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The Smartkuber case study: Lessons learned from the development of an Augmented Reality serious game for cognitive screening

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Abstract. In this work, we present a case study, examining the design, development, and evaluation of an Augmented Reality serious game for cognitive screening (namely Smartkuber), which aims to provide reliable and motivating cognitive screening for the elderly. This case study can be of interest for the game designers and researchers, allowing them to build on previous experiences and lessons learned. Smartkuber's development process took place in four stages: 1) analysing the state of the art and defining characteristics, 2) setting up and examining the interaction method, 3) adding and evaluating the game content, and 4) evaluating cognitive screening performance and future direction. The "lessons learned" around the design and development of serious games for cognitive screening are discussed, with focus on Augmented Reality, interaction, test validity, and game motivation aspects.

Keywords: Augmented Reality; cognitive screening; elderly; serious games;

1 Introduction

Best practices in dementia care emphasise the importance of early detection; yet, cognitive impairment is still under-recognised and under-diagnosed [30, 34, 10]. Early diagnosis has many benefits, providing an explanation for changes in behaviour and functioning and allowing the person to be involved in future care planning [30].

Cognitive screening represents the initial step in a process of further assessment for dementia and can help identify potential cases for management, thus leading to early diagnosis. Screening for dementia is usually accomplished by means of a global cognitive scale through cognitive tests (such as the Mini-Mental State Exam [9] and the Montreal Cognitive Assessment [28]). However, 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), "white coat" and learning effects and the user's potential lack of motivation [4, 30, 33].

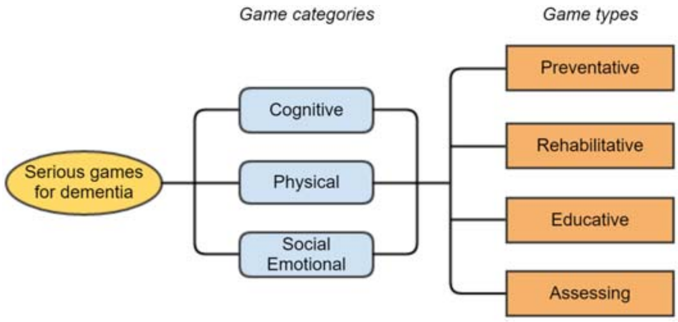

Fig. 1. The schematic of the "serious games for dementia" taxonomy, as published in [26].

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 [4, 36]. 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 [4, 23, 37].

In this work, we present a case study, examining the design, development, and evaluation of an Augmented Reality (AR) serious game for cognitive screening (namely Smartkuber), which commenced in 2012 and aims to provide reliable and motivating cognitive screening for the elderly. The case study describes in detail the software release life cycle of Smartkuber (Alpha, Beta, and Release Candidate version) and can be of interest for game designers, game developers, and researchers of the Serious Games and Augmented Reality fields, allowing them to build on previous experiences and lessons learned.

The Smartkuber's design, development and evaluation processes are described in the following sections (Sections 2 - 6), leading to the "lessons learned" of Section 7.

2 Analysing the state of the art & defining characteristics

The analysis of the state of the art was a significant, first step in order to identify the research gaps and best practices for us further defining the proper game characteristics, which the developed game should have in order to achieve the desired cognitive goals. A literature review of dementia-related serious games [25] and a taxonomy of serious games for dementia [26] (Fig. 1) took place, at that stage and several important observations were made, ranging from the *content* of the games (e.g. interaction methods and problems, platforms, cognitive tasks, et al.) to their *context*, thus to generic conclusions regarding the health functions

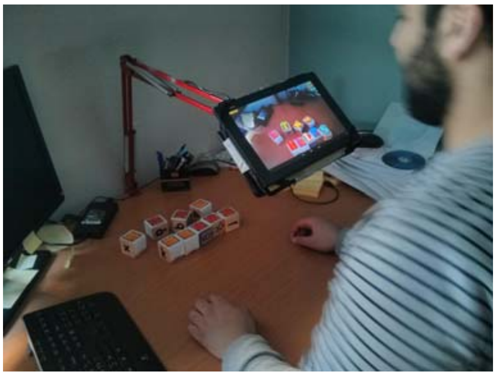

Fig. 2. Testing the interaction technique of an early version of Smartkuber through a pilot study.

and health uses that they serve (e.g. most games were serving preventative and rehabilitative cognitive purposes, less educative games, no assessing games).

