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"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 serious 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 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 game scores of the first and last game sessions of each player (Delta scores).

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 indicating no 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.

Introduction

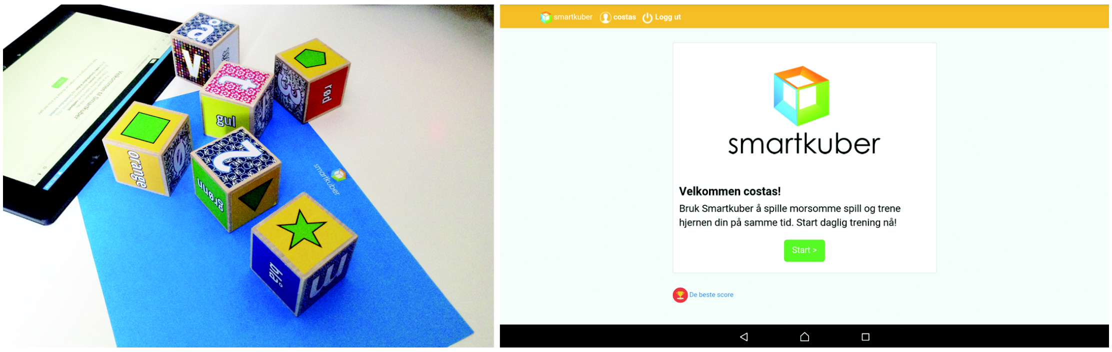
Cognitive impairment in the elderly can be associated with the normal ageing process, or be a symptom of the onset of dementia.[1, 2] Symptomatic cognitive impairment is under-recognised and under-diagnosed, even though early detection in dementia care is of great significance and has many benefits, including providing an explanation for changes in behaviour and functioning, and allowing the person to be involved in future care planning.[3-6]

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.[1] 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).[1, 6-10] Furthermore, there is significant economic burden associated with increased screening.[1, 7] 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.[1, 6, 11]

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.[1, 12] 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.[1, 7]

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.[1] 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.[6, 13, 14] 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.[14, 15] Compared to the other widely-used brief cognitive measure, i.e. the Mini-Mental State Examination (MMSE)[16], MoCA has been found to perform better on detecting age-related cognitive decline across the adult lifespan.[17] For our assessment, we use the lower cutpoint (e.g. 22 or 23 out of 30) as suggested by recent research.[6, 13, 17]

Figure 1. The Smartkuber setup consisted of the 6 cubes and the Smartkuber board (left) and the Smartkuber main menu (right).



The current work presents, examines, and evaluates a serious game for cognitive health screening of the elderly, namely Smartkuber (Table 1, Fig. 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 impaired 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.[1, 18] 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 [19, 20] resulted in the shaping of the characteristics and the theoretical description of the gaming system,[1, 21] followed by an iterative development process and the examination of several interaction, game design, and game content aspects.[22, 23]

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.

Table 1. Characteristics of a Videogame for Health ("Smartkuber").

Characteristic	
Health topic(s)	Cognitive health screening
Targeted age groups	Elderly adults (60+ years old), mild cognitive impaired adults, all adults
Short description of game idea	A collection of 5 cognitive training mini-games, addressing various cognitive abilities and played in a linear sequence, resulting to a total game score, which can be used for cognitive health screening purposes
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
Type of game	Cognitive training game for cognitive health screening
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
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
Estimated play time	5-10 minutes/session

Materials and Methods

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.[22, 23] 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).[24, 25] 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.

