Increased enjoyment using a tablet-based serious game with regularly changing visual elements: A pilot study

Aniket Nagle MSc[a]
Domen Novak PhD[b]
Peter Wolf PhD[a]
Robert Riener PhD[a]

[a]Department of Health Sciences and Technology, ETH, Zürich, Switzerland, E: aniket.nagle@hest.ethz.ch, E: peter.wolf@hest.ethz.ch, E: robert.riener@hest.ethz.ch; [b]Department of Electrical and Computer Engineering, University of Wyoming, Laramie, USA, E: dnovak1@uwyo.edu

A. Nagle, D. Novak, P. Wolf, R. Riener. Increased enjoyment using a tablet-based serious game with regularly changing visual elements: A pilot study. Gerontechnology 2015;14(1):32-44; doi:10.4017/gt.2015.14.1.001.00 Serious games are designed to be enjoyable, to increase their functional effect and replay value. The most popular method for this purpose is dynamic difficulty adjustment (DDA), i.e., adjusting game difficulty to match user performance. DDA explicitly adjusts only game mechanics, without considering other game components. In particular, dynamically changing the visual elements of a game can also increase enjoyment, since visual variety is inherently pleasurable. In the present study, the effect of regularly changing visual elements (background, foreground, and animations) combined with DDA ('DDA-VISUAL') was compared against only DDA in a simple working memory serious game played by 14 older adults on a tablet for three sessions on three days. Participants in DDA-VISUAL experienced significantly higher enjoyment, played more rounds in the last two sessions and performed significantly better than participants in DDA. The results indicate that regularly changing visual elements combined with DDA is a simple and effective method to elicit higher enjoyment and attention in serious games, in comparison to DDA alone.

Keywords: DDA; combining visual element change with DDA; acceptance of tablets; enjoyment

Serious games are games meant for purposes other than entertainment[1], finding uses in fields such as rehabilitation[2], training[3], education[4], and learning[5]. They come in various shapes and sizes depending on the application area[6]. Serious games targeted at applications like post-trauma stress disorder rehabilitation are often immersive and realistic, because they need to accurately simulate the situations in which the trauma occurred[7]. Serious games for training specialized skills, like surgery, have to be equally faithful in reproducing the real world, since real-world fidelity is critical in developing the skills[3]. Serious games for cognitive training, in contrast, are simpler, two-dimensional in nature, with the primary mode of interaction being mouse click or touch interface. Prominent examples are commercial off-the-shelf serious games for cognitive training, such as Brain Age[8], Cogmed[9], Lumosity[10], etc.

Two important factors in designing serious games are effectiveness and attractiveness[11]. Making serious games effective depends on the functional outcome for which they were designed, and involves customizing the game mechanics and tasks to the application area. A more general factor that is independent of application area is attractiveness, which is the measure of how enjoyable users find the serious game. Attractiveness is an important factor, since enjoyable serious games are more beneficial[12-15], and have a higher replay value[16].

Enjoyment of any media, including games, is a complex phenomenon, theorized to be a result of a combination of user prerequisites (for instance, interest in the media), user motives (for instance, achievement, competition), and media prerequisites (for instance, aesthetics, content)[17]. In such a framework, serious games can be made more enjoyable by targeting an audience likely to be interested in the game (user prerequisite), making the game aesthetically pleasing and content-rich (media prerequisites), and satisfying user motives to play the game. Among various user motives to play games, the wish to challenge oneself is probably the most important one[17,18]. In fact, studies about games with older adults have shown that the challenge motive is rated highly[19,20]. Therefore, serious games that strive to be enjoyable, especially ones that are targeted at older adults, should satisfy the challenge motive. Playing any new game, serious or otherwise, at a certain difficulty level can be challenging. After a while, however, the user is likely to be quite good at the game, and will not be challenged anymore. On the other hand, if the initial difficulty level is too high, the user is likely to get frustrated and give up the game altogether. Therefore, the key to always keeping the user challenged is to dynamically change the game difficulty according to user ability. Such a balancing of difficulty and ability is theorized to keep users in a state of flow[21], where they experience optimal enjoyment[22-24]. In serious games (and also video games in general), difficulty-ability balancing is achieved by a technique known as 'dynamic difficulty adjustment' (DDA).

DDA is the process of modulating the systems of a game world to respond to a particular player's abilities over the course of a game session[25]. In general, it consists of two complementary functions: an evaluation function that evaluates player performance based on the game state, and an adjustment function, that makes some changes to the systems of the game world based on the evaluation[25]. The systems being changed have a bearing on the game difficulty, and vary with the game genre. For example, player inventory in first-person shooter games[25], or level complexity in side-scrolling games[26] determine the game difficulty, and can be adjusted with DDA. In cognitive training games such as the one considered in the present study, the game system that has a bearing on difficulty is the training task itself. In such simple serious games, DDA can be implemented by evaluating how well the player is performing at the game task and changing task difficulty based on the performance[27-30].

DDA adjusts difficulty of game tasks and thus targets core game mechanics. However, the game as a whole has many other components: the visual elements in which the game tasks are framed; the sounds which help to maintain a certain ambience; in-game rewards which spur users on to play longer; character customization which gives users a level of control over the gameplay, etc. Some of these elements could conceivably be adjusted during gameplay, in addition to difficulty, to achieve a high enjoyment level.

Game visuals in particular are a patent target for adjustment. Visual elements are the primary output modality of games through which users view and interact with the game and derive sensory pleasure[31]. Therefore, a game is often defined by the amount of detail of visual elements it contains, termed 'visual complexity'[32,33]. A game like Crysis[34], which is a first-person shooter in a 3D rendered world in which the player has to move through varying landscapes fighting aliens, has photo-realistic scenery and a detailed game world and thus has high visual complexity. On the other hand, Super Mario Bros[35], the well-known side-scrolling platform game in which the user controls a 2D character and moves through simple levels, has low visual complexity. One way of using visual elements as a determinant of enjoyment is to set the visual complexity of a game to different levels, which can affect perceived enjoyment[36]. A problem with this approach is that the link between visual complexity and enjoyment is not clear and can differ with players[37]. It has been suggested that owing to older adults' reduced visual acuity, games for older adults be of low visual complexity[38, 39]. However, in a study about a motion-based serious game, visual complexity was found not to affect enjoyment among older adults[33]. Among younger players on the other hand, increased visual complexity resulted in increased enjoyment[36]. Therefore, setting an appropriate visual complexity to increase enjoyment can be challenging. Visual elements can also be changed during a game based on some criterion function. An example is scenario adaptation[40-42], where parts of the game environment are dynamically generated based on criterion functions like a pedagogical model of user learning[40] or an assessment of user performance[41,42].

Although scenario adaptation works well for games with complex environments, it does not transfer easily to simple, two-dimensional serious games. Moreover, scenario adaptation does not really take into account enjoyment as a criterion function. Another example of dynamic visual element change is the paradigm of 'levels', where players move through differently appearing game worlds. However, as with scenario adaptation, creating levels is more suitable to larger, more complex games.

