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Evaluating a Gaming System for Cognitive Screening and Sleep Duration Assessment of Elderly Players: A Pilot Study

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Abstract. Using serious games for cognitive screening can provide a motivating and entertaining alternative to traditional cognitive screening methods. Cognitive decline is usually measured by tests of mental processing, however age-related changes in sleep may also reveal signs of cognitive decline among older individuals. The current work presents and evaluates a gaming system for cognitive screening and sleep duration assessment of the elderly. The gaming system consists of an original serious game for cognitive screening (Smartkuber) and a smartwatch (Basis Peak). A pilot study is conducted to identify and improve the weaknesses of the gaming system and to evaluate the gaming system as to its usability and the game experience it offers for elderly players, assesing its suitability for a large-scale study. The pilot study lasted for 6 weeks and 101 gaming sessions were recorded from 5 elderly players. Elderly players were entertained by the game, while they were impressed by the smartwatch's performance. Limitations of the study and future directions are discussed.

Keywords: Cognitive screening; serious games; smartwatch;

1 Introduction

Cognitive impairment is often associated with the normal ageing processes; they can however signal early onset dementia [4, 21, 6]. Unfortunately, cognitive impairment is still under-recognised and under-diagnosed [6, 11, 23, 25, 28]. Cognitive screening represents the initial step in the assessment process for dementia and can help identify potential cases for assessment, thus leading to early diagnosis [4, 21, 6].

Serious games for cognitive screening are presented as an alternative to traditional, pen-and-paper and computerised cognitive screening tests, potentially motivating and engaging the user to regularly perform cognitive screening tasks, increasing the recognition of cognitive impairment [4, 6, 29, 17]. Cognitive screening serious games can address the limitations of the traditional, pen-and-paper cognitive screening tests [6]. They can be economical of time and cost, provide accurate and frequent response recording, eliminate learning effects (due to dynamically updated content), be self-administered or require little training, provide a pleasant experience and reduce the psychological stress caused by the regular screening processes [4, 6, 18]. Moreover, cognitive screening serious games - when consisted of accredited cognitive exercises - can provide an indicative measurement of the player's cognitive performance through the game score [27, 6, 16]. They can be validated against established tests used in clinical practice and consequently provide the players with constant monitoring of their cognitive health, in an entertaining, motivational and engaging way [4, 6, 30].

Even though, cognitive screening practices mainly focus on examining the performance of mental processes, there are also other indicators of cognitive decline, one of the most strongly associated being sleep quality [22, 1]. Detrimental changes in sleep duration and quality are more common with increasing age. Age-related changes in sleep may contribute to cognitive decline among older individuals, with intermediate sleep durations (> 6-9 hours/night) exhibiting significantly higher cognitive scores than individuals with short sleep (0-6 hours/night) or long sleep duration (> 9 hours/night) [12, 14]. Associations between sleep duration and cognitive function measures have been shown to be U-shaped with poorer cognitive function scores at the short and long ends of the sleep distribution [12].

The measurement of sleep duration and sleep quality is a challenging issue. Many studies utilise subjective, self-report measures (such as the Pittsburgh Sleep Quality Index [10]), as objective measures of sleep quality present several challenges mostly due to the obtrusive character of the measurement instruments, such as encephalogram (EEG) head sets. However, the recent advances in smartwatches provide the ability to record sleeping habits [7]. Naturally, their accuracy - compared to formal medical practices - is being actively researched, while devices like the Basis Peak, or Apple Watch smartwatch, provide an opportunity to test low-cost, unobtrusive, objective measurements of sleep quality, for simple indicative results and correlation effects [7].

The current work presents, examines, and studies a gaming system for cognitive screening and sleep duration assessment of the elderly. The pilot study aims to 1) identify and improve the weaknesses of the gaming system, 2) evaluate the gaming system as to its usability and the game experience it offers to a small sample of elderly players, from a qualitative point of view, and finally, 3) assess the suitability of the system for a large-scale study. The gaming system consists of an original serious game for cognitive screening, namely Smartkuber, and the Basis Peak smartwatch (Fig. 1). Smartkuber is a cognitive screening mobile game, addressing the cognitive and motor skills of the players by utilising an interaction technique based on Augmented Reality (AR) and the manipulation of tangible, physical objects (cubes). The game has been analysed in a previous study and has demonstrated high concurrent validity with the MoCA test, high level of internal consistency, satisfying levels of predictive and content validity, and no learning effects [6]. This article presents the next step of the project, building on the design and evaluation of the cognitive screening game, described in the previous study [6]. In our attempt to further improve the specificity and sensitivity of the game, the smartwatch device is integrated, in order to perform sleep duration assessment, thus creating a gaming system. The ultimate goal of the project is a system that will triangulate its measurements (by measures of cognitive skills,

Fig. 1. The cognitive screening gaming system: the Smartkuber setup (*left*) and the Basis Peak smartwatch (*right*).

motor skills, and sleep duration/stages) in order to trigger reliable referrals 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.

