IMPROVING THE SIGHT EFFICIENCY OF VISUALLY IMPAIRED PEOPLE WITH GAMES THAT CAN BE PLAYED WITH MOTION CAPTURE SYSTEMS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF INFORMATICS
OF
THE MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF GAME TECHNOLOGIES

DECEMBER 2014

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this wok.

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ABSTRACT

IMPROVING THE SIGHT EFFICIENCY OF VISUALLY IMPAIRED PEOPLE WITH GAMES THAT CAN BE PLAYED WITH MOTION CAPTURE SYSTEMS

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December 2014, 48 pages

This thesis researches whether the life skills and eye-body coordination of the visually impaired children can be improved through the use of video games which use motion capture system as input. It also researches what kind of video games can be developed and how they can be used in order to provide benefit to visually impaired children. This study was conducted as a mix of qualitative and quantitative studies. It was carried out in six phases. In the first phase, the psychomotor development areas of the visually impaired children were listed and discussed in a meeting. In the second phase a game prototype was developed based on input from the first phase. The meeting in which the prototype was discussed formed the third phase. In the fourth phase, three additional games were developed that addressed the issues that were found in the prototype. Next one was the experiment phase, which was conducted with five visually impaired children and four games. Children were observed while playing those games and their reactions were noted. Their scores and in game actions were recorded using the tools that were embedded in the games. In the sixth phase, results were reviewed and presented. Our findings indicate that games that can be played with motion capture systems could be important rehabilitation tools for the low vision. Results, limitations and future work were discussed and a list of specifications on how to design games for the visually impaired is provided.

Keywords: Visually Impaired, Games, Motion Capture, Kinect

ÖZ

HAREKET ALGILAMA SİSTEMLERİ İLE OYNANABİLEN OYUNLAR ARACILIĞIYLA GÖRME ENGELLİ BİREYLERİN GÖRÜŞ ETKİNLİKLERİNİN GELİŞTİRİLMESİ

Konya, Oğuz
Yüksek Lisans, Oyun Teknolojileri Bölümü
Tez Yöneticisi: Prof. Dr. Kürşat Çağıltay

Aralık 2014, 48 sayfa

Bu çalışma, görme engelli çocukların yaşam becerilerinin ve göz-vücut koordinasyonlarının hareket algılama teknolojisi kullanan oyunlar ile arttırılıp arttırılamayacağını incelemektedir. Bu çalışmada aynı zamanda hangi tür oyunların geliştirilebileceği ve bunların görme engelli çocukların yararına nasıl kullanılabileceği araştırılmaktadır. Bu çalışma nicel ve nitel çalışmaların bir karışımı olarak altı aşamada yürütülmüştür. İlk aşamada çalışmanın danışmanlarıyla psikomotor gelişim alanları listelenmiştir ve bu listeler üzerinde tartışmalar yapılmıştır. İkinci aşamada bu tartışmalar üzerinden bir oyun prototipi geliştirilmiştir. Prototipin tartışıldığı toplantı üçüncü aşamayı oluşturmaktadır. Dördüncü aşamada, prototip oyunda bulunan eksiklikleri giderecek şekilde üç oyun daha geliştirilmiştir. Bir sonraki aşamada beş görme engelli çocuk ve dört oyunla bir deney yürütülmüştür. Altıncı aşamada deney sonuçları incelenmiş ve sunulmuştur. Deneyin sonuçları hareket algılama sistemleri ile oynanabilen oyunların görme engelliler için önemli bir rehabilitasyon aracı olabileceğini göstermektedir. Çalışmanın sonunda sonuçlar, kısıtlamalar ve ileride yapılabilecek çalışmalar tartışılmış, görme engelliler için oyun geliştirmede izlenmesi gerekebilecek kurallar listelenmiştir.

Keywords: Görme Engelli, Oyunlar, Hareket Yakalama, Kinect

ACKNOWLEDGMENTS

I express sincere appreciation to Prof. Dr. Kürşat Çağıltay for his guidance, his patience and insight throughout the research. I would like to thank Prof. Dr. Veysi İşler and Assist. Prof. Dr Hüseyin Hacıhabiboğlu for the Game Technologies program and the great experience that comes with it. The technical and educational assist of Turan Delimehmetoğlu is gratefully acknowledged. Thanks go to Gönül Turgut Special Education and Consultancy Center and its dedicated instructors, Mrs. Gönül Turgut, and Mr. Kemal Binici. My special thanks are extended to the brave children who participated in the experiments of this research. I would like to express my deep gratitude to my wife Ekin, for her endless support and her faith in me.

