flowchart of a full gaming session with Smartkuber.

with vivid colours and with large-sized icons, text, and buttons. The relevant game objects have clear elements, which are highlighted through contrast and colour settings [5, 6, 28].

13.2.8 Game content

In order to address the various cognitive abilities that should be stimulated, Smartkuber consists of 5 different cognitive mini-games (Table 13.2). Three of the games (i.e. "Reconstruct the flag", "Reconnect old friends" and "Repeat the pattern") present visual elements (i.e. a flag, two faces, and a 3-shape pattern respectively) that the player has to memorise and recreate using the cubes. "Numerical calculation" displays the numbers of a numerical calculation and the "Find the word" quiz presents a textual description of a word, as a word

Table 13.2: The mini-games of Smartkuber.

Mini-game title	**Goal**	**Main cognitive abilities**
Reconstruct the flag	The player has to memorise the flag and use the cubes to reconstruct it	Attention, Memory, Motor Skills, Executive functions: Working Memory, Flexibility, Response Inhibition
Reconnect old friends	The player has to memorise the friend's faces and use the cubes to form the right pair of friends	Attention, Memory, Motor Skills, Visual Processing, Executive functions: Working Memory, Flexibility, Response Inhibition
Repeat the pattern	The player has to memorize a shape pattern and use the cubes to form it	Attention, Memory, Motor Skills, Visual & Spatial Processing, Executive functions: Working Memory, Flexibility, Response Inhibition
Numerical calculation	The player has to do a numerical calculation and use the cubes to form the right answer	Attention, Memory, Motor Skills, Executive functions: Problem Solving, Decision Making, Working Memory, Flexibility, Response Inhibition
Find the word	The player is given a word quiz and uses the cubes to form the right answer	Attention, Memory, Motor Skills, Language, Executive functions: Problem Solving, Decision Making, Working Memory, Flexibility, Response Inhibition

clue, while the player has to use the numbers and letters on the cubes to form the correct numerical and word answers respectively (Fig. 13.3).

13.2.9 Study design

The current study of Smartkuber follows a mixed methodological approach, utilising a correlational study and a questionnaire. The methodology focuses on examining Smartkuber's test validity as a valid measure of cognitive score, assessing the content validity as to the stimulated cognitive abilities and the learning effects, and conducting a quality assurance process, to identify development/design issues, which - when addressed - could improve the game, both as an entertaining and a cognitive health assessment tool [19, 12].

13.2.10 Participants

A sample of thirteen older adults (n = 13) was recruited between July and November 2015. Inclusion criteria included being ≥60 years old, independently performing activities of daily living (ADL), not diagnosed with any kind of dementia, and familiar with technology (i.e. using or having used laptop, tablet PC, smartphone, etc.) and video games (i.e. playing or having played video games before). The inclusion criteria addressed the technology-use and video-gaming biases, which can be present in game studies when participants are asked to use systems that have no experience or interest in. All participants gave consent and agreed to participate in the study.

13.2.11 Data collection / procedures

Demographic data were collected at the initial stage of the study.

Participants received technical assistance on installing and running the game on their personal tablet PC devices, were given and presented the 6 Smartkuber cubes and the board, and received instructions on how to play the game. Two trial runs were allowed before scoring commenced and instructions regarding the game tasks and how to use the cubes were re-iterated during the trial run.

The Montreal Cognitive Assessment test (MoCA) was administered prior to playing the game, scored by a trained rater, blind to the interpretation of the results and the diagnosis.

The game was tested under realistic conditions, therefore the participants were allowed to take Smartkuber with them and play it at their own place of will (e.g. home, office), for as many sessions as they wanted, within a period of 6 weeks. A frequency of 2 game sessions/week (each session on a different day) was proposed as the regular frequency (for data collection purposes), even though that frequency was only a suggestion, which was not forced on the participants and they were still free to make their own schedule. Technical problems reported were addressed and solved instantly (within 1-12 hours). The game data were collected remotely.

Between weeks 4 and 6, the in-Game Experience Questionnaire (iGEQ) was administered to quantitatively document the participants' game experience.

13.2.12 Measures

Demographic data included age, sex, level of education attainment, frequency of technology use ("never", "rarely", "most days", "everyday"), and experience with technology (participants listing devices they own and use).

