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Supporting School Aged Children to Train Their Vision by Using Serious Games

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Abstract: Several children struggle with vision difficulties caused by problematic coordination between their left and right eye muscles, i.e., oculomotor dysfunction (OMD). Many OMDs can be improved by training the eyes via physical exercises defined and supervised by vision experts. The aim of this paper is to investigate the feasibility of utilizing Serious Games (SGs) and eye-tracking technologies (ETs) for training the eyes of children having OMD. Via these activities, a trainee can, with her eye gaze, follow objects which are moving, change their directions and speed, or pop up on the screen. The results present mapping the current physical training goals to activities for SGs using input from ETs, and illustrate this correspondence for designing and developing six games. The games' feasibility evaluation is done via semistructured interviews and evaluating user experiences. Three vision teachers (VTs) were involved in design and development, ensuring achievement of training goals, and five VT students in evaluations. The findings demonstrate the potential of using SGs and ETs to train OMD and point to future needs for improvements.

Keywords: OMD; eye-tracking; serious games; training; vision impairment; rehabilitation; vision teachers

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1. Introduction

Vision plays a leading role in our daily activities, influencing our interaction with the outside world. Of all school-aged children, 25–30% have vision problems [1], and many of these were not detected before [2,3]. A child who can clearly see objects at a certain distance can still have a functional vision impairment at other distances [4].

Vision impairments can cause later impediments in academic success, and by this is influencing the education system, public health system, and social well-being [5–7]. A particular part of vision impairments can be corrected by glasses or surgery. A large number of school-aged children (17–30%), such as those having Oculomotor Dysfunctions (OMD), can be helped via vision therapy or training their eyes.Already a few weeks of training can improve their vision [4,8–10]. By school-age children, we mean children who are beginning their school education. OMD hinders automatic control of one's eye muscles for more extended periods than a few seconds, which results in reading or seeing difficulties. Adults also can have OMD, especially after a brain injury [11]. However, they can articulate their problems, while many children are unaware of having OMD and cannot understand its negative influence on their performance [4]. OMD is difficult to detect due to missing resources to screen all school-aged children [4,12]. Since rehabilitation or training takes longer time periods it is even more challenging to support it [13].

In many countries, the last mandatory control of eyes is with a health control at the age of 3–4, while in contrast, their sight is still under development when they begin school [5,14].

A hypothesis behind this work is that supporting technologies would reduce resources for experts or parents responsible for improving children's vision problems. The first step towards this is investigating how technologies can complement the current physical training of OMD.

While the "end-users" of rehabilitation are children having OMD, the enablers for training and using these technologies as new and complementing methodologies for traditional training are the professionals suggesting and often supervising training. This work focuses on these professionals, the special educators, which are also called vision teachers (VTs). VTs are responsible for children's vision impairments and understanding teaching and education activities [13].

The aim of this paper is to illustrate how serious games (SG) and eye-tracking technologies (ETs) can complement vision training for children with OMD from the perspective of vision teachers (VTs). This is done by describing current training, identifying possible SG support, and testing the feasibility of SGs by VT students. There have been three VTs involved in developing games and five VT students in evaluations. The methodology is inspired by Grounded Design methodology [15], ending with a feasibility study of six SG prototypes based on data from semistructured interviews and user experience evaluation [16,17].

One of the main challenges of this work has been to work interdisciplinary and translate the physical guidelines the VTs identified to improve OMD in children via vision training to guidelines needed for developing games. Another challenge has been to systematically compare the visual stimuli on the computer screen with the physical eye exercises. This paper defines and evalautes the suggested prototypes and describes challenges for further development.

The limitation of this study is in evaluations with end-users. To carry out experiments in children and test the progress and outcomes of using this type of training needs to be done in the next step. However, this step cannot be conducted before investigating the usefulness of the games with vision experts. This paper focuses on VTs as a main stakeholder group, enabling vision training in children.

The structure of this paper is the following. After presenting the literature background (Section 2), we describe the study design via applied methods and materials (Section 3). This is followed by the results (Section 4) in three subsections—the first presents the activities needed to be done during physical vision training. The next examines how these activities can be mapped and triggered with playing SGs. The last subsection contains feasibility evaluation of the suggested SG prototypes by the VTs. The last Sections are the Discussion and future work (Section 5) and Conclusions (Section 6).

2. Literature Background

2.1. OMD as a Vision Impairment That Can Be Supported with Vision Training

Good vision is vital for cognitive, physical, and social progress during early childhood and into later years. Many vision problems can be corrected by eyeglasses [18], contact lenses, or laser refractive techniques [18,19], and many, often the functional eye motoric problems, can be improved by training [4].

Some possible reasons for functional vision problems such as OMD in children are innate, brain abnormalities, unmatured muscles, stress, or too little stimulation. [20].

A significant number of children (17–30%) with OMD have normal vision acuity (sharp vision), but insufficient eye motoric abilities [4]. OMD is associated with problems in coordinating the movements of the eyes (mainly measured via fixation, saccade, and smooth pursuit). A fixation is an ability to pause the eye movement on a particular region for gathering visual information [21]. A saccade is a rapid change of fixation to another fixation [22]. Smooth pursuit occurs when an eye tracks a moving object [23]. A person having anomalies in any of these three eye movements can be diagnosed with OMD. OMD may lead to difficulty to read, difficulty to write, eye fatigue, headache, poor development in eye-hand coordination, or eye fixation loss [9,24]. Children with learning disabilities often have vision problems related to OMD [21,22], and many of them can be helped by timely access to quality eye care [25].

There are several vision experts who provide screening (identification) or treatments (rehabilitation) of eye problems [26]. These are vision specialists, such as ophthalmologists, optometrists, orthoptists and dispensing opticians, often focusing on different parts of the eyes. Many of them, e.g., ophthalmologists, don't necessarily understand how important the children's visual function is, e.g., vision balance or eye accommodation [27]. If an ophthalmologist sees "vision screening," they mainly think about eye diseases, identifying problems that can be corrected via prescriptions of medicine, eyeglasses, or contact lenses. The focus in this paper is vision screening focusing on identifying functional eye problems and vision training for improving these. In Norway and in many other countries the special educators with competence in vision, the vision teachers (VTs), are the main responsible for identifying such problems.

