Developing an Adaptive Memory Game for Seniors

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Abstract. This paper describes the development of a game application for seniors to train their memory and learning abilities. From an initial co-discovery evaluation participants were found to prefer more cognitive challenge and expected more synergy between the games. Based on this feedback, a redesign was developed consisting of nine cognitive games, which were integrated in a higher-level maze game. In addition, each game was extended with five difficulty levels. The results of a two week field trial show that training positively affects performance, although this effect is mediated by subjective vitality. In addition, the amount of effort that participants put into playing the games contributed significantly to their experience of engagement, this in turn positively affected performance, which positively affected participants' motivation to play the games. Participants with a high community rank experienced more pressure than participants with a lower acquired rank.

Keywords: seniors, memory, cognitive decline, gaming, community, engagement, motivation.

1 Introduction

After World War II many Western countries saw an increase in their birth rate, a generation now called 'Baby Boomers'. This generation currently represents a significant proportion of the population and will result in a rapid growth of the elderly population in the coming years. These seniors are an interesting target group not only due to its size, but also with regard to their changing needs. For example, many seniors are confronted with transition phases, which often involve adjustments in their way of life, like finding a new way to spend the day, find a new purpose and challenge in life and rearranging ones social network. Common transition phases are retirement, becoming a grandparent and changes in physical and cognitive abilities.

In the course of our lives, our cognitive abilities are said to increase until our late thirties or early forties, then a period of stability until our mid-fifties or early sixties, followed by a gradual decline [1]. The onset and course of this decline is difficult to determine, since it is not directly related to age. In spite of the stage they are in, cognitive decline is often a major concern for seniors. Fortunately, studies have

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shown that training can indeed significantly improve cognitive performance ([2] [3] [4] [5] [6] [7]). In fact, this also seems to be common sense knowledge among seniors, since they frequently mention keeping up their cognitive abilities as a motive to play games or puzzles (as was also found during our user tests).

In addition to focusing on supporting healthy aging for this target group for the coming years, it is important to approach them from a more lifestyle-oriented perspective. For that purpose a game application was developed to support seniors with training their cognitive abilities, which is above all fun to play.

1.1 Information-Universal Versus Information-Specific Theories

[6] sort the theories that have been applied to explain age-related declines in cognitive performance into two categories, namely information-universal versus information-specific theories.

The mechanism underlying cognitive aging in information-universal theories is independent of the type or structure of the information that is being processed. For example, the *general slowing theory* (or *global-speed theory*) states that the speed of executive cognitive operations decreases with aging, regardless of the type of task or the mental operations involved in the task ([8] [9]) which causes an increase in time to perform the task and an increase in the error rate. In contrast according to the information-specific theories, the type or structure of the memory units play an important role in the effects of cognitive aging. For example, the *specific gain/loss theory* argues that the pattern of spared and impaired cognitive functions in old age is related to concurrent age-related neurobiological changes in the brain. More specifically, the hippocampus and the frontal lobes and the cognitive functions that rely on these parts of the brain are most susceptible to the effects of aging.

There is growing evidence for process-specific age-related differences on top of a global trend, affecting all processing components ([10]). In their comparison of the predictive power of the global-speed theory and specific gain/loss theory, [10] used two sets of tasks, which propose different demands on cognitive processing. For the executive function tasks higher demands are made on cognitive processing and performing these tasks relies heavily on the frontal brain structures. A typical example of executive function tasks are response selection, in which a right-hand response is required after the appearance of stimuli on the left side of the screen. Non-executive function tasks make fewer demands on cognitive processing and constitute simple-reaction tasks, which requires a speeded response to any stimulus appearing anywhere on the display. Thus according to the global-speed theory, it can be expected that performance on both executive and non-executive tasks will decline in similar proportions as a result of aging, whereas according to the specific gain/loss theory, age-related cognitive decline will be more prominent in the performance for the executive tasks, since these rely more heavily on the brain structures that are most susceptible to aging. However, the analysis of their data suggests that both global processing speed and executive functioning account for the age related decline in the efficiency of cognitive processing. Young adults and seniors differed both on global processing speed as well as on executive functioning. This indicated that the demands on executive functioning affect the speed of responding over and above global-speed effects.