The MoCA is a psychometrically sound, highly sensitive short cognitive test [26], which consists of 13 tasks organised into eight cognitive domains including Visuospatial/Executive Function, Naming, Memory, Attention, Language, Abstraction, Delayed Recall, and Orientation. A total score out of 30 is gen-

Table 13.3: Demographics, MoCA and Smartkuber scores.

Demographics	**n = 13**
Age, years	68 (7.24)
Sex (M/F)	8/5
Education, %	
Completed primary	0
Completed secondary	31 (n = 4)
Completed tertiary	69 (n = 9)
Technology use frequency, %	
Never	0
Rarely	0
Most days	8 (n = 1)
Everyday	92 (n = 12)
Playing video games frequency, %	
Never	0
Rarely	31 (n = 4)
Frequently	46 (n = 6)
Everyday	0
Similar tasks	23 (n = 3)
MoCA	**n = 244**
Visuospatial	4.62 (0.51)
Naming	2.92 (0.28)
Attention	5.85 (0.38)
Language	2.46 (0.66)
Abstraction	1.62 (0.51)
Delayed recall	3.46 (0.66)
Orientation	5.92 (0.28)
MoCA total score	26.85 (2.20)
Smartkuber	**n = 244**
#1: Reconstruct the flag	733.73 (48.61)
#2: Reconnect old friends	728.91 (52.75)
#3: Repeat the pattern	713.78 (79.29)
#4: Numerical calculation	706.75 (69.09)
#5: Find the word	681.53 (109.97)
Smartkuber total score	3564.70 (294.60)

Age, MoCA scores, and Smartkuber characteristics and scores are given as mean with standard deviation in parenthesis

erated by summing scores across the eight domains. For the purpose of the present study, we use the total score and the individual domain scores.

Smartkuber's scoring is related to the successful completion of the cognitive task and is also inversely related to the level completion time; therefore the

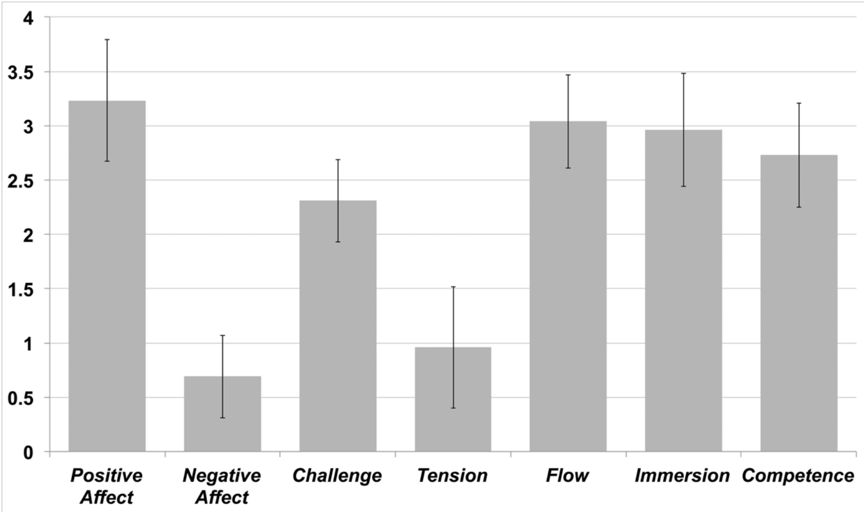

Figure 13.5: The iGEQ mean scores (with SD bars) across the seven dimensions of Game Experience, for the Smartkuber game.

faster the player completes each level's task, the more points he/she scores. The level completion time is logged on a per mini-game/level basis, as well as totally, and it is calculated as the elapsed time between fully loading the level and successfully completing the cognitive task (score range: 0 - 800 points/level, 0 - 4000 points totally). Respectively, the game score was calculated per mini-game/level and as a total.

To investigate the learning effect, which may arise from playing the game iteratively and to evaluate the level-randomisation process (which attempts to minimise the learning effect), the Delta score measure was created. Delta score is defined as the score difference between the mean total score of the 20% last sessions (e.g. for a player with 20 sessions: the last 4 sessions) minus the mean total score of the 20% first sessions.