For OMD problems, VTs guide rehabilitation, which includes usually more than three weeks. To support these activities may involve other, often nonprofessional stakeholders, e.g., school teachers or parents. While the effect of vision training in general has been highly debated for several decades [28], there is evidence for the positive effects of vision training [29]. Research and practical studies tested the impact of training the eye-muscles in children with OMD, and found significant improvements in reading skills and decreased duration of unnecessary gaze fixations already after three weeks of regular training [30–33]. The length of the training varies, depending on who defined it the type of the OMD problem and the child. As there is no consensus about an exact test battery for vision screening identifying OMD, there is no consensus for a vision training method. Usually, several exercises are recurring in the different batteries.

Vision training batteries are developed by VTs and include exercises where the children need to move their eyes or focus on particular objects in the surrounding environment. These exercises can be as simple as following a pen back and forth, from left to right or up and down, or more complex, e.g., throwing a ball back and forth, working with puzzles, drawing through a maze using a pencil, jumping around on one leg or finding matching items in a pile [34]. Some of the exercises involve books, and others involve working with paper figures (see Figure 1).Some of the exercises require the participant to sit still, while others encourage full-body movement. Especially at the start many of the activities need help from an expert, being either a VT, or a vision therapist, but later may be complemented or replaced by the assistance from educated teachers or parents in the children's network. There is often a need for creating an individual training program and a personalized set of exercises depending on the diagnosed problem. Depending on the progress the training may also be changed by the experts.

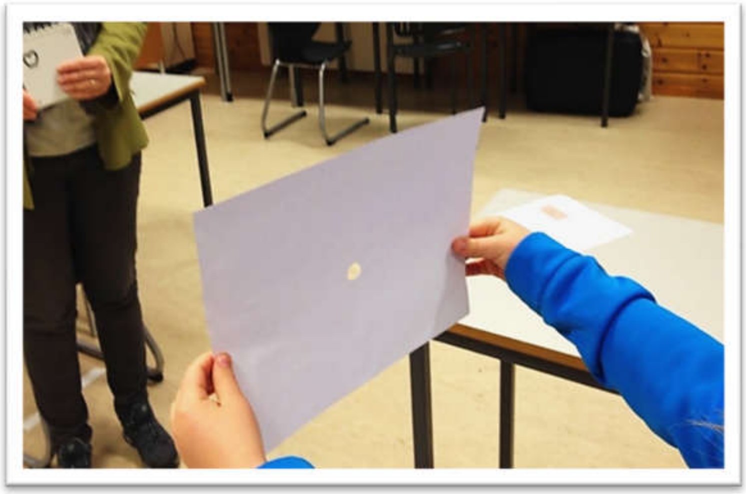


Figure 1. An exercise requiring papers (the child holds it) and pictures (in the hand of a VT) to examine distance eye dominance.

Expertise and planning is needed to design these exercises and make them attractive to children. Therefore, to define adequate training, creativity is an essential aspect VTs need to posses, besides having deep insight into vision problems. Motivating young children to perform repeated activities several times is not easy. Additionally, a VT needs to develop ideas for exercises to fit the individual's specific needs.Ensuring that movements are correctly performed, the VTs can use anaglyphs, lenses, septa, stereoscopes, computer programs, paper, pencil, and miscellaneous tasks in the office and home vision training sessions [35].

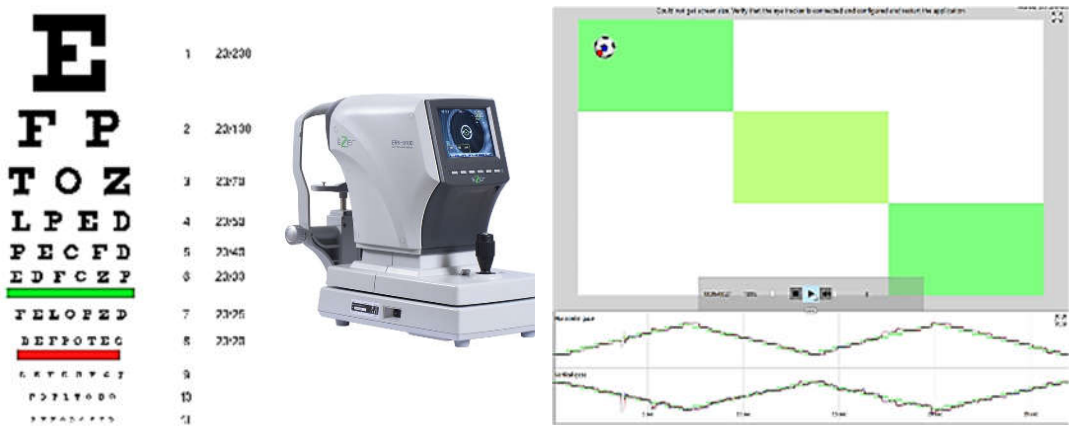
Many of the VTs do not have experience in using ET technologies today. Those who are familiar with computerized solutions are using e.g., using *Visagraph* (https://www.readingplus.com/visagraph/ (accessed on 14 April 2021)) and *ReadAlyzer* (Information of the recently improved ReadAlyzer 2K can be seen at https://www.compevo.se/ (accessed on 14 April 2021)) reading assessment kits for the vision assessment [36]. While considerable attention is on developing technologies supporting reading in general (see Figure 2a,b), the focus of this study is not on reading proficiency, but on connecting eye problems to several problems, such as reading.

2.2. The Role of Eye-Trackers in Vision Screening and Training

One method for studying eye movements is to track the point a user is looking at with ET technology (see Figure 2c). ETs are mainly used to determine the focus of visual attention on the screen or in the environment. An ET records the gaze position while the eyes are looking at a stimulus in real-time [35]. There are numerous ET applications used in research, many in marketing or evaluating the usability of interfaces [37–39].

ET technology has been a successful research tool used in the clinical settings for the diagnosis of patients in psychology, neurology, and ophthalmology [40]. It is widely used in clinical applications for diagnostic and screening purposes or to detect various disorders and home-based rehabilitative treatments [41]. Graphical representations on a screen can both be attention catching and can be followed by subjects who cannot read. Therefore, combining the use of ETs and graphical images with for instance SGs can be considered helpful methods to examine eye problems in youngsters [36,42].

In order to support screening OMD vision impairments, ETs need to be able to register the movements from the left and right eyes separately and correctly and examine these together with information from the environment. The environment is needed for references, e.g., knowing what one is looking at and for how long time, is important to determine visual attention. Figure 2 illustrates some conventional, instrumental, and software-based vision screening tools.