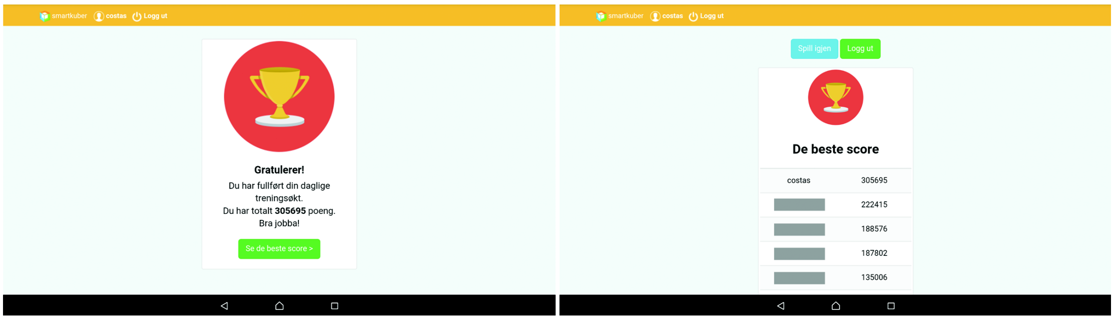
Design requirements

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 game on 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.[1] 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 frequently, 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.

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.[22] Consequently, Smartkuber was developed to be a stand-alone, mobile game for tablets, 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, like the MoCA[13] and MMSE[16]), supporting casual gaming, targeting both tactical and logistical players (motivated by Mastery, i.e. challenge and strategy, according to the Gamer Motivation Model[26]), 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. 2).

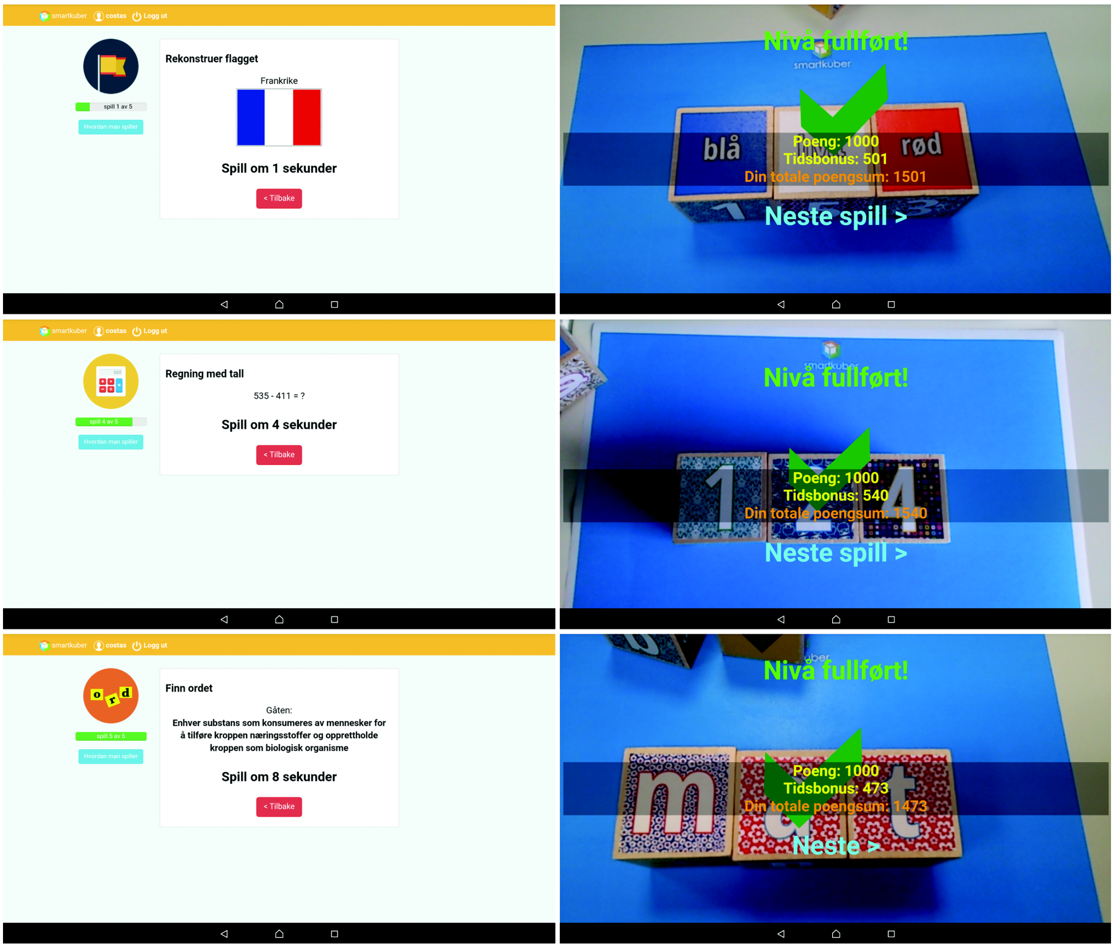
Figure 2. A Smartkuber's session final screen with the points display (left) and the Smartkuber leaderboard (right).