The players' game experience was measured by asking participants to fill out the In-Game Experience Questionnaire (iGEQ) [15]. The iGEQ contains 14-items, rated on a five-point intensity scale ranging from 0 ("not at all") to 4 ("extremely"), distributed in pairs between seven dimensions of player experience: 1) Immersion, 2) Flow, 3) Competence, 4) Tension, 5) Challenge, 6) Negative affect and 7) Positive affect. The iGEQ has been used in several gaming studies and is of sufficient quality to accurately report gameplay experience. The iGEQ is the shorter and reliable in-game version of the Game Experience Questionnaire (GEQ), and it was chosen so as not to tire the participants [5, 14].

13.2.13 Statistical analysis

All data were analysed using the Statistical Package for Social Sciences (SPSS) version 22. Significance level was set at $p < 0.05$. Descriptive analysis was used

Table 13.4: Correlations between the Smartkuber mini-games and MoCA total scores.

	Smartkuber					
MoCA	#1: Reconstruct the flag	#2: Reconnect old friends	#3: Repeat the pattern	#4: Numerical calculation	#5: Find the word	Total score
Visuospatial	0.74**	0.73**	0.64*	0.54	0.49	0.63*
Naming	0.52	0.68*	0.82**	0.68*	0.79**	0.75**
Attention	0.54	0.64*	0.68*	0.56*	0.61*	0.64*
Language	0.61*	0.65*	0.52	0.67*	0.50	0.60*
Abstraction	0.34	0.47	0.61*	0.43	0.32	0.45
Del. recall	0.18	0.15	0.11	0.08	-0.04	0.08
Orientation	0.57*	0.68**	0.71**	0.79**	0.87**	0.78**
Total score	0.76**	0.85**	0.83**	0.79**	0.70**	**0.81****

* $p < 0.05$
** $p < 0.01$

to depict the demographic data of the participants. The Pearson correlation coefficient was used to measure the strength of the linear association between the MoCA scores and the Smartkuber scores, as well as their sub-elements. Linear regression assessed and modelled the relationship between the MoCA scores and the Smartkuber scores, focusing on the prediction of the MoCA score using the Smartkuber score. The paired samples T-test was used to compare the mean total scores of the players' first and last game sessions and determine the significance of the Delta scores. Internal consistency was measured using the Cronbach's Alpha coefficient.

13.3 Results

In total, 13 participants (mean age: 68.69, SD: 7.24, male/female: 8/5) were recruited for the correlational and the game experience study. The main demographics are presented at Table 13.3. Regarding experience with technology, all the participants (n = 13) were using a laptop or desktop PC and at least one mobile device (tablet, smartphone, or e-reader), while 69.2% of them (n = 9) were also using a second mobile device.

All participants successfully completed the two-month period playing the game at an open and free rate (Table 13.3). 244 gaming sessions (mean number of sessions/player: 18.77, SD: 2.68) were recorded from the 13 participants. The 244 Smartkuber sessions resulted in a mean total score of 3564.70 (SD: 294.60). The Smartkuber mini-games' scores demonstrated a high level of internal consistency (Cronbach's alpha = 0.84).

Table 13.5: The players' Delta score.

Player	Delta score	t	Sig. (2-tailed)
1.	86.75	0.86	0.46
2.	43.5	1.07	0.36
3.	-48.5	-1.29	0.29
4.	150.75	1.82	0.17
5.	87.75	0.93	0.42
6.	33.67	0.73	0.54
7.	285.75	2.96	0.06
8.	-64	-0.67	0.57
9.	-27.5	-0.60	0.59
10.	4.33	0.03	0.98
11.	16.25	0.59	0.60
12.	-31.67	-0.32	0.78
13.	95.25	1.34	0.27

All participants successfully finished the MoCA test with a mean score of 26.85 (SD: 2.20) and completed the iGEQ questionnaire, displaying high values of Flow, Positive Affect and Immersion, moderate values of Challenge, moderate-to-high values of Competence, and low values of Negative Affect and Tension (Fig. 13.5).

The correlational study (Table 13.4) revealed a high, significant correlation between the Smartkuber mean total scores and the MoCA total scores (r[11] = 0.81, p = 0.001) and it also demonstrated a high statistical power of 0.95. The correlation between the Smartkuber mean mini-games/total scores and the MoCA subtests/total scores are described in Table 13.4.