(**a**) (**b**) (**c**)

Figure 2. Different tools and software programs supporting vision screening: (**a**) Snellen chart [43] used for traditional vision screening; (**b**) Ezer (http://usophthalmic.com/Ezer-ERK-9100-Autorefractor-Keratometer (accessed on 14 April 2021)) autorefractor is an instrumental device used for measuring refractive error; (**c**) C&Look [44] is an ET based computer software for screening OMD.

There are efforts to make ETs small and affordable devices for this; at the present stage, there are no commercially available small devices, e.g., mobile phones or tablets, which can be calibrated well [45] or which can measure the left and the right eye movements separately. Similarly, algorithms for handling ET with good enough accuracy for measuring eye movements in immersive environments, e.g., for using HMDs, are complex [46]. Additionally, HMDs with good enough ETs are quite expensive. Therefore, rehabilitation exercises utilizing the entire space need to be improved for better supporting vision training. Todays' vision training is based on exercises using the surrounding space, with possibilities to be complemented by computer-supported exercises. The exercises are seldom connected directly to measuring eye movements. One of the overall goals of this study is to design and develop such exercises, i.e., to automatically follow and measure a child's eye movements when she is training her eyes.

ETs can detect and record eye movements following the point of gaze continuously. Figure 3 illustrates a picture from a video recording of a child following a frog via an ET and her left (blue) and right (red) eye gaze on the screen. Having the video recording and the eye positions from an ET, one can measure and visualize coordination problems between the left and right eyes.

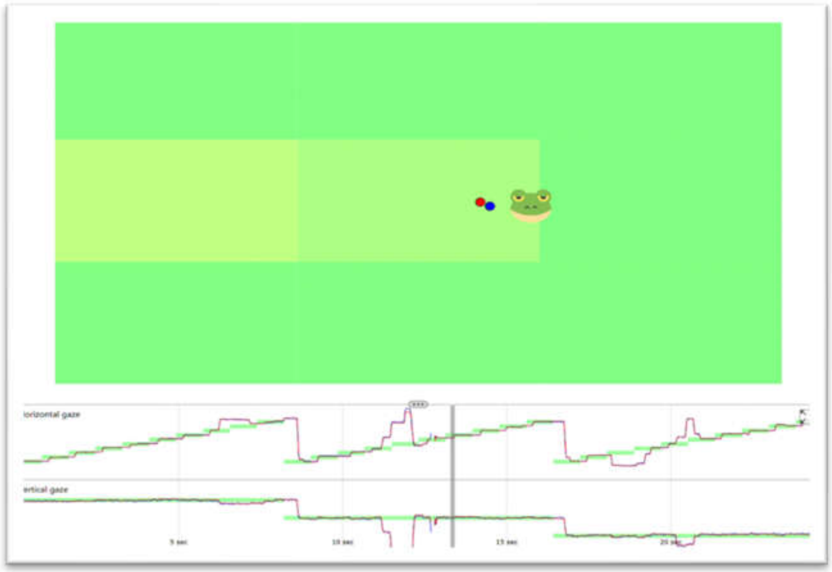


Figure 3. The video follows the frog's graphical representation on the screen superimposed by the representation of the eye gaze from the left and right eyes. The movement of the frog was from up to down (and from left to right). The two lines in the bottom show (problems with) smooth pursuit movements after 11–12 s.

Creating an associated program that can be used after the test to see the eye movements by visualizing these during the performance gives an opportunity to detect eye misalignment. Such programs are e.g., RightEyes program [47] or C&Look [48]. Figure 4 illustrates how the left and right eyes diverge for a child with OMD for saccadic problems in a left eye, during a given time. The left eye movement is visualized with the blue line and the right with the red line. The horizontal eye movements are visualized by the lines on the upper part and vertical movements on the lower part of Figure 4.

Figure 4. ET-based OMD examination program (via C&Look [48]) showing saccadic movements with left eye (vibrating) problems. The green line illustrates the "normal" area.

This work builds on the C&Look software for identifying (but not training) OMD problems [44,49]. The C&Look software uses visual tasks to stimulate the eyes of the participants and records their eye trace via an ET. The tracker records multiple metrics such as the Point of Gaze (POG), meaning the point on the screen where the participants' eyes are directed, fixations, saccades, and smooth pursuit. This data is then visualized by using plots so that the discrepancy between the left and right eyes can be examined and quantified, as is shown for saccadic vision problems in Figure 4.

The idea for this C&Look is based on the idea from an earlier, MS-DOS-based non-portable technology developed in the 1980s in Sweden. This MS-DOS-based technology is still in use by the center for special education in Oslo, Norway. C&Look was found equally good to recognize OMD problems as solutions using more expensive ETs by several classes of children [50] and the cheaper version it is used in follow up studies in Norway and Tanzania.

2.3. Serious Games and Other Technologies Supporting Vision Problems

Several SG-based training software offer improvements with increased motivation and high user experiences, especially for younger children [51]. Digitizing and gamifying the training and learning has several advantages: it makes it more motivating to perform exercises [52,53] which focus on learning basic, often boring things, e.g., methods in engineering [54], or allowing repeated training for increasing skills and competencies in handling emergency cases [55–57].

SG is used on several platforms and often incorporates new technologies. Examples are: using mobile technologies to allow learning outside of a classroom [53], ETs to steer and react to eye movements [13,36], hand-tracking to respond to hand gestures [58], or allowing more immersive experiences, e.g., via head-mounted displays [59] or augmented reality [60]. By recording and examining each movement, one can measure the progress in these games, often automatically and immediately.

SGs can support not only the identification or screening of eye problems, but also training.Current rehabilitation can be boring, due to the requirements to repeat simple movements many times. SGs are used for supporting children's vision training, especially for reading, e.g., via Lexplore [61]. Irazoka and his colleagues present a number of SG tools supporting mild cognitive impairments [62]. This review includes CogPack (http://markersoftware.com/USA/frames.htm (accessed on 15 April 2021)), a computer-based application supporting training, which influenced the programs developed in this study. It incorporates a large number of games, and according to our knowledge, this was one of the first games for vision training, developed in 1986 and still in use.

Other SG-based programs influencing this study are VisionBuilder (https://visionbuilder.com/login/ (accessed on 15 April 2021)), and ReadAlizer (https://www.compevo.se/ (accessed on 15 April 2021)). With VisionBuilder, a user can train saccades, recognition, word reading, stereo vision (with red/blue glasses), mainly to improve reading. ReadAlizer allows measuring reading progress and also promises to help reading. These methods and tools were also developed by including vision experts but are not directly connected to recognizing and treating OMD problems.

