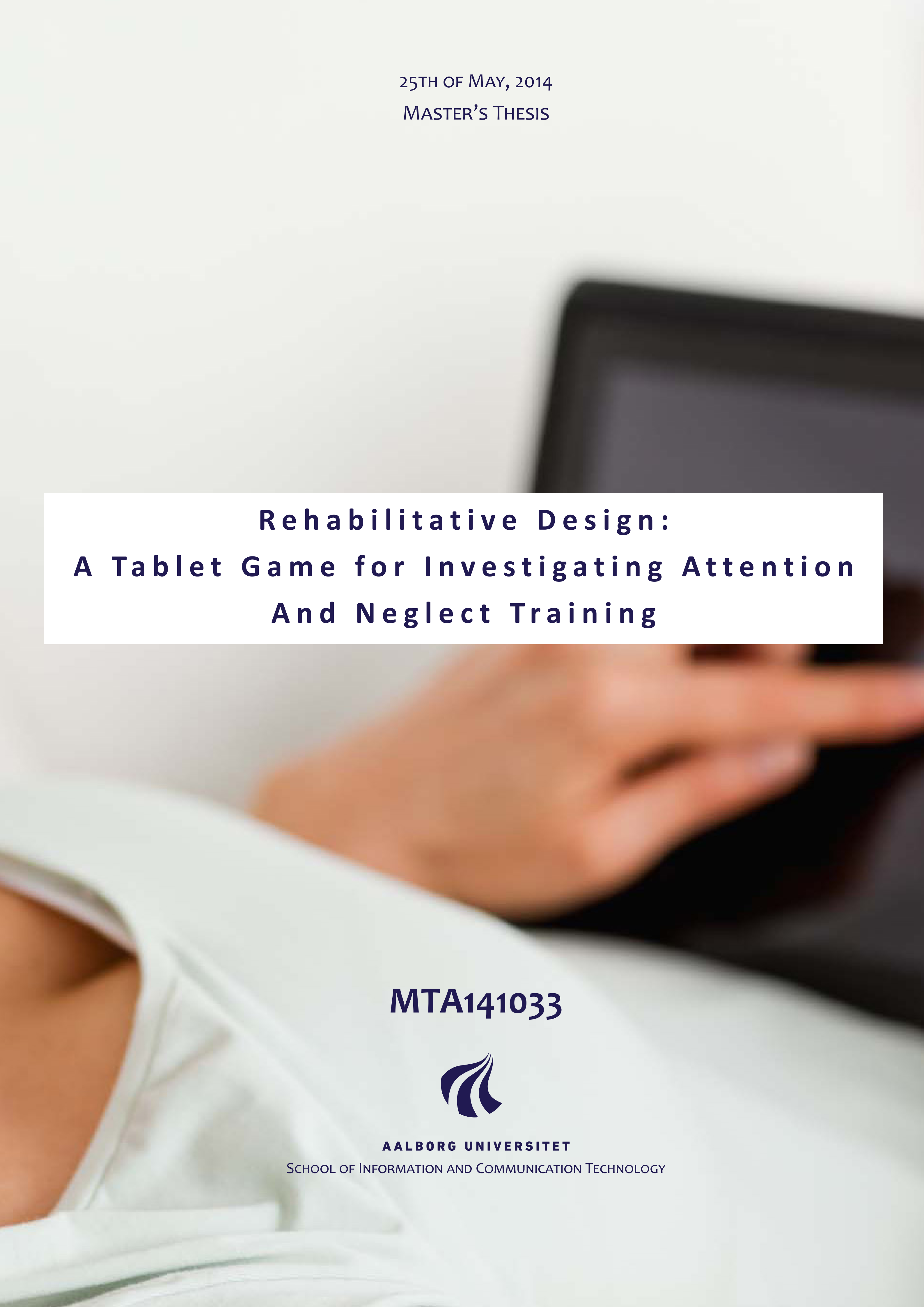

25TH OF MAY, 2014

MASTER'S THESIS

Rehabilitative Design: A Tablet Game for Investigating Attention And Neglect Training

MTA141033

AALBORG UNIVERSITET
SCHOOL OF INFORMATION AND COMMUNICATION TECHNOLOGY

AALBORG UNIVERSITET

Department of Architecture, Design and Media Technology

Medialogy, 10th Semester

Title: Rehabilitative Design: A Tablet Game for Investigating Attention and Neglect Training

Project Period: 1st of February, 2014 - 25th of May, 2014.

Semester: Master Thesis

Supervisor: Hendrik Ole Knoche

Abstract:

In this study we examined whether a tablet game could work as a rehabilitative tool for patients with cognitive impairments. More specifically, whether it was possible to achieve a restoration of the visual field for patients suffering from left sided visual neglect. Through three tests and redesign iterations a game was created allowing a quantification of a patient's reaction time, visual field limits, and their general touch precision. The implemented design shows promise, and results show that it is possible to detect whether a patient suffers from left sided visual neglect, with significantly higher reaction time on left side target identification. There was tendencies for an expansion of the visual field for some patients, however not significantly. The simplistic game also proved usable for unassisted training. This opens up the possibility for the further development of gamified tools aimed at rehabilitating patients with cognitive impairments.

Projectgroup no.: MTA14033

Members:

Danny Tamsen	(Specialization: Games)
Lars Holm Jespersen	(Specialization: Games)

Danny Tamsen ____________________

Lars H. Jespersen ____________________

Contents

1. Preface

This master's thesis was written by group MTA14033 in the spring semester of 2014. The project was done in collaboration with therapists and patients at the Center of Neurorehabilitation in Brønderslev, Denmark.

The enclosed CD contains the AV-production, test footage, test data, a PDF version of this report, and the a copy of the utilised prototype for each study performed in both PC (.EXE) version and Android (.APK).

2. Introduction

People who have suffered brain injury, often due to a cerebral hemorrhage, can posteriorly experience cognitive deficits such as visual neglect or other types of attention deficit disorders. Rehabilitation of these patients typically focuses on otherwise trivial real world physical exercises facilitated by various types of therapists, and mundane computer-based cognitive rehabilitation. These aspects combined can limit a patient's motivation and puts time constraints on their rehabilitation.

Research within the the field of vision and perceptual learning is lately reporting effects of long-term sensitivity improvement with basic visual tasks as a result of training and brain plasticity of sensory brain regions [Sagi, 2011]. In leuve of these findings digital games is slowly gaining attention as a beneficial factor in the training of a diverse spread of cognitive abilities [Green, 2012][Granic, 2014][Deveau, 2014] and an increased focus is slowly being encouraged by the likes of Bavelier and Davidson [Bavelier, 2013] proclaiming that neuroscientists should help developing games that boost brain function and improve well-being.

A meta-analysis of the effect of computer-based cognitive rehabilitation (CBCR) for people with stroke found that there should be sufficient evidence to use CBCR in treating patients who have suffered from one or more strokes [Cha, 2013].

In this study we want to investigate whether a gamified tablet application can help rehabilitation in patients suffering from left sided visual neglect, and in extension patients suffering from attention deficits. We will investigate this by designing a tablet game adapting to the attentional abilities of the user. This will serve as an indicator of whether tablet games, even in their simplest form, is a viable rehabilitation method for patients suffering from visual neglect and attention deficit disorders.

3. State of The Art

3.1 Visual Neglect and Attention

Neglect patients have a strongly biased attention towards events on the ipsilesional side causing effects similar to inattentional blindness on the contralesional side. This is most noticeably in competitive situations where multiple stimuli compete for attention.

Extinction, a disorder of visual attention often found in patients suffering from neglect, is the inability to detect stimuli presented on the contralesional side in the presence of a second stimuli presented on the ipsilesional side. Often when, and if, neglect fades over time a patient is left with extinction [Snowden et al., 2006]. Multiple stimuli is typically present at the same time in everyday life causing complications for both patient, and rehabilitative measures trying to isolate to the contralesional side.

Evidence support the notion of two somewhat separate visual attention systems [Eysenck et al., 2010]. A stimulus-driven exogenous system that automatically shifts attention, and a goal-driven endogenous system that is controlled by the individual's intentions and expectations. Patients suffering from visual neglect have been linked to damage in the stimuli-driven system, where three separate abilities are involved in controlling the stimuli-driven system. These are the disengagement of attention from a visual stimuli, the shifting of attention from one stimuli to another, and the engagement or locking of attention onto a new stimuli.

Sturm investigated whether specific attention deficits needed specific training, and findings support the hypothesis of a hierarchical organisation of attention functions [Sturm, 1997] similarly to the clinical model of attention [Sohlberg, 1989]. Lowest level being alertness or focused attention, sustained attention, or vigilance, and are prerequisites for higher selective functions of attention such as selective, and alternating attention which again is a prerequisite of the ability to divide attention.

In a study performed on a group of patients with chronic neglect DeGutis et al found that 9 days of training on continuous performance task that promotes tonic and phasic alertness significantly improved spatial and non-spatial attention [DeGutis, 2010]. It is suggested from a follow up experiment that training alertness is a more effective treatment approach than directly training spatial attention.

Thimm engaged neglect patients in a stimulating computer game for a prolonged period of time (~45 min) each day to improve tonic (general) alertness, and found that after three weeks of training, patients improved their overall alertness and improved on at least one of the standard spatial neglect tests administered [Thimm, 2006]. Where tonic alertness is the intrinsic arousal involved in sustaining attention and providing cognitive tone for performing more complicated functions such as working memory and executive control. [DeGutis, 2010]

3.2 Computer Based Cognitive Rehabilitation

During correspondence with the Center of Neuro Rehabilitation in Brønderslev, Denmark, D.Richter (personal communication, May 21st, 2014) estimated the use of their CBCR solution COGNIsoft [COGNIsoft, 2014] to be utilised to some extent in ~50-60% of the occurrences where it would be of use for the patient. The solution is reported most often used in investigating the patients impairment, and later for self training or assisted self training of memory and attention problematics. Amount of training varies from three or four times a week to two times daily, and five times a week depending on the need for therapist presence. Reasoning as to why the software is not always utilised among patients include aspects such as therapist assistance is needed to boot and correctly set the software, and the tasks being too cognitively demanding for some patients. Furthermore, if the therapist should desire to utilise the software solution to increase the patient's condition awareness, the therapist will need a large insight in the specific cognitive impairment of the individual patient. Finally focus is often on training with concrete activities, as these are more transparent to the patient.