Based on the findings, the project was decided to focus on the *cognitive* function of the players, serving *preventative* and *assessing* purposes and covering the preclinical stages of cognitive impairment. The technical details of the existing systems were documented and analysed in order to form the basis for chosing our system's interaction method [25].

3 Setting up & examining the interaction method

The interaction technique of the game was based on the examination of the state of the art, in combination and alignment with our desired goals. We required that the technical infrastructure of the game - supplementary to the game content - would be able to stimulate the elderly players cognitively, while taking into consideration their specific interaction needs [24, 14, 16].

After examining the related research, the interaction technique of the system was chosen to be based on the manipulation of tangible objects, i.e. cubes, and the use of the Augmented Reality (AR) as the underlying technology (i.e. Tangible Augmented Reality [2]). AR was utilised in the project since it can be beneficial for mental processes, supporting spatial cognition and mental transformation and reducing cognitive load by minimising attention-switching. Moreover, AR can evoke the initial engagement of the player utilising the "wow effect" and utilise a variety of sensors, allowing the recording of valuable secondary data related to the users' motor skills. The cubes were chosen as an interaction component because of their properties as accredited assistive tools for occupational therapy [29], cognitive training [13, 11], cognitive assessment [31], and motor rehabilitation [11]. The game element that is associated with the cube, makes them appealing to a wide target audience - ranging from children to elderly players [13, 35, 1]. In our case, the cubes provide also a promising platform for augmentation with various gaming "skins" [3].

Table 1. The usability, game design, and technical requirements for the cognitive screening game [5].

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

The Alpha version of Smartkuber focused on interaction aspects and included two demo mini-games. The implemented interaction technique featured the player sitting at an office, playing the game on a tablet PC by manipulating AR cubes, which are placed on the actual desktop. The whole system was quite portable; it consisted of 9 cubes of 3,5 cm/edge, a tablet PC and a base stand, which the player could adjust according to his/her position, in order to have clear view of the desktop, where he/she would interact with the cubes using both hands (Fig. 2). In order to utilise and test the interaction technique, we developed two demo mini-games. Those games were designed so as to implement two different gaming and interaction styles, that would allow us to witness the player's performance under two different conditions. The first game was a word game, where the player should use 9 letters (displayed as 3D models on the cubes) to form as many words as possible within 5 minutes. The second game was a speed/shape-matching game, where the player should match simple shapes (cube, sphere et al.) of different colours as quickly as possible. The first game favoured a more focused and calm interaction, whereas the second game favoured fast movements [3].

A pilot study with the Alpha version of Smartkuber and regular players was conducted in order to study the interaction with the AR cubes, aiming at improving the system for later testing, thus safeguarding the elderly players [3]. The study was exploratory in nature, looking for interaction problems, specific user behaviours and it was based on direct observation and semi-structured, informal interviews. The study led to the discovery of several AR technology-related limi-

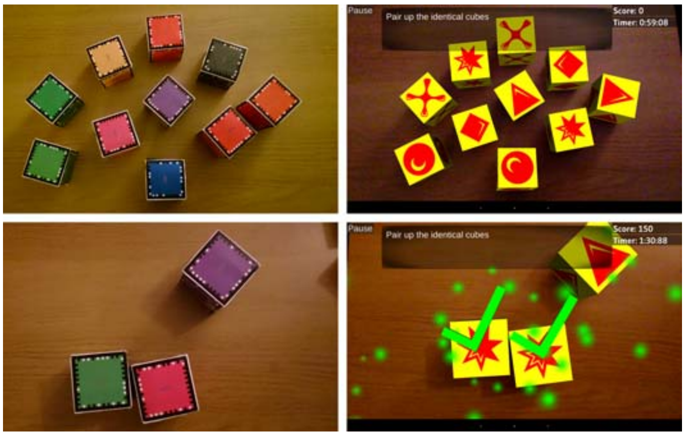

Fig. 3. The real world view (*left*) and the augmented view, as seen on the tablet PC screen (*right*). A screenshot from "Shape match" with all the cubes on scene (*upper part*) and a success message after a correct shape match (*lower part*).