Recently, there are some new ET-based solutions available in the market for vision screening or vision therapy e.g., RightEye (https://righteye.com/ (accessed on 15 April 2021)), Clinical eye tracker by Thomson Software Solutions (https://www.thomson-software-solutions.com/clinical-eye-tracker/ (accessed on 15 April 2021)), or Vivid Vision (https://www.seevividly.com/ (accessed on 15 April 2021)). These are expensive solutions for commercial purposes, mainly for clinicians. Vision therapists often use the Computer Orthoptics liquid crystal system to train for vergence, oculomotor skills, and accommodative eye movements [63]. However, this system is an office-based-solution that must be used under the supervision of vision therapists.

3. Study Design

3.1. Methodology

Developing a new and innovative artifact incorporating a number of SGs used for health purposes needs a number of quantitative and qualitative approaches [64]. For this study, the qualitative methods are inspired by the Grounded Design approach defined by Rohde and his colleagues [15], having its roots in Participatory Design [65] and Action Research [66,67]. Grounded Design is applied in case studies for reconstructing "social practices observed before and during the design and appropriation of innovative IT artifacts" (p. 163, [15]). The quantitative method is by adopting the user experience evaluation questionnaire (UEQ) from Schrepp et al. [16].

To design and develop supportive technologies facilitating change processes, i.e., from physical training to SG supported training, involves VTs and computer scientists. Understanding the current situations, suggesting changes, and testing these requires interdisciplinary work. According to the Grounded Design traditions, we consider three important steps.followed by The three steps are:

Step 1. Determining which training can be supported by technologies and how (called pre-study or context study by Rohde et al. [14]). This means finding necessary information about the current vision training (defining the main requirements for the physical vision training today) and which activities can or need to be supported.

Step 2. Finding appropriate prototypes for this support (called working on the artefact by Rohde et al. [14]). This means suggesting changes for practice (through finding and suggesting design solutions for SGs) and improving these (in laboratory settings).

Step 3. Feasibility study—the examination of the appropriateness of the prototypes for actual practices (the part working with the artefact towards building the knowledge based by Rohde et al. [14]). This means esting the prototypes and determining needs and possibilities for the practice in the field. This last part includes a user experience evaluation [15]

The first two steps are based on data from participatory observation during several meetings. Data in the last step are coming from interviews and usability evaluation.

Step 1 was performed during a number of meetings between three VTs and five computer scientists and identified the main eye-movements needed to be trained for OMD problems and discussed if and how SGs could support eye movement for training. For this, the suitability of some earlier games and new existing games were also examined (see Section 4.1.).

Step 2 included meetings identifying and improving the six games chosen to support training through four iterations and involved the same three VTs and computer scientists. Each iteration was evaluated by at least one of the three VTs and five computer graphics and games experts. The computer experts involved had earlier experiences from developing the ET-based program, *C&Look* for vision screening [48].

Step 3 presented the evaluation of the final prototype. The results came from a Background Questionnaire (BQ), and user experience questionnaire (UEQ) from [16], and was used to measure user acceptance (data from semistructured interviews). Data came from five VT MSc students in Special Education, with earlier experience in teaching and also in screening and training OMD from their current education (see Section 4.3.). The data was collected right after the VT students supported 30 children's vision training, a three-week long training period, without computer-supported training. All the VT students tested the games with technical assistance from a computer scientist (who also participated in Step 1 and Step 2).

The three VTs contributing to finding or designing and developing the games were VTs with several years of experience in their professional area, including using ETs in Norway. The five VT students evaluating the games for training were MSc students in Special Education from Tanzania. Only one of these five students had used ET technology before the evaluation of the games. They filled in the BQ and UEQ by themselves and answered the semistructured interview with questions and discussions about the games' applicability and possible improvements. All participants were female and aged between 30–55.

3.2. Materials

Most of the technologies supporting vision training today are not easily portable, affordable or accessible for children. To keep the prototype portable, the hardware used in the development and testing of this system was a Lenovo Thinkpad T460S Ultrabook™ with a 2.40 GHz Intel Core™ i5 processor, 16 GB of RAM, and a 14-inch multitouch widescreen.

The ET was an EyeX (http://tobiigaming.com/product/tobii-eyex/ (accessed on 15 April 2021)) with a sampling rate of 60 Hz developed by Tobii (https://www.tobii.com/ (accessed on 15April 2021)), a low-cost commercially available ET (that costs approximately 250$) that can be used with most commercial laptops. Examples of similar products currently available are laptops with integrated eye-tracking from Acer, Dell, or MSI.

The games were developed in the Unity (https://unity.com/ (much is based on http://response.unity3d.com/games-by-the-numbers-q2-2016-report, accessed on 15 April 2021)) game engine using the programming language C#, and applying the EyeX and the C# "Gaze API" provided by Tobii. Unity also features out-of-the-box physics, making it easy to create 2D or 3D objects that act naturally in the applied environment. Since the OMD training application consists of several small games, there is essentially one application for each game connected through Unity's scene management, allowing the user to transition between games smoothly.

Before usage, the eye tracker had to be calibrated to fit a user's head and eyes. This calibration was implemented in the application through the Gaze API. A user calibrated her eyes by looking at three points for 2 s, one after the other. After a point disappeared, the calibration was performed for that specific area. The calibration time lasted a few minutes (3–5 min). The interaction with the games was performed using eye gaze and pushing some keys on the keyboard.

4. Results

4.1. How Can Children with OMD Train Their Eyes Eoday? (Step 1)

There is no generally accepted set of guidelines supporting training programs for children who struggle with OMD.

The most commonly recognized eye motoric challenges (also described in Section 2), the activities they trigger and the physical exercises needed to perform the challenge are described in Table 1, which was built on the suggestion from a vision teacher included in our group [34]. The first three columns in the table illustrate the identified important movements the trainee needs to perform with her eyes to strengthen her visual abilities.The exercises seen in Table 1 are all broad in the sense that one can train more than just one specific ocular muscle movement with each exercise. For example, practicing "Searching/scanning" may train both fixations, endurance, saccades, and mini saccades, depending on how the exercise is performed. Since elements in the vision system are interconnected, one challenge has multiple terms connected to it and several exercises. However, it is necessary to be aware of the fact that children can be stressed and exhausted, and a trainee can also be overloaded if this is done without professional competenceVisual efficiency disorders are classified into accommodative disorders, binocular vision disorders, amblyopia, and ocular motility disorders [68]. Ocular motility disorders are problems with eye movements such as fixations, saccades, and smooth pursuit [69]. After this identification, the primary mission was to choose games that systematically trigger eye movements to perform exercises needed to support the ocular motor activities from Table 1.