Vision restoration therapy (VRT) is claimed to enhance visual field loss in stroke and brain injury patients with neurological visual deficits by continually presenting visual stimuli at the border of the patients field of vision [NovaVision, 2014].

Studies have found that VRT both improves stimulus detection and results in a shift of the position of the border of the blind field. It is also found that age, time from lesion, etiology, and type of visual field defect did not have an influence on field expansion. Patient testimonials as a result of these confirm improvement in everyday visual functions [Mueller, 2007, Romano, 2008]. Authors in both studies might suffer from conflicts of interest since being either employed by, consultant to, or shareholder of NovaVision Inc. which is the patent holder [Mueller, 2007, Romano 2008].

Arguments have been made by Horton, J.C [Horton, 2005] that the beneficial effects gained from VRT may be an artefact of compensatory eye movements towards the hemianopic or neglected areas, but an independent study found no such correlation confirming earlier studies, that VRT is a viable concept in neurological rehabilitation [Kasten, 2006].

It is proposed that the use of top-down signals, such as visuospatial cues, links visual and attentional neural networks with the effect of a permanent increased conscious visual perception, and suggests to amplify the long-term neural plasticity [Poggel, 2004]. However, other findings provide evidence that attention is not always needed in order to train the perceptual systems, repeated exposure can work despite being hardly visible [Watanabe, 2001].

Finally it is worth noting that an increasing number of studies found that learning outcome can be generalized to untrained stimuli and tasks under some conditions, where better generalization is seen during shorter sessions with coarse discriminations, and in training with two or more stimuli [Sagi, 2011].

3.3 Cross Modality

The coordination of attention across two or more modalities is referred to as cross-modal attention, and cross-modal effects occur when visual attention to a given location also attracts auditory and/or tactile attention to the same location [Eysenck et al., 2010]. Findings suggest that audiovisual multisensory interactions can be exploited to yield more efficient learning of sensory information than unisensory visual training [Seitz, 2006, Seitz, 2008].

Multisensory interactions on touch screen smartphone used by an elderly sample was investigated by adding auditory, tactile, and audio tactile feedback and comparing resulting error rates [Hwangbo, 2013]. Patients were asked to press targets in a simple application. It was found that both task completion time, and amount of errors reduced with auditory and audio tactile feedback. This supports similar findings that haptics in general produces faster and more accurate task performance [Lindeman, 2005, Jeong, 2003].

A study found that seeing touches affects visual perception depending on which sensory modality is damaged, where patients with a selective visual deficit, but no tactile deficit, would improve the visual impairment. The experiment used rTMS to simulate the specific deficits. Observation of touch supports activation of brain areas underpinning direct tactile experience, namely the somatosensory cortices [Bolognini, 2012].

3.4 Limitations of Touch Interaction

Pointing performance on touchscreen devices among elderly have been shown to be significantly influenced by size, spacing and location. Pointing performance studies on touchscreen devices are predominantly isolated to smartphone usage, and as such are results of thumb interaction, however it is feasible that index finger performs at the levels of thumb interaction, if not even outperforms. Target size findings on thumb interaction is assumed to apply to tablets. A study performed on a 4.3” android device involving square targets found strong correlation between target size, task completion time and error rate resulting in ~0 errors on 12mm targets [Hwangbo, 2013]. Similarly a study performed on a 4.0” android device novel game found same correlations resulting in an error rate of <5% on targets 14 mm or larger [Leitão, 2013]. Finally a study involving circular targets utilising a novel game on a myriad of android devices identified an error rate of ~10% with targets of 15 mm, where the heightened error rate compared to other research is assumed partly due to time pressure native to the game design [Henze, 2011].

Spacing between targets have been found to be relevant only in the case of targets of such size that general error rates become a problem. If targets are large enough spacing should be irrelevant [Hwangbo, 2013, Leitão, 2013]

Positioning of touch targets could potentially interfere with touch interaction. Both Henze et al [Henze, 2011] and Leitão [Leitão, 2013] identified higher rates of error close to the border for the interaction surface, and best performance towards the centre. Both results could be a problem of thumb reachability, which should not be a problem with index finger performance on tablet devices. In more detailed findings Henze et al [Henze, 2011] identified a general offset on touch inputs in a right downwards direction and attempted to negate this effect with a corresponding offset which on average reduced the number of errors by 3.5%.

One existing theory to quantify interaction is Fitt's Law, which describes the time it takes to point to a target depending on the distance from the starting position of the hand to the position of the target, and the size of the target [Mackenzie, 1992]. Fitt's Law has been proven to be quite accurate, and data tend to fit a linear line with a correlation coefficient of 0.95 or higher. A large study found correlations to the distance of the target, corresponding with Fitt's law, whereas the targets size had a much smaller effect on the time required [Henze and Boll, 2011].

3.5 Sound

Sikora et al. examined whether users prefered real world sounds over musical sounds, and what type of sound mapped most efficiently to specific functions. It was found that real world sounds mapped more reliably to specific functions, however the users consistently preferred the musical sound [Sikora, 1995].

4. Game Design

To investigate our research question we identified the following requirements for a rehabilitative game for people with attention deficit disorders and visual neglect.

4.1 Initial Assumptions

- Competing stimuli should be kept at a low, specifically if stimuli is presented both on the left and right of the visual field as this can cause attentional suppression.
- The stimuli-driven exogenous system should be guided by the game to minimise problems with disengagement, shifting, and locking of attention between different sources of stimuli and goals.
- Progression through the hierarchical levels of attentional functions should be reflected during gameplay in accordance to the players' capabilities to minimize frustration.
- A rehabilitative game's core functionality should through prolonged amount of training in the form of short focused sessions of addictive gameplay afford the training of alertness, while being encouraging for further training.
- A rehabilitative game for neglect patients should repeatedly present stimuli along the border of the patient's field of vision, to aid in the expansion of said field.
- The use of crossmodal effects and interactions should be utilized to yield more efficient learning of sensory information and fewer interaction errors.
- Buttons and objects of interaction should have a minimum target size of 12-15mm to limit the amount of interaction errors. Spacing should not be relevant with targets of such size or larger.
- Auditive design should be focused on real world sounds for interaction, and carry musical subtext for general feedback.

4.2 Basic Concept

The most suitable genre of games in the context of integrating alertness training is the arcade genre, providing simple, yet paced style of play fitting a tablet game. We came up with the simple concept that the player must methodically press first a button at the center of the tablet, then subsequently identify and press a target appearing on the screen as quickly as possible. The game continues in this fashion, with added variation, and the player must repeat this process of spawning an object, and then pressing it.

Theme development was purposely limited to spare time, and allow for creative freedom in the design of mechanics. A minimalistic, abstract style with near solid colors and a low detailed background was chosen.

5. Study1: Patient Performance Assessment

In order to get an initial understanding of the patients impairments, and how these influence the interaction with a tablet device, a study was conducted on an early prototype of the game.

The study included five patients with a wide spread of impairment. three of whom were women, mean age 63 with eldest 75 and youngest 52. All patients suffered from some level of attention deficit disorder, where three suffered from left side neglect caused by right side brain lesion.

5.1 Test Description

The test was formally conducted by a therapist who instructed and assisted the patients in terms of how to interact with the game. All sessions were video documented with close-up of facial expression, close-up tablet interaction, and overview of both therapist and patient. The patients played a single session, in which they were to correctly hit ten targets. The tablet had a fixed flat position on a table.

5.2 Prototype Description

The prototype included simple touch interaction based on typical 'contact down' and 'contact up' as described by Benko et al [Benko, 2010].

Gameplay was limited to pressing a green button at the center of the screen, wait a short period of time while the button is yellow, and then subsequently pressing a circular (d = 6mm) white target appearing at random somewhere on the screen when the button is red. This was then repeated until a total of ten targets were successfully hit whereupon the game would end. Size was purposely smaller than earlier findings to better represent the position desired to evaluate, where larger size results in larger area of visual stimulation.

Targets would indicate appearance with a musical 'pip' like sound, and would visibly bounce in size in with a rhythmically 'tok' like sound and interval. When no target was present the button at center would visibly bounce in size with a rhythmically 'tok' like sound and interval. Targets would disappear if not correctly hit within a timeframe of 8 seconds.

5.3 Results

Qualitative data showed large issues regarding touch interaction, resulting in the therapist having to intervene by pressing the targets for the patient in three of the five occurrences. The therapist indicated precision as the main problem.

Touch interaction among three of five patients were performed as one would expect it of a tactile button, performing a three step interaction in the order of ‘contact down’, ‘press down’, ‘contact up’ resulting in long times of individual touches, and therefore unregistered touches on the targets, due to the used touch algorithm.

Breakdown in sustained attention was noticed in three of the five patients, indicated by patients forgetting that they were supposed to press the center button for a new target to spawn until the therapist intervened. One patient in particular was noted to have problems with understanding the traffic light analogy. The breakdown was also noticed during inhouse pilot testing on healthy persons, and we therefore hypothesize the traffic light analogy to cause an unnatural break on intrinsic arousal involved in sustaining attention.

Sound did not seem to create any disturbance among participants. Although we hypothesize that the rhythmically ‘tok’ sound might have contributed as a disturbing factor in sustained attention, when the traffic light analogy forces the player to wait.

5.4 Conclusions

All patients were able to comprehend and solve gameplay tasks and thereby completing the game session, indicating that cognitive abilities allow for more advanced gameplay.