1.2 The Effects of Practice on Cognitive Decline

Cognitive intervention studies suggest that cognitive decline in old age, for many older adults, might be attributed to disuse rather than to the deterioration of the physiological or neural substrates of cognitive behavior [11]. Relatively preserved in old age is memory performance involving highly practiced skills and familiar information, including factual, semantic and autobiographical information. Relatively impaired in old age is memory performance that requires the formation of new connections, such as recall of new facts. For example, studies have shown that elderly typically experience a decline in word retrieval, but not in retrieval of word meaning ([12]).

However, practice might ward off cognitive decline. In their longitudinal study on the effects of cognitive training on cognitive decline, [4] found that of the participants for whom a significant decrement was documented over a 14-year period, roughly 40 percent returned after training to the level at which they had functioned when first studied. Furthermore, 60 percent of the men and 70 percent of the women showed significant training gain (that is, a training improvement of 1 standard error of measurement). A 7-year follow-up study further demonstrated that those subjects who showed significant decline at initial training retained a substantial advantage over untrained comparison groups [4]. [5] also found that cognitive training positively affected performance on memory training, reasoning training and speed-of-processing training, both immediately after the intervention as well as at a 2-year follow up (although the training impact decreased over time, but it remained significant). The largest effects were found for speed-of-processing training. Note that cognitive training will also be effective in enhancing the performance of young adults, so age differences tend to remain robust ([13]).

1.3 Explaining the Effects of Practice

[14] proposed the differential-preservation hypothesis versus the preserved-differentiation hypothesis to account for the effects of practice. According to the *differential-preservation hypothesis* cognitive performance in older age depends on the level of mental activity a person engages in. On the other hand, the *preserved-differentiation hypothesis* argues that cognitive performance in older age depends on the level of mental activity that a person engaged in during his younger years. See figure 1 for a graphical overview of these hypotheses.

[2] illustrates this distinction with the finding that bridge players tend to have higher levels of cognitive functioning than people who do not play bridge. The differential-preservation hypothesis would suggest that playing bridge builds mental muscle that prevents deterioration of mental ability, whereas the preserved-differentiation hypothesis would suggest that a minimum level of mental strength is needed for individuals of any age to be capable of playing bridge.

A cultural advantage might account for the differences in mental activity as depicted by the preserved-differentiation hypothesis. [15] found that the trend for cognitive decline in late adulthood applies equally to individuals with different socio-economic backgrounds, although people from culturally and socially advantaged backgrounds entered old age at a higher average level of functioning and retained this advantage. Similarly, comparisons between people with high and low levels of

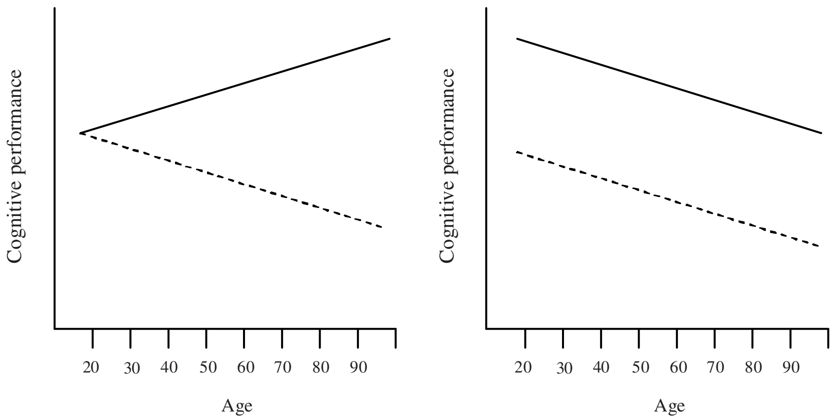

Fig. 1. *Cognitive performance* (accuracy and response time) at a given *age* as a function of *high mental activity* (*black line*) and *low mental activity* (*dotted line*). The left panel illustrates the differential-preservation hypothesis, while the right panel illustrates the preserved-differentiation hypothesis.

general intelligence have indicated that these people decline in similar rates, that is they decline with a similar amount of points. Hence a person with an original test score of 150 will be less affected by general decline, than a person with an initial test score of 70 ([16]).