Table 1. Training of eye motoric challenges by activities with different exercises.

Challenge	Ocular Motor Activities	Exercises
Field of view	Saccades Visual attention Regression	Horizontal movements Vertical movements Diagonal movements Circular movements
Visual acuity	Fixations Endurance Saccades Mini saccades	Searching/scanning Find objects in a crowd Horizontal movements Vertical movements Diagonal movements Circular movements Smooth pursuit Find pairs/similarities Trace the eyes through a labyrint
Stereopsis	Accommodations Convergence Double vision	Movements and flashes at a distance—different depths Objects that varies in size
Eye-hand coordination		Use the mouse or keyboard-based on events on the screen, and vice versa.

Since "Field of vision" and "Visual acuity" are broad fields, different games were required to complement each other to cover all movements which need to be performed during the training.

Stereopsis was not a priority in this game because it is hard to simulate animations that could complement accommodations or convergence eye movements on a computer screen. This could be addressed in a future version using an HMD device with integrated eye and hand tracking.

4.2. Finding, Designing, Developing, and Adjusting Games (Step 2)

4.2.1. Earlier Programs Influencing This Study

Several existing games were investigated to design games for the required exercises (see column 3 from Table 1). These were, first of all, games available from Tobii, or VisionBuilder (mentioned earlier). Cocos2D (http://cocos2d.org/ (accessed on 15 April 2021)) was also considered for this project. However, he code was considered out of date and therefore hard to maintain and develop further. The main problem with Cocos2D was its lack of information about integrating other softwares, and the fact that it had a less comprehensive graphical workflow can make the development process slower. While Tobii provides a low-level C++ SDK that was easier used with Tobii's ET, this was chosen for this project. The games available and possible from Cocos2D but without ET support were also considered more advanced than necessary for this project, having the baseline the games from CogPack.

As we pointed out earlier, there are some existing computer-based applications supporting training. The games that most influenced the development are within the package of 64 games offered by CoGPack. Examining these existing games and having the requirements for exercises presented in Table 1, the VTs identified some more needs the new games should satisfy for covering OMD problems of different severities:

- high screen contrasts,
- usable for color-blind people,
- possible to control object speed by eyes, and
- possible to change the background color(s).

During the four iterations of development, several other properties of the graphical interfaces were discussed with designers and vision teachers. Examples are:

- the possibility to use on-screen documents
- have challenging and adjustable-sized images for different vision impairements
- that both video and audio should be supported (important for reading)
- that both 2D and 3D graphics should be supported.

Younger children who cannot read can be screened and trained by using graphical images and adjusting its sizes to fit individual problems. These requirements are coming from lessons from experiences from an earlier version of ReadAlizer that could only be used for children who could read texts. The VT's believed in using more graphics, except 3D graphics, at this stage. Several of the identified properties were implemented during the development. After examining additional games, including the ones available through the eye-tracker providers, and CogPack six games (presented in the next Section) were chosen for this study.

4.2.2. Games Triggering Desired Eye Movements

The games were designed and improved based on Table 1 to cover most of the necessary ocular motor activities. Improvement on game design, such as adjusting representations, speed, colors, levels and time to play, were done through four iterations. The software and graphics were improved based on the VTs' experiences regarding images, colors, and movements. First of all, these requirements were adjusted to fit a child's capabilities with a medium-level OMD problem, which is not necessarily an observable vision impairment. These improvements were made during four meetings with programmers and VTs.

The reason for adjusting the settings in each game, e.g., the size, colors, and type of the letters, objects sizes, their spedd and visibility on the screen, number of focus points, was to connect the game difficulty level to the children's capability and considering her vision imediments. The levels must fit each child's problem and it must be possible to adjust the difficulty in games as children learn, or as their vision capabilities improve. Before evaluating the functional prototypes, the three VTs mapped the games' challenges and activities to the challenges identified for physical training described in the first and second columns of Table 1.

4.2.3. The Games

Game 1: Compare words

In this game, the user has to look at two similar words and find (and mark) if these words are identical or different. It is inspired by one of the games in CogPack. To identify differences, the user must perform saccades between the words and micro-saccades while studying the single words. The exercise trains both reading, big saccades, and the brain's ability to identify the content. The games can be adjusted with respect to the difficulty of the words, the letter sizes, colors, the language, and the game duration. The number of correct choices for recognizing the same and different words can be seen in the left corner (see Figure 5a).

Game 2: Maze

The second game's goal is to allow the user to navigate through a maze back and forth with her own gaze without hitting the maze walls (see Figure 5b). After every successful navigation, the user earns one point. The educators could spot the difference in gaze position between the right and the left eyes during the game. This game trains the smooth pursuit, i.e., the ability to follow a path with the gaze and keeps the attention on the road while avoiding obstacles.