Instead of using particular criterion functions or constructing levels, dynamic visual element change can be more simply viewed through the inherent enjoyable nature of the change itself. In general, monotony in any form is boring[43], while variety is pleasurable. This is especially true for the visual system. Previous work suggests that visual diversity is pleasurable[44] and positively influences task motivation[45], whereas visual monotony negatively impacts task performance[46]. In games, Malone includes variation in visual stimuli as an element of sensory curiosity, citing it as one of the heuristics to make instructional computer games more enjoyable[47]. While there are certain minimum prerequisites for games to be enjoyable (being aesthetically pleasing, content-rich, etc.), there is a potential to make them even more enjoyable through dynamic visual element change. In commercial games, such change is often rendered through animations, altering scenery, different levels, etc.

Cognitive-training serious games, like the one considered in the present work, usually contain only a few foreground and background visual elements. In such serious games, visual element change can be realized more simply by regularly altering the appearance of the elements. However, performing visual element change in isolation has a limited effect. A previous work found that altering only the visual themes of a serious game, without any other adjustments, does not significantly affect enjoyment[48]. Therefore, visual element change was deemed better suited as an add-on to a serious game that already contains some minimum enjoyment functionality. DDA, which balances difficulty and ability, is one such functionality of enjoyable serious games[49,50]. While DDA has been used in several cognitive-training serious games[27-30], the effect of adding visual element change to DDA has not been empirically tested for. Understanding this effect could enable designers to make serious games more enjoyable and effective without drastically increasing development effort.

Therefore in the present study, a simple tablet-based memory training serious game was designed and augmented with two modes: one which consisted of DDA with no visual element change (DDA) and the second in which DDA was combined with regularly changing visual elements (DDA-VISUAL). The two modes were tested with older adults who played the game on a tablet over three sessions on three different days. It was hypothesized that:
H1. Participants in DDA-VISUAL will experience higher enjoyment than participants in DDA.
H2. Participants in DDA-VISUAL will perform better than participants in DDA.
H3. Participants in DDA-VISUAL will be less distracted and more focused on the gameplay, as exhibited by them playing more rounds than participants in DDA.

Materials and Methods

Participants

Fourteen older adults (13 females) participated in this study. Twelve were recruited from two assisted-living facilities, and two were an autonomously living couple. Participants were between 68 and 95 years old, with a mean of 82.7 years and standard deviation of 8.25 years. The inclusion of 13 females was not a premeditated decision, but came about as a result of the gender ratio among residents of the two assisted-living facilities where the study was conducted. None of the participants had prior experience in tablet-based games, although most of them reported playing some kind of board game or card game on a regular basis. Three participants reported having used a tablet a few times before.
Inclusion criteria were:

- Age > 65
- Cognitively unimpaired, determined using cognitive assessment information maintained by the assisted-living facility and a pre-study interview in case of the twelve assisted living facility residents, and a pre-study interview in case of the autonomously living couple
- Physically able to use a 7-inch tablet.

Recruitment was done through presentation and demonstration at assisted living facilities, and placing advertisements in newspapers. Participation was voluntary and not reimbursed. Written informed consent was collected from the participants prior to the study and participants were informed that they could drop out of the study at any time. Prior to starting the study, ethics approval was obtained from the institutional ethics committee.

The serious game

The serious game used in this study was a tablet-based memory-training game in which participants had to memorize and recall a sequence of multiple characters. The characters would be displayed one at a time, and had to be recalled in the same order as they were displayed. After recalling one sequence, a different sequence with possibly different number of characters would be displayed. The game proceeded in such repetitive rounds for the duration of a session. To compensate for age-related visual deficits, previous research guidelines about designing games for older adults[51,52] were followed in designing visual elements of the game (*Table 1*). The game was played at a resolution of 1280x800.

The game environment consisted of a 2D scene depicting a view of looking out of a window (*Fig-*

Table 1. Guidelines[51,52] about designing games for older adults and implementation in the present study

Guideline item	Implementation
-In general, increased levels of ambient and task illumination are required to optimize visual performance for older adults	-Brightness of game objects and the tablet was set to a sufficiently high amount
-Increased levels of luminance contrast are required to meet the visual needs of older persons	-High contrast was provided for reading characters (red against white or red against blue)
-Choose text font sizes of at least 12-point in character height to accommodate the needs of those 60-75 years of age	-The sequence was displayed in 14-point font
-Minimize dependence upon peripheral vision	-The characters in the sequence to memorize were presented at the center of the screen

ure 1a). At the center of the environment was a trigger coin, which upon touching revealed either a letter or a number (*Figure 1b*). The character would remain visible for 2 seconds. The entire sequence was viewed by touching on the trigger coin one at a time, with no time limit between two touches. At the end of the sequence, the game displayed a message indicating that the sequence had to be recalled in the same order. Subsequently, four option spheres appeared, one of which contained the correct character at the first position (*Figure 1c*). After clicking on a sphere, four new spheres appeared, one of which contained the character at the second position, and so on and so forth. No time limits were imposed, either for revealing the characters, or for recalling the sequence. At the end of the recall, participants were informed of the result, which was either a motivating message in case of a correct recall or a simple statement in case of wrong recall. Such instant feedback could, in potential, keep the participants motivated[53,54]. Thereafter a new round was started. At any point during recall participants could click on a 'Pass' button which started a new round immediately.

Equipment

The ASUS MeMO Pad HD7 tablet was used in the study, running on Android version 4.2, with a screen size of 7 inches, and a screen resolution of 1280x800.

The study modes

The serious game in the present study was augmented with two modes: DDA, which consisted of only DDA with no visual element change and DDA-VISUAL, in which DDA was combined with regularly changing visual elements. The game environment was a 2D scene in which an illusion of looking out of a window was created