The general impairments among the patients are however a limiting factor in further gameplay complexity, specifically competing sources of attention is a point to be aware of.

Imprecision is very likely an effect of small target size (circular, d = 6mm), and should be negated by an increase in size in accordance with findings in section 3.4 Limitations of Touch Interaction. There was no indication of problems identifying the targets beyond those caused by the condition of the patients, it would therefore be most ideal to keep the visual size, but increase the area of touch registration of the targets.

Touch interaction should be simplified for elderly. A possible solution is to simply register by ‘contact down’ and ignore ‘contact up’, resulting in immediate feedback. It would also be beneficial to add auditory, visual, tactile, or combinatory feedback to both the center button, individual touches, and the targets.

The center button analogy should be simplified. Qualitative data indicated that the waiting time (yellow) introduced as a grace period allowing patients to remove their hands from occluding the tablet is speculated as a disturbing factor, allowing room for sustained attention to break. Unnatural breaks on intrinsic arousal combined with competing or distracting sources of attention such as the rhythmetic ‘tok’ sound should be avoided.

Finally findings indicate that another preliminary gameplay and interaction test should be conducted before a final study, to ensure any further development on the interaction and game mechanics will still be viable with similar patients.

6. Study 2: Interaction & Game Mechanic Evaluation

A second study was conducted to evaluate the proposed mechanics of more advanced game design, meaning the different stages of the game. Secondary elements to be evaluated were the touch interaction improvements and implemented logging system for quantitative data.

The study included two patients suffering from neglect and attention disorders with different degrees of impairment. One with average capabilities and one with above average capabilities. Both were women in their late fifties.

6.1 Test Description

The test was was formally conducted by a therapist acting as facilitator who instructed and assisted the patients in regards to how to interact with the game. All sessions were video documented with a close-up view of the tablet interaction. The tablet had a fixed flat position on a table. Both patients played a single session consisting of six different stages of the game. Each stage of the game was played for two minutes resulting in a total of 12 minutes per session. Changing between stages was handled at a 2 minute mark where upon the therapist would change to the next stage. The game's adaptive behaviour could however purposely result in a patient proceeding to the next stage naturally if he/she did well, resulting in some stages being played more than once. The forced changing was added to ensure both patients tried all stages.

6.2 Revised Prototype Description

All touch interaction was simplified to register on 'contact down'. Immediate feedback in the form of an auditory 'click' sound resembling that of a real world mouse click followed all registered touches, and all interactible targets provides immediate visual response. Better task performance is expected by use of real world sounds as found in section 3.5 Sound.

Precision problems were attempted to be negated by increasing all touch areas in the game to a minimum size of d = 12mm, while retaining visual size. This should correspond with findings from section 3.4 Limitations of Touch Interaction to provide reasonable rates of error (~10%) while still leaving space for targets to be presented close together without overlapping in touch areas.

The center button was streamlined to a simple on/off analogy, and the waiting time for a target to spawn was removed. This should result in a more transparent conveyance of what to interact with. Colors were changed to a simple green for ready to be pressed and white for neutral off, switching from green to white immediately when the player presses the center.

Removing the waiting time for a target to spawn is expected to foremost ensure that the players are focusing their vision at the center of the screen when a target spawns, but also secondary to be more rewarding, provide better feedback, and ensuring equal traveltime on all directions from the center. A byproduct is a more fast paced game which should be more enticing in terms of motivation. A possible resulting problem could be a factor of occlusion by the interacting hand. However areas likely to be affected by occlusion could later be excluded from data analysis.

Attentional guidance back to the center button is added by making a successfully hit target fly with a visual trail in a direct line into the center. Additionally the center button is visually punched upon target return, and a small particle explosion occurs. Both are exogenous cues supposed to grab the player's attention, and thereby guide the player to spawn a new target by pressing the center button.

We added a logging system to provide quantitative data about the users' performance. This system should keep track of a large range of interaction information describing the users' performance with the system. Included metrics are: current stage, reaction time, angle of target, distance of target from center, targets position, touch position, and whether the target was hit, missed, or expired. This was logged on the event of a successfully hit target, a miss click, and an expired target.

Visible targets would visually bounce in scale with equal intervals as a visual exogenous cue drawing attention to itself. There was no rhythmic 'tok sound' or other background sound. The musical 'pip' like sound played upon target spawn as response to successfully pressing the center button was replaced with a more pleasant musical bell like sound. This kept the attentional strengthening cue, but making it more pleasurable. Additionally a lower pitched bell like sound was added to be played upon successfully hitting a target enforcing additional feedback to touch interaction in that scenario. Furthermore, in situations where targets are consecutively hit within a one second timeframe, chosen arbitrarily, the hit sound would slightly increase in pitch. This is expected to provide variation, and thereby hindering irritation, as well as a motivating factor to perform optimally.

A total of six stages have been added to the game split among two distinct phases as illustrated in Figure 1. Phase one is designed for visual identification by simply pressing one or more targets appearing and promotes focused and sustained attention. Phase two is designed for visual distinction and search by identifying two active targets among eight distractor targets and thereby trains selective attention.

All spawning of targets have been limited to ten specific angles centered in the center of the screen with equal distancing in between (360/10) skewed by eighteen degrees such that five angles will lie on the right side of the screen and five on the left side. This restriction will provide less variance in collected data, and provide basis for adaptability.

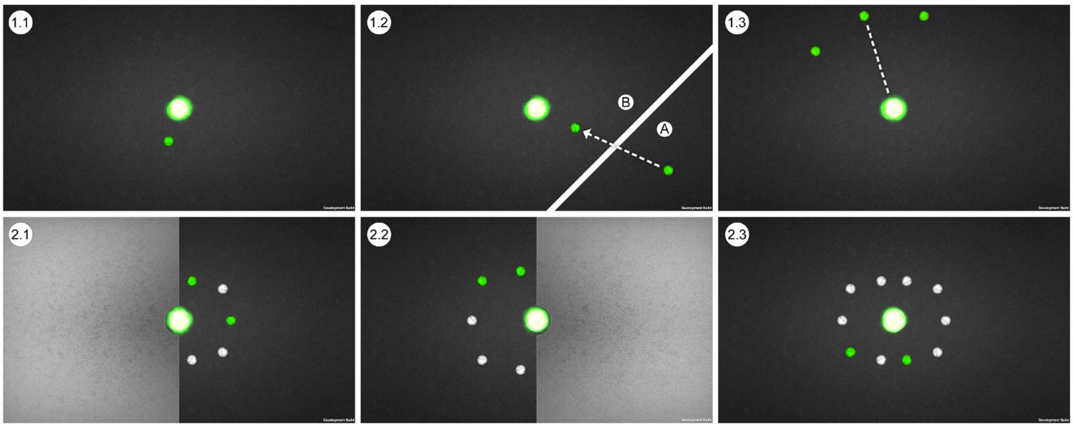

Figure 1. Illustrations are from the final version of the prototype. **1.1:** A singular target must be pressed. **1.2:** Two targets must be pressed in succession on the same angle with different distances, first A then B. **1.3:** Three targets appear, which can be pressed in any order. **2.1:** Two active targets must be pressed, but only on the right side of the screen. **2.2:** Two active targets must be pressed, but only on the left side. **2.3:** Two active targets must be pressed, and can be present at any one of the ten angles.

Adaptability was added for both phases of the game. Phase one would slowly restrict spawn distances from the center button on each angle as illustrated in Figure 2, and calculated in Figure 3. In the case of a minimal distance between the two thresholds, the maximum would be extended by six millimeters. The two distances will update every time a target is hit or expires. This adaptability is expected to limit target spawning to the border of the player's visual field in accordance with VRT as mentioned in section 3.2 Computer Based Cognitive Rehabilitation. Phase two would simply adapt on whether all targets are hit, or not, and subsequently expand or contract the ring of targets by a distance of ten percent of the maximum distance for each angle simultaneously.

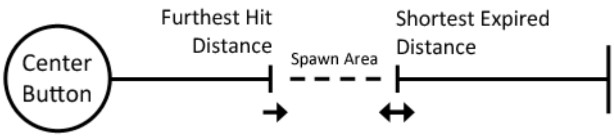

Figure 2. Illustration of adaptability for the phase one angles on a single angle. Where 'Furthest Hit' is the minimum spawn distance, and 'Shortest Expiration' is the maximum. Arrows indicate possible direction of adaptability for the two distances.

$$Distance = X \sim U([FH[i], SE[i]])$$

Figure 3. Adaptation formula calculating distance 'X' where 'X' is a random value within the range 'U' of 'FH[i]' and 'SE[i]' where 'FH' is an array of 'Furthest Hits' on angles, 'SE' is an array of 'Shortest Expirations' on angles, and 'i' is the angle.

6.3 Results

Quantitative data collected from the logging system on correctly hit targets showed a mean imprecision among the two patients of x = 0.95mm, y = -1.46mm, resulting in an offset with a distance of 1.74mm in the downwards right direction as illustrated in Figure 4 correlating with directional findings in section 3.4 Limitations of Touch Interaction.

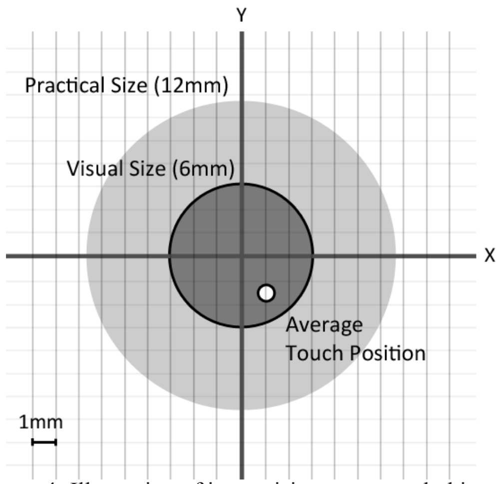

Figure 4. Illustration of imprecision on correctly hit targets.