From the literature reviewed here it can be concluded that although cognitive decline is part of normal aging, two main nuances are important to take into account in this respect, namely that it is not a matter of consistent overall decline and that cognitive training has a positive effect on cognitive functioning.

2 Developing the Prototype

2.1 Co-discovery Evaluation

Based on literature a first version of the game was tested in a lab setting by means of a co-discovery evaluation. At this point the game consisted of a set of six games focusing on memory and learning abilities, which were inspired by traditional laboratory tests to assess cognitive performance. Games included in this version were vigilance, passive working memory, active working memory, selective attention, pattern recognition and stimulus discrimination. In addition, participants were presented with various conceptual designs of score feedback, both for their individual performance history as well as their relative performance compared to peers.

Since the TV is the most accepted and familiar interactive device in the home environment, the prototype was implemented as an interactive application on a TV. Interaction with the prototype was done through a standard remote control with only numerical and arrow keys. No special function keys were used in order to not confuse the target users and to make the interaction as simple as possible.

Fig. 2. The maze game consisting of nine sub-games

Fourteen senior participants (6 male and 8 female, all between the ages 56-79 with a mean age of 71) were invited in pairs to a home-like environment at Philips Research for a co-discovery evaluation of the prototype. During the co-discovery evaluation participants were asked to perform a number of tasks together. Using pairs of users enhances the value of their statements compared to single users thinking aloud ([17]). The seniors who were invited to participate in this test were asked to bring someone along he/she knows well to facilitate their willingness to reflect their personal opinion in an open and friendly atmosphere.

For most participants the interface was clear and they either immediately started playing the games by pressing the numbered buttons on the remote control or they pressed 'ok' to read the instructions. Participants liked the feedback on their selections (such as buttons switching to a darker color to represent being pressed), the interaction style with the remote control and the colorfulness of the application. Participants remarked that they thought these types of games would be beneficial for memory, although in their current form they thought they were too easy and short. The games required neither much concentration nor involvement, although this is what people would expect from activities to train memory. Participants noted that they liked to be challenged, whereas these games lacked difficulty levels and therefore were not sufficiently interesting.

2.2 Redesign of the Application

Based on the results of the lab test, a redesign of the games was developed. These modifications are now discussed. First, to make the games more challenging and engaging, they were integrated into one overall maze game (see figure 2). In addition, each individual game consisted of five difficulty levels, which would be adapted according to players' scores. The maze game consisted of nine sub-games, which are presented as icons throughout the maze. In addition to the existing games in the earlier version of the prototype, which were extended to make them more challenging, the games target detection, iconic memory, episodic memory and spatial memory were added as sub-games (vigilance was left out). The theme of the application was a sea setting, since it was evaluated as the most attractive theme during the co-discovery evaluation. A player is represented by a diver that can be operated by manipulating the arrows on the remote control. Each time a player runs into an obstacle or icon, the corresponding sub-game is initiated. The goal of this maze game is to find the exit and collect as many points as possible on the way by playing the sub-games.

In addition to these nine games, players have the option to view their scores, both in relation to their own personal history as well as in relation to their peers' scores.

3 Testing the Application in the Field

Although an evaluation in a controlled environment such as a laboratory provides valuable information, we acknowledge the value of studying the use of our prototype in real life settings. While we cannot control the context and prescribe the actual usage of the prototype in field settings, it will provide complementary insights into the evaluation of the application's usage.