tations, like the marker occlusion problem, AR lagging, losing depth perception, and dealing with limited 3D AR gaming space [3].

The technical issues would be addressed in the next version of the game, where the game content would also be added.

4 Defining system requirements

The examination of Smartkuber's Alpha version gave us a better overview of the future technical and interaction needs of the system. Therefore, while started working on the Beta version and adding the game content, we considered the establishment of the system requirements to be an important and necessary action for guiding the following game design and development processes (Table 1). The system requirements originated from our observations and findings regarding the Alpha version of the game, as well as from the set project objectives: (1) the game should be an entertaining game that can stimulate the cognitive abilities of the players for screening purposes, (2) the game should target elderly players, and (3) the game should adopt the positive characteristics of the widely-used screening tests and address the negative ones.

The establishment of the system requirements, very early in the Beta version of the game, facilitated the design of Smartkuber and served as a guide and a checklist, which we would use to stay "on target".

5 Adding & evaluating the game content

Following the system requirements, the game content was added and the Beta version of Smartkuber (working title: CogARC) was developed and evaluated [5]

Table 2. The characteristics of the game's Beta version and the cognitive abilities they address [5].

Title	**Goal**	**Cognitive abilities**
Shape match	Match same shapes	Perception, Attention, Executive functions: Flexibility, Response Inhibition
Colour match	Match one word's meaning to another word's colour	Perception, Visual Processing, Attention, Motor Skills, Executive functions: Flexibility, Response Inhibition
Sum tower	Use the numbers to create the desired total sum	Motor Skills, Executive functions: Problem Solving, Decision Making
Building blocks	Find the answer to simple arithmetic calculations	Motor Skills, Executive functions: Problem Solving, Decision Making
Pattern memory	Memorise a 3x3 matrix pattern of coloured tiles and recreate it	Attention, Visual and Spatial processing, Motor Skills, Executive functions: Working Memory
Word game	Use letters to form as many words as possible	Language Processing, Motor Skills, Executive functions: Problem Solving, Decision Making, Working Memory

(Fig. 3). A mini-game architecture was followed in order to address a spectrum of cognitive abilities. Six mini-games were designed and developed with the valuable help of the team's neuropsychologist (Table 2). The mini-games scoring computation formula was related to the successful completion of the cognitive task and 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), 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. 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 Smartkuber's Beta version was specifically designed for elderly players and was based on the principles of simplicity and intuitiveness [5].

A usability and game experience testing was conducted as part of the game's quality assurance process [5]. The testing was focused on qualitative observations, investigating the game experience that the Beta version of the game offered (using the in-Game Experience Questionnaire [18–20]), the usability of the system (using the System Usability Scale [8]), 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 and determine the players' satisfaction with the game. A convenience sample of five healthy, older adults (n = 5, mean age: 67.6, SD: 5.77) participated in the testing. The results showed that some AR issues of the previous stage, such as the loss of the

Fig. 4. The Smartkuber game setup [7].

depth perception and lagging problems, remained. Furthermore, there was a mixed perception of the reality-virtuality space by the elderly players (i.e. perceiving the markers as AR game content), leading to confusion, and also three mini-games presented interaction and content issues. However, cubes were considered by the players to be a suitable component.