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CHAPTER 1

INTRODUCTION

Blindness is the health condition of decreased visual capacity. There are many different types of blindness. World Health Organization (WHO) defines visual function as follows:

> “There are 4 levels of visual function, according to the International Classification of Diseases -10 (Update and Revision 2006):
>
> - normal vision
> - moderate visual impairment
> - severe visual impairment
> - blindness.
>
> Moderate visual impairment combined with severe visual impairment are grouped under the term *“low vision”*: low vision taken together with blindness represents all visual impairment. [1]”

In their report of “The Prevention of Blindness”, the WHO Study Group defined categories of blindness and in this report, the visual acuity between < 0.05 and no light perception is suggest to be defined as blindness [2]. International Classification of Diseases -10 (ICD-10) defines blindness as suggested by the WHO Study Group [3]. In respect to WHO’s definition, International Council of Ophthalmology (ICO) agrees that blindness refers to a total vision loss and the term of low vision is “to be used for lesser degrees of vision loss” [4].

Although the term of blindness is used to describe a severe vision loss in common, according to these definitions, it actually should be referred to a complete lack of light perception, a condition where a person cannot even tell whether there is a light source nearby or not. On the other hand, people diagnosed with low vision are able to differentiate dark from light and can point a light source. ICD-10 defines low vision as the visual acuity between < 0.3 and >= 0.05 [3]. In this study, the term “blind” and “low vision” will be used interchangeably, however the intended meaning will always be low vision, the target audience of this study.

Eye disorders such as myopia, hyperopia, astigmatism, cataract, albinism or glaucoma can cause visual impairments as well as brain or nerve disorders [1]. According to WHO, major causes of blindness are uncorrected refractive errors (43%), unoperated cataract (33%) and glaucoma (2%) and it is estimated that 285 million of the world's population are visually impaired. While 39 million of them are blind, the remaining 246 million have low vision [1]. Of the 285 million visually impaired, 19 million are children and 1.4 million of these children are irreversibly blind.

Besides attending regular academic classes, visually impaired children are generally trained in a special set of skills; such as orientation and mobility, or reading Braille. Orientation and mobility training aims to teach blind people travel independently, using white canes, guide dogs or GPS devices. Some governments install truncated domes on pavements, footpaths, stairs and subway or bus stations to provide a tactile surface for the blind to travel on [5]. These surfaces have detectable protrusions which are easily recognizable when stepped on or touched with a cane.

1.1 Motion Capture Systems

This section provides a brief introduction to motion capture systems that are used in gaming devices.

1.1.1 Microsoft Kinect

Kinect is a motion capture input device which was developed by Microsoft originally for the Xbox 360 game console [6]. It allows players to play and control games without a conventional controller, through gestures and sound. A driver for Windows was released in following years after the initial release which enabled developers to develop games and motion controlled applications on PCs.

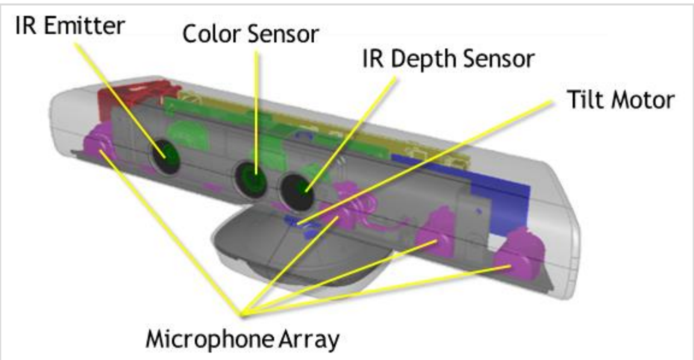


Figure 1: Kinect camera and its components

Kinect features an RGB camera which stores three channel data in 1280x960 resolution and an infrared depth sensor in order to provide data for its motion detecting and interpreting software. This software is able to recognize faces and track full-bodies, both in standing and sitting position. Although Kinect includes a microphone array which provides voice recognition and acoustic source localization, this feature is often overlooked.

Kinect has a viewing angle of 57.5 degrees horizontal and 43.5 degrees vertical, and can tilt its camera ±27 degrees vertically [7]. Although it has a viewing range between 0.8 meters and 4 meters, it is generally not practical to play in this range. Kinect’s motion capture system works best between 1.5 meters to 3.5 meters and in lighting which is not too dim or too bright. Also, objects that are being tracked should not be too reflective.

In order to track users and recognize motions, Kinect assigns a skeleton to body-like images that it detects. This skeleton is comprised of twenty joints which provide detailed information of a player’s body. Kinect can detect up to six players in a single view.