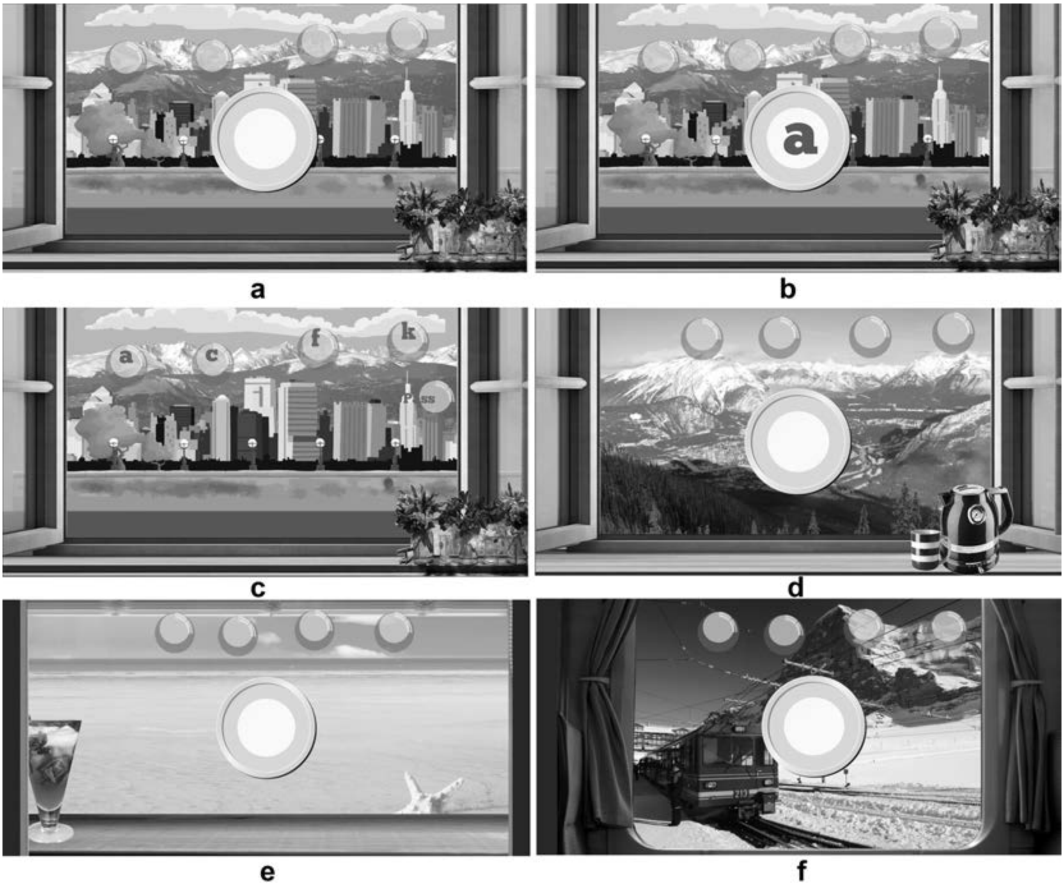

Figure 1. Screenshots of the serious game used in the present study; (a) Scene of looking out to a city, with the trigger coin at the center; (b) Upon touching the trigger coin, the first character in the sequence is revealed; (c) After the entire sequence is revealed, one character at a time, four option spheres appear, one of which contains the correct character at the first position; There is also a 'Pass' button on the right, which participants can touch to skip the current round and start a new round; (d)-(f) Visual element change done by changing the background and foreground

using a distant background image, the image of a window and an object placed on the window sill, and animations of animals or other objects moving 'between' the window and the distant background (*Figure 1*).

DDA

Hunicke has described a general DDA algorithm consisting of an evaluation function, which maps from the state of the game world to an evaluation of the player's performance, and an adjustment policy which maps this evaluation to some set of adjustments in the game world[25]. In the present study, the evaluation function checked for the success or failure of rounds. If there were three consecutive successful rounds, player performance was evaluated as 'good'. If there were two consecutive unsuccessful rounds, player

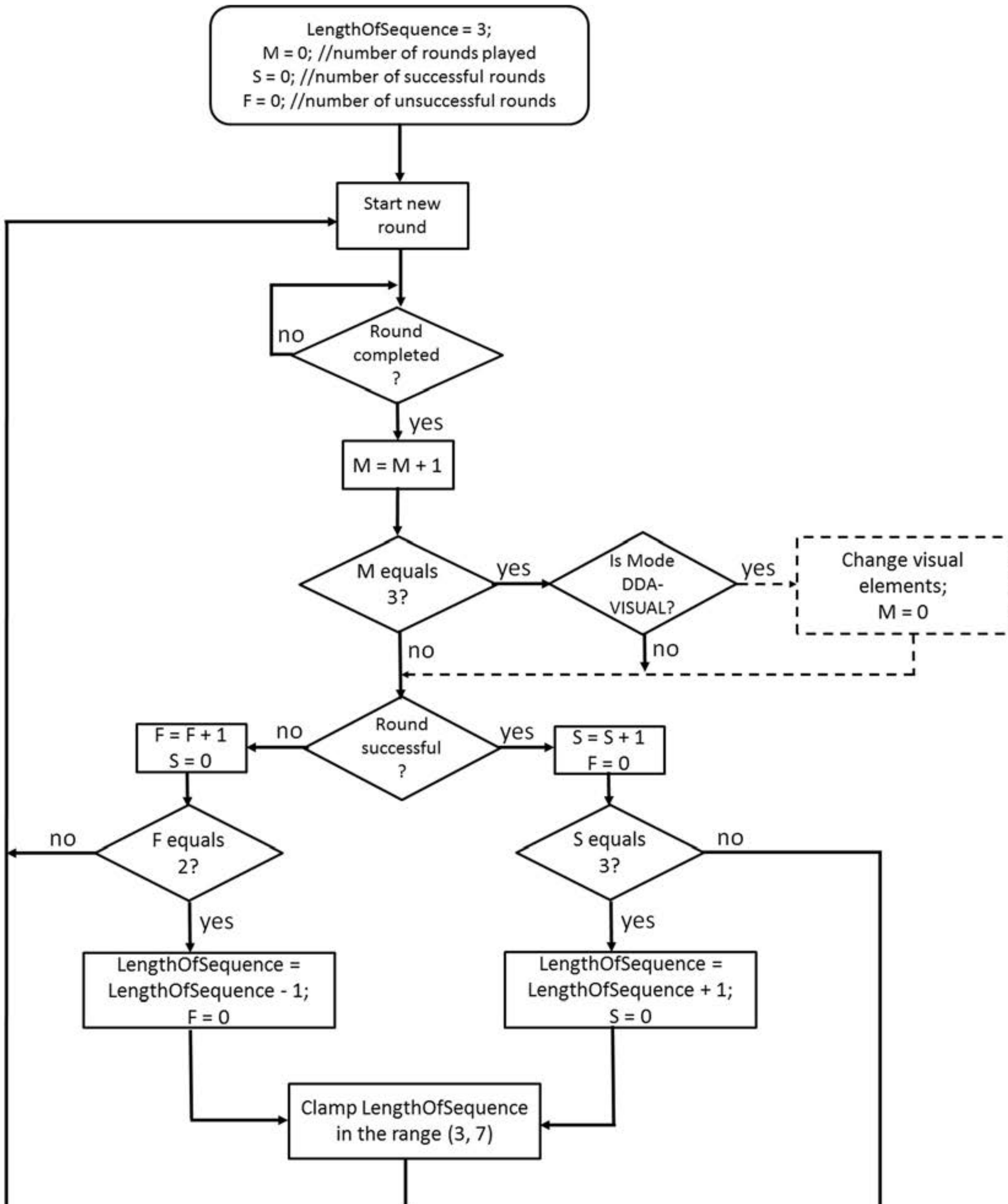

Figure 2. Flowchart of the game; The DDA mode ran through the solid blocks; The DDA-VISUAL mode ran through the dashed block in addition to the solid blocks; The initial value of sequence length was set to three, for both modes