The outcomes of the testing would form the Release Candidate (RC) version of the game [7] (Fig. 4). Redefining the role of the utilised AR technology in the Reality-Virtuality spectrum and redesigning the game content were among the issues that were addressed. The Tangible Augmented Reality implementation - so far - was borrowing elements from Mediated Reality. The game interaction technology "moved" towards the Reality spectrum on the Reality-Virtuality Continuum [27] and the main part of Smartkuber's interaction and its game content were placed at the real world. Augmented Reality was utilised solely for real-world recognition and for verifying the correct, real-world game tasks.

The interaction technique and its components were also adjusted [7]. The RC version of Smartkuber utilised just 6 cubes of 4.4 cm/edge with game content on every side (e.g. letters, numbers, colours, faces, shapes) (Fig. 4). The tablet base stand was removed as an interaction component and the game tasks are performed by the player getting the instructions on the tablet PC and then leaving it aside to manipulate the cubes - using both hands - in order to form the right answer. The RC version followed a linear gameplay and two mini-games were "killed" since they did not perform well at the evaluation of the Beta version. A basic narrative was added for every game task. The mini-games of the RC version of Smartkuber are presented in Table 3 and can be seen in Fig. 5.

To evaluate the game experience that the RC version of Smartkuber offered, a game experience study was conducted utilising the in-Game Experience Questionnaire (iGEQ) [7]. 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. Thirteen elderly players (n = 13, mean age: 68.69, SD: 7.24, male/female: 8/5) completed 244 Smartkuber gaming sessions over the period of 6 weeks (mean number of sessions/player: 18.77, SD: 2.68). The measurements

Table 3. The mini-games of Smartkuber (Release Candidate version) and the cognitive abilities they address [7].

Title	Goal	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

revealed a high level of players' cognitive involvement with 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 players demonstrated high values of positive and low values of negative feelings, thus potentially highlighting the entertaining and motivating nature of Smartkuber and the suitability of its UI and interaction technique for the elderly players [7]. The same study also explored the test validity of the game, which is described in the following section.

6 Evaluating cognitive screening performance & future direction

The described quality assurance process of Smartkuber produced a promising and valuable instrument, which should be further examined for its validity as an assessment tool. At this stage, the evaluation of the cognitive screening performance of Smartkuber (RC version) took place by investigating the game's construct, criterion (concurrent and predictive), and content validity, assessing its relationship with the MoCA screening test [7]. For examining the concurrent validity, the correlation between the Smartkuber scores and the MoCA scores was calculated (using the Pearson correlation). The predictive ability was 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