Smartkuber mean total scores (β = 0.007, p = 0.001) were significant predictors of MoCA scores, explaining 62.1% of MoCA total score variance, when controlling for age, education, gender, frequency of technology use and video gaming (S = 1.35, F[1,12] = 20.70 with p = 0.001).

The players' Delta score, which is indicative of the learning effect, is presented in Table 13.5 on a per-player basis. The Delta score differences were not statistically significant ($p > 0.05$) for any of the players. The correlation between the Delta score and the MoCA score of every player was also examined, however no significant linear statistical relationship was found.

13.4 Discussion

13.4.1 Game experience

The game experience study of Smartkuber provided significant feedback regarding the elderly players' experience, which will guide the ongoing development of the game (Fig. 13.5). The Flow and Immersion elements are of great significance for the evaluation of the cognitive stimulation that Smartkuber offers, since they attempt to quantify the subjective experience of the player's engagement and cognitive involvement with the game. Both those elements demonstrated high values revealing a high level of players' cognitive involvement with Smartkuber. The moderate-to-high Competence value suggests that the players felt skilful enough while playing Smartkuber, though the moderate (and lower than Competence) Challenge value may demonstrate that the difficulty level needs further tweaking to challenge the players more. Finally, the high value of Positive Affect and the low values of Tension and Negative Affect potentially highlight the entertaining and motivating nature of Smartkuber, the suitability of the UI and the interaction technique for the elderly players.

13.4.2 Correlational study

The correlational study provided important insights on the utilisation of the Smartkuber cognitive training game as a cognitive health screening tool for elderly players. The Smartkuber scores - both totally and individually - revealed significant correlations with the MoCA scores, while demonstrating a high value of internal consistency. The significant correlation between the Smartkuber total scores and the MoCA scores likely reflects the cognitive demand of the tasks, addressing the visuoperceptual, attention, working memory, language, motor and inhibitory response skills of the players (Table 13.2) and suggesting they tapped into the cognitive domains screened by the MoCA test.

Overall, the Smartkuber game had high concurrent validity with the MoCA test. However a higher correlation would be possible by addressing the individual mini-games' significant correlations with the MoCA scores. The adjustment of the mini-games level difficulty may be a way to establish a more robust Smartkuber performance for the players of various MoCA scores, thus strengthening the relationship between the variables. Especially, for the "Find the word" mini-game, which is stimulating the language skills of the player, and which presents a weak statistical relationship with the MoCA Language subtest, the difficulty-level adjustment may be a promising solution for further improving the concurrent validity of the mini-game and the Smartkuber game, in general.

The MoCA Delayed recall subtest score did not correlate significantly with any individual Smartkuber mini-game scores. This may reflect that the Smartkuber tasks test delayed recall through visual memory (e.g. flags, faces, shapes) rather than verbal memory, as in MoCA (using 5 words), utilising different and potentially competing cognitive processing centres [31, 30, 25]. Adding textual elements to the mini-games' memory tasks may address the issue and enhance the correlation.

Regression results indicate that Smartkuber total scores were significantly predictive of MoCA total scores after adjusting for demographics. Therefore, the above results suggest that the Smartkuber cognitive training game may have utility for predicting the player's MoCA score - iteratively, over time - and, if adjusted accordingly, detect signs of cognitive decline, although this was not investigated for this article.

13.4.3 Learning effect

The Delta scores showed no significant difference in scoring between the first and the last players' sessions and all the players managed to demonstrate steady game performances. Therefore, the results revealed no learning effects during the Smartkuber game sessions, implying that the iterative gameplay of the cognitive screening game instrument did not rely on or affect the players' short-term memory. Randomisation of the mini-games' levels succeeded in considerably minimizing the learning effect, thus adding an important element to the content validity of the instrument and its test validity, in general.