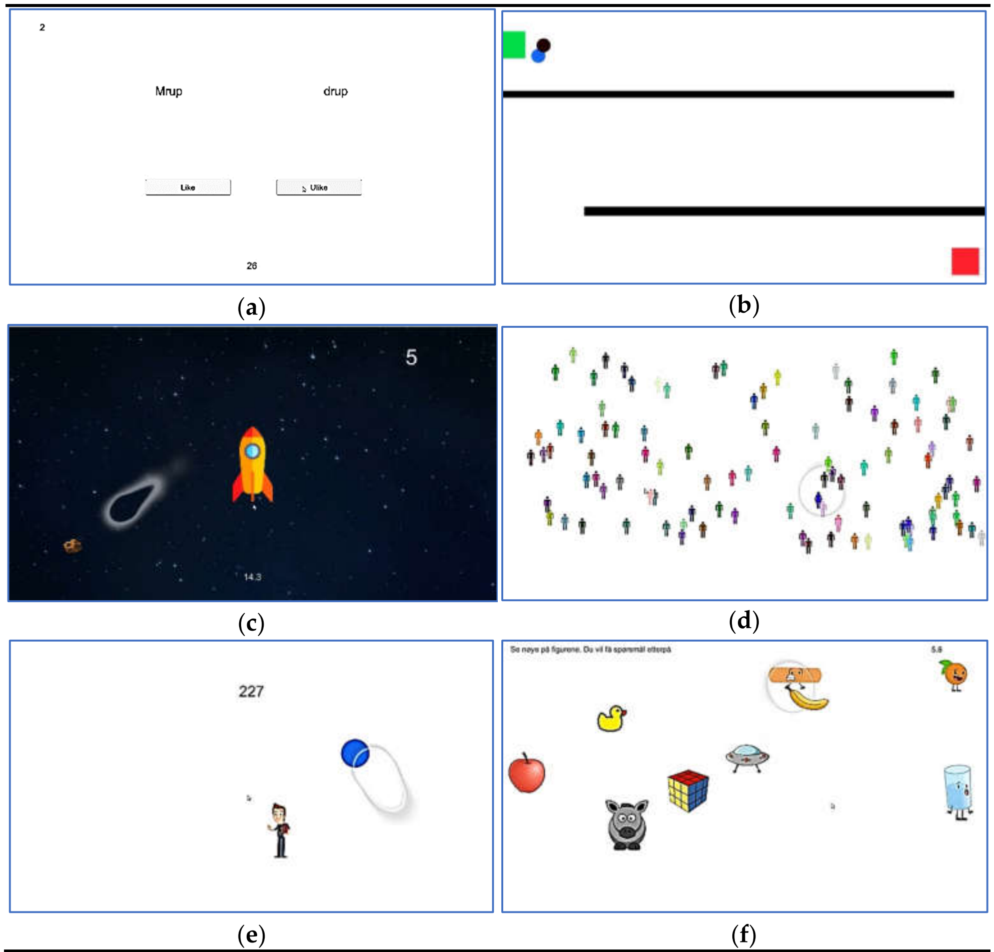


Figure 5. Screenshots from the games: (**a**) Compare words, with the number of correct choices in the top left corner; (**b**) Maze; (**c**) Save the rocket; (**d**) Find the outstanding object; (**e**) Follow the ball; (**f**) Which one is missing?

Game 3: Save the rocket

In this game, a user needs to save a rocket located in the center of the screen from meteors (see Figure 5c). The meteors fly in from the edge of the screen and are eliminated by fixing the gaze at it. If any meteor hits the rocket before the time runs out, the user has failed. The supervisor can set the difficulty level by adjusting the game duration, the number of meteors, and their speed. This game is chosen for training visual attention and continuous performance of saccades.

Game 4: Find the outstanding object

The fourth game includes several objects on the screen, and one of them is different from the others (see Figure 5d). The goal is to find this object and fix the gaze at it for a couple of seconds. This game is much like the game Where is Waldo, with ET input. In this game, it is possible to change the difficulty level by changing the number of distractor objects. It is also possible to choose the types of figures that are shown. The game counts how many seconds the user needed to find the object. Like the game from Figure 5c, this game also trains visual attention. The difference is that the stress level of the environment can be varied by the number of distractions, and also by giving the user more or less time to think and process all the presented objects. The user must continuously perform saccades to move their gaze between the objects, and fixations for analyzing a specific one.

Besides, the user needs to utilize the peripheral vision to find interesting areas to look towards.

Game 5: Follow the ball

In this game, the user needs to follow a ball that moves smoothly across the screen (see Figure 5e). When the user's gaze is pointed at the object, the score increases. Distractions appear at random places on the screen, but the user should ignore that and keep looking at the chosen moving object. This game runs until a defined number of points is gained. It trains smooth pursuit movement and the ability to control the fixation during distractions.

Game 6: Which one is missing?

The last game is a memory game where the user looks at several objects in the first screen. In the next screen, one of theobjects is missing. Then the user must find and pick with their gaze the extra object in the second screen (see Figure 5f for a first screen). When the missing object is found, the user must move it onto a square using their gaze, and press the space button to release it. If this object was the correct one, the level is completed. This game trains visual memory, visual attention, and saccades. When the user is looking at the various objects, the eyes are continually performing saccades.

4.2.4. Connecting the Games to Necessary Eye Movements

Figure 5 presents the last iteration (for a typical screenshot) of the games. They were chosen from a large number of games [70] fulfilling these criteria: suitable for training, possible to use them on portable devices (laptops), suitable for use by affordable eye trackers.. The main criterion was that they would be suitable for training for OMD children.

Table 2 includes the rationale behind the games via the correspondence between Column 2 (what has to be trained) and Column 3 (via which eye movements), and Column 4 (what are the games triggering these eye movements). These correspondences were discussed and games were selected during several meetings with the three VTs involved in the design during a 3–4 month long period, approximately for 1–2 h long meetings with at least one VT involved per week.

Table 2. Training of eye motoric challenges by activities with different exercises. The last column (Game) is for Step 2, synthetizing the opinions of VTs, e.g., which games are complementing the challenge and ocular motor activities. See game numbering in Figure 5.

Challenge	Ocular Motor Activities	Exercises	Game No
Field of view	Saccades Visual attention Regression	Horizontal movements	1, 2, 3, 4, 6
		Vertical movements	2, 3, 4, 6
		Diagonal movements	2, 3, 4, 6
		Circular movements	3, 4
Visual acuity	Fixations Endurance Saccades Mini saccades	Searching/scanning	4, 6
		Find objects in a crowd	4
		Horizontal movements	1, 2, 3, 4, 6
		Vertical movements	2, 3, 4, 6
		Diagonal movements	2, 3, 4, 6
		Circular movements	3, 4
		Smooth pursuit	5
		Find pairs/similarities	1
		Labyrinths point to point	2
Stereopsis	Accommodations Convergence Double vision	Movements and flashes at a distance—different depths Objects that varies in size	None
Eye-hand coordination		Use the mouse or keyboard-based on events on the screen, and vice versa.	1, 6

4.3. Evaluating the Feasibility of SG Prototypes for Vision Training (Step 3)

4.3.1. Results from the User Experience Questionnaire (UEQ)

Table 3 presents the UEQ, with in total 25 aspects to rate. These are examining different aspects of the game ranked from 1 to 7 based on their experience, where 1 was the lowest (most negative), and 7 was the best (most positive) [17]. The respondents were told to put a cross in the circle that represented their answer.

Table 3. Answers for the UEQ for all games. The evaluation is done after playing the games.