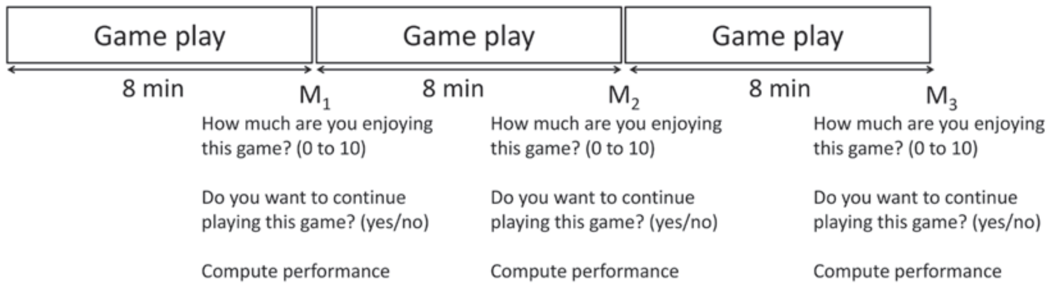

Figure 3. Study protocol for one session, with the 24 minutes session divided into three chunks of 8 minutes, interspersed with two questions related to enjoyment and automatic computation of performance

performance was evaluated as 'bad'. The adjustment policy was:
If (Player Performance is good) **then** Increase sequence length by 1.
Else if (Player Performance is bad) **then** Decrease sequence length by 1.
The initial sequence length was set to three, and clamped between three and seven in the subsequent rounds (*Figure 2*). In the DDA mode, the scene remained constant (*Figure 1a*), without any visual element changes.

DDA-VISUAL
In the DDA-VISUAL mode, difficulty was changed exactly as in DDA (*Figure 2*). Additionally, three types of visual elements were regularly changed: background, foreground, and animation. Since the number and complexity of visual elements can influence game difficulty[36], the visual element change was done without changing the number or complexity of the individual elements. Additionally, it was ensured that the elements being changed did not relate to the actual memorizing task.

There were three kinds of visual elements in the game: background, foreground, and animation. A different combination of the three elements changed the visual appearance of the game. Fourteen combinations of the elements were designed, with each combination being stored in a <background, foreground, animation> triplet. Each triplet represented a real-world scene of looking out of a window, since it was expected that the participants could relate more easily and be comfortable in this theme. The triplets included scenes like looking out into a city (*Figure 1a*), looking out from a train (*Figure 1f*), looking out from a mountain hut (*Figure1d*), looking out from a beach house (*Figure 1e*), etc. Visual element change was realized by iterating through each triplet after every three rounds. If the last triplet was reached before the end of the session, the game would cycle back to the first triplet. Each triplet was designed to be sufficiently different from the others, so that the participants would notice a change in the visual elements. The change in difficulty and change in visual elements operated independently of each other. Since the difficulty adaptation upped difficulty after every three consecutive successful rounds (*Figure 2*), only in a perfect gameplay session would the difficulty and visual element change happen concurrently.

Study protocol
Participants played the game for three sessions on three different days in a week. The duration of each session was 24 minutes (*Figure 3*), with all participants successfully finishing the entire session on all three days. Participants were pseudo-randomly assigned to one of the two modes, in single blind manner, ensuring that each mode contained an equal number of seven participants. The mean age of participants in DDA was 83 years with a standard deviation of 9.68 years; the mean age of participants in DDA-VISUAL was 82.5 years with a standard deviation of 5.72 years. Of the three participants who reported having used a tablet a few times before, two were in DDA-VISUAL and one was in DDA. Before the first session, participants were told about the study, with a special emphasis on the fact that the study was purely about game-design research. Then the game was explained

Figure 4. Four participants in an assisted living facility playing the game together

to them followed by around 10 minutes of trying out the tablet and the game. Once the participants reported that they were comfortable playing the game, a new game instance was started and the session began. There were five tablets in total, with participants given the option to either play alone, or in a group (*Figure 4*). Out of the fourteen participants, two were an autonomously living couple who played the game simultaneously in different rooms of their apartment. Of the remaining twelve, six participants each were residents of two different assisted living facilities.

Measures

There were three primary outcome measures of interest:

(i) Enjoyment

Participants were asked the following two questions, three times during a session, roughly after 8 minutes, 16 minutes and 24 minutes (*Figure 3*):

(a) How much are you enjoying playing this game? This was to be answered on an analog scale, implemented in the game as a horizontal GUI slider. The leftmost edge of the slider represented 'not enjoying at all', and the rightmost edge represented 'enjoying a lot'. Participants answered the question by moving a thumbnail in the horizontal slider.

(b) Do you want to continue playing this game? This was an option between 'yes' and 'no'.

(ii) Performance

The performance metric computed, for every successful round, the ratio of sequence length in that round to the maximum possible sequence length at that moment. Since the difficulty-adaptation algorithm was completely deterministic (*Figure 2*), the sequence length at any instant could be determined. Unsuccessful rounds would cause the sequence length in subsequent rounds to deviate from the ideal, which would then reflect in a lower performance number. In the end the total was divided by the number of rounds multiplied by 100 (Equation 1). Thus, the performance number expressed percentage of maximum possible performance. For a perfect gameplay, the performance number would be 100.

$$\frac{1}{N}\sum_{i=1}^{N}\left(\frac{C(i)*p(i)}{max(\left\lfloor\frac{(i-1)}{3}\right\rfloor+3,\ 7)}\right)*100 \qquad [1]$$

Here, N = number of rounds

$C(i)$ = sequence length in round i

$p(i)$ = 1, if round i finished successfully, else 0

(iii) Number of rounds played

This was the total number of rounds played in a session, including both successful and unsuccessful rounds, but excluding skipped rounds. Additionally, at the end of the study, subjects in the DDA-VISUAL mode were asked the following two questions:

(a) "Did you notice that the background, foreground, and animations changed regularly when you were playing the game?" This was an option between 'yes' and 'no'

(b) "Did you like the regularly changing background, foreground, and animations while playing the game?" This was an option between 'yes', 'no', and 'didn't care'.

Data analysis

Mixed ANOVA was used with time as the within-subjects factor and mode as the between-subjects factor. Participants answered the enjoyment question by moving a thumbnail in a horizontal slider. For the purposes of analysis, the position of the thumbnail within the slider was interpolated to a real number between 0 and 10. Performance was computed according to Equation 1 at the same three time points that the enjoyment question was asked, approximately after 8 minutes, 16 minutes and 24 minutes in a session (*Figure 3*). Previous work suggests that among the older population, there are age-related group differences between the 'younger old' (60-85 years of age) and 'oldest old' (85 years of age and older)[55]. Therefore, age group (<85 years of age versus >=85 years of age) by mode interactions on the three outcome measures were examined. IBM SPSS Statistics version 22.0 was used to run statistical analyses.