13.4.4 Study limitations

The present study was limited by the small sample size. The study's inclusion criteria and the fact that the technology-use and video-gaming biases are addressed, restrict the target population of the screening process. The scientific assumption that no player experienced any major cognitive decline during the study duration is also made. Furthermore, even though the individual Smartkuber mini-games and the MoCA subtests are not individually validated, the examination of their correlation values (Table 13.5) was of exploratory - and not confirmatory - nature, in order to examine the game's content validity, to identify the performance of the Smartkuber mini-games and to seed the discussion around the improvement of the game as a cognitive health screening tool [31]. A further limitation is that the MoCA test, while being a widely-used and reliable screening instrument, presents certain weaknesses (e.g lack of specificity in populations with cardiovascular diseases and risk factors) and may not be the optimal standard - by itself - by which to determine the game's construct validity [24].

13.5 Conclusions

Smartkuber, overall, succeeded in providing an entertaining, engaging, and motivating gaming experience to elderly players. The game, also, demonstrated high concurrent validity and satisfying levels of predictive and content validity, versus the MoCA test.

However, the study revealed that adjustments to the game difficulty level of the mini-games and to its textual elements should be made to establish an even more stimulating cognitive experience. The game's relationship with other widely-used cognitive screening tools (e.g. MMSE, CogState) should be assessed, in order to further establish the game's construct validity [9, 8].

Apart from the aforementioned improvements, the future direction of the project will be to examine the utilisation of the cognitive screening game as the main part of a smart devices' ecosystem (along with smartwatches, smartphones, etc.), which will screen and log the user's cognitive and cognitive-related information (e.g. motor skills and sleeping habits) and create his/her cognitive profile, over time.

13.6 Acknowledgements

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13.7 Bibliography

[1] BARANOWSKI, T., BUDAY, R., THOMPSON, D., LYONS, E. J., LU, A. S., AND BARANOWSKI, J. Developing games for health behavior change: Getting started. *Games for Health Journal 2*, 4 (2013), 183–190. 134, 161

[2] BILLINGHURST, M., GRASSET, R., SEICHTER, H., AND DÜNSER, A. *Human-Computer Interaction. Ambient, Ubiquitous and Intelligent Interaction*. Springer Berlin Heidelberg, 2009, ch. Towards Ambient Augmented Reality with Tangible Interfaces, pp. 387–396. 163

[3] BOLETSIS, C., AND MCCALLUM, S. Augmented Reality cube game for cognitive training: An interaction study. *Studies in Health Technology and Informatics 200* (2014), 81–87. 35, 60, 61, 132, 133, 135, 136, 137, 138, 148, 149, 160, 161, 162, 163

[4] BOLETSIS, C., AND MCCALLUM, S. Connecting the player to the doctor: utilising serious games for cognitive training & screening. *DAIMI PB 597* (2015), 5–8. xiii, 3, 4, 5, 15, 31, 48, 60, 132, 134, 157, 158, 160, 162

[5] BOLETSIS, C., AND MCCALLUM, S. Augmented Reality cubes for cognitive gaming: Preliminary usability and game experience testing. *International Journal of Serious Games 3*, 1 (2016), 3–18. 37, 53, 54, 60, 61, 66, 160, 161, 163, 165, 169

[6] BROX, E., FERNANDEZ-LUQUE, L., TØLLEFSEN, T., ET AL. Healthy gaming–video game design to promote health. *Applied Clinical Informatics 2*, 2 (2011), 128–142. 164, 165

[7] Connolly, A., Gaehl, E., Martin, H., Morris, J., and Purandare, N. Underdiagnosis of dementia in primary care: variations in the observed prevalence and comparisons to the expected prevalence. *Aging & Mental Health 15*, 8 (2011), 978–984. 3, 132, 158

[8] Falleti, M. G., Maruff, P., Collie, A., and Darby, D. G. Practice effects associated with the repeated assessment of cognitive function using the cogstate battery at 10-minute, one week and one month test-retest intervals. *Journal of Clinical and Experimental Neuropsychology 28*, 7 (2006), 1095–1112. 174

[9] Folstein, M. F., Folstein, S. E., and McHugh, P. R. mini-mental state: a practical method for grading the cognitive state of patients for the clinician. *Journal of psychiatric research 12*, 3 (1975), 189–198. 134, 159, 162, 174

[10] Gamberini, L., Fabregat, M., Spagnolli, A., Prontu, L., Seraglia, B., Alcaniz, M., Zimmerman, A., Rontti, T., Grant, J., Jensen, R., and Gonzales, A. Eldergames: videogames for empowering, training and monitoring elderly cognitive capabilities. *Gerontechnology 7*, 2 (2008). 15, 16, 123, 124, 135, 136, 163