2 Materials and Methods

2.1 Gaming system

The cognitive screening gaming system utilises the Smartkuber game - as its main component - for stimulating the cognitive and motor skills of the players, and the Basis Peak smartwatch for providing unobtrusive and - as reliable as possible - measurements of sleep duration (Fig. 1). The measurements coming from both instruments are stored in a database (namely the "Cognitive Passport"), which essentially constitutes a user profile, tracking the player's performance over time.

2.2 Cognitive screening game

Smartkuber is a collection of cognitive mini-games of preventative health purpose and is targeting elderly players (60+ years old), mild cognitive impaired players and, secondarily, healthy adults, with an interest in video gaming. The stimulating cognitive training with Smartkuber is aiming to screen the cognitive abilities of the players on a frequent basis (even daily).

The main components of Smartkuber's interaction design are: the tangible, physical objects, which serve as input mechanisms - i.e. the cubes - and the Augmented Reality technology, for real-world recognition and content verification purposes. The interaction technique of Smartkuber features the player using a tablet device to load the game tasks and then manipulating the cubes to perform those tasks [6]. The 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 content verification purposes [6].

Table 1. The titles and the descriptions of the Smartkuber mini-games.

1. Reconstruct the flag: The player has to memorise the flag and use the cubes to reconstruct it
2. Reconnect old friends: The player has to memorise the friends' faces and use the cubes to form the right pair of friends
3. Repeat the pattern: The player has to memorise a shape pattern and use the cubes to form it
4. Numerical calculation: The player has to do a numerical calculation and use the cubes to form the right answer
5. Find the word: The player is given a word quiz and uses the cubes to form the right answer

Smartkuber consists of 5 different cognitive mini-games (Table 1), addressing various cognitive abilities, like Attention, Memory, Motor skills, Visual and Spatial processing, Language, and Executive functions: problem solving, decision-making, working memory, flexibility, and response inhibition. 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 learning effects, while the difficulty level is tweaked to a challenging, yet "normal" level [6].

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 game features a leaderboard with all the players' scores (Fig. 2) [6].

2.3 Smartwatch

The smartwatch chosen for our gaming system is the Basis Peak (Fig. 1). Its choice over several competitors was based on the several metrics captured by the sensors, as well as the simple user interaction required. The charging and uploading-data (syncing) process of the Basis Peak is straight-forward (by just connecting it to an external device, e.g. laptop or mobile), while it is able to automatically recognise the user's activity state (e.g. sleeping) without the user pressing any button to mark the start or end time of the activity (which is the case with many similar smartwatches) [7]. The Basis Peak translates the user's biosignals into metrics on how everyday activities affect the body [7]. Its sensors include: optical blood flow sensor, 3D accelerometer, body temperature, ambient temperature reading, and galvanic skin response. The sleep analysis attempts to recognise the sleep stages (REM, light, and deep sleep) and records the sleep duration for each stage, as well as total sleep duration [7]. A measurement of unknown stage is also recorded and calculated in the total duration, when the device is not able to identify the sleep stage. Since the Basis is not a medical device, there is the issue of the validity and accuracy of the physical health data [7]. However, the Basis smartwatch has been shown to provide valuable and reliable data for the home-based dementia care [7], and also that the sleep analysis algorithm of the smartwatch demonstrated excellent agreement with polysomnography data for sleep duration and sleep staging [20].