Results

Enjoyment, performance, rounds played

Data points for the day-wise analyses were obtained by averaging the three data points on each of the three days. Mode was the between-subjects factor in both; timepoint was the within-subjects factor in the first case and day was the within-subjects factor in the second case (*Figure 5, 6*).

Means and standard deviations for enjoyment and performance are listed in *Table 2*. Within one session on each day, the effects of time point and interaction between time point and mode were non-significant for both enjoyment and number of rounds played. Performance exhibited non-significant interaction between time point and mode; the effect of time point on performance, however, was significant on all three days ($F=13.9$, partial $\eta^2=0.538$ on Day 1, $F=17.8$, partial $\eta^2=0.6$ on Day 2, $F=16.5$, partial $\eta^2=0.579$ on Day 3; $p<0.0001$ for all days).

Day-wise, there was a significant effect of day and a significant interaction between day and

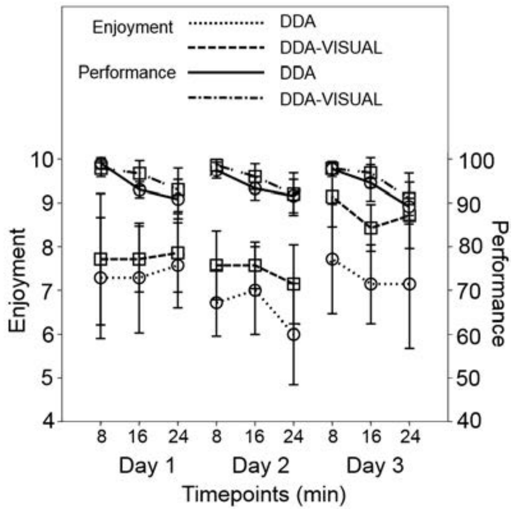

Figure 5. Enjoyment and performance (as % of maximum possible) at the nine time points

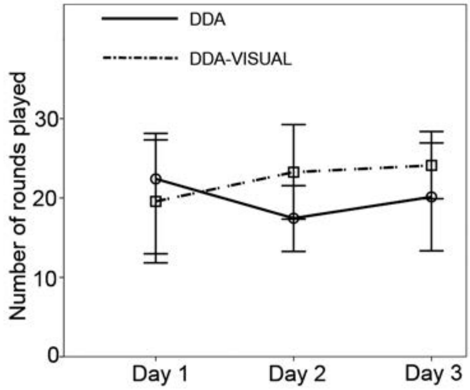

Figure 6. Number of rounds played on the three days

Table 2. Means and standard deviations of enjoyment and performance values for the time points in the two modes; Enjoyment values range from 0 to 10, performance values from 0 to 100; DDA=dynamic difficulty adjustment; DDA-VISUAL=dynamic difficulty adjustment combined with regularly changing visual elements

Day	Time point	Enjoyment		Performance	
		DDA	DDA-VISUAL	DDA	DDA-VISUAL
1	1	7.28±1.38	7.71±1.49	99.00±1.29	97.85±1.86
	2	7.25±1.25	7.67±0.75	93.00±1.82	96.71±2.92
	3	7.57±0.97	7.85±0.89	90.85±4.48	93.00±4.93
2	1	6.71±0.75	7.57±0.78	97.42±1.81	98.57±1.39
	2	7.00±1.00	7.57±0.53	93.28±2.69	96.00±2.94
	3	6.00±1.15	7.14±0.89	91.57±3.77	92.00±4.86
3	1	7.71±1.25	9.14±0.69	97.71±1.70	97.85±1.34
	2	7.14±0.89	8.42±0.53	94.57±4.15	96.85±3.43
	3	7.24±1.46	8.71±0.75	89.14±1.95	91.00±5.80

mode for enjoyment and number of rounds played; performance exhibited non-significant effects of both (*Table 2*). Simple main-effects analysis revealed that enjoyment and number of rounds played were significantly higher in DDA-VISUAL than DDA on Days 2 and 3 (*Table 3*). Overall, the main effect of mode was significant for all three outcome measures (*Table 4*). Pairwise comparisons based on estimated marginal means with a Bonferroni adjustment for multiple comparisons between the two modes revealed that enjoyment (mean difference=0.889, p=0.023), performance (mean difference=1.47, p=0.042), and number of rounds played (mean difference=3.24, p=0.011) were significantly higher in DDA-VISUAL than DDA. Interactions between age group and mode were not significant for any of the outcome measures (p>0.05). In answer to the question of whether they wanted to continue playing the game, every participant answered yes at all three time points in all three sessions.

End of experiment questions

At the end of the study, participants in the DDA-VISUAL mode were asked two questions. The first question on noticing the changes, all 7 participants answered with 'yes'. The second question on if they liked the changes was answered with 'yes' by 4 participants, 'no' by one, while 2 'Didn't care'.

Discussion and conclusions

Three hypotheses were postulated: participants in DDA-VISUAL will enjoy more (**H1**), perform better (**H2**), and play more number of rounds (**H3**) than participants in DDA. On average, participants in DDA-VISUAL experienced higher enjoyment than participants in DDA over the three days, although the differences were significant only on Days 2 and 3, thus partially fulfilling **H1**. The difference in enjoyment between the two modes increased over the days, suggesting that the effect of DDA-VISUAL became more pronounced with time. A previous study about the effect of different motivational features in a memory-training serious game played over three days found that changing visual themes, by itself, did not affect enjoyment[48]. However, the visual theme change in that study was done only between days, with the authors speculating the lack of theme change during a session being a possible reason for the change not affecting enjoyment[48]. The present result about enjoyment being higher in DDA-

Table 3. Simple main effects between the two modes for enjoyment, performance and number of rounds played on the three days; significant differences (p<0.05) are in bold; adjustment for multiple comparisons: Bonferroni; degrees of freedom=12

Day	Enjoyment		Performance		Number of rounds played	
	p	Mean difference	p	Mean difference	p	Mean difference
1	0.452	0.38	0.125	1.57	0.239	-2.86
2	0.02	**0.86**	0.247	1.42	0.001	**5.86**
3	0.005	**1.43**	0.141	1.43	0.001	**6.71**

VISUAL, which changed visual elements during a session, partially supports the speculation.

Since the visual element change was not contingent on performance, but was based only on the number of rounds played in the game, it was unlikely to be perceived as a reward, and therefore could enhance intrinsic motivation[56] and hence enjoyment[47]. Overall, performance was significantly higher in DDA-VISUAL than DDA, although no significant differences were observed on the individual days. Moreover, the overall mean difference in performance between the two modes was quite small compared to the range of performance values. Therefore, the second hypothesis **H2** was also only partially fulfilled. DDA ensures that participants play the game at the highest difficulty level possible for them, which translates to increased training effect[57]. The performance result of DDA-VISUAL indicates that the addition of visual element change did not hamper DDA's function of maintaining high difficulty level, but actually made it marginally better. Combining visual element change with DDA could therefore be a viable strategy to make serious games enjoyable and effective.