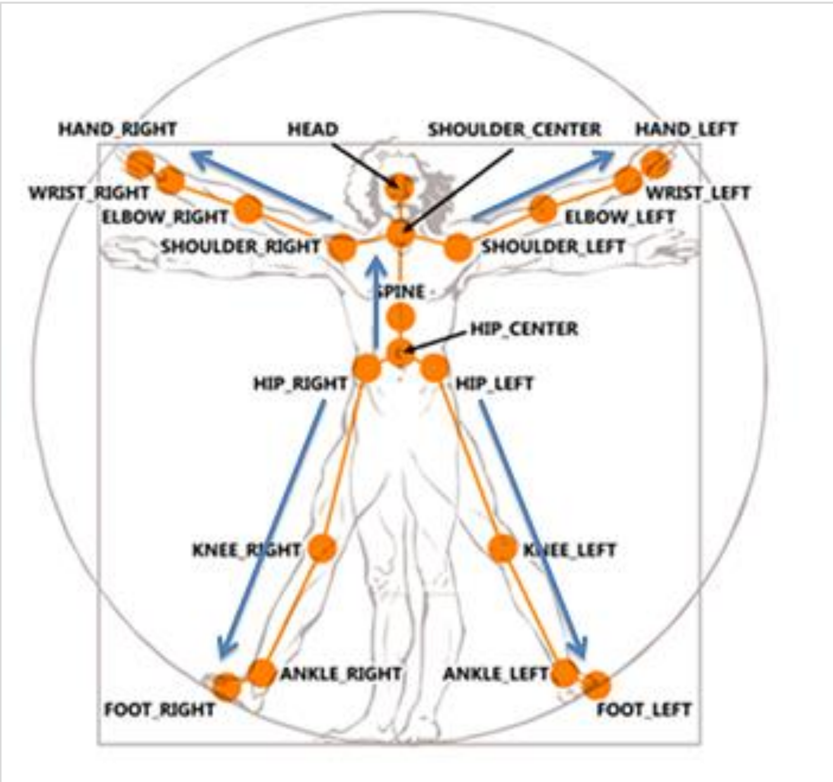


Figure 2: Joints that Kinect assigns to body-like images

1.1.2 Nintendo Wii

Nintendo Wii is a gaming console released by Nintendo which introduced a controller called Wii Remote (or sometimes WiiMote for short) which can detect motion in three dimensions. A WiiMote connects to Wii via Bluetooth, has buttons on it and can be attached to an additional controller called Nunchuck which provides two more buttons and an analog controller. This controller also has an accelerometer and can detect motion just like WiiMote. However, unlike Microsoft's Kinect, Wii Remote is a handheld device, which in return can provide only a single point's (two if Nunchuck is connected) position in 3D space. Moreover, Wii does not have an official SDK for Windows, or any other platforms, leaving the developers to target only Wii.

1.1.3 Sony PlayStation Move

PlayStation Move is the motion detecting controller that was released by Sony for PlayStation 3. Move is more similar to WiiMote than Kinect, as it is a handheld device, offers buttons on it and can be accompanied with an additional controller. Sony offers an SDK for Move, called Move.me which allows programmers to develop games for PS3 that uses Move motion capture system.

1.2 Consultants of the Study

This study was carried out under the supervision of Prof. Dr. Kürşat Çağıltay, an expert on education and a professor in METU Computer Education and Instructional Technology. The educators of Gönül Turgut Special Education and Consultancy Center; Gönül Turgut, the founder of the center and an expert on special education, Kemal Binici, a music teacher, also an expert on special education, and Turan Delimehmetoğlu, an expert on education of the blind who also is suffering from low vision himself were the consultants of this study.

1.3 Purpose of the Study

Today, when children are diagnosed with visual impairment, they are generally accepted to be blind; blind as it was defined by WHO and ICO, meaning that they represent a complete lack of vision. Doctors overlook or ignore the possibility of low vision, even have no knowledge of it in some cases. Not only the children are left in the dark, but also their parents and they are suggested to be enrolled in schools for the blind, where children are thought to read Braille, develop sensory emotions, walk with a cane and follow a wall with their hands. Although this training is necessary for the visually impaired, the children who have low vision can be trained to use their remaining vision up to its limit and walk without a cane or even read print. In this study, we suggest that the life skills and eye-hand or eye-body coordination of visually impaired children can be improved through games that accept motion as input. Many studies indicate that video games improve hand eye coordination or visual perception [8], [9]. However, these studies are mostly carried out with sighted participants. Since people with low vision can see light, which might mean that they have a sight which can be improved in coordination with their bodies. If video games can lead to better eye-hand coordination in laparoscopic surgeons [8], it is likely worthwhile to research whether games can also help the visually impaired or not.

However, games are generally developed for the sighted and developers mostly aim for visual pleasure. Hence, it would require a different discipline and different heuristics in order to build games for the blind. Finding out what kind of games which uses motion capture systems (Microsoft Kinect in this case) as input devices can be developed and how these games can aid the children's development is the main purpose of this research. At the end of the study, it is intended to provide a set of specifications for developing games for the visually impaired.

1.4 Significance of the Study

Combining the motion capture technology with the training of the low vision, this study aims to be a pioneer and open up a new way in improving visuo-motor skills of people with low vision. This study provides the results of the first experiments in literature, in which the visually impaired children play video games via a motion capture system. These results may lead to other studies, in which the current methods that are used in the rehabilitation of the blind are questioned and improved with the newer technology.