Quantitative data collected by the logging showed that patient one, of average impairment, had a total of 56 expired targets among a total of 351 presented targets. 46 of the 56 targets which expired were presented on the left side of the screen, 15 upper quadrant, 15 lower quadrant, and 16 on the border between the two. Same data showed that patient two, of above average impairment, had a total of 6 expired targets among a total of 492 presented targets. 2 of the 6 expired targets were presented on the left side of the screen, residing along the border of the top and bottom quadrant.

Hand positioning away from the center area of the screen while scanning for targets were observed in high degree for patient one, and in much lesser degree for patient two. This causes a bias, unintentionally heightening the travel time, and as a result reaction time, for targets opposite direction from the center than that of the hand, and quantitative data from logging could hence be skewed. Both patients however adapted over the course of the session slowly minimising distancing of the hand away from the center.

Reaction times (RT) extracted from the quantitative data showed interesting preliminary findings. A paired samples one-tailed t-test comparing patient one's RT's for left and right side targets during phase one found that there was a significant difference in the in the RT's for left (M = 1.62), and right (M = 1.41) conditions; $p = 0.05$. Same setup comparing targets during phase two found no significant difference in the RT's for left (M = 1.23), and right (M = 1.20) conditions; $p = 0.05$. Same test comparing patient two's RT's during phase one found significant difference in the RT's for left (M = 1.04), and right (M = 0.87) conditions; $p = 0.05$. Comparing targets during phase two found that there was a significant difference in the

RT's for left (M = 1.36), and right (M = 1.09) conditions; $p = 0.05$. These results suggest that even though both patients successfully identified and hit most of the targets presented, they experienced problems visually identifying them on the left side and resorted to visual search.

Neither patients had noticeably problems with the implemented stages 1.1 through 1.3 of the game according to the qualitative data. Both patients did initially show confusion at the introduction of a blue target introduced in stage 1.2A. This confusion however vanished after a few hits. Stages 2.2 and 2.3, presenting targets on the left half, was noticeable difficulty for patient 1 compared to stage 2.1 which only presented targets on the right half. An increased difficulty in these stages is however expected for patients with left side neglect. We did however hypothesize that the inconsistency of activating, at random, either two or three targets could unnecessarily further heighten the difficulty.

Analysing the quantitative data we identified a need for better categorisation of both hit targets, and hit types in the log files. Specifically it would be beneficially to distinguish between the order of target hit in stages 1.2 through 2.3 and not just which stage the target belonged.

Finally a need for a more structured form of randomisation was identified from the quantitative data with targets being spawned on some of the ten angles only a few times, and others a multitude through the course of the game. This caused an inconsistent amount of samples within the collected data itself.

6.4 Conclusions

Qualitative data showed that touch interaction problems had significantly decreased, also indicated by the therapist not having to intervene in any of the two sessions. A large quantity of unresponsive touches were however still observed. We believe these to be caused by inaccuracy. It would be interesting to incorporate a logging event on miss-clicks as the above data concerning imprecision does not factor in any attempted touch interaction which did not hit a target.

The logged data successfully indicated by both, information on expired targets, and information on reaction time, that the average performing patient one was suffering from neglect. For the above average performing patient two however, only information on reaction time provided indications of suffering from neglect. It is interesting that the therapist felt the patient had no performance deviations or problems during the session, while the data however showed a tendency for the patient to perform better on the right side in terms of reaction time.

A calibration system should be added to the game to help identifying when the player is hitting a target due to having spotted the immediate spawning of the target, and when the player is late hitting a target as a result of having resorted to consciously visually searching the screen. This information should be utilised by the adaptation system to avoid incorrectly increasing target spawning distance as a result of the user resolving to visual search. Information regarding hits and late hits should be included in the logging system allowing for detailed analysis.

We expect travel time biasing caused by hand positioning to decrease as the patients adapt to playing the game. As a result quantitative data from the first playthrough of the game in the final trials should not be included in the data analysis.

An evaluation screen should be displayed after finishing a playthrough to quantify, and illustrate how well the patient performed. Both patient one and the therapist expressed a desire for such evaluation, alongside an expectation that such evaluation screens will help the patients to better understand the condition. We hypothesize that such evaluation could also motivate the players further.

Patient one also noted a desire for feedback upon target expiration. Such feedback should be well thought out to avoid becoming an aspect of frustration for players having a high amount of expired targets.

Finally a bug was identified through observation, unintentionally allowing the players to spawn a new target in certain situations where previous targets were still alive. This was taken into account in data analysis

7. Study 3: Rehabilitative Evaluation

A final study was performed to evaluate the rehabilitative potential of the application. Secondary elements to evaluate includes identifying areas to improve in case of further development.

A minimum of 10 participants was intended, but unfortunately very few patients with left side problematics were at the time admitted to the Neuro Rehabilitation Center in Brønderslev, Denmark.

The study contained four participants, two of whom were women, mean age 71, with eldest 78 and youngest 60. All patients suffered from some level of attention deficit disorder, where two suffered from left side neglect caused by right side brain lesion.

7.1 Test Description

The final trials were formally conducted by a therapist at the Neuro Rehabilitation Center in Brønderslev, Denmark. The therapist assisted the patients in terms of basic guidance such as instructions and how to begin the game. The trials ran over a course of a week, where each patient played a session in the morning and a session in the afternoon. Instructions were given to allow for more sessions if desired. The very first and very last sessions of play were video documented with close-up of facial expression, close-up of tablet interaction, and an overview of both therapist and patient. All sessions were documented in quantitative data gathered from logging. On the last day of training each patient and the therapist took part in video documented individual semi-structured interviews.

All sessions were conducted with the tablet lying flatly on a table, and the patients sitting. Each game session had a fixed time of eight minutes.

Data should primary be analysed as within-subject, but could be analysed as between-subject to compare performance difference between patients suffering from neglect, and those suffering only from attention deficits.

7.2 Revised Prototype Description

The game was given a graphical overhaul to be more aesthetically pleasing, on the basis that this could improve motivation. Results of this overhaul in gameplay is as seen in Figure 1. The visual look of targets presented during stage 1.2A where changed to match those of the other targets in order to create a better consistency. Menu items were also given a graphical overhaul resulting in buttons of larger size and confirmation dialogs prompting to confirm user selection.

Target spawning was adjusted to get a more balanced presentation of targets, and thereby a more balanced sample size in the data logging. Targets are spawned with semi-structured randomisation by presenting a target for each angle in a randomised order, before again presenting a target for each angle. Angles in stage 1.1 is furthermore weighted to spawn twice for each runthrough since we expect angles on the neglected field of vision to remain in stage 1.1, and want to present as many targets as possible along the border of the vision. Similar form or structured randomisation is utilised in stages 2.1 through 2.3, where the latter would always present a target on both sides of the screen allowing for later investigation of extinction.

A calibration phase zero was added approximating the users average reaction time (aRT) at the beginning of each session. Fifteen targets are spawned randomly as in stage 1.1, isolated on the right side of the screen, with a distance of ⅔ the maximum distance of the spawn angle. Upon hitting the 15th target the system will calculate the aRT and transition to phase one. The two first targets are not included in calculating aRT to account for the fact that players are rarely immediately ready, and a value of 0.15ms is added to the aRT to account for additional travel time to targets with a higher distance in accordance to expectations from fitts law.

A fixed game length of 8 minutes was established. The therapist judged ten minutes to be the maximum amount of time the patient could maintain attention on a task at a time. Previous testing and personal experience with the game also illustrated a physical strain during prolonged play.

Transition between stages of the game were automatic. During phase one each angle would progress in stage depending on player performance. If distance is maxed at an angle which is currently stage 1.1 that angle would progress to stage 1.2. If an angle of stage 1.2 finds its corresponding opposite, 180° difference between the two, changing to stage 1.2 both will transition to stage 1.3. Transitioning to phase two will either happen when all angles are in stage 1.3 or enforced when passing ⅔ of the session time. Transitioning in phase two will happen upon maximum expansion of target distance since all targets expand or contract simultaneously. The game session will end upon maximum expansion in stage 2.3. This last mentioned condition can cause the session to end before the fixed session length for the skillful player.

A miss-click event was added to the logging system containing information regarding touch position, location of the intended target, distance to the target, angle of target, and the time of the touch.

Auditory feedback upon target expiration was added. It was arbitrarily chosen that the auditory feedback should at most be played twice within 20 seconds to avoid becoming an element of frustration in the case of players failing to correctly hit many targets in succession.

Two evaluation screens providing information regarding the players performance during the session were added as illustrated in Figure 5. These appeared upon game session completion. Both evaluation screens illustrated data according to the ten angles, where one evaluation screen presented the amount of targets hit and expired during the session, and the other illustrated the average reaction time for each angle. These screens are expected to foremost help the therapist and the patient to understand his condition, and secondary provide intrinsic motivation across sessions.

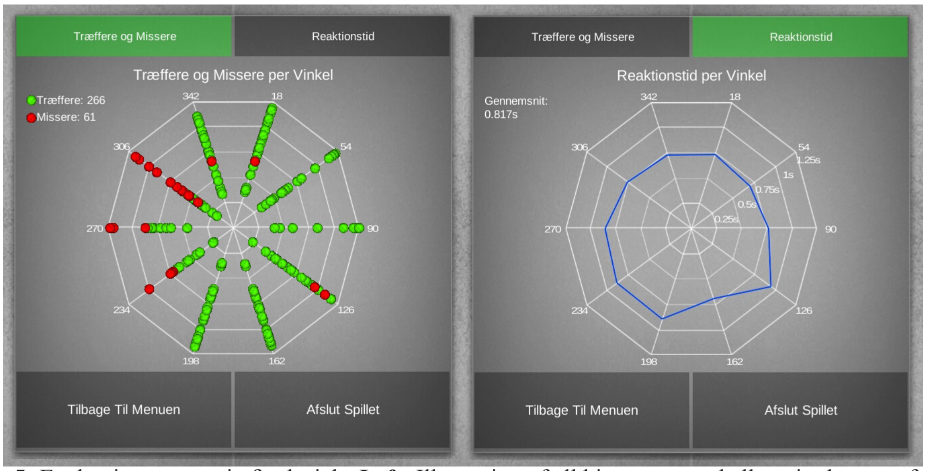

Figure 5. Evaluation screens in final trials. **Left:** Illustration of all hit targets, and all expired targets for each angle, where distance is specified in percentage. **Right:** Illustration of the average reaction time dor each angle.