Interaction components

Smartkuber's interaction is based on the Tangible Augmented Reality technology, i.e. the combination of an Augmented Reality system and a tangible user interface.[27] Therefore, the main components of Smartkuber's interaction design are: the tangible, physical objects, which serve as input mechanisms - i.e. the cubes (Fig. 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.[22, 23, 28-30] Augmented Reality is a technology, which is strongly connected with the users' perception, as well as their cognitive and physical functionality.[21, 22] In previous, related studies, Augmented Reality has been found to manifest technical and perceptual issues, when cubes are digitally augmented with game content.[22, 23] To overcome these issues, Smartkuber places the main part of the interaction and the game content at the real world, i.e. the game content is placed physically on the cubes, and AR is utilised solely for real-world recognition and content verification purposes, i.e. verifying the correct, real-world game tasks (Fig. 3).[23] The AR functionality of the game is based on marker-based tracking.

Figure 3. The "Reconstruct the flag", "Numerical calculation", and "Find the word" mini-games' main screens (left) and the success message of completing the levels (right).



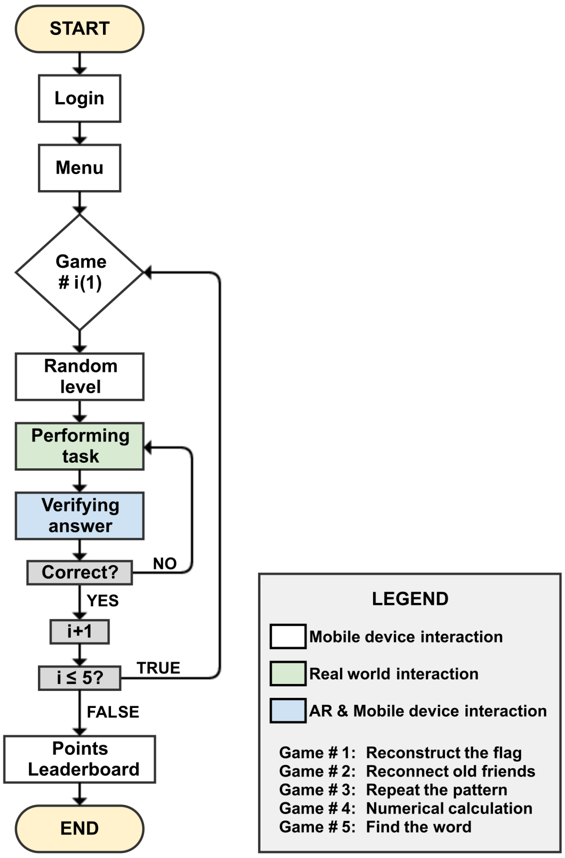
Interaction technique

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. 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. 1).

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. 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 (Fig. 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.

Figure 4. The flowchart of a full gaming session with Smartkuber.



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.[31] The menus are clear and simple in structure, 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. [23, 31, 32]

Game content

In order to address the various cognitive abilities that should be stimulated, Smartkuber consists of 5 different cognitive mini-games (Table 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 clue, while the player has to use the numbers and letters on the cubes to form the correct numerical and word answers respectively (Fig. 3).