The proposed study also aims to create a set of specifications for game developers on how to develop games for the visually impaired. Since game developers with no visual impairment develop their games for the people with no visual impairment, they might not know what the people with low vision can see or how they play games. Observations that are done during the experiments of this study and the feedback of the children provide an insight on how to develop games for the blind.

Moreover, this study covers an important gap in the rehabilitation of the visually impaired. Although the people with low vision receive a training on how to read with special magnifying glasses or identifying objects according to their shapes, their training do not include an exercise for improving the eye-hand or eye-body coordination. Trainers and educators who are specialized in the education of the blind should be able to create a new curriculum or alter their current ones according to the results of this study.

1.5 Research Questions

This research seeks answers to these questions:

1- Is it possible to improve the effectiveness of the remaining vision of a person with low vision? Can they improve their eye-hand and eye-body coordination?

2- Are motion capture systems suitable for the visually impaired as gaming controllers? What can motion capture systems offer to the visually impaired?

3- What kind of games can be developed for the visually impaired? What specifications should be followed along with the heuristics of game design?

CHAPTER 2

LITERATURE REVIEW

Since this study represents a novelty in its area and a combination of two different research topics, it is imperative to first look into rehabilitation through video games and then review studies that also cover visual impairment.

2.1 Games for Rehabilitation

Rehabilitation through video games has been the topic of many studies, such as research on improving the motor ability, improving the visual perception and/or cognition or motor rehabilitation. In their article, Rosser et al. researched the correlation between the video game play and laparoscopic surgical skills and found out that the surgeons who play video games make fewer errors and have a faster completion rate while suturing in comparison to non-playing surgeons [8]. They have conducted an experiment with thirty-three surgeons; twenty-one of them were residents with an average of 3.1 years of surgical experience and twelve of them were attending with an average of 12.9 years of experience. Their video game experience and skills are compared to their skills in Rosser Top Gun Laparoscopic Skills and Suturing Program. Results showed that "surgeons who had played video games in the past for more than 3 h/wk made 37% fewer errors, were 27% faster, and scored 42% better overall than surgeons who never played video games". Rosser et al. suggested that "video games may be a practical teaching tool to help train surgeons".

Green and Bavelier's research on the video games' effects on visual perception suggested that playing action video games may actually enhance visual processing [9]. In their experiments, they have researched whether playing action video games can improve spatial resolution. For this, they have used a crowding paradigm, where the player needed to identify a target among other distractors. They stated that "… whichever interpretation of crowding may prevail, all parties agree that crowding reflects a fundamental limitation on the spatial resolution of the visual system". Their experiment group of twenty right-handed males was divided into two groups; video game players and non-video game players. Participants were asked to indicate the orientation of a stimulus while it was crowded by distractors. The results of this experiment suggested that “VGPs have both smaller regions of spatial interaction and better visual acuity thresholds than NVGPs”. However, researchers believed that the selected group of video game players might already have better visual skills, so they have decided to conduct another experiment. This time, a group of all non-video game players were divided into two groups. First group was trained on an action game, while other group was trained on a less intense game. A similar experiment was applied to these participants after the training program and results showed that the group that was trained on the action game exhibited a decrease in crowd threshold, suggesting that there is a correlation between action video game play and spatial resolution.

In their study, Vanacken et al. developed a co-operative rehabilitation game (which must be played with a partner) for the multiple sclerosis (MS) patients for the rehabilitation of their upper limbs [10]. The first game that they have developed was based on force-feedback systems, which steers the users’ movements to the objects of the tasks. However, since the aim was to develop a collaborative rehabilitation tool, this approach was found to be insufficient even though it was good enough for patients to play themselves. Hence, a co-operative game was developed, in which the players do a pumping gesture to raise a pump together in the game and collect stars. In this setting, the patient is accompanied by a healthy person. While the healthy person uses a simple controller such as WiiMote, the patient uses a haptic feedback device, which provides force according to patient’s movements. Their game concept proved to be effective on patient’s motivation in rehabilitation.

As it was used in Vanacken et al.’s study, the commercial gaming console Wii and its peripheral devices WiiMote and Wii Balance Board has been the subject of many other studies. In the study that was conducted with a patient who was suffering from spastic diplegic cerebral palsy by Deutsch, Borberly, Filler, Huhn and Guarrera-Bowlby, Wii console and Wii Sports game was used [11]. The 13-year-old patient was selected due to the fact that his capability in using his hands to control the Wii controller, WiiMote was found to be sufficient. He also had “… sufficient cognitive skills to follow directions, stay on task, and understand the games”. The patient played boxing, bowling, baseball, tennis and golf games in 11 sessions over 4 weeks and each session lasted between 60 and 90 minutes. Results of this experiment were reported as “visual-perceptual processing improved in all domains except visual memory”, “postural control improved in a variety of measures” and “functional mobility … increased during the training … and continued to increase …”.