7.3 Results

7.3.1 Reaction Time

We hypothesized that patients with neglect would be significantly slower at reacting to targets on the left hand side, compared to the right hand side, whilst for the patients with only attention deficit disorders there would be no significant difference between the two sides.

Reaction times (RT) extracted from the quantitative data, and a paired one-tailed t-test comparing neglect patients RT's for left and right side targets during phase one found that there was a significant difference in the RT's for left ($M = 1.35$), and right ($M = 1.11$) condition; $p = 0.01$, supporting the hypothesis that patients with left sided visual neglect would perform significantly worse on their left hand side, than on their right hand side. Conducting the same test on RT's for patients with only attention disorders found no significant difference where left ($M = 1.21$), and right ($M = 1.24$) condition; $P = 0.05$.

Looking at the neglect patients individually both patients showed significant difference with one patient; left ($M = 1.41$), right ($M = 1.23$) condition; $p = 0.01$, and the other; Left ($M = 1.34$), right ($M = 1.08$) condition; $p = 0.01$ proving that both patients are suffering from problems, and previous findings are not just a bias caused by collapsing the data together. None of the attention patients showed any significant difference in RT's between left and right side targets with $p = 0.05$.

Figure 6 illustrates the average reaction times of both patient groups displayed across rounded collections of distances for all hit targets. Here we clearly see that right and left side problematics in terms of RT is mostly dominant for neglect patients, especially as distance increases.

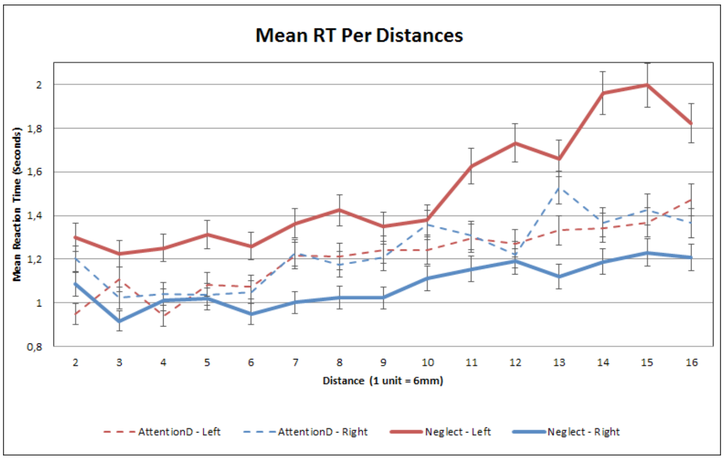

Figure 6. Illustration of average reaction time for all registered hits. Note that distances have been binned together in rounded collections and occluded angles have been sorted out.

Mean reaction time for both groups displayed across rounded collections of distances for only successfully hit targets within the timeframe found during calibration is illustrated in Figure 7. Here we note that all RT's are fairly close together in terms of the two patient groups providing evidence that the calibration system is working as intended. It is especially noteworthy that no patient in the neglect group successfully hit any targets with a distance greater than 13*6 mm, providing evidence that the adaptation and calibration system is collaborating to restrict target presentation.

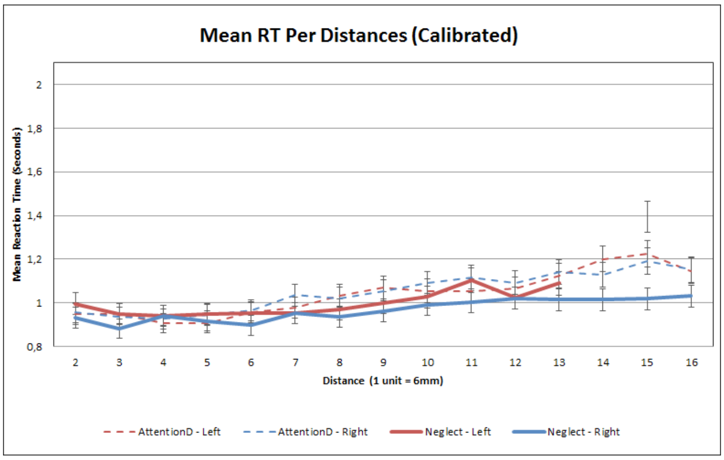

Figure 7. Illustration of mean reaction time for all targets hit within the timeframe found during calibration. Note that distances have been binned together in rounded collections and occluded angles have been sorted out.

One single occurrence of a hit for a neglect patient on a distance of 15*6 mm was observed. This however is probably caused by faulty calibration due to the high RT of 1.39 seconds, and no other occurrences on neither higher or lower distance.

Finally, both Figure 6 and Figure 7 show clear indications among both patient groups that distance influences task completion time, fitting Fitt's law. Comparing trend lines of left and right side, average reaction times on calibrated targets according to the rounded distances we see correlation coefficients of left; 0.79, and right; 0.92 with all patients included. Note that left side coefficient is weaker due to higher spread, probably caused by neglect patients. Also note that target size is information not factored in since all targets are of equal size.

7.3.2 Visual Field Improvement

We hypothesized that patients with neglect would achieve greater distance on left side targets over the course of sessions, whilst for patients with only attention deficit disorders there would be no such difference.

Average target distances for each day of training extracted from the quantitative data and a paired one tailed t-test comparing the neglect groups average left side distances for the first and last day of training found no significant difference in the mean distances for the first ($M = 6.45$, $SD = 2.5$), and last ($M = 9.31$, $SD = 2.7$) day of training, condition; $p = 0.05$, failing to support the hypothesis that neglect patients would achieve greater distances through the training period. Note that distances are specified in software units and can be converted by multiplying with 6mm.

However a trend can be noticed in Figure 8 illustrating the average distance of calibrated targets during the course of the trials. Here we see indication of improvement for neglect patients on the left side in respect to the average distance of targets, while the average distance among attention patients on both sides are fairly identical, with small indication of improvement on left side targets. There is the possibility that this improvement is caused by patients learning the game, while there is also the possibility that the patients base attentional improvements could cause an improvement in his or her's visual capabilities in relation to spatial attention [DeGutis, 2010].

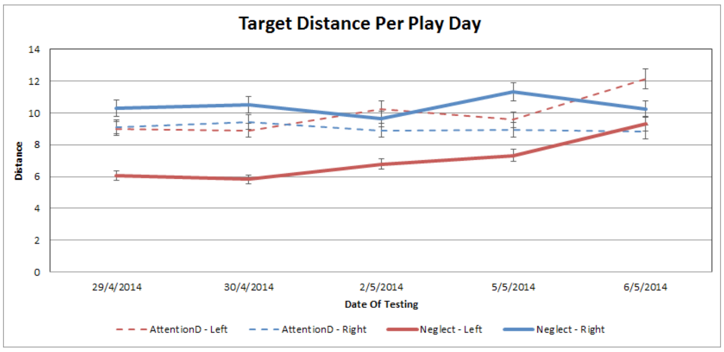

Figure 8. Illustration of mean distance of calibrated targets during the course of trials with 95% probability error lines. Note that occluded angles have been sorted out.

7.3.3 Imprecision

We hypothesize that patients will have an average touch offset in a south-eastern direction, and that this offset is independent of patient impairment and screen side.

Qualitative video data showed a tendency to sometimes touch the tablet with the lower palmar of the interacting hand creating an unnatural, or biasing effect, on the quantitative data in regards to miss-click events. This data was filtered with a distance threshold of one standard deviation, resulting in a reduction from 3274 to 2619 miss-clicks intended to hit a target.

Quantitative data after filtering for intended interactions showed an error percentage of 24.2% with miss-clicks (N = 2619), and successful hits (N = 8191). These findings deviate from those of Hwangbo, Henze, and Leitão who had similar sizes of targets, indicating a problem with either patients or software. Inspecting individual amount of miss-clicks we found that one attention deficit user in particular accounted for 1052 out of a total of 2619 miss-clicks resulting in 40.1% of all faulty interaction. Qualitative video data show that this person had a tendency to interact with the tablet in such a way he was prone to creating a double click, essentially making a miss-click in the same position as he had just previously made a correct hit.

Mean imprecision on successfully hit targets among all patients for each axis extracted from the quantitative data showed a mean offset of X; 0.69, Y; -1.34, resulting in a mean distance of 1.51 millimeters from center of target to average point of touch, where N = 8191. This mirrors the results found in study two in terms of imprecision, confirming a south-eastern direction of imprecision. Similarly we see a mean offset of Y; -0.54, X; -8,24, resulting in a mean distance of 8.26 millimeters from center of target to average point of touch, where N = 2619. This is similar to findings in study two, but results in a south-western direction. Comparatively both of the two offsets are directly south of desired targets with a minimal skewness of ~0.5 millimeters to either side. This downwards direction indicate that patients have a tendency to press below the target, possibly due to them wanting to see the target while pressing it. Going through the qualitative data of first and last session, we were able to confirm these data results by looking at the video footage of the patient's interaction with the tablet. Interestingly a two tailed t-tests comparing imprecision on the right and left side for the X, and Y axis's on all successfully hit targets showed significant difference (N = 8832, P = 0.05), providing evidence similar to Henze et al's [Henze and Boll, 2011] findings that precision is dependent upon screen position.

A paired one-tailed t-test was conducted to see if there was a difference between the mean imprecision of miss-clicks in terms of total distance for visual neglect patients and the patients with attention deficit disorder, and no significant difference was found (P=0.05).