[11] Gluhm, S., Goldstein, J., Loc, K., Colt, A., Van Liew, C., and Corey-Bloom, J. Cognitive performance on the mini-mental state examination and the montreal cognitive assessment across the healthy adult lifespan. *Cognitive and behavioral neurology: official journal of the Society for Behavioral and Cognitive Neurology 26*, 1 (2013), 1–5. 159

[12] Gold, S. C., and Wolfe, J. The validity and effectiveness of a business game beta test. *Simulation & Gaming* (2011), 1–25. 133, 166

[13] Hausknecht, J. P., Halpert, J. A., Di Paolo, N. T., and Moriarty Gerrard, M. O. Retesting in selection: a meta-analysis of coaching and practice effects for tests of cognitive ability. *Journal of Applied Psychology 92*, 2 (2007), 373. 158

[14] Herrewijn, L., and Poels, K. Putting brands into play. *International Journal of Advertising 32*, 1 (2013), 17–44. 144, 169

[15] IJsselsteijn, W., van den Hoogen, W., Klimmt, C., de Kort, Y., Lindley, C., Mathiak, K., Poels, K., Ravaja, N., Turpeinen, M., and Vorderer, P. Measuring the experience of digital game enjoyment. In *Proceedings of Measuring Behavior* (2008), pp. 88–89. 39, 43, 169

[16] Ismail, Z., Rajji, T. K., and Shulman, K. I. Brief cognitive screening instruments: an update. *International Journal of Geriatric Psychiatry 25*, 2 (2010), 111–120. 3, 4, 105, 132, 158

[17] JACQMIN-GADDA, H., FABRIGOULE, C., COMMENGES, D., AND DARTIGUES, J.-F. A 5-year longitudinal study of the mini-mental state examination in normal aging. *American Journal of Epidemiology 145*, 6 (1997), 498–506. 158

[18] JULAYANONT, P., PHILLIPS, N., CHERTKOW, H., AND NASREDDINE, Z. S. *Cognitive Screening Instruments: A Practical Approach*. Springer London, 2013, ch. Montreal Cognitive Assessment (MoCA): Concept and Clinical Review, pp. 111–151. 158

[19] KATO, P. M. Evaluating efficacy and validating games for health. *Games for Health Journal 1*, 1 (2012), 74–76. 133, 134, 161, 166

[20] LUIS, C. A., KEEGAN, A. P., AND MULLAN, M. Cross validation of the montreal cognitive assessment in community dwelling older adults residing in the southeastern us. *International journal of geriatric psychiatry 24*, 2 (2009), 197–201. 158

[21] MCCALLUM, S., AND BOLETSIS, C. Augmented Reality & gesture-based architecture in games for the elderly. In *pHealth*, vol. 189 of *Studies in Health Technology and Informatics*. IOS Press, 2013, pp. 139–144. ix, 15, 31, 33, 34, 35, 122, 124, 134, 137, 160, 163

[22] MCCALLUM, S., AND BOLETSIS, C. Dementia games: A literature review of dementia-related serious games. In *Serious Games Development and Applications*, vol. 8101 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2013, pp. 15–27. 14, 17, 27, 28, 29, 58, 59, 61, 91, 95, 97, 106, 122, 160

[23] MCCALLUM, S., AND BOLETSIS, C. A taxonomy of serious games for dementia. In *Games for Health*. Springer Fachmedien Wiesbaden, 2013, pp. 219–232. 14, 17, 27, 29, 58, 59, 61, 160

[24] MCLENNAN, S., MATHIAS, J., BRENNAN, L., AND STEWART, S. Validity of the montreal cognitive assessment (moca) as a screening test for mild cognitive impairment (mci) in a cardiovascular population. *Journal of Geriatric Psychiatry and Neurology 24*, 1 (2011), 33–38. 55, 173

[25] MOREY, C. C., AND COWAN, N. When do visual and verbal memories conflict? the importance of working-memory load and retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition 31*, 4 (2005), 703–713. 47, 172