Another research that was done by Saposnik et al. compared the effectiveness of Wii games against recreational therapy, such as playing cards or bingo [12] on stroke patients. Patients were divided into two groups and one group was treated with Wii games while the other was treated with recreational therapy. Activities in recreational therapy included activities similar to the Wii games. Experiment was conducted in 8 sessions over a two week period. Four weeks after the last session is finished, follow-up data were collected. Out of 22 patients who started the study, sixteen of them were able to complete it. The results suggested that Wii “is a feasible, safe, and potentially effective intervention to enhance motor function recovery in patients with a recent stroke and represents a proof-of-concept trial".

2.2 Kinect Based Rehabilitation Games

Since its release on November 2010, Kinect probably has been more prevalently used in academic research than actual video games. With the development of open source drivers by PrimeSense, the company that created motion tracker that is used in Kinect, game developers and researchers started building highly innovative projects.

For example, in their study Lange et al. proposed developing a low cost, game-based rehabilitation tool using Kinect [13]. They have developed a game which instructs the player to do balancing based therapeutic movements in order to collect items in game to complete a level. Later on, this game was used in an experiment which was conducted with twenty stroke patients of which eight of them were unable to perform motions the game required due to their conditions. Feedbacks of ten clinicians were also recorded. This study showed that a Kinect based rehabilitation game could provide fun and custom tailored rehabilitation programs can be easily implemented.

Chang, Chen and Huang's research was also developing Kinect based rehabilitation tool which can be used in a public school to assist therapists [14]. They have carried out an experiment with two young patients, one with cerebral palsy and the other with acquired muscle atrophy. Experiment was conducted in ABAB sequence, A being the baseline phase and B being the intervention phase. In the baseline phase, patients were instructed by a therapist to complete a rehabilitation program. In the intervention phase, patients played the developed Kinect game and instructed by cues in the game. Errors in movements in each phase were recorded and compared. Results stated that Kinect could be a valuable tool in "autonomous physical rehabilitation prescribed by the therapist". Moreover, Chang et al. stated that "[the participants] indicated that the system increased their motivation to participate in rehabilitation".

2.3 Kinect Based Rehabilitation Games for the Visually Impaired

In respect to these studies, there are also some other research which study visual impairment and Kinect together. In their study, Rector, Bennett and Kientz pointed out that the visually impaired are generally not able to exercise due to variety of difficulties they face daily [15]. In order to address this issue, they have developed a feedback system called Eyes-Free Yoga that acts as a yoga instructor using Kinect. Six yoga poses were selected and rules that are informed by yoga instructors are defined so that the Kinect could match the captured motion to actual pose. An auditory feedback was added to instruct the visually impaired to do the pose correctly. The results of the experiment that was carried out with sixteen blind or low vision participants indicated that Kinect can also be a yoga instructor.

As exercising can be problematic for the visually impaired, playing video games can be difficult, too. Although Kinect's motion capture system removes the dependency on a controller, since many games provide visual feedback, players who are blind or have low vision are still unable to play them. Morelli and Folmer's study provides a solution which processes the image on the screen and looks for the visual feedbacks in order to re-generate them as tactile cues in real time [16]. This system enables blind players to play Kinect games as sighted players. The results of their experiments suggested that even though their system had some limitations, the performance of the visually impaired and sighted had no significant difference.

Mobility along with orientation is two of the most challenging aspects in a visually impaired person's life. Having a motion capture camera, Kinect might provide a solution in this area also. One example of this kind of a solution is the blind navigation system that was developed by Mann et al. [17]. They have mounted six vibrating actuators inside of a helmet to provide haptic feedback using the depth information that is coming from the Kinect mounted on top of the helmet. The proprietary depth data generated by Kinect is converted to actual depth data in metric units by using a formula. This allowed researchers to create a distance map and partition it in six pieces so that each part of the distance map is matched to a single actuator on the helmet. This system was not used in an experiment, however, their findings proposed a new way to use the technology for the benefit of visually impaired. Shrewsbury developed a similar system to Mann et al.'s, in which the Kinect's sensor data is fed to a glove instead of a helmet that produced haptic feedback [18].

In their study, Zöllner, Huber, Jetter and Reiterer proposed a navigation system which not only provide vibrotactile feedback but also synthesized voice instructions [19]. To warn the user about the obstacles in a closer range, vibrotactile cues were used. This kind of navigation was called "micro-navigation". For "macro-navigation", synthesized voice feedback was used, which instructed the users to navigate in an area which was marked with augmented reality markers. These markers are detected with Kinect's RGB camera.