There was no significant change in enjoyment within one session; performance, however, decreased significantly as a session progressed (*Figure 5*). The drop in performance in the latter part of the sessions can be attributed to participants not being able to successfully complete rounds at higher difficulty levels, and consequently deviating from the ideal maximum possible performance. Participants in DDA-VISUAL played significantly more rounds on Days 2 and 3 than those in DDA, partially confirming **H3**.

When asked at the end of the study, one participant in the DDA-VISUAL group reported not liking the changing visuals, while two did not care either way; four reported liking the change. This result, where four of the seven participants in the DDA-VISUAL group reported liking the visual change coupled with the higher self-reported in-game enjoyment and the higher number of rounds played in DDA-VISUAL suggests that most participants subconsciously liked the changing visuals, although some of them did not notice or remember it afterwards, partially similar to the effect observed in Piselli et al.[36]. There were no dropouts: when the game asked them if they wished to continue playing, all fourteen participants consistently answered yes at all three time points in all three sessions. There could be two possible reasons for this. A desire to continue playing may simply be the result of the overall high enjoyment level experienced by all participants (*Figure 5*). An inclination to complete the sessions in their entirety might also be a manifestation of the Hawthorne Effect, which is generally defined as the problem in experiments that subjects' knowledge that they are in an experiment modifies their behavior from what it would have been without the knowledge[58].

Acceptance of the tablet-based game was quite high. Even though eleven of the fourteen participants reported no prior experience with using a tablet, none of them had any major usage problems. In post-study feedback, several participants also stated that such a game could be a good mobile application for residents of assisted-living facilities to play every day. Additionally, many inquired if they could purchase the tablet, which was an encouraging sign of acceptance of the technology, although it could also simply be the effect of novelty. From the outset, the study was advertised as being merely about game-design research. No claims were made about any possible training effect on memory, both for ethical reasons, and also not to confound the results. In spite of this, participants overwhelmingly en-

Table 4. Differences in enjoyment, performance, and number of rounds played between DDA-VISUAL (dynamic difficulty adjustment combined with regularly changing visual elements) and DDA (dynamic difficulty adjustment) over the three days, as assessed by mixed ANOVA; significant p-values (p<0.05) are in bold; df=degrees of freedom; η_P^2 = partial eta squared

Source	Enjoyment			Performance			Number of rounds played		
	F	p	η_P^2	F	p	η_P^2	F	p	η_P^2
Within-subjects effects									
Day; df:2,24	13.0	**<0.0001**	0.52	0.32	0.726	0.026	3.5	**0.046**	0.226
Day x mode; df:2,24	3.25	**0.046**	0.21	0.007	0.993	0.001	8.9	**0.001**	0.427
Between-subjects effects									
Mode; df:1,12	6.76	**0.023**	0.36	5.2	**0.042**	0.31	8.89	**0.011**	0.426

joyed the game, contradicting an assumption that older adults are willing to invest time in a serious game only if they foresee a real training benefit[52,54]. McLaughlin et al.[54] propose a cost-benefit model to suggest that older adults will invest time in playing a serious game only if the benefits outweigh the costs. Participants in the present study might have associated our serious game to the pen-and-paper memory training tasks performed regularly in assisted living facilities. Thus, in spite of being told the contrary, they might have internalized some benefit from playing the game. In any case, the cognitive and perceptual costs involved in playing our game were minimal, largely due to its simplicity. Serious game designers can use these results to increase the acceptability of their games among older adults.

There were five tablets in total, with participants given the option to play in a group. However, in the beginning of the first session, some participants began expressing the desire to be alone so that they could better concentrate, suggesting that the game was able to elicit a high level of attention. Those participants who did play in a group exhibited no major differences in any of the outcome measures, indicating that playing alone or in a group was not a factor in the gameplay experience. A couple of participants also gave a post-study feedback that they would have enjoyed the game more had they been able to choose a visual theme of their choice. This kind of customization to increase enjoyment among older adults has indeed been suggested before[53].

This study has a couple of limitations. Firstly, the sample size was small and heterogeneous. The low number of participants lessens the generalizability of the results to a bigger population. Heterogeneity of the sample could also play a part, since ageing research often divides older adults into the 'younger old' (60-85) and the 'oldest old' (85+), with differences between the two groups[55]. Age-related differences in the older population are often manifested in aspects like reduced physical mobility, loss of handgrip strength, and impairment in vision and hearing[59]. The latter two might have affected perception of the visual element change, and ease of use of the tablet, respectively. No age-related differences were found for either. Additionally, none of the outcome measures exhibited an effect of age. Admittedly, the absence of an effect of age could be due to the small sample size. Nevertheless, we believe that the results can be applied to the entire age range of the older population.

Secondly, enjoyment results from residents of assisted-living facilities might not generalize to the general population of autonomously living older adults. The prevalence of cognitive impairment tends to be higher among residents of assisted -living facilities than among autonomously living older adults[60,61]. Therefore, the former might foresee a bigger benefit from playing memory training games, and hence enjoy more[52]. Overall, however, tablets appear to be a convenient input modality for serious games among older adults, reinforcing previous findings[53,62]. Enjoyment and acceptance results of the present study could help in making future tablet-based training programs more autonomous and potentially more effective[63]. For example, home-based training, whereby participants are given a tablet to keep at home for a certain number of weeks and asked to play the game at their convenience, might be viewed as a more autonomous form of training and could yield more generalizable results. In any case, regularly changing visual elements is a simple and low-effort method to sustain enjoyment and attention in serious games. It could also be combined with an option for users to select game scenery of their choice, thus enabling them to customize the game environment and potentially enjoy more. Although evaluating the effect of visual element change on training outcomes requires further studies, such an approach has the potential to leverage game visuals towards increased enjoyment with minimal added development costs.

Acknowledgements

The authors gratefully acknowledge the support of Diana Siedler and Sabina Eipe, who assisted in participant recruitment. This work was funded by ETH, Zurich.

References

1. Abt CC. Serious games: The art and science of games that simulate life. New York: Viking; 1970; doi:10.1177/000276427001400113
2. Rego P, Moreira PM, Reis LP, editors. Serious games for rehabilitation: A survey and a classification towards a taxonomy. Information Systems and Technologies (CISTI), 2010 5th Iberian Conference; IEEE; 2010
3. Sabri H, Cowan B, Kapralos B, Porte M, Backstein D, Dubrowskie A. Serious games for knee replacement surgery procedure education and training. Procedia - Social and Behavioral Sciences 2010;2(2):3483-3488; doi:10.1016/j.sbspro.2010.03.539
4. Graafland M, Schraagen J, Schijven M. Systematic review of serious games for medical education and surgical skills training. British journal of surgery 2012;99(10):1322-1330; doi:10.1002/bjs.8819
5. Wouters P, van der Spek E, van Oostendorp H. Current Practices in Serious Game Research: A Review from a Learning Outcomes Perspective. In: T. Connolly MS, Boyle L, editors. Games-