	1	2	3	4	5	6	7		Mean
annoying	○	○	○	○	●	○	○	enjoyable	5.25
not understandable	○	○	○	●	○	○	○	understandable	3.75
dull	○	○	○	●	○	○	○	creative	4
difficult to learn	○	○	○	●	○	○	○	easy to learn	4.5
inferior	○	○	○	○	●	○	○	valuable	5.34
boring	○	○	○	○	○	●	○	exciting	5.5
not interesting	○	○	○	○	●	○	○	interesting	5.25
unpredictable	○	○	○	○	●	○	○	predictable	4.75
fast	○	○	○	●	○	○	○	slow	3.5
inventive	○	○	○	●	○	○	○	conventional	4
obstructive	○	○	○	○	○	●	○	supportive	5.5
bad	○	○	○	○	○	●	○	good	5.75
complicated	○	○	○	●	○	○	○	easy	4.25
unlikable	○	○	○	○	●	○	○	pleasing	5.25
usual	○	○	○	●	○	○	○	leading-edge	4
unpleasant	○	○	○	○	○	●	○	pleasant	6.75
not secure	○	○	○	○	○	●	○	secure	6
demotivating	○	○	○	○	●	○	○	motivating	5.5
does not meet expectations	○	○	○	○	●	○	○	meets expectations	5.25
inefficient	○	○	○	○	○	●	○	efficient	5.75
confusing	○	○	○	●	○	○	○	clear	4
impractical	○	○	○	○	○	●	○	practical	5.75
cluttered	○	○	○	○	○	●	○	organized	5.75
unattractive	○	○	○	○	○	●	○	attractive	5.75
unfriendly	○	○	○	○	○	●	○	friendly	5.75

The questions are grouped in three groups and evaluated via four questions for each property:

1. attractiveness
    - via enjoyable, good, pleasing, pleasant, attractive, and friendly.
2. design quality
    - via stimulation, valuable, exiting, interesting, motivating,
    - via novelty, creative, inventive, leading-edge, innovative.
3. use quality
    - via efficiency, fast, efficient, practical, organized,
    - via perspicuity, understandable, easy to learn, easy, clear,
    - via dependability, predictable, supportive, secure, meets expectations.

The results mirror some of the actual situations, i.e., that the attractiveness of the games is appreciated. While the innovativeness or certain design aspects are not appreciated equally high, the use quality is recognized.

It is challenging to run statistics based on only five participants, so responses have to be treated carefully.

4.3.2. Answers After Semistructured Interviews

The VT students' first impressions of the games were positive. Answering the question if they would like to use it in their daily work, all, except one, answered yes. The motivation for the "no" was that the game is "*not self-instructing today*." Those who wish to use it also expressed their wishes to have time to find out more about how the games complement the training.

Opinions on using games to support vision training

Answering the question "What would make use of games more supportive", two VTs expressed their wish "*to have some instructions from the beginning, both for the trainee and the instructor*."

Discussing opinions for trainees versus instructors, the VTs expressed that the games are "*good for the kids, and they can better understand them* [than instructions for physical exercises, in general]."

One expressed her wish to be able to better adjust the levels in the games to the participants, their age, preferences, and vision impairment. Some games were quite hard to follow, even for those with not severe OMD (Game 2, the Maze, and Game 6, Which one is missing).

VTs expressed their wish to better understand games and their concrete benefit for OMD training. They wished to have some categorization or interface helping the teachers choose and adjust the right games for the expected treatment. An example of this was Game 5 (Follow the ball), as one of the participants noted: "[While this would be a] *good exercise for smooth pursuit movement, it is not completely clear. Maybe you can make different levels of difficulty with different speeds and sizes or colors of the ball? Unsure about the usefulness of the appearing person. Is it actually for concentration or the vision* [attention]*?*"

General usability

The participants estimated all games as usable in relation to the general usability of objects on the screen (information placement, sizes, colors, etc.). Still, they suggested improvements, especially for Game 2 (the Maze).

They commented on the colors, the speed, and the way that one can progress in the games. For representing the results on the screen, i.e., for Game 3 "Save the rocket", they believed the number illustrating the scores takes too much attention. Perhaps a number showing the time spent with the game might be useful.

Only one of the VT students thought that training with ET-based games could replace physical vision training today, but all participants believe that games have an important place in training and rehabilitation and have a great potential to complement VTs work. The special pedagogy education they follow does not include computer courses, but they think they would manage to handle the games after an easy setup. They do not express any doubts that trainees can learn the games easily, but they could not imagine, at the present state, how trainees could use it by themselves at the beginning.

The VTs like games without many objects on the screen, and they wished to have more contrast. As a VT student expressed, "*For me, it was too low contrasts, even with the calibration dots in the beginning. These should also be bigger*."

Concerning the screen size (playing the games on laptop computers), they believe that a larger screen can allow much more training. However, they also wished to have such supporting games on mobile phones in the future.

Overall experiences of possible use and improvements of the game

Game 1 (Word differences) was quite outdated, similar to one of the games from CogPack, but "*a good exercise for left-right saccades and fast reading*." Some further development suggestions were to make the game run for x words instead of x seconds and count seconds instead. This would be a better way to track progress. It should also be possible to choose the words' background and position to cover up-down and diagonal saccades.

Game 2 (Maze) was too hard and should be made much easier by making the walls shorter with a longer distance. Apart from that, the game is a good way of training to navigate the eyes through a road avoiding obstacles. One feature that was discussed in this game was initially a bug; when one eye is closed, the user could use the other eye to push the ball through the maze. This could have been a fun element and a new challenge to implement. In this game, it would be good that the VT could see the position of the user's eyes at all times. This may also contribute to the detection of problems during the training.

Game 3 (Save the rocket) This game is very similar to another CogPack game where the user should eliminate incoming shots in a box. The new thing here is that this game features ET and has better graphics. One way of improving this game could be to give a different amount of points per exploding meteor according to how far away from the rocket the meteor is. This would encourage more "searching" and less waiting in the middle. The game could also feature different types of elements instead of only a rocket and meteors, or the contrasts could vary. Apart from that, the game is considered supportive for training saccades and for visual attention by forcing the user to search around the screen. Another suggested improvement regarding these games was to apply a touch screen, where the user had to touch the meteors to eliminate them and examine eye-hand coordination.

Game 4 (Find the outstanding object) could be a replacement for different types of books used in training today. It is very straightforward and fits people of all ages. The game trains saccades between objects as intended, both left-right, up-down, and diagonal. For improvement, it would be nice to be able to choose where in the screen the objects should appear, the spread, and adjust the levels for possible improvements.