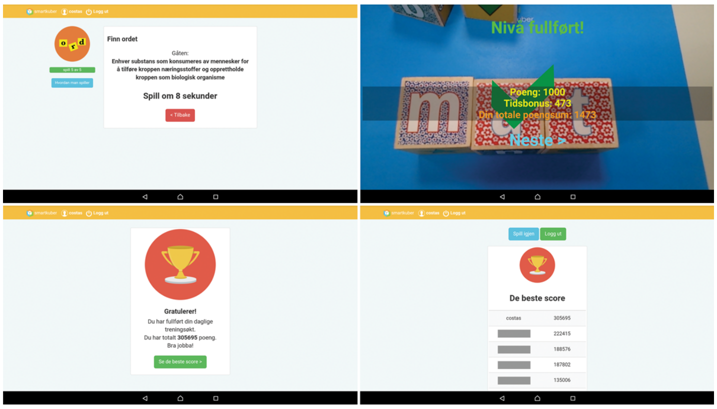

Fig. 2. Playing the "Find the word" mini-game (*upper part*), finishing the session and checking the Smartkuber high scores (*lower part*).

2.4 Database

The game scores, game times, the sleep stages, and the sleep duration measurements of each player are stored in a database, called the "Cognitive Passport" (coming from the concept of the Biological Passport [26]). The database constitutes the players' user profiles with the player's cognitive-related measurements and performance, over time (Fig. 3). The Cognitive Passport sets 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.

2.5 Study design

A qualitative methodological approach, enhanced by quantitative methods, was followed for the usability and game experience evaluation of the gaming system. The focus of the pilot study was on qualitative observations related to usability and game design issues.

The study design was divided into two stages. The first stage consisted of weekly, open-ended, and semi-structured interview sessions, which were taking place with each one of the five elderly players, addressing the negative and the positive points of their experience with the gaming system. The weekly interview sessions would take place until the reported technical, interaction, and game design or experience issues were solved, since the current study follows the concept of data saturation [15]. In this case, data saturation was defined as the point where the collection of new data regarding technical and game design issues would not shed more light on the system's usability and the game experience it offered.

The data saturation point was estimated at approximately 8 weeks, based on the fact that the Smartkuber game was already evaluated and has succeeded in providing an entertaining, engaging, and motivating gaming experience to elderly

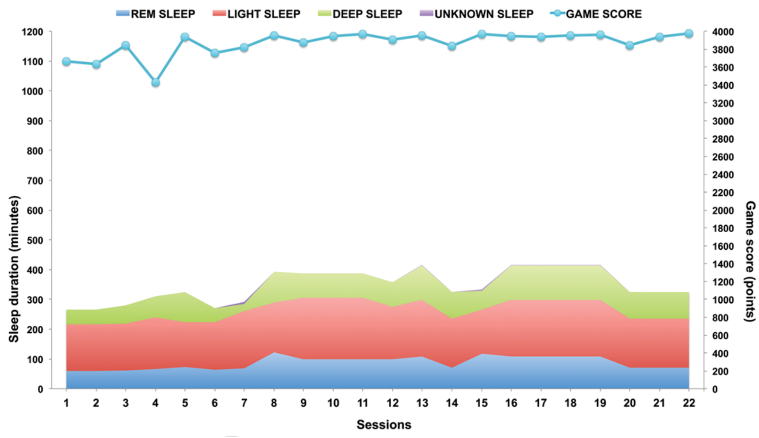

Fig. 3. A stacked visualization of a player's game scores and sleep duration measurements (22 sessions), as stored in the Cognitive Passport database.

players at a previous study [6]. The study's sample size was determined, based on the experience we have acquired from previous related testings and studies [5, 3] and the notion that iterative sessions would take place, naturally, targeting data saturation.

The second stage of the study's methodology took place during its last week and it deployed a multi-analytical standpoint. At first, the iGEQ and SUS surveys were administered. Then, the overview of the system was further discussed at a final, open-ended, semi-structured interview session, where the players' overall remarks were documented. The quantitative methods (the iGEQ and SUS surveys) were used in a "triangulation" context, further evaluating the qualitative analysis and the results coming from the final interview, thus verifying the data saturation process.

The methodology supported the examination of the game experience and the usability of the system after addressing all the technical and game design issues that were discovered during the first weeks and which may have heavily affected the game experience and, therefore, skewed the results.

2.6 Participants

A sample of five older adults (n = 5) was recruited between July and December 2015. The inclusion criteria stated that the participants should be ≥60 years old, independently performing activities of daily living (ADL), not have been diagnosed with any kind of dementia, be familiar with technology (i.e. using or having used laptop, tablet PC, smartphone, et al.) and video games (i.e. playing or having played video games before). 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 [6]. All participants gave consent and agreed to participate in the study.