Based Learning Advancements for Multi-Sensory Human-Computer Interfaces: Techniques and Effective Practices. Hershey: IGI Global; 2009; pp. 232-250; doi:10.4018/978-1-60566-360-9.ch014
6. Connolly TM, Boyle EA, MacArthur E, Hainey T, Boyle JM. A systematic literature review of empirical evidence on computer games and serious games. Computers & Education 2012;59(2):661-686; doi:10.1016/j.compedu.2012.03.004
7. Rizzo AS, Difede J, Rothbaum BO, Reger G, Spitalnick J, Cukor J, McLay R. Development and early evaluation of the Virtual Iraq/Afghanistan exposure therapy system for combat-related PTSD. Annals of the New York Academy of Sciences 2010;1208(1):114-125; doi:10.1111/j.1749-6632.2010.05755.x
8. Nouchi R, Taki Y, Takeuchi H, Hashizume H, Akitsuki Y, Shigemune Y, Sekiguchi A, Kotozaki Y, Tsukiura T, Yomogida Y, Kawashima R. Brain Training Game Improves Executive Functions and Processing Speed in the Elderly: A Randomized Controlled Trial. PLoS ONE 2012;7(1):e29676; doi:10.1371/journal.pone.0029676
9. Chacko A, Bedard AC, Marks DJ, Feirsen N, Uderman JZ, Chimiklis A, Rajwan E, Cornwell M, Anderson L, Zwilling A, Ramon M. A randomized clinical trial of Cogmed Working Memory Training in school-age children with ADHD: a replication in a diverse sample using a control condition. Journal of Child Psychology and Psychiatry 2014;55(3):247-255; doi:10.1111/jcpp.12146
10. Hardy JL, Drescher D, Sarkar K, Kellett G, Scanlon M. Enhancing visual attention and working memory with a web-based cognitive training program. Mensa Research Journal 2011;42(2):13-20
11. Sinclair J, Hingston P, Masek M. Exergame development using the dual flow model. Proceedings of the 6th Australasian Conference on Interactive Entertainment, Sydney: ACM; 2009; pp 1-7; doi:10.1145/1746050.1746061
12. Grahn CE, Borgquist B. Motivation as a predictor of changes in quality of life and working ability in multidisciplinary rehabilitation. Disability and Rehabilitation 2000;22(15):639-654; doi:10.1080/096382800445443
13. Blunsdon B, Reed K, McNeil N, McEachern S. Experiential learning in social science theory: An investigation of the relationship between student enjoyment and learning. Higher education research and development 2003;22(1):43-56; doi:10.1080/0729436032000056544
14. Gomez EA, Wu D, Passerini K. Computer-supported team-based learning: The impact of motivation, enjoyment and team contributions on learning outcomes. Computers & Education 2010;55(1):378-390; doi:10.1016/j.compedu.2010.02.003
15. Mitchell TJ, Chen SY, Macredie RD. The relationship between web enjoyment and student perceptions and learning using a web-based tutorial. Learning, Media and Technology 2005;30(1):27-40; doi:10.1080/13581650500075546
16. Giannakos MN, Chorianopoulos K, Jaccheri L, Chrisochoides N. “This Game Is Girly!” Perceived Enjoyment and Student Acceptance of Edutainment. E-Learning and Games for Training, Education, Health and Sports. New York: Springer; 2012; pp 89-98; doi:10.1007/978-3-642-33466-5_10
17. Vorderer P, Klimmt C, Ritterfeld U. Enjoyment: At the heart of media entertainment. Communication theory 2004;14(4):388-408; doi:10.1111/j.1468-2885.2004.tb00321.x
18. Vorderer P, Hartmann T, Klimmt C. Explaining the enjoyment of playing video games: the role of competition. Proceedings of the second international conference on entertainment computing; Pittsburgh: Carnegie Mellon University; 2003; pp 1-9
19. Whitbourne SK, Ellenberg S, Akimoto K. Reasons for playing casual video games and perceived benefits among adults 18 to 80 years old. Cyberpsychology, Behavior, and Social Networking 2013;16(12):892-897; doi:10.1089/cyber.2012.0705
20. De Schutter B. Never Too Old to Play: The Appeal of Digital Games to an Older Audience. Games and Culture 2011;6(2):155-170; doi:10.1177/1555412010364978
21. Csikszentmihalyi M. Flow: the psychology of optimal experience. New York: Harper Collins; 1990;1:991
22. Sherry JL. Flow and Media Enjoyment. Communication Theory 2004;14(4):328-347; doi:10.1111/j.1468-2885.2004.tb00318.x
23. Chen J. Flow in games (and everything else). Communications of the ACM 2007;50(4):31-34; doi:10.1145/1232743.1232769
24. Reich S, Vorderer P. Online Games, Player Experiences. In: The International Encyclopedia of Digital Communication and Society. Hoboken: Wiley; 2015; doi:10.1002/9781118767771.wbiedcs064
25. Hunicke R. The case for dynamic difficulty adjustment in games. Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology; Valencia: ACM; 2005; pp 429-433; doi:10.1145/1178477.1178573
26. Jennings-Teats M, Smith G, Wardrip-Fruin N. Polymorph: dynamic difficulty adjustment through level generation. Proceedings of the 2010 Workshop on Procedural Content Generation in Games; Monterey: ACM; 2010; pp 1-4. doi:10.1145/1814256.1814267
27. Simpson T, Camfield D, Pipingas A, Macpherson H, Stough C. Improved processing speed: online computer-based cognitive training in older adults. Educational gerontology 2012;38(7):445-458; doi: 10.1080/03601277.2011.559858
28. Barnes DE, Yaffe K, Belfor N, Jagust WJ, DeCarli C, Reed BR, Kramer JH. Computer-based cognitive training for mild cognitive impairment: results from a pilot randomized, controlled trial. Alzheimer disease and associated disorders. 2009;23(3):205-210; doi:10.1097/wad.0b013e31819c6137

