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 (≥60 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.

Keywords: *Augmented Reality, cognitive screening, cognitive training, dementia;*

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 [1, 2]. Best practices in dementia care emphasise the importance of early detection; however, cognitive impairment is still under-recognised and under-diagnosed [3-6]. More than 50% of dementia and 80% of mild cognitive impairment (MCI) cases go unrecognised in primary care [6-8]. 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 [6].

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 [6, 2, 9-11]. 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 [2, 9].

Cognitive training has also shown promise as a preventative treatment in the premorbid stage [2, 12]. 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 [13, 2]. 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) [12, 2].

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 [2, 14]. 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 [15-17]. Cognitive screening tests and cognitive training exercises have game-like elements or, at least, elements that can be gamified [18, 2]. 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 [2].

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 [19]. The "Cognitive Augmented Reality Cubes" (CogARC) system is designed and developed with this more holistic approach to cognitive assessment.

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 mini-games of preventative nature and is targeting elderly players (≥60 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 [19]. 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).

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 [20, 21]. 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 2 describes the CogARC game design elements, focusing on the interaction technique, the game content and the gameplay. Section 3 presents the preliminary usability and game experience testing of CogARC. Section 4 discusses the results of the testing, while the paper is concluded in Section 5.

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 [22, 20]. 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.

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 [23], as well as design and usability suggestions for elderly players [24, 25], were taken into consideration when forming the usability requirements of CogARC (Table 1, Req. 1-5). The usability requirements address the comprehensibility and perceptibility (Table 1, Req. 1, 2), the learnability and simplicity (Table 1, Req. 3), the attractiveness (Table 1, Req. 4), and the operability of the system (Table 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-over-time abilities) [26, 27]. 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) [28], the Mini-Mental State Examination (MMSE) [29], 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 [6, 2]. 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 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 [30]). By addressing the "learning effect" issue (Table 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 1, Req. 7). Furthermore, a cognitive screening game can entertain and engage the player (Table 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.

Table 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

The following subsections present how these requirements were addressed.

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 [24]. 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 [31]. 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 [24, 32, 31, 25].

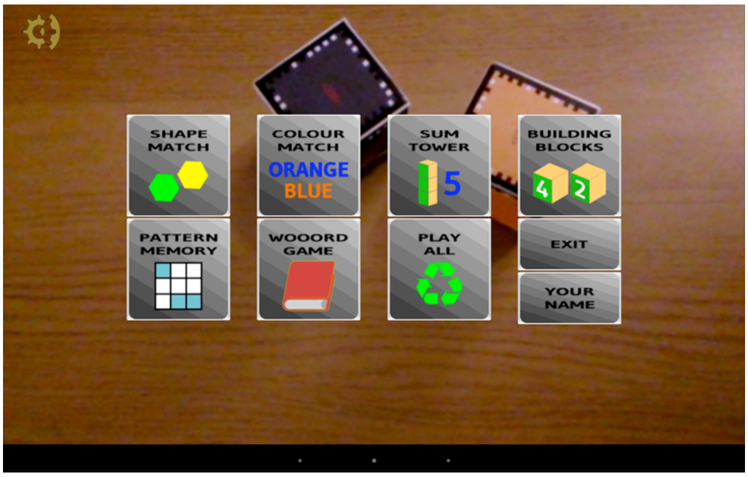

Figure 1. The main menu of CogARC.

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 [33, 19] and, more specifically, cubes are an accredited assistive tool for occupational therapy [34], cognitive training [35, 36], cognitive assessment [33], motor rehabilitation [36], and neurodevelopmental treatment [37]. 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 [35, 38, 39, 19]. 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 the use of AR in the cognitive gaming context [19].

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 [27, 19]. 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 [19]. 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. [19].

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. 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 [19]. 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 [40]. 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 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 [19]. 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.

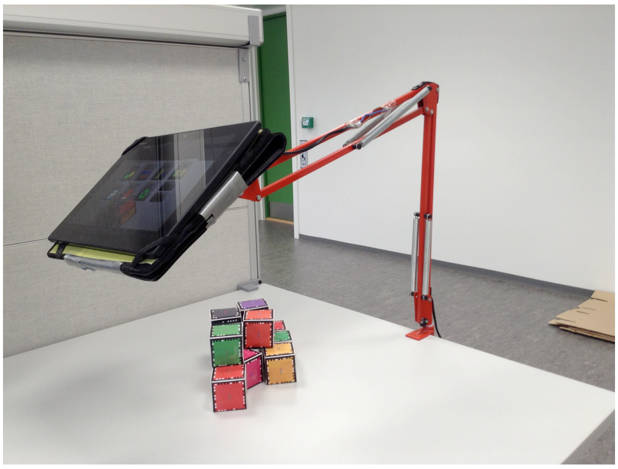

Figure 2. The CogARC interaction setup: the 10 cubes and the tablet PC on the base stand.

2.5 Game content

CogARC features 6 mini-games, which address various cognitive abilities (Section 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 2).

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

Table 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

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 [41]. 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. 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.