The field trial was carried out to test whether the redesign of the game application suited the needs of the target user. Participants who subscribed to the experiment were asked to invite their peers to play along with them. In total 17 participants signed up for the field test, of which two discontinued their participation before the end of the experiment and for one participant installation was not possible due to technical complications in the Internet subscription. Hence, in total 14 participants completed the study (11 male and 3 female), all between the ages 46-78 with a mean age of 65, all living independently. However, the results of one participant could not be used for further analysis because he did not play all of the games in the maze and also did not fill in the questionnaire or diary.

Participants subscribed with peers, resulting in six communities (three communities with one player, one community with three players and two communities with four players).

Participants were asked to play the games on their own account during a two week period. They could contact the researchers when required, but they were not contacted to avoid additional external stimulation.

Several specific research questions were addressed in this part of the study relating to cognitive performance, interaction design and social stimulation, namely:

1. Does cognitive performance change over time?
2. Does cognitive performance differ for different people?
3. How can engagement be employed in the design to make the games more intrinsically motivating?
4. How does the feedback of scores affect motivation to play?
5. How does adaptivity of gaming level make the games more challenging?
6. Does a community stimulate people to play the games?

These questions were answered by using various methods, namely logging participants' playing behavior (frequency, timing and performance), a diary maintained by the participants, a questionnaire and an interview. The diary included day to day questions on participants' experiences. In addition to the diary, participants were sent a questionnaire towards the end of the field test, which they were asked to complete after the fourteen days of the trial. This questionnaire consisted of the following components:

- Questions relating to the socio-economic status of participants,
- Subjective vitality questionnaire ([18]). This questionnaire measures people's self-assessed feeling of being alert and having energy,
- The intrinsic motivation inventory ([19]). The Intrinsic Motivation Inventory (IMI) assesses participants' interest/enjoyment (which is considered to be the self-report measure of intrinsic motivation), perceived competence, effort, value/usefulness, felt pressure and tension, and perceived choice, thus yielding six subscale scores,
- The presence questionnaire ([20]). Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another. In this presence questionnaire the questions are categorized in different factors, namely involvement/control, natural interaction, resolution and interface quality. Questions relating to auditory and haptic information were left out since these do not apply to the game application,
- Engagement questionnaire ([21]). The engagement questionnaire was included to measure game playability and interaction design. Subjects are asked to what extent they experience certain game aspects during the use of the application regarding three themes, namely engagement, control and richness.

Dutch translations of these questionnaires were used, since our participants were all Dutch. The field trial was concluded with an interview to discuss in more detail aspects like interaction, feedback, appearance, adaptivity, score representation, community overview and future use. The goal of the interview was to uncover motives and reasons behind people's opinions and to inquire suggestions for improvement.

3.1 Results of the Field Trial

The results in relation to the change in cognitive performance over time are limited due to the relatively short field trial. However, some inferences can be made when looking at the data from the frequent players in the sample. Statistical analysis showed a significant effect of playing frequency on the reaction time for stimulus discrimination ($F=4.59$; $p=0.032$) and a close to significant effect on percentage correct scoring on episodic memory ($F=3.56$; $p=0.060$) (playing frequency, percentage correct scores and reaction times were divided into five equally sized categories). Furthermore, some games seem to show an improvement in performance patterns for frequent players. More specifically, the games attention, pattern recognition, spatial memory, target detection and iconic memory consistently show an increase in the amount of correct responses, a decrease in the response time or both (for example see figure 3). However, it should be taken into account that the games might be more appealing to the frequent players and that this positively affects their performance.