Filipe et al.'s Kinect navigation system included neural networks [20]. The depth data that was obtained from Kinect was analyzed by a neural network and classified as no obstacle, obstacle, upstairs or downstairs. The system was tested on 714 input samples and the results were presented as a confusion matrix. According to the result data set, the neural network successfully recognized approximately 99% of the images. However, the remaining %1 can be more than problematic, as Filipe et al. suggested "two samples from upstairs class and two samples from downstairs class were misclassified as no obstacle. This may present a potential danger situation to the blind user since he is not informed about a potential risk on his way".

2.4 Turkey and the Visually Impaired

In Turkey, visually impaired studies are generally carried out by two academic institutions which are both located in Ankara; Ankara University Graduate School of Health Sciences, Rehabilitation of the Low Vision Graduate Program and Gazi University Division of Visually Impaired Students Teaching. The first program aims to provide visual aids, training on how to use them and medical examination for the visually impaired. The latter program concentrates on educating the teachers who will be teaching the visually impaired. There are also some private institutions which offer special training programs for the low vision and blind, such as Gönül Turgut Special Education Center [21], Kurtulus Special Education and Rehabilitation Center [22] or Işık Eye Center [23].

In these centers, people who are suffering from low vision generally trained on how to use optical aids which are specifically designed for them. These optical aids can be magnifiers, binoculars or even telescopes. Some of these aids even include lighting devices. Unfortunately, even though, many technological devices provide accessibility features such as voice activated ATMs, use of technology in the rehabilitation of the low vision is limited to text-to-speech applications and GPS equipped white canes.

On the other hand, academic studies in Turkey are somewhat limited. There are only a few articles which cover the importance of technology and games in the education of the blind. In their article, Ataman discussed the importance of games in the education of the blind, and discussed that games help children develop many skills, such as using hands, having a freedom of mobility and life experience [24]. In their study, Dal developed a GPS system to overcome the mobility issues that a blind may encounter in a university campus [25]. Alptekin designed an internet based learning system for the blind, which has an interface that can be controlled with a mouse and audio [26]. A research carried out by Koray, proposed a obstruct notification system which is mounted on a hat and converts the frequency that is provided by ultrasonic sensors into vibration feedback [27].

CHAPTER 3

METHODOLOGY

This study was conducted as a mix of qualitative and quantitative studies. It was carried out in six phases in the following order: pre-development study, developing first game prototype, study on the game prototype, additional game development, experiment and reviewing results (see: Figure 3). The first five phases are presented on this chapter, while the last phase is given in Chapter 4: Results.

In the pre-development study, consultants (see: 1.2 Consultants of the Study) of the project listed the psychomotor development areas of the visually impaired children in order to find out what kind of games can be developed. This list was discussed in a meeting with the consultants and the supervisor of the project. As a result of this meeting, it was decided to develop a game as a prototype, and study on it further more. A game which requires players to catch falling balls with their hands was planned to be developed in the next phase. Moreover, consultants suggested some key points to consider while developing games for the visually impaired.

First prototype was developed in about a month using Unity game engine [30]. After the development phase, a study was conducted on the game prototype. Another meeting was held with the consultants and the supervisor and in this meeting, game was found to be adequate to start the experiment phase. However, the prototype game and the Kinect technology had some minor issues. To minimize the effects of these issues on the experiment, it was decided to develop three more games which address these issues. Ideas for these additional games were also developed in this meeting.

As a result of discussions in this study on the prototype, three more games were developed using Unity game engine and this process took about four months. After the development phase was completed, the experimental phase began.

The experiment was conducted with four games and five visually impaired children in Gönül Turgut Special Education and Consultancy Center. Children were observed while playing those games and their reactions were noted. Their scores and in game actions (e.g. the position of their hands, completion times, etc) were recorded using the tools that were developed along with the games and embedded in them. These recordings were exported as XML files by the games automatically at the end of play sessions.