2.7 Procedures

Demographic data were collected at the initial stage of the study. Afterwards, the components of the gaming system were given, along with instructions on their functionality. The gaming system 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 (a frequency of 2 game sessions/week was proposed, but not forced). The participants wore the smartwatch during the study period. Minor technical problems, which were reported and could be addressed remotely, were solved within 1-12 hours. The two stages of the study followed (as described in Section 2.5).

2.8 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 players' game experience was measured by asking participants to fill out the In-Game Experience Questionnaire (iGEQ) [19]. 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 is the shorter and reliable in-game version of the Game Experience Questionnaire (GEQ), and it was chosen so as not to tire the participants [5, 13].

The usability of the system is measured using the System Usability Scale (SUS) [8]. The System Usability Scale 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. SUS has been demonstrated to be a reliable and valid instrument, robust with a small number of participants, 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 [5, 9, 2].

3 Results

In total, 5 participants (mean age: 72, SD: 10.15, male/female: 4/1) were recruited for the pilot study. Four participants have completed tertiary education and one has completed secondary. All of the participants were using technology on an everyday basis, using a laptop or desktop PC and at least one mobile device (tablet, smartphone, or e-reader). The participants had some degree of experience with video games (two of them playing video games "rarely" and the other three "frequently"). All participants successfully completed the study, playing the game at an open and free rate. 101 gaming sessions (mean number of sessions/player: 20.2, SD: 1.48) were recorded from the 5 participants.

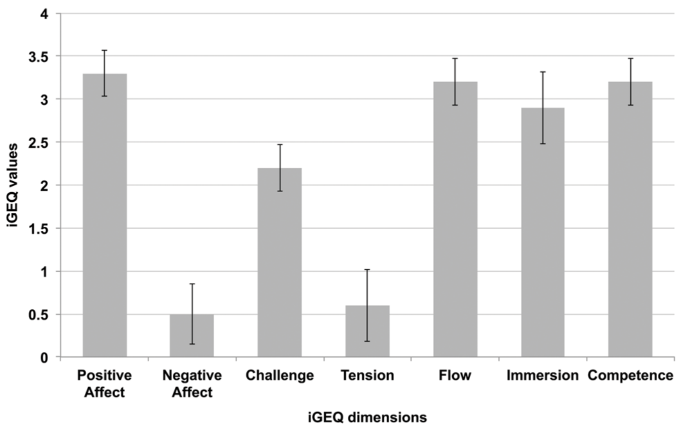

Fig. 4. The iGEQ mean scores (with SD bars) across the seven dimensions of Game Experience, for the gaming system.

The period of study was 6 weeks. The first stage of the study (i.e. the weekly interview sessions) lasted for 5 weeks until we reached and verified data saturation. The second stage of the study (iGEQ-SUS surveys and the final interview) took place during the last 6th week, when the gaming system's performance was formally evaluated.

The weekly interviews resulted in the discovery of a main technical issue related to the Basis Peak smartwatch's syncing process (i.e. uploading users' data to the database). The syncing process was too slow and it was confusing to four out of five users. The issue was addressed by providing technical instructions for a better syncing process (via Bluetooth) and the device's firmware was updated. The issue was solved by the third week. Several Smartkuber bugs (mostly concerning user-interface and device-compatibility issues) were reported via e-mail and they were fixed instantly or within 1-12 hours. On the positive side, participants enjoyed playing the Smartkuber game and competing with each other, while the interaction technique was simple and did not cause any issues. Furthermore, the elderly participants enjoyed using the smartwatch, as well as reading their sleep-related performances. Even though, the technical issues and the positive observations were collected and addressed by the third week, we decided to let the players have two more weeks of gameplay (and interview sessions), in order for them to have a more complete gaming experience and for us to be able to verify data saturation.

During the second stage of the study, all participants completed the iGEQ questionnaire, displaying high values of Flow, Positive Affect, Immersion, and Competence, moderate values of Challenge, and low values of Negative Affect and Tension (Fig. 4).

The data acquired by the SUS survey provided extra insight on the usability of the system and, especially, the integration of the smartwatch and the use of Tangible Augmented Reality (TAR). The average SUS score for the gaming system

Table 2. The elderly player's remarks as collected from the final interview session.