7.3.4 Extinction

In order to evaluate the phenomenon of extinction we looked at the data from stage 2.3 where stimuli is purposely presented on both sides of the screen simultaneously. This was the last stage of the game and wasn't always reached by all of the patients. One of the visual neglect patients never managed to reach this stage. From comparing the amounts of hits sorted by calibration with later hits its possible to see which target (left side or right) a patient chose to press first. See Table 1.

Table 1. Hits, late hits, and expired targets for each patient on their left and right side in stage 2.3. The second neglect patient did not reach this stage and therefore is not represented.

	Hit		LateHit		Expired	
	Left	Right	Left	Right	Left	Right
AttentionD						
Patient 1	12	17	31	25	3	4
Patient 2	11	8	17	20	2	3
Neglect						
Patient 3	13	68	48	36	40	0

For the attention deficit disorder patients it was generally evenly distributed in regards to all hit types as expected. However for the neglect patient we see a much larger amount of hits on the right side, similarly with late hits, and most interestingly all expired targets in this phase is located on the left side. These provide strong evidence of extinction for this particular patient.

Finally, the fact that the other neglect patient did not reach this stage in any play session, is most likely due to the patient struggling with stage 2.2 where targets are isolated to the left side. This finding provides clear indication that this patient is in fact suffering from neglect.

7.3.5 Play Time

Out of the four patients only the two attention deficit patients managed to finish the game early by completing all stages in phase 2.3 before the eight minute mark. Of the two, one patient was predominantly responsible with four out of eight sessions ending early, whereas the other patient only finished early once out of eight sessions.

7.3.6 Patient Application Usage

It was hypothesized, and a criteria for the game, that it was possible for the therapist to hand over the tablet with the application to a patient, and without more than simple instructions allow the patient to train on their own, as a means to both ease the schedule of the therapist and allow patients to train more often than they would otherwise. After final trials we conducted a semi-structured interview with the affiliated therapist, and each patient.

The therapist mentioned that the patients had varying degrees of enthusiasm in regards to having to play the game, noting that those who felt they were benefitting from the game seemed more eager to play. When asked what caused the enthusiasm, she continued: "*I think it's because they can feel its something that challenges them, and it helps them. And also that they can sit for themselves and do something which improves their own situation - that gives them a good feeling.*"

The therapist also explained that for the patients in general she felt the game was a good tool to help them with their attention problems. She noted that one particular patient typically had so severe attention problems that she would often contact staff members during the day to ask clarifying questions, and was generally unable to perform any form of complex task without help. She expanded by saying "*She has had large difficulties doing things on her own because whenever small problems would arise she would contact staff. But this game is simple enough. And its good to have things for them to fill up their time*".

She summarized the usage of the game among patients by saying: "*But it's been quite good for these patients to give them this, because after two usages they have been able to do it themselves.*"

When asked if they would theoretically like to continue playing the game if it was possible for them, both of the neglect patients answered yes, while the others were more hesitant. When asked what they perceived as the goal of the game, both neglect patients correctly answered that it was to train their attention and vision, while the others had not gained the same understanding. The lack of understanding of the purpose of the game could possibly have had an effect on their motivation to not only play but also to further continue using the game.

One of the visual neglect patients showed great interest in the game due to feeling it helped her vision and requested a copy of the game to continue training on her own.

8. Discussion

Number of Sessions

One aspect that could have influenced the results is the case that one patient played more sessions than the other three. Even though this has been kept in mind in evaluating the data, it is possible that the extra training could have influenced this particular patient's improvement over the time period. The amount of sessions were generally quite low compared to other similar studies in the field of VRT, and it would have been advantageous to have patients play for a prolonged stretch of time matching those of other studies.

Number of Participants

Due to the nature of the requirements for the patients for this study the number of the participants were lower than intended, partially due to the rarity of the specific disorder, but also due to a coincidentally lower amount of left sided neglect patients present at the affiliated clinic at the time. It would have been beneficial to have a larger group of patients.

Secondary Rehabiliation

As the patients participating in the study were also part of other rehabilitative courses at the Center of Neurorehabilitation in Brønderslev, Denmark, it should be noted that any improvements for the patients which this study have found could be influenced by secondary rehabilitative exercises.

Correcting Touch Offset

As it was found that patients persistently had a touch interaction offset, it would have been beneficial to incorporate an algorithm to adjust or adapt for this beyond just increasing the touch size of touch areas. One way to do this would be to continuously measure this offset while the user is playing, and adjusting the touch areas offset to fit. By doing this, the problem of a patient pressing below a target would be circumvented by having the targets touch area match that specific users pattern of interaction. This however should only be done within a certain threshold to ensure some consistency in the interaction, and the offset should likewise scale the touch area size, or practical size, to ensure that it always covers the visual size despite the offset. Another way of doing this would be to offset the registered touch position on all touch events to match those of the user.

Tablet Positioning

There is a possibility that the users could be using the tablet rotated at a slight angle, but it is assumed that the angle discrepancy which would arise from this problem is negated by having merely ten angles.

Further Game Play Design

In communication with the participating patients an interest for more challenging gameplay was indicated. In future development it would be interesting, and beneficial to account for, and adapt to higher levels of attention such as selective, alternating, and divided attention. Phase two was designed to cater selective attention, but with a low amount of distracting stimuli. The implementation of such phases is expected to provide more variation, and thereby intrinsic motivation among the users. Another stage was intended focusing on both memory and selective attention by, in a way similar to that of stage 1.2 spawn an initial target, but a symbol on it. Once pressed, the target would spawn an amount of surrounding targets containing different symbols, and the task would then be for the player to press the target with a symbol matching that of the original target. Other suggestions are targets to purposely avoid or ignore, and selective sequencing by patterns.

Phase two did not adapt progression in the same manner as phase one. This was intentional to ensure that the targets would form a ring which could help guide a player to an active target. However there is no evidence pointing towards this guidance being a necessity, and the shift to this phase is rather abrupt. It could be interesting to modify this phase such that either: 1. It is an extension on phase one where each angle changes stage, and in this stage the individual target remains and behaves similar to that of phase two, serving as a single distractor on that angle when not being an active target, or 2. It has an adjusted adaption of distances of targets to a similar manner of that seen in phase one resulting in targets progressing outward, or inward individually instead of uniformly, resulting in a more varied arrangement of targets.

Evaluation screens at the end of a playthrough should be logged such that it is possible to review individual progression on the tablet by comparison. This desire was identified in qualitative data from semi-structured reviews with therapist and patients. It is expected to add better evaluation, and progression indications for both therapist and patients, which in turn could increase motivation to use the game.

In order to negate the problem of hand occluding it would be a possibility to avoid spawning in the lower quadrant where the hand is positioned. From a player's perspective this would change the game experience very little and would most likely not be noticeable in the entire first phase of the game. In phase two the inactive (white) target on this angle could still exist, however still it should never become active (green).

Inconsistent Auto Change

The game was designed to auto change to phase two after having played two thirds of the entire game time of a session. This was to enforce data collection for these stages regardless of how well players were progressing. However a bug was found which occurred twice, resulting in auto changing not happening, resulting in players being stuck in phase one. Proper precautions were taken during data analysis.

9. Conclusion

The game design had promising implications. This was indicated by the final trials where we found that there is clear evidence that through the application it is possible to evaluate the performance of patients to such a degree that neglect patients can be separated from patients with other attention deficit disorders. Furthermore the application was able to identify a significantly higher reaction time between left, and right side targets for neglect patients, and provide indication of visual field expansion, or at least expansion of visual field awareness.

It is unlikely that neglect patients achieved an improvement to their visual field, or it is at least not represented properly in the measured data. A small tendency was however discovered for neglect suffering patients, and one of the mentioned patients was of the firm conviction that said application had helped her.

The possibility for unassisted training among patients with this tablet game design is very likely, and opens up the possibility for further tablet based applications aimed at rehabilitating patients with attention deficit disorders in general, however specifically it can be beneficial for patients with visual neglect.

Finally we recommend that another study be performed with a prolonged trial period, better instructions, and without any concurrently running cognitive training for the participating patients, in order to properly determine whether the expansion of the visual field of neglect patients is possible in these settings.

10. References

Bavelier, Daphne, and Richard J Davidson. 2013. “Brain Training: Games to Do You Good.” Nature 494 (7438): 425–26. doi:10.1038/494425a.

Bolognini, Nadia, Elena Olgiati, Annalisa Xaiz, Lucio Posteraro, Francesco Ferraro, and Angelo Maravita. 2012. “Touch to See: Neuropsychological Evidence of a Sensory Mirror System for Touch.” Cerebral Cortex (New York, N.Y.: 1991) 22 (9): 2055–64. doi:10.1093/cercor/bhr283.

Cha, Yu-Jin, and Hee Kim. 2013. “Effect of Computer-Based Cognitive Rehabilitation (CBCR) for People with Stroke: A Systematic Review and Meta-Analysis.” NeuroRehabilitation 32 (2): 359–68. doi:10.3233/NRE-130856.

COGNIsoft. 2014. Windows (version 5.0.5). Sættedammen 5, 3400 Hillerød. Accessed May 25. http://www.cognisoft.dk/.

Degutis, Joseph M, and Thomas M Van Vleet. 2010. “Tonic and Phasic Alertness Training: A Novel Behavioral Therapy to Improve Spatial and Non-Spatial Attention in Patients with Hemispatial Neglect.” Frontiers in Human Neuroscience 4. doi:10.3389/fnhum.2010.00060.

Deveau, Jenni, Daniel J. Ozer, and Aaron R. Seitz. 2014. “Improved Vision and on-Field Performance in Baseball through Perceptual Learning.” Current Biology 24 (4): R146–R147. doi:10.1016/j.cub.2014.01.004.

Eysenck, Michael William, and Mark T. Keane. 2010. Cognitive Psychology: A Student’s Handbook, 6th Edition. Taylor & Francis Group.