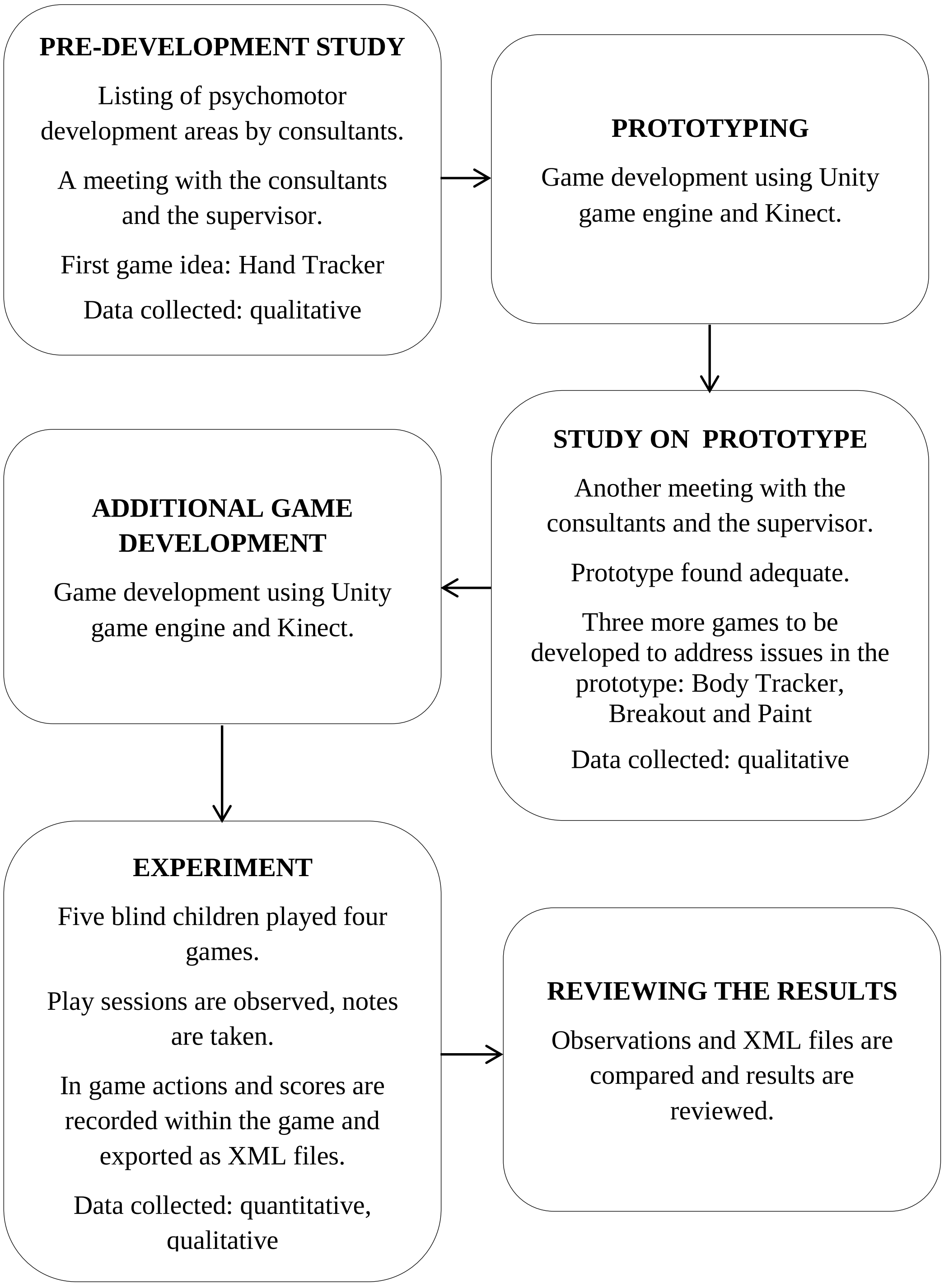


Figure 3: A visual representation of the study

After the experiments, the data that is collected from the XML files were converted into tables. This quantitative data was compared to qualitative data which was collected during observations and the results were presented.

3.1 Data Collection

In this study, both qualitative and quantitative data are collected. Qualitative data is collected through meetings and observations, while quantitative data is collected through experiment. Data collection phases, their collection methods and how they are used are given below:

1- Pre-Development Study (qualitative data): Psychomotor development areas are listed and a discussion was carried out on game ideas. The list was formed by consultants of the project while game ideas were suggested by both consultants and the supervisor. This data is noted down during the meetings and used to form a game development document for the prototype.

2- Prototyping: No data was collected.

3- Study on the Prototype (qualitative data): Another meeting was held to review the prototype. In this meeting, possible issues are pointed out and three more game ideas were suggested by both consultants and the supervisor in order to address these issues. This data is noted down during the meeting and used to apply some minor changes on the prototype and develop three more games.

4- Additional Game Development: No data was collected.

5- Experiment (qualitative and quantitative data): Participants were observed during the experiment and these observations were noted. Notes included items such as: "participant suggested that he can play better in the dark", "participant suggested that she was not able to see the hand avatar", "participant stated that he did not like the game and play something else" etc. These notes were reviewed and given in section 4.2.2 Qualitative Results.

On the other hand, quantitative data was collected through games. A script was written in order to record positions of participants' bodies (Vector3, relative to game world, on each frame) and hands (Vector3, relative to game world, on each frame), positions of items in games (Vector3, relative to game world, on each frame), completion times (float) and scores (int). This data was recorded to XML files at the end of each game and used to compare participants' success at the beginning and the end of the experiment, in order to find out if there was improvement. This data is given in tables in section 4.2.1 Quantitative Results.

6- Results: No data was collected; however, the data that was collected in other phases were reviewed and presented in Chapter 5: Results.