29. Gaitán A, Garolera M, Cerulla N, Chico G, Rodriguez-Querol M, Canela-Soler J. Efficacy of an adjunctive computer-based cognitive training program in amnestic mild cognitive impairment and Alzheimer's disease: a single-blind, randomized clinical trial. International Journal of Geriatric Psychiatry 2013;28(1):91-99; doi:10.1002/gps.3794
30. Schmiedek F, Bauer C, Lövdén M, Brose A, Lindenberger U. Cognitive enrichment in old age: Web-based training programs. GeroPsych 2010;23(2):59-67; doi:10.1024/1662-9647/a000013
31. Niedenthal S. What we talk about when we talk about game aesthetics. 2009; www.digra.org/wp-content/uploads/digital-library/09287.17350.pdf; retrieved July 23, 2015
32. McLaughlin T, Smith D, Brown IA, editors. A framework for evidence-based visual style development for serious games. Proceedings of the 5th International Conference on the Foundations of Digital Games; ACM; 2010; doi:10.1145/1822348.1822366
33. Smeddinck J, Gerling KM, Tiemkeo S, editors. Visual complexity, player experience, performance and physical exertion in motion-based games for older adults. Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility; ACM; 2013; doi:10.1145/2513383.2517029
34. Crytek. Crysis 2015; www.crysis.com/; retrieved July 23, 2015
35. Nintendo. Mario 2015; http://mario.nintendo.com/; retrieved July 23, 2015
36. Piselli P, Claypool M, Doyle J, editors. Relating cognitive models of computer games to user evaluations of entertainment. Proceedings of the 4th International Conference on Foundations of Digital Games; ACM; 2009; doi:10.1145/1536513.1536545
37. Vitz PC. Preference for different amounts of visual complexity. Behavioral Science. 1966;11(2):105-114. doi:10.1002/bs.3830110204
38. Gamberini L, Raya MA, Barresi G, Fabregat M, Ibanez F, Prontu L. Cognition, technology and games for the elderly: An introduction to the ELDERGAMES Project. PsychNology Journal 2006;4(3):285-308
39. Gerling KM, Schild J, Masuch M, editors. Exergaming for elderly: analyzing player experience and performance. Mensch & Computer series. Berlin: De Gruyter; 2011; doi:10.1524/9783486712742.401
40. Hussaan AM, Sehaba K, Mille A, editors. Tailoring Serious Games with Adaptive Pedagogical Scenarios: A Serious Game for Persons with Cognitive Disabilities. Advanced Learning Technologies (ICALT), 2011 11th IEEE International Conference; 2011; doi:10.1109/ICALT.2011.152
41. Lopes R. Scenario adaptivity in serious games. Proceedings of the 5th International Conference on the Foundations of Digital Games. Monterey: ACM; 2010; pp 268-270; doi:10.1145/1822348.1822389
42. Buttussi F, Chittaro L, Ranon R, Verona A, editors. Adaptation of graphics and gameplay in fitness games by exploiting motion and physiological sensors. Lecture Notes in Computer Science 2007;4569;85-96; doi:10.1007/978-3-540-73214-3_8
43. Dunn N, Williamson A. Mitigating the effects of monotony: The role of task complexity. In: Dadashi N, editor. Rail Human Factors Around the World: Impacts on and of People for Successful Rail Operations 2012; pp 774-782; doi:10.1201/b12742-87
44. Stamps AE. Entropy, Visual Diversity, and Preference. The Journal of General Psychology 2002;129(3):300-320. doi:10.1080/00221300209602100
45. Dunlap G, Koegel RL. Motivating autistic children through stimulus variation. Journal of Applied Behavior Analysis 1980;13(4):619-627; doi:10.1901/jaba.1980.13-619
46. Thiffault P, Bergeron J. Monotony of road environment and driver fatigue: a simulator study. Accident Analysis & Prevention 2003;35(3):381-391; doi:10.1016/S0001-4575(02)00014-3
47. Malone TW. What makes things fun to learn? Heuristics for designing instructional computer games. Proceedings of the 3rd ACM SIGSMALL symposium and the first SIGPC symposium on Small systems; Palo Alto: ACM; 1980; pp 162-169; doi:10.1145/800088.802839
48. Katz B, Jaeggi S, Buschkuehl M, Stegman A, Shah P. Differential effect of motivational features on training improvements in school-based cognitive training. Frontiers in human neuroscience. 2014;8; doi:10.3389/fnhum.2014.00242
49. Alexander JT, Sear J, Oikonomou A. An investigation of the effects of game difficulty on player enjoyment. Entertainment Computing 2013;4(1):53-62; doi:10.1016/j.entcom.2012.09.001
50. Aponte M-V, Levieux G, Natkin S. Scaling the Level of Difficulty in Single Player Video Games. Lecture Notes in Computer Science 2009;5709:24-35; doi:10.1007/978-3-642-04052-8_3
51. Schieber F. Human factors and aging: Identifying and compensating for age-related deficits in sensory and cognitive function. In: Charness N, Warner Schaie K, editors, Impact of Technology on Successful Aging. New York: Springer; 2003; pp 42-84
52. IJsselsteijn W, Nap HH, Kort Y de, Poels K. Digital game design for elderly users. Proceedings of the 2007 conference on Future Play; Toronto; 1328206: ACM; 2007; pp 17-22; doi:10.1145/1328202.1328206
53. Vasconcelos A, Silva PA, Caseiro J, Nunes F, Teixeira LF, editors. Designing tablet-based games for seniors: The example of CogniPlay, a cognitive gaming platform. Proceedings of the 4th International Conference on Fun and Games; 2012: ACM; doi:10.1145/2367616.2367617
54. McLaughlin A, Gandy M, Allaire J, Whitlock L. Putting Fun into Video Games for Older Adults.

Ergonomics in Design: The Quarterly of Human Factors Applications 2012;20(2):13-22; doi:10.1177/1064804611435654
55. Suzman RM, Willis DP, Manton KG. The oldest old: Oxford University Press; 1995.
56. Deci EL. Effects of externally mediated rewards on intrinsic motivation. Journal of Personality and Social Psychology. 1971;18(1):105-115; doi:10.1037/h0030644
57. Greitzer FL, Kuchar OA, Huston K. Cognitive science implications for enhancing training effectiveness in a serious gaming context. Journal on Educational Resources in Computing. 2007;7(3):2-16; doi:10.1145/1281320.1281322
58. Adair JG. The Hawthorne effect: A reconsideration of the methodological artifact. Journal of applied psychology. 1984;69(2):334-345; doi:10.1037//0021-9010.69.2.334
59. Smith J, Borchelt M, Maier H, Jopp D. Health and Well–Being in the Young Old and Oldest Old. Journal of Social Issues 2002;58(4):715-732; doi:10.1111/1540-4560.00286
60. Graham JE, Rockwood K, Beattie BL, Eastwood R, Gauthier S, Tuokko H, McDowell I. Prevalence and severity of cognitive impairment with and without dementia in an elderly population. The Lancet. 1997;349(9068):1793-1796; doi:10.1016/S0140-6736(97)01007-6
61. Di Carlo A, Baldereschi M, Amaducci L, Maggi S, Grigoletto F, Scarlato G, Inzitari D, for the Italian Longitudinal Study on Aging. Cognitive Impairment Without Dementia in Older People: Prevalence, Vascular Risk Factors, Impact on Disability. The Italian Longitudinal Study on Aging. Journal of the American Geriatrics Society 2000;48(7):775-782; doi:10.1111/j.1532-5415.2000.tb04752.x
62. Werner F, Werner K, Oberzaucher J. Tablets for seniors - An evaluation of a current model (ipad). In: Ambient Assisted Living. New York: Springer; 2012; pp 177-184; doi:10.1007/978-3-642-27491-6_13
63. Langfred CW, Moye NA. Effects of task autonomy on performance: an extended model considering motivational, informational, and structural mechanisms. Journal of Applied Psychology 2004;89(6):934-945; doi:10.1037/0021-9010.89.6.934