Game 5 (Follow the ball) should have more settings. One way is for instance to remove the distraction for the easy levels and maybe add more distractions for the harder levels. One could also vary the size of the ball according to the level of difficulty. The ball could also have a more defined movement. Instead of the current solution, the progress could be measured by the number of points achieved during a limited time. Apart from this, the game is good training for smooth pursuit movements.

Game 6 (Which one is missing?) This game was experienced as too difficult because many objects need to be remembered. It should be possible to choose the level of difficulty and maybe have increasing difficulty for each round. In this game, the space bar is used to pick up items. Maybe blinking to pick up objects can contribute to another layer of difficulty? The game is good training for visual memory and saccades and could be used in training.

Overall experiences of the games

The VT students were enthusiastic, liked the games, and stated that they were better than existing computerized solutions, but that at the present stage, they cannot fully replace expert-assisted physical training. The main reasons are the limited size of computer screens for peripheral vision training and the lack of possibilities to support depth-training. This was true for all the games. Another reason is the missing overview to see the effect of the training effect, or exactly what is happening during a game, e.g., the visual information on the screen and the eye movements associated with some measures about the movements. Two of the VT students noted that it would be interesting to look at different methods to make the game experience even more enjoyable as some of the exercises were somewhat monotonous.

5. Discussion and Future Work

Vision training, as most training for rehabilitation purposes, takes time. With a large number of trainees, which there are according to the statistics [3,27], it would be essential if a part of this training could be performed without using more expert resources than necessary. However, it is a long way ahead to substantial digitally assisted training, and expert participation is still critical. There are also hypotheses that schools and general teachers could help and take a more significant role in such training [4,12,13]. At the present moment, the VTs role is also essential. They need to determine the training process and design improvement goals; however, it is not necessarily that they need to support the entire rehabilitation process.

This study investigated the feasibility of SG prototypes. On the way to develop a working product, several aspects can be considered, but probably the most important is to define enablers for utilizing the technologies. In the following parts it is discussed how this can be possible in a more general term.

5.1. Understanding the whole process via interventions and rehabilitation

Today screening and training are separate activities, which may be connected to enable children-centric vision care. For helping children with OMD problems many of the actors involved in screening and training are the same, but there are also separate actors, and they should know about the data that are related to the whole process. Ultimately, it would be valuable to contribute to creating tools that foster more children-centric vision care, where much of the training activities could be performed at home, and e.g., progress could be followed by experts.

Screening may also benefit from game-based methods, as this activity is often perceived as boring for children in clinical settings [46], and some children find it hard to sit still during screening. If the screening process could be made more interesting by applying more game elements, this could improve data quality and make screening more accessible. The software also needs to be further developed to better illustrate the connections between exercises, the functional vision, and the effect of training.

5.2. Supporting technologies: Understand what to complement and how

The sensemaking process (*Step 1* and *Step 2* for understanding rehabilitation goals and methods and technologies) is crucial for knowledgeable vision experts to understand technologies' possibilities and define basic requirements for developing technologies. The cooperation with the vision expertise during the development of the game was highly appreciated. Eventually, this shared understanding can be supported by process steering instruments, e.g., Design Thinking.

As we pointed out earlier, a critical aspect is to investigate to what extent game-based training can complement the current training methods. Since depth vision in games is not possible at the present stage, and peripheral vision is limited in the present games, these training exercises have to be supported by physical exercises. With the development of immersive technologies and applications, such training may be possible. There can be better possibilities to use HMDs for short and long-distance or peripheral vision training. However, for this the HMD technology and handling graphics in HMDs also needs to be improved. However, there are already some examples. Nowak and his colleagues [44] showed the potential of using HoloLens (a see-through HMD using physical space and virtual images) for the rehabilitation of amblyopia (lazy eye) in children, and Ziak et al. [45] used HMD's for adults.

5.3. Enablers (for using technologies)—are not necessarily the users

One of the main benefits of starting this project was realizing that the enablers for using the technologies are vision experts. Their opinions is not only important for their expertise with handling vision difficulties but also their willingness and competencies for handling the technologies.Their user experiences may differ from the end-user's (the children's) wishes for games but necessary fo accepting the games for rehabilitation tools. The evaluation with children will probably determine more requirements on game challenges, attractive images, and ways to increase user experiences and presence to sit in front of a computer and train their eyes.

5.4. Possibilities for developing future games

Since literature demonstrates that positive results can be achieved already after 3–6 week vision training, different new possibilities to make this training need to be investigated. One option is to understand whether it is possible to perform parts of the training alone or be supported by nonprofessionals, and also better understand the role of the professionals and how they can be involved.

Vision screening using ET produces *measurable*, objective results and is a valuable tool for identifying OMD. When training is performed, this method can also be used to evaluate progress. Today screening and training are separate activities and are done by using screening and training software packages separately. However, by integrating evaluation into the games-based training software, using ET technology, it is possible to create training software where the user may perform training and assess progress, potentially without continuous professional support and supervision (see above). At the very first step we develop measurement methods for the necessary aspects from Tables 1 and 2 regarding OMD activities for the suggested games.

Having an OMD screening program in the background will allow measuring the progress automatically and immediately. We have made use of affordable ET hardware, and our goal is to make the software open source. This contrasts with existing computerized solutions for OMD, which to our knowledge, uses proprietary software and expensive ET hardware. One of the main motivations behind this is the intention to make the programs usable for many. The possibilities to access data from many users mean that AI algorithms can identify and develop more supportive training solutions.

6. Conclusions

This project has shown the design of a prototype system for vision training with three VTs, which has been tested by five other VT students, evaluating several aspects of its quality and usefulness with the main qualities to trigger the same eye movements as the necessary eye movements with today's non computer supported vision training.

By this the study shows the possibility of integrating computer games into the vision rehabilitation process from the VTs perspective, by considering concrete rehabilitation goals and designing games to find measurable aspects supporting training and training fulfillment. Based on guidelines for creating a training program for children who struggle with OMD, we have created a collection of exercises based movements implemented in six computer games and evaluated them by Norwegian and Tanzanian vision experts and found and presented a number of issues needed to be taken in consideration for further development and acceptability for supporting rehabilitation.

Another benefit of this study can be the interdisciplinary approach it follows. While several stakeholders from different domains are involved in developing games for rehabilitation, this is a long and complex process, requiring intense collaboration for translating goals from one domain into goals in another domain. While the results are only partial, they have to be discussed within the scientific community. For this process, we consider Grounded Design helpful.

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