Granic, Isabela, Adam Lobel, and Rutger C M E Engels. 2014. “The Benefits of Playing Video Games.” The American Psychologist 69 (1): 66–78. doi:10.1037/a0034857.

Green, C S, and D Bavelier. 2012. “Learning, Attentional Control, and Action Video Games.” Current Biology: CB 22 (6): R197–206. doi:10.1016/j.cub.2012.02.012.

Henze, Niels, and Susanne Boll. 2011. “It Does Not Fitts My Data! Analysing Large Amounts of Mobile Touch Data.” In Proceedings of the 13th IFIP TC 13 International Conference on Human-Computer Interaction - Volume Part IV, 564–67. INTERACT’11. Berlin, Heidelberg: Springer-Verlag. http://dl.acm.org/citation.cfm?id=2042283.2042377.

Henze, Niels, Enrico Rukzio, and Susanne Boll. 2011. “100,000,000 Taps: Analysis and Improvement of Touch Performance in the Large.” In Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services, 133–42. MobileHCI ’11. New York, NY, USA: ACM. doi:10.1145/2037373.2037395. http://doi.acm.org/10.1145/2037373.2037395.

Horton, J C. 2005. “Vision Restoration Therapy: Confounded by Eye Movements.” The British Journal of Ophthalmology 89 (7): 792–94. doi:10.1136/bjo.2005.072967.

Hwangbo, Hwan, Sol Hee Yoon, Beom Suk Jin, Young Suk Han, and Yong Gu Ji. 2013. “A Study of Pointing Performance of Elderly Users on Smartphones.” International Journal of Human-Computer Interaction 29 (9): 604–18. doi:10.1080/10447318.2012.729996.

Jeong, Wooseob, and Myke Gluck. 2003. “Multimodal Geographic Information Systems: Adding Haptic and Auditory Display.” Journal of the American Society for Information Science and Technology 54 (3): 229–42. doi:10.1002/asi.10202.

Kasten, Erich, Ulrike Bunzenthal, and Bernhard A Sabel. 2006. “Visual Field Recovery after Vision Restoration Therapy (VRT) Is Independent of Eye Movements: An Eye Tracker Study.” Behavioural Brain Research 175 (1): 18–26. doi:10.1016/j.bbr.2006.07.024.

Leitão, Roxanne. 2012. "Creating Mobile Gesture-Based Interaction Design Patterns for Older Adults: A Study of Tap and Swipe Gestures with Portuguese Seniors."

Lindeman, Robert W., John L. Sibert, Erick Mendez-Mendez, Sachin Patil, and Daniel Phifer. 2005. "Effectiveness of Directional Vibrotactile Cuing on a Building-Clearing Task." In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 271–80. CHI '05. New York, NY, USA: ACM. doi:10.1145/1054972.1055010. http://doi.acm.org/10.1145/1054972.1055010.

MacKenzie, I. Scott. 1992. "Fitts' Law As a Research and Design Tool in Human-Computer Interaction." Hum.-Comput. Interact. 7 (1): 91–139. doi:10.1207/s15327051hci0701_3.

Mueller, Iris, Henning Mast, and Bernhard A Sabel. 2007. "Recovery of Visual Field Defects: A Large Clinical Observational Study Using Vision Restoration Therapy." Restorative Neurology and Neuroscience 25 (5-6): 563–72.

NovaVision. 2014. Accessed May 25. http://www.novavision.com/.

Poggel, Dorothe A, Erich Kasten, and Bernhard A Sabel. 2004. "Attentional Cueing Improves Vision Restoration Therapy in Patients with Visual Field Defects." Neurology 63 (11): 2069–76.

Romano, Jose G, Patricia Schulz, Sigrid Kenkel, and David P Todd. 2008. "Visual Field Changes after a Rehabilitation Intervention: Vision Restoration Therapy." Journal of the Neurological Sciences 273 (1-2): 70–74. doi:10.1016/j.jns.2008.06.026.

Sagi, Dov. 2011. "Perceptual Learning in Vision Research." Vision Research 51 (13): 1552–66. doi:10.1016/j.visres.2010.10.019.

Seitz, Aaron R, Robyn Kim, and Ladan Shams. 2006. "Sound Facilitates Visual Learning." Current Biology: CB 16 (14): 1422–27. doi:10.1016/j.cub.2006.05.048.

Shams, Ladan, and Aaron R Seitz. 2008. "Benefits of Multisensory Learning." Trends in Cognitive Sciences 12 (11): 411–17. doi:10.1016/j.tics.2008.07.006.

Sikora, Cynthia A., Linda Roberts, and La Tondra Murray. 1995. "Musical vs. Real World Feedback Signals." In Conference Companion on Human Factors in Computing Systems, 220–21. CHI '95. New York, NY, USA: ACM. doi:10.1145/223355.223534. http://doi.acm.org/10.1145/223355.223534.

Snowden, Robert J., Peter Thompson, and Tom Troscianko. 2006. Basic Vision: An Introduction to Visual Perception. Oxford University Press.

Sohlberg, McKay Moore, and Catherine A. Mateer. 1989. Introduction to Cognitive Rehabilitation: Theory and Practice. Guilford Publications, Incorporated.

Sturm, Walter, Klaus Willmes, Bernt Orgass, and Wolfgang Hartje. 1997. "Do Specific Attention Deficits Need Specific Training?" Neuropsychological Rehabilitation 7 (2): 81–103. doi:10.1080/713755526.

Thimm, M, G R Fink, J Küst, H Karbe, and W Sturm. 2006. "Impact of Alertness Training on Spatial Neglect: A Behavioural and fMRI Study." Neuropsychologia 44 (7): 1230–46. doi:10.1016/j.neuropsychologia.2005.09.008.

Watanabe, T, J E Náñez, and Y Sasaki. 2001. "Perceptual Learning without Perception." Nature 413 (6858): 844–48. doi:10.1038/35101601.

11. Appendix - Implementation

11.1 Calibration

The calibration system serves the purpose of distinguishing between targets identified by visual identification and targets identified through visual search. This is a necessity since we want to evaluate the players' visual fields, and thereby their ability for visual identification.

The need for calibration is furthermore underlined due to the fact that players will get more proficient with the game the more often they play, and that players will have different baselines of reaction time.

The calibration system identifies the average time it takes for the player to perform a successful hit on a spawned target - hereby referred to as mean reaction time. The mean reaction time is then increase by a small grace period of 150ms resulting in the adjusted reaction time (aRT). This grace period is added due to fitt' law dictating that longer travel needs more time, and targets may appear further away from center than the calibration targets do.

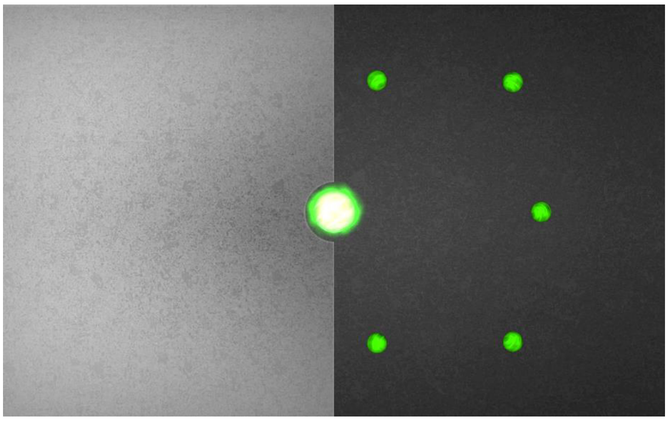

Figure 9. Figure illustrating the five possible target angles and their location during the calibration. Note that during calibration these are presented sequentially in randomised order, and not simultaneously as illustrated here.

To identify the mean reaction time an amount of targets is spawned on the five right side angles with ⅔ of the max distance from center to the edge of the screen as can be seen in Figure 9. To be sure we get targets of each angle, targets are spawned as follows in Code 1. The first 3 targets are extruded from the calculation since it is expected the player will be slow on these due to learning circumstances.

```
private void SpawnCalibration()
{
    //If CalibrationList Empty
        //Fill list with one target of each angle

    //Pick random CalibrationList index
    //Spawn target according to index with 2/3 of max distance for the angle
    //Remove target from CalibrationList by index
    //Increase calibrationCount
}
```

Code 1. Spawning calibration code.

The aRT found by the calibration system is then used throughout the rest of the game session as a threshold value on the targets lifetime for the adaptability of the game. As is illustrated on Figure 10 each targets has a given lifetime during which it appears, awaits a touch, and then if no touch is found during the lifetime, it disappears. The aRT then functions as a threshold meaning, that if the target was touched by the player before the aRT threshold, the target hit is registered as a 'Hit' meaning that the target was identified through visual identification. Otherwise if the target was touch by the player after the aRT threshold the target hit is registered as a 'LateHit' meaning that the target was identified through visual search. Last case being that the target is not touched by the player within the lifetime of the target, and in this case the target disappears, and is registered as an 'Expired' target.

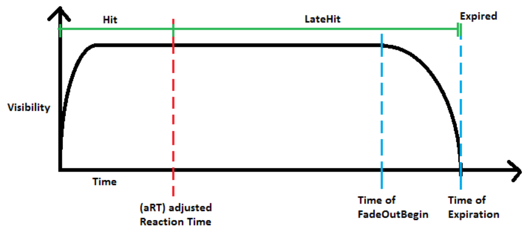

Figure 10. Illustration of target visibility over its lifetime. Note the HitType indicated at the top bar, based on within which time frame the player touched the target, if touched.

11.2 Data Logging

The game logs several kinds of information during a playthrough. When a new playthrough is started, a check is made to ensure that the correct /data/ folder exists in the device's Application.persistentDataPath. Likewise, on startup of a new play through, a corresponding .txt file is created, and named appropriately with current user ID and date and time, for example: "*User1 - 04-04-2014 14-57-55.txt*".