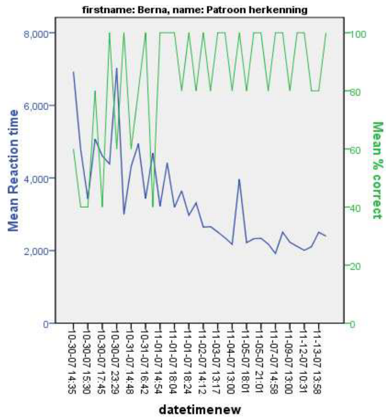

Fig. 3. Cognitive performance (*mean reaction time indicated by the blue line and mean percentage correct response indicated by the green line*) per trial (*date and time*) on the game pattern recognition for player ‘Berna’

To test the effect of vitality on performance a one-way ANOVA was used. The analysis generated one significant effect, for percentage correct on passive working memory (F=9.72; p= 0.044), and two nearly significant effects, percentage correct for pattern recognition (F=6.64; p=0.073) and reaction time for spatial memory (F=5.54; p=0.093). Hence, vitality positively affects performance for the passive working memory game and seems to affect performance on the games pattern recognition and spatial memory. Vitality also affected participant’s intrinsic motivation to play the games (F=10.78; p=0.038). That is, participants who felt healthier were also more motivated to play the games. No other effects of vitality were found on the intrinsic motivation variables.

In addition, a one-way ANOVA showed an almost significant effect of vitality on playing frequency (F=7.26, p=0.065) (playing frequency was divided into five equally sized categories), indicating that subjects who felt healthier might have been more frequent players.

Several aspects were implemented in the application to enhance engagement, namely natural interaction, involvement/control, richness, interest/enjoyment, perceived competence, effort/importance and perceived choice. The effects of these variables on engagement were tested by means of a one-way ANOVA. Only a significant effect was found for effort/importance (F=9.46; p=0.045). That is, putting effort into and trying hard on the activity enhances people’s feeling of engagement. In addition, the effect of engagement on intrinsic motivation was tested, also by means of an ANOVA, but this did not generate a significant effect. The effect of effort/importance on intrinsic motivation was also not significant.

Another approach is to see whether engagement affects people’s playing behavior. That is, does engagement stimulate people to play the games and does it stimulate people’s performance. The answer to the first part of the question was no, since the effect of engagement on playing frequency did not yield a significant result. Regarding the second part of the question the answer might be yes. That is, engagement positively affected the reaction time for passive working memory

(F=9.03; p=0.048) and the percentage correct for pattern recognition (F=8.97; p=0.049) and stimulus discrimination (F=10.68; p=0.038), while it also seemed to affect the percentage correct scoring for passive working memory (F=6.37; p=0.078) and iconic memory (F=6.69; p=0.073).

With regard to the effect of people's individual scores on their motivation to play, significant effects were found for percentage correct scoring on spatial memory (F=5.28; p=0.022), percentage correct scoring on iconic memory (F=5.58; p=0.019) and a close to significant effect was found for percentage correct scoring on episodic memory (F=3.13; p=0.080). So it seems that participant's achievements on at least some of the games enhance their motivation to play. From the interviews it became clear that for some people their personal history was more important, while for others the community comparison was more important. Participants who found their own personal history more important stated that they were not competitive and that they did not really care about or were stimulated by the performance of others. Also the community overview would not reflect their development over time and hence for them it would not give a reliable result. Participants, who found the community overview more important than their personal history, stated that they were very motivated by the performance of others and thought the competitive aspect of the application was fun. These participants also mentioned that they played extra when they noticed that others were getting better. However, some people mentioned that they were also demotivated by the community view when they had already acquired a top score, since playing would put them at risk of losing their top position.

One-way ANOVA revealed that neither the rank that was achieved in the community nor the size of the community affected the playing frequency. A close to significant effect was found for the size of the community on engagement (F=3.21; p=0.084). Hence, it seems that people who were part of a bigger community also experienced more engagement when they were playing the games. An effect was also found for community rank on perceived pressure/tension (F=6.26; p=0.014). Hence, the higher the rank that people achieved in the community the more pressure/tension they felt when they were playing the games. In addition, pressure/tension affected participants' scores regarding the reaction time on stimulus discrimination (F=6.85; p=0.017).