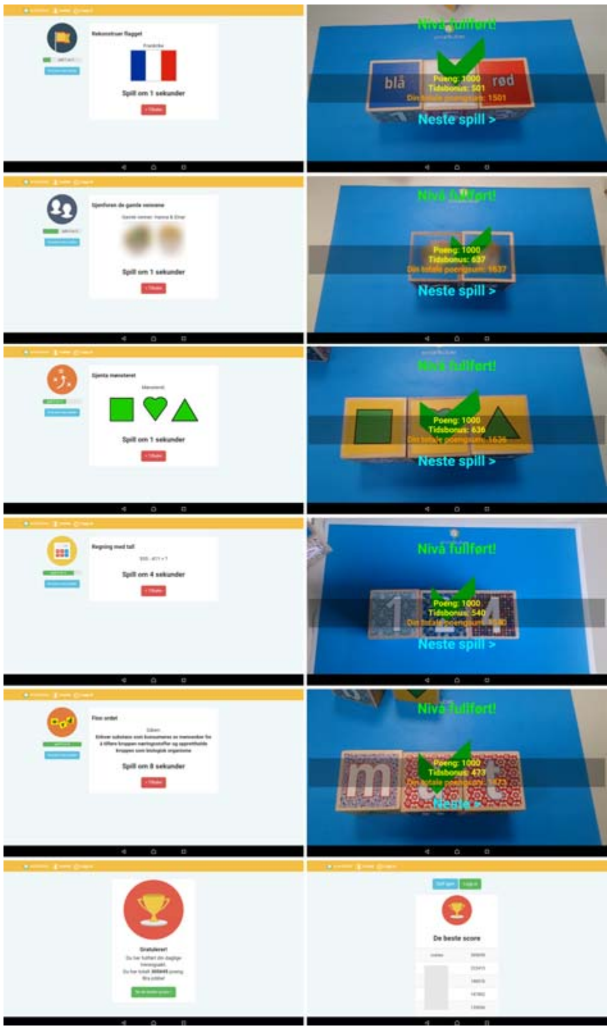

Fig. 5. The 5 mini-game levels of a Smartkuber gaming session (tablet PC view), their solutions (AR view), and the endgame screen - leaderboard (tablet PC view).

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.

As mentioned above, 13 participants were recruited for the correlational study [7]. 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.

Table 4. Correlations between the Smartkuber mini-games and MoCA total scores [7].

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****

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

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 Smartkuber mini-games' scores demonstrated a high level of internal consistency (Cronbach's alpha = 0.84).
- 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 4.
- Smartkuber mean total scores ($\beta = 0.007$, $p = 0.001$) 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 correlational study provided important insights on the utilisation of the Smartkuber game as a cognitive health screening tool for elderly players [7]. 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 reflected 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. Regression results indicated that Smartkuber total scores were significantly predictive of MoCA total scores after adjusting for demographics. The Delta scores showed no significant difference in scoring between the first and the last players' sessions and all the

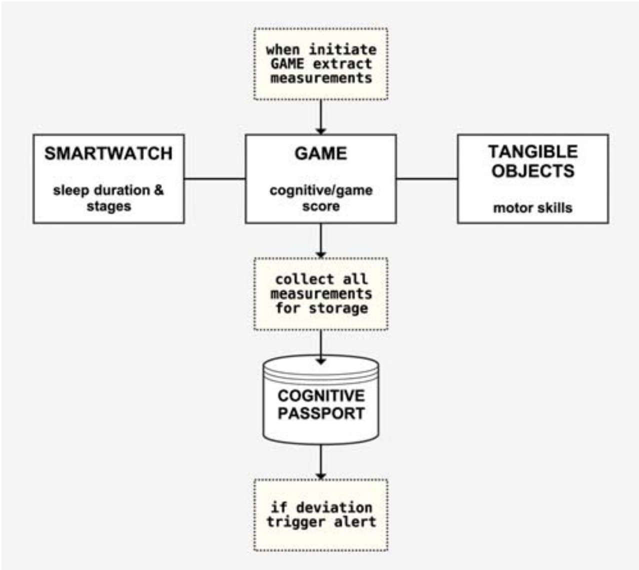

Fig. 6. The functionality of the Cognitive Passport database [6].

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.

The future direction of Smartkuber take many forms:

– The use of Smartkuber as the main part of a gaming system for cognitive screening and sleep duration assessment of the elderly is a direction which is currently under examination [6]. Smartkuber is used in combination with a smartwatch to record performances related to cognitive performance and sleep quality, which is another indicator of cognitive decline. A pilot study focusing on technical and usability issues has already been conducted, to that direction. The ultimate goal of this direction is a system that will triangulate its measurements (by measures of cognitive skills, motor skills, and sleep duration/stages) in order to trigger reliable referrals for a more comprehensive assessment [6].
– Another direction can be the development of the "Cognitive Passport" (coming from the concept of the Biological Passport [32]), i.e. a database where the game performance (and potentially the sleep stages, and the sleep duration measurements from the smartwatch device mentioned above) of each player is stored (Fig. 6). The database will constitute the players' user profiles with the player's cognitive-related measurements and performance, over time. The Cognitive Passport will set each player's baseline performance and provides the opportunity to detect changes related to the individual performance, rather than just measuring performance against population means.

– A long-term direction is a Smartkuber game for kids targeting entertainment and learning, as well as a Smartkuber game of dual identity, targeting trans-generational play and grandparents playing along with their grandchildren.