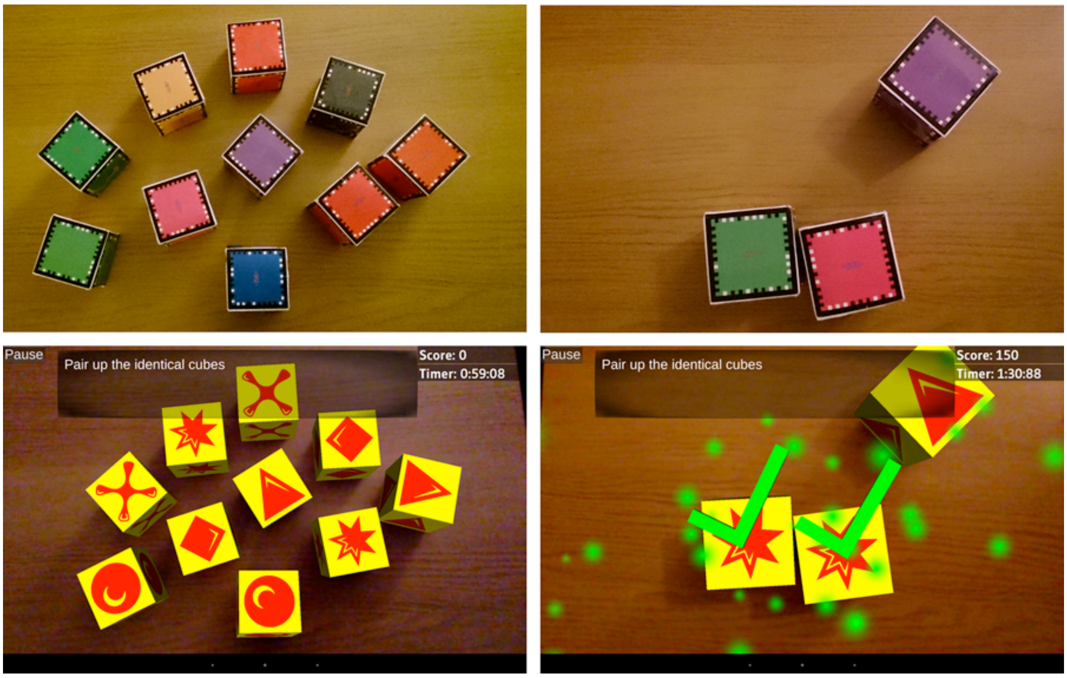

Figure 3. The real world view (*upper left & right*) and the augmented view, as seen on the tablet PC screen (*lower left & right*). A screenshot from "Shape match" with all the cubes on scene (*lower left*) and a success message after a correct shape match (*lower right*).

"Colour match" is a game inspired by traditional Colour Matching Tasks and the Stroop effect [42]. 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 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.

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.

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.

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 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 2.5. The mini-games were randomly sorted and the levels of the mini-games were randomly generated (as stated in Section 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.

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

3.3 Measures

The players' game experience was measured by filling out the In-Game Experience Questionnaire (iGEQ) [43]. 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 [43-46]. The iGEQ has been used in several gaming studies and is of sufficient quality to accurately report game-play experience [47, 48, 44-46]. The iGEQ is the shorter - but reliable - in-game version of the GEQ [43], and it was chosen so as not to tire the players when completing the full questionnaire per mini-game [49].

The usability of the system is measured using the System Usability Scale (SUS). The System Usability Scale [50] 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 [50, 51]. SUS has been demonstrated to be a reliable and valid instrument [52, 53], robust with a small number of participants [54], 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 [55, 51].

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, 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.

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.

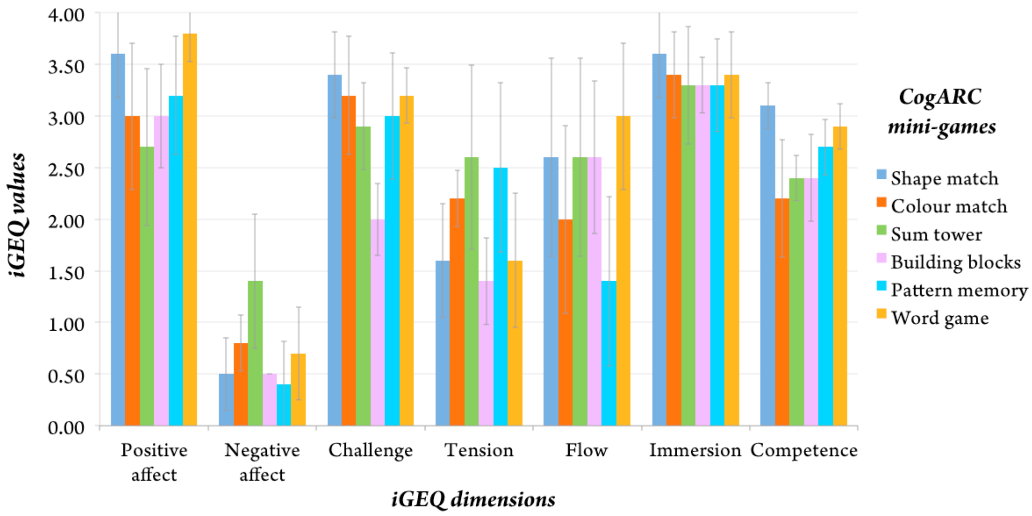

Figure 4. Mean iGEQ scores (with standard deviation bars) across the seven dimensions of Game Experience, for the mini-games of the CogARC game.

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. 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 [55, 52, 56, 57], the average SUS score across various 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 [57]. 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 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).

Table 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.

4. Discussion

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. 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 [19]. 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. 4.

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 [58]. 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 [59] 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 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.

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 [60, 19] 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 [24], 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.

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 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.

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