Table 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

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.[25, 33]

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, et al.) 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.

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, et al.), 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 rapidly (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.

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,[13] 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 generated 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 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 last 20% of sessions (e.g. for a player with 20 sessions: the last 4 sessions) minus the mean total score of the first 20% of sessions.

The players' game experience was measured by asking participants to fill out the In-Game Experience Questionnaire (iGEQ).[34] 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 game-play 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.[23, 35]

Statistical analysis

All data was analysed using the Statistical Package for Social Sciences (SPSS) version 22. Significance level was set at $p < 0.05$. Descriptive analysis was used 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. 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.

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 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.

Table 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)

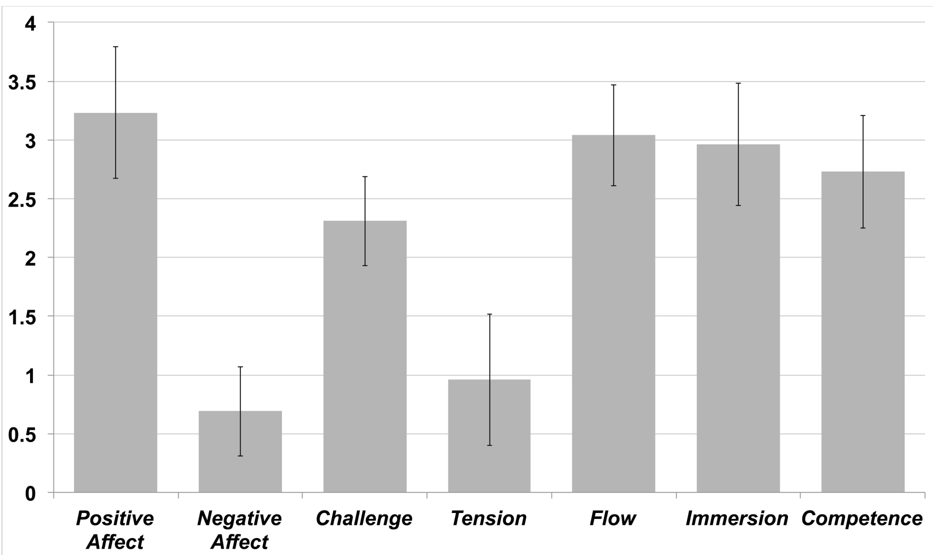
#4: Numerical calculation	706.75 (69.09)
#5: Find the word	681.53 (109.97)
Smartkuber total score	3564.70 (294.60)

Age, MoCA scores, and Smartkuber characteristics and scores are given as mean with standard deviation in parenthesis

All participants successfully completed the two-month period playing the game at an open and free rate (Table 3). 244 gaming sessions (mean number of sessions/player: 18.77, SD: 2.68, range: 14-22) 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) 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 (Table 4).

Figure 5. The iGEQ mean scores (with SD bars) across the seven dimensions of Game Experience, for the Smartkuber game.



The correlational study (Table 5) 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.

Table 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
Delayed 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**

* $p < 0.05$; ** $p < 0.01$.

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 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.

Table 5. The players' Delta scores.

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

Discussion

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. 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.

Correlational study

The correlational study provided important insights on the utilisation of the Smartkuber 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 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 manual tuning 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 tuning 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.[6, 36, 37] 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 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.

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. The randomization 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.

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. We also assume that no player experienced major cognitive decline during the study duration. Furthermore, even though the individual Smartkuber mini-games and the MoCA subtests are not individually validated, the examination of their correlation values (Table 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 offer valuable insight and feedback to the improvement of the game as a cognitive health screening tool.[6] 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.[38]

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. et al.) should be assessed, in order to further establish the game's construct validity.[16, 39]

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, et al.), 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.

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