No significant effects were found for the levels that were acquired in the individual games on challenge. Also no significant effects were found for the levels that were acquired in the individual games on intrinsic motivation and engagement. Hence, it seems that gaming level does not affect the challenge that participants experience, nor the intrinsic motivation to play the games and the feeling of engagement. During the interviews participants mentioned that they noticed the adaptivity in the games and most of them appreciated this because it made the games more fun and challenging and it showed progress. They also noted that is was rather unclear how their scores affected the increase in levels. The participants who did not like the adaptivity thought it made the games more difficult, which did not add to their enjoyment.

4 Conclusions and Discussion

From the literature study and the lab evaluation it became clear that elderly have an apparent need to keep their cognitive abilities fit and that they are actively looking for ways to do this. This study also confirmed that cognitive training by means of our game application seems to enhance cognitive performance. Since no differences were found between the active components in memory and the passive components, it is difficult to relate these findings to either the information-universal or information-specific theories of cognitive decline.

The question remains on how this improvement in cognitive performance translates to daily activities. In their study on the effects of cognitive training on cognitive abilities and performance on Activities of Daily Life (ADL) and Instrumental Activities of Daily Life (I-ADL), [5] found no significant effects of such training on everyday functioning. However, they concluded that this was due to the lack of functional impairment at baseline. Since the everyday abilities remained intact over a 2-year period, improved cognitive function could not improve these abilities. Also during our interviews participants noted that their game performance this did not translate to their daily activities.

Regarding the differences in performance between participants it was found that for some games there seemed to be a difference in performance patterns for people who perceived themselves as very vital and people who perceived themselves as less vital. Vitality also appeared to affect participant's intrinsic motivation to play the games. People who felt less vital were less motivated to play the games than people who felt very vital. This is reasonable and some participants mentioned that they skipped playing for several days because they were not feeling well.

Another aspect that affected people's performance was the feeling of engagement. The more engagement participants experienced, the better their performance on some of the games. Engagement in turn was influenced by the amount of effort people had put into the activity of playing the games.

For some games it was found that people's achievements, as reflected by their personal scores, affected their motivation to play the games. This is in line with Cognitive Evaluation Theory (CET), which states that social-contextual events (such as feedback and rewards) that conduce toward feelings of competence during action can enhance intrinsic motivation for that action ([22]). However, these feelings of competence will not enhance intrinsic motivation unless accompanied by a sense of autonomy, which is an internal perceived locus of causality. Since people had been playing the games individually this is indeed the case.

Statistically, the community overview did not appear to affect people's playing behavior, although it was mentioned during the interviews that when participants noticed they were lagging behind in the community view that this triggered them to play the games. From the analysis it was further found that the community rank that was achieved indeed affected the experienced pressure/tension when people were playing the games. Hence, although a direct effect between community rank or size and playing frequency could not be demonstrated, people do feel a certain pressure when they have achieved a high rank within their community to maintain this position.

Another aspect that is important for intrinsic motivation is challenge. It could not be statistically demonstrated that the level structure as implemented in the application indeed enhanced the challenge experienced by the games, but participants explicitly mentioned during the interviews that this adaptivity made the games more fun and challenging. Perhaps with a larger sample this finding could have been statistically supported as well.

With regard to the methods that were used to evaluate the prototypes it can be concluded that during the interviews in the lab test the seniors were very open in describing their personal situations and opinions. Little additional encouragement from the interviewer was required, since participants often encouraged each other to elaborate on their own experiences. The diary that the participants were asked to complete during the field trial appeared to work well since all participants noted down their experiences in the diaries, some of whom extended this with printed records of their scores, and additional notes. People also wrote down the reasons if they had not been playing on a particular day. All in all, participants were very committed to adhere to the researchers' requests, regarding the use of the application, filling in the diary and questionnaire and during the reflection of their experiences during the interviews.

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