1.	The Smartkuber high score competition was motivating and entertaining.
2.	The smartwatch presented a technical, syncing problem, which was solved later on.
3.	The fact that the game score and the sleep duration/stages measurements over time - as stored in the Cognitive Passport database - were available, provided useful feedback and motivated for better performances.
4.	The Smartkuber game was quick, stimulating, and fun.
5.	The TAR interaction and the cubes provided a user-friendly interaction technique.
6.	The smartwatchs seamless functionality, in combination with the accurate sleep duration measurements were impressive to the users.
7.	The smartwatch felt like a regular wristwatch and it was not interfering with ADL.

was 84 (SD: 6.75, range: 77.5-95), placing its percentile ranking around 93%, according to the percentile rankings of SUS scores [24, 2]. The SUS score of 84 is placed at the top 10% of scores and it indicates that the gaming system has a higher usability score than approximately 93% of all applications tested.

The final interview session was focused on the overall positive and negative points of the gaming system and it resulted in the following qualitative results/remarks, presented in Table 2. The remarks were further organised and are listed according to their frequency of occurrence (top to bottom, top being the most frequently occurring remark).

4 Discussion

The examination of the cognitive screening gaming system showed promising results. Overall, the two stages of the pilot study helped us not only to evaluate the gaming system, but also to improve it. The first stage allowed us to collect and address all the system's issues, as well as document its positive points. The second stage provided a formal evaluation of the gaming system's usability and game experience, utilising both quantitative and qualitative tools. The fact that the pilot study was based on data saturation, having an open timeframe and a relatively small sample size, allowed us to optimise the system over time, as well as "build" a meaningful collaboration with the elderly players and involve them in the design process.

As documented in Remark #4 (Table 2) and supported by the high iGEQ value of Positive Affect (Fig. 4), elderly players considered the gaming system to be entertaining, while they felt extrinsically motivated by the competitive nature of Smartkuber and by playing against other elderly players (Remark #1). The gaming system's feedback, also, managed to tap into the players' intrinsic motivators and their individual need to always want to perform better - as reported in Remark #3 - by providing their game scores and sleep duration/stages measurements over time, through the Cognitive Passport database. The remarks can also be supported by the high iGEQ Flow and Immersion values.

The gaming system managed to offer challenging content and to stimulate the players cognitively. Naturally, the cognitively stimulating features of the gaming system come from the Smartkuber cognitive screening properties, leading to a quick, stimulating game experience (Remark #4). The challenging and stimulating character of the gaming system can be potentially revealed by the high iGEQ values of Immersion and Challenge.

The evaluation of the gaming system's usability was one of the main goals of the current pilot study. Overall, the interaction of the gaming system proved to be user/elderly-friendly, scoring high at the System Usability Scale, while presenting high iGEQ Competence and Positive Affect and low Negative Affect and Tension values. The Smartkuber interaction technique, utilising Augmented Reality and tangible objects, was considered to be user-friendly for the elderly (Remark #5). The Basis Peak smartwatch performed satisfactorily. Even though there was a technical problem during the first sessions (Remark #2), its low complexity, seamless performance and accuracy were impressive to the elderly users (Remarks #6 and #7).

Undoubtedly, the gaming system's main component is the Smartkuber game. The findings related to Smartkuber agreed with the ones of the previous study [6]. Furthermore, the smartwatch's integration was beneficial for the gaming system, with the elderly players being impressed by the fact that a device that looks and feels like a regular wristwatch can provide so much information about their sleeping habits. Within the context of the gaming system's current version, the use of the smartwatch is not related with the game mechanics, since we wanted to have a clear picture of the device's usability performance, without being affected by extrinsic game motivators. Naturally, the next step for the smartwatch is highlighting its role in the system as an active gaming component, by gamifying its use frequency, thus adding extrinsic motivation around the smartwatch's use and sleep duration assessment.

The present small-scale pilot study was limited by the inclusion criteria and the fact that the technology-use and video-gaming biases were addressed, restricting the target population of the cognitive screening and sleep duration assessment process. In the study, the motor skills of the players - even though stimulated - were not directly measured, since the technical implementation is a challenging task, which falls into the future-work timeframe.

5 Conclusion

The gaming system for cognitive screening and sleep assessment described herein managed to provide stimulating cognitive challenges, user-friendly interaction, as well as an entertaining and motivating gaming experience. The pilot study was of great significance for improving and evaluating the gaming system from a user-centered perspective and preparing it for the next research step, which will focus on utilising a larger sample size and evaluate the sleep duration assessment as for its concurrent validity against the Smartkuber score. From a game design and development perpective the smartwatch's use will be gamified, the measurement of motor skills will be technically implemented, and the Cognitive Passport database will be utilised to develop a user platform with the players' performance profiles.

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