7 Lessons learned

Through the Smartkuber project - and so far - we have learned a few valuable lessons, which could be generalised and be of use for serious game designers, AR developers, and researchers:

– Serious games have great potential as motivating, valid measures of cognitive performance and evaluating their test validity is a promising research field. In this context, test validity refers to the serious games being evaluated and developed with a combination of subjective assessments and correlational studies, which demonstrated that they successfully assess cognitive performance [22]. So far there are many works examining the experimental validity of serious games for cognitive training, referring to treatments or interventions that impact cognitive-related outcomes. The test validity of cognitive serious games can act supplementary to their experimental validity, thus creating a strong defence line against cognitive impairment. The examination of the state of the art [25, 26] showed that there is a promising, unexplored, research space for serious games as entertaining, motivating, and valid measures of cognitive performance and this project demonstrated positive results about it.
– Tangible Augmented Reality is a technology that can be suitable for the elderly and can help bridging the technology gap between ICTs and the elderly users. The tangible, real artifacts add a level of familiarity and playfulness with the TAR interaction method and it empowers elderly users to comprehend what AR is, how it works, as well as how to use it effectively. Naturally, the implementation of the TAR technology should be based on many iterations and adhere to specific design guidelines related to the elderly users' target group, in order for it to be utilised properly.
– Testing a serious game under realistic conditions, at the player's place of will and for a long duration, can lead to better game-motivation analysis. Evaluating a serious game performance in laboratory settings can sometimes skew the results around the motivating power of the game. Allowing the player to play the game at a familiar environment of his/her choice, whenever he/she wants and for a long period of time, trully tests the motivation and the engagement that the game can offer.
– The Competition, Reward, and Feedback game mechanics can strongly motivate elderly players. The use of competition, challenges, performance feedback, and leaderboards can create a fun and entertaining environment with the elderly discussing and comparing their performances. 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.

– Augmented Reality can be utilised in a meaningful way, within the context of a cognitive screening game. Many times in games, AR is used just to provide the "novel" label and to trigger the "wow effect". In cognitive screening games, AR can offer much more than just fascinating the player, since it can add an underlying level of cognitive complexity, which does not affect the game difficulty level and, at the same time, manages to stimulate the player cognitively and physically (motor skills). The challenging part of implementing AR in a cognitive screening context is finding the right balance between the utilised AR elements that could serve the game scenario and the ones serving screening process. In our project, we had to adjust the interaction method in order for AR to have meaningful presence and to be technically robust [5, 7].
– The design and ethical guidelines around elderly users should be respected and implemented when designing serious games for such a sensitive and unique target group. Serious games for elderly players target a niche market and should be designed accordingly, thus catering to the special interaction needs of the elderly population [15, 17, 21]. Furthermore, all the safeguarding procedures and ethical guidelines should be applied, as well as many iterations and testings should take place, in order to confirm that the final product is not only entertaining, motivating, and effective, but also safe.
– A mini-game architecture can facilitate the cognitive screening performance of a serious game by addressing a spectrum of cognitive abilities. Mini-games can be a resource in their own right, incorporating different gameplay mechanics, and - when united - focusing on a single topic [12]. Furthermore, mini-games provide the opportunity for the player to explore various and different game scenarios and experience the motivating feeling of achievement that comes from the completion of a level or a mini-game, more frequently [12, 4].
– Cubes can be a valuable tool for cognitive screening serious games and suitable for elderly players. The game element that is associated with the cubes, combined with the fact that they have been successfully used as assistive tools for cognitive training and cognitive assessment [13, 11, 31] can create a promising interaction component for cognitive screening serious games.

8 Conclusion

Serious games for cognitive screening is a promising subfield of the "serious games for health" domain, while Augmented Reality can be a suitable, enabling technology, with the proper adjustments. Our work on Smartkuber led to several findings that could be potentially generalised and benefit the Serious Games and Augmented Reality communities. Ultimately, through the project, we managed to show that, even though the field of cognitive screening serious games presents many unique, research challenges, it can highly contribute to the fight against cognitive impairment and dementia, in a meaningful and innovative way.

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