[26] NASREDDINE, Z. S., PHILLIPS, N. A., BEDIRIAN, V., CHARBONNEAU, S., WHITEHEAD, V., COLLIN, I., CUMMINGS, J. L., AND CHERTKOW, H. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society 53*, 4 (2005), 695–699. 41, 46, 54, 65, 105, 134, 158, 159, 162, 167

[27] Persson, J., Nyberg, L., Lind, J., Larsson, A., Nilsson, L.-G., Ingvar, M., and Buckner, R. L. Structure-function correlates of cognitive decline in aging. *Cerebral Cortex 16*, 7 (2006), 907–915. 3, 103, 132, 157

[28] Plaza, I., Martín, L., Martin, S., and Medrano, C. Mobile applications in an aging society: Status and trends. *Journal of Systems and Software 84*, 11 (2011), 1977–1988. 165

[29] Prince, M., Bryce, R., and Ferri, C. *World Alzheimer Report 2011: The Benefits of Early Diagnosis and Intervention*. Alzheimer's Disease International (ADI), 2011. 3, 132, 158

[30] Rothmayr, C., Baumann, O., Endestad, T., Rutschmann, R. M., Magnussen, S., and Greenlee, M. W. Dissociation of neural correlates of verbal and non-verbal visual working memory with different delays. *Behavioral and Brain Functions 3* (2007), 56. 47, 172

[31] Scanlon, L., O'Shea, E., O'Caoimh, R., and Timmons, S. Usability and validity of a battery of computerised cognitive screening tests for detecting cognitive impairment. *Gerontology Epub ahead of print* (2015). 3, 47, 54, 65, 132, 134, 158, 159, 172, 173

[32] Sharlin, E., Itoh, Y., Watson, B., Kitamura, Y., Sutphen, S., and Liu, L. Cognitive cubes: A tangible user interface for cognitive assessment. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2002), CHI '02, pp. 347–354. 123, 135, 163

[33] Smith, T., Gildeh, N., Holmes, C., et al. The montreal cognitive assessment: validity and utility in a memory clinic setting. *Canadian Journal of Psychiatry 52*, 5 (2007), 329. 54, 158

[34] Tong, T., Guana, V., Jovanovic, A., Tran, F., Mozafari, G., Chignell, M., and Stroulia, E. Rapid deployment and evaluation of mobile serious games: A cognitive assessment case study. *Procedia Computer Science 69* (2015), 96 – 103. 3, 14, 15, 58, 158

[35] Waldemar, G., Phung, K., Burns, A., Georges, J., Hansen, F. R., Iliffe, S., Marking, C., Rikkert, M. O., Selmes, J., Stoppe, G., and Sartorius, N. Access to diagnostic evaluation and treatment for dementia in europe. *International journal of geriatric psychiatry 22*, 1 (2007), 47–54. 3, 132, 158

[36] Yee, N. The Gamer Motivation Model in Handy Reference Chart and Slides, 2016. http://quanticfoundry.com/2015/12/15/handy-reference/ (Last visited: April 14th, 2016). 162

[37] Zhou, Z., Cheok, A., and Pan, J. 3D Story Cube: an interactive tangible user interface for storytelling with 3D graphics and audio. *Personal and Ubiquitous Computing 8*, 5 (2004), 374–376. 124, 136, 163

[38] ZUCCHELLA, C., SINFORIANI, E., TASSORELLI, C., CAVALLINI, E., TOST-PARDELL, D., GRAU, S., PAZZI, S., PURICELLI, S., BERNINI, S., BOTTIROLI, S., ET AL. Serious games for screening pre-dementia conditions: from virtuality to reality? a pilot project. *Functional neurology 29*, 3 (2014), 153–158. 4, 14, 15, 16, 58, 158

[39] ZYGOURIS, S., GIAKOUMIS, D., VOTIS, K., DOUMPOULAKIS, S., NTOVAS, K., SEGKOULI, S., KARAGIANNIDIS, C., TZOVARAS, D., AND TSOLAKI, M. Can a Virtual Reality Cognitive Training Application Fulfill a Dual Role? Using the Virtual Supermarket Cognitive Training Application as a Screening Tool for Mild Cognitive Impairment. *Journal of Alzheimer's Disease 44*, 4 (2015), 1333–1347. 4, 5, 14, 15, 160