The logging happens continuously while playing, and is done through a autonomous script with a public LogData() function. This function is called from the ObjectHandler scripts on targets, and is called whenever a target is missed or hit. The LogData() function includes a range of arguments for the specific target. See Code 2.

```
public void LogData(string _stage, float _reactiontime, int _angle, float _distance,
Vector3 _targetposition, Vector2 _touchposition, string _hitType, int _targetID,
int _angleID)
```

Code 2. The LogData function including arguments.

These pieces of information is retrieved from each target once it is hit, and is subsequently in that function modified into a string separated by semicolons, which is written to the aforementioned .txt file. The combined string looks as the following, Code 3:

```
currentStringToWrite = “”+userID+”;”+sessionID+”;”+targetID+”;”+stage+”;”+GetStageI
D(stage)+”;”+time+”;”+reactiontime+”;”+angleID+”;”+angle+”;”+distance+”;”+targetpos
itionX+”;”+targetpositionY+”;”+touchpositionX+”;”+touchpositionY+”;”+hitType+”;”+Ge
tHitTypeID(hitType);
```

Code 3. Combined string for a data entry, which is written to the current .txt file.

UserID is a number relating to which user has been chosen in the menu before a playthrough begins. These accessible user profiles has been predefined to match the expected users participating in the final test. SessionID describes which session a current playthrough is for this specific user. TargetID is a number representing which target this entry relates to, in an ascending order. Stage and StageID is descriptors in text and number explaining to which stage a target belongs. Time is the point in time at which the logging occurs, which in turn means the time at which a target was missed or hit. Reaction time is the time it took from a target was spawned until the player successfully hit it. Angle and angleID represents the angle in degrees, and an ID from 1 to 10 describing which angle the target existed in. Targets can only be spawned in ten specific angles to minimize variance. The positions are the two dimensional vector of a target’s position, and the position the player pressed. HitTypes and ID are indicators of whether a target was a calibration, hit, miss, or hit too late in accordance with a player’s expected reaction time, or a miss-click.

Miss-clicks is any case in which a player pressed anywhere on the tablet that is not a target or the centerbutton. This is to be able to differentiate whether a players slower reaction time on a target was due to a previous missclick. In the cases where a value is non-existent, such as the reaction time of a miss-click, a value is set to 0.

The resulting .txt file is easily importable into excel, while using the semi-colons a seperators of columns.

11.3 Performance Evaluation Screen

The endgame evaluation screen which illustrates to a player how well they have performed consists of two parts. One part, which is initially presented once a playthrough is completed, displays a scatterplot of the hits and misses a player has done. The second part, which can be accessed by pressing the corresponding button, displays the average reaction time a player used to hit a target on the specific angles.

Both versions are displayed on a simple 2D texture grid which is segmented into ten angles and five lengths, within which the hits/misses and reaction times are scaled.

11.3.1 Hits And Misses

Hits and misses are stored as Vector3 positions throughout the game in two lists. Once a game is over, the lists are returned to the evaluation screen which first instantiates a hit icon in all the corresponding position, and subsequently misses. By doing it in this order the misses visually lay on top of the hits, which is prefered due to their mostly limited number. However, since the patients due to their conditions have problems attending to visual stimuli on their left hand side, the above mentioned grid does not facilitate the entire screen. This is to ensure they are able to see the representation of how they have performed. By scaling it down they might very well get a better sense of what they can and can't see. Therefore the positions returned from the lists, in terms of length away from the center of the screen, are all scaled down to match the grid. See figure Figure 11.

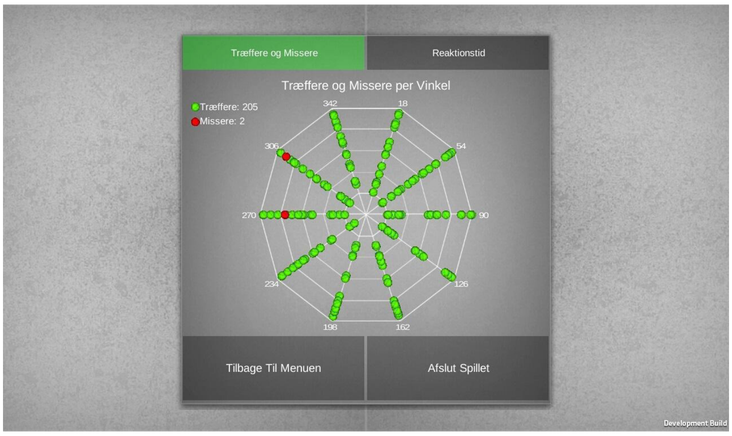

Figure 11. Screenshot of the evaluation screen depicting hits and misses.

The total hits and misses are displayed in numbers on the left hand side with explanations of what the hit and miss icons look like.

11.3.2 Reaction Time

The reaction time evaluation screen depicts a graph illustrating the average reaction time for a player on each angle. Ie. the position of the line on specific angle is the average reaction for all the targets encountered on this specific angle throughout the play through. This gives an overall indication of which angles were more troublesome for a player.

The reactions times are logged throughout a playthrough, just as the hits and misses. This is done per angle. The averages are calculated per list, and an invisible node gameobject is instantiated in a length away from the center, at that specific angle, corresponding to the average reaction time. Then for each of these nodes a LineRenderer is accessed and a line is drawn from the nodes own position to the next node in the array of nodes. See Figure 12.

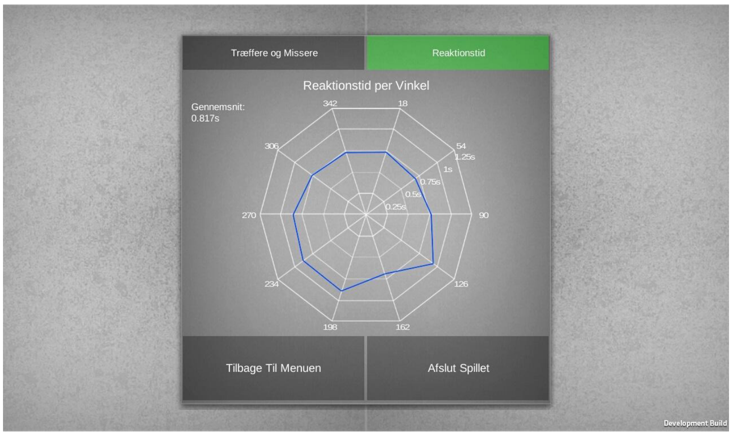

Figure 12. Screenshot of the reaction time evaluation screen.

As patients reaction times can differ by quite a lot, the limits of the grid scales automatically. This is done by checking what the greatest average reaction time is, and then using an outer limit that lies above that, either 1.25s, 2.5s, or 5.0s.

11.4 Visuals

11.4.1 Center

As the spherical center button is the main object a player will be interacting with throughout a playthrough, it is essential that it communicates information in a proper way. The center has different states, namely awaiting to be pressed, awaiting for a small target to be pressed, and being punched. In Figure 13 the different states are shown.

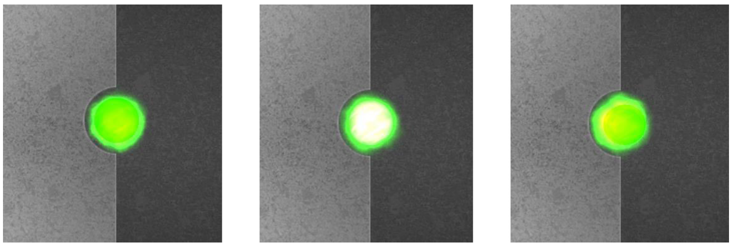

Figure 13. The different visual states the center button can be in; from left to right: awaiting press, awaiting target press, and being punched.

When the center is awaiting to be pressed it lights up green and has a pulsating glow. This glow is achieved by placing a particle emitter on top of the actual spherical object. The spherical object in itself only has a simple texture which is subsequently colored either green or white, depending on which state the button is in. Once the button has been pressed it becomes deactivated, indicated by the center mass of the object turning white. Likewise the pulsating effect stops occurring once it has been deactivated, and is awaiting the correct hit on a small target. When this small target has been successfully hit it returns to the center, and the center gives a punch both by manipulating the dimensions of the spherical object to become oblong in the specific angle it was hit from.

The particle effect uses a simple texture (See Figure 14), which has a long lifetime in roughly the same position. It uses a color over lifetime which both fades in and out in opacity in beginning and end which adds to the glow effect since there is no abrupt appearing and disappearing particles.

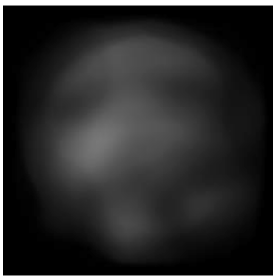

Figure 14. The texture used for the particle effects.

In order to make it look less static the particles has a slow rotation over its lifetime. On punches a separate similar particle effect is played on top which gives a short burst outwards.

11.4.2 Targets

When a target is spawned it is solely a spherical texturised object, and has a pulsating effect on its size. See Figure 15. When a target gets pressed the spherical object is deactivated and a particle emitter is placed instead which gives the illusion that the target turns to dust which then subsequently flies towards the center target. The particle emitter has a subemitter which leaves a trail of dust as it flies towards the center.

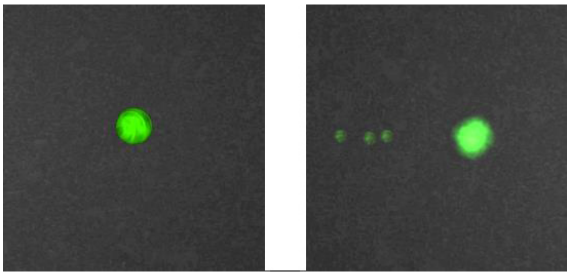

Figure 15. The two states of a target; awaiting hit and returning to center button.

All of this helps the player refocus from the position of the target when they pressed it and back towards the center object which they must press next.