3.2 Pre-Development Study

After carefully examining psychomotor learning and development, consultants of the projects have listed sub-modules and the gains as below:

Module 1: Movements That Require Physical Coordination

1. Does warm-up exercises as instructed.
2. Rolls in variable directions.
3. Reaches out in variable directions.
4. Walks as instructed.
5. Runs as instructed.
6. Crawls in a specified range.
7. Climbs up a specified height.
8. Climbs down a specified height.
9. Jumps from a specified height.
10. Leaps over an obstacle.
11. Pedals.
12. Does coordinated and rhythmic movements with a gadget.
13. Catches thrown objects.
14. Throws objects.

Module 2: Movements That Require Hand-Eye Coordination

1- Collects small objects.
2- Pours objects from one container to another.
3- Stacks objects on top of each other / side by side / nested.
4- Plugs in objects.
5- Plugs out objects.
6- Strings objects.
7- Uses gadgets that require hand skills.
8- Combines objects to from new objects.
9- Paints using different materials.
10- Draws lines as instructed.
11- Draws shapes using variable objects.
12- Folds materials in variable ways.
13- Cuts materials as instructed.
14- Glues materials as instructed.
15- Ties materials as instructed.

Module 3: Movements That Require Large and Small Muscles

1- Pushes variable objects.
2- Pulls variable objects.
3- Lifts variable objects.
4- Rotates variable objects.
5- Walks while carrying objects in variable weights.
6- Tears variable objects.

7- Squeezes objects.
8- Stretches objects.
9- Shapes materials using her hands.
10- Shapes materials using gadgets.

Module 4: Movements That Require Balance

1- Walks on variable surfaces.
2- Walks on shapes that are drawn on surfaces.
3- Stands on one foot.
4- Jumps on one foot / both feet.
5- Covers a specified range jumping on one foot / both feet balanced.
6- Jumps forwards / backwards on both feet.

After listing these development areas, a discussion was carried out on which items in this list to address and what kind of games to develop. In their research, Green and Bavelier suggested that “Video game play has been shown to dramatically enhance visuo-motor skills [28]. In particular, video game players have been shown to possess decreased reaction times, increased hand-eye coordination and augmented manual dexterity”. Considering the results of this study, in this meeting with the consultants and the supervisor of the project, we have decided that developing a game that is aimed that improving hand-eye coordination would be more beneficial for visually handicapped children. In order to achieve this task, we have determined “collects small objects” gain as our primary objective for our game. Moreover, it has been agreed upon that the game that is going to be developed should follow these rules:

1- Kinect camera should keep track of both hands.
2- Game should reflect the positions of hands on the screen (avatars of hands).
3- Subjects should collect items in game by simply moving their hands (hence, avatars of their hands) over the items.
4- An audial feedback should be provided upon collection of an item.

Additionally, the consultants of the project, Turan Delimehmetoğlu and Gönül Turgut suggested the following restrictions:

1- In game objects (such as hands and collectible items) should be colored so that they can be separated from background easily.
2- Game should be played on a large screen (preferably a 50+ inch TV) which emits light (due to the fact that the projected images do not reflect light enough for the visually impaired to see).
3- Game should not provide negative feedback or a sense of losing the game as most of the children suffering from low self-esteem.

3.3 Development of the First Game Prototype

Due to its simple nature and ability to prototype games quickly, Unity game engine was used in order to develop the first game [30]. Programming was done in C# language and only Unity primitive objects were used as models. Microsoft Kinect camera was installed on a notebook using Kinect Beta Driver 1.0. The specifications of the notebook were as follows: Intel Core i7 CPU M620@2.67GHz, 6,00 GB RAM, ATI Mobility Radeon HD5650 Graphics Card, running on Windows 7, 64-bit. In order to control Kinect and receive input from it into Unity, the Kinect Wrapper for Unity which was developed by Entertainment Technology Center of Carnegie Mellon University was used. Development process took about a month.

Finished game has a plain background, on which the player's hands are reflected as two hand icons, left hand green and right hand yellow, so that the players are able to differentiate between them. Kinect's hand joints are assigned to these icons; left hand joint to left hand icon, right hand joint to right hand icon. Players are able to move these hand icons by standing in front of the Kinect camera and move their hands up-down or left-right. At specific time intervals, red balls appear above the screen randomly distributed and start falling down at a specific speed. Players' objective is to catch these red balls before they disappear at the bottom of the screen. The time between the red balls' appearance, their fall down speed and their size change during the game depending on the player's success or failure, which provides an internal difficulty level. If the player catches five red balls consecutively, difficulty goes up a level, and time interval shortens, red balls' size are reduced and fall down speed increases by five percent. If the player misses five red balls consecutively, difficulty level goes down a level, time interval stretches, red balls' size are increased and fall down speed decreases at the previously mentioned rates. If the player cannot catch or miss five red balls consecutively, game stays at the same level it currently resides. Game starts at the middle level, with five upper and five lower levels, it offers a total of eleven levels. An audial feedback is provided for a catch (a ding sound). A score of one is given for each catch. No score is given or deducted for a miss. This game is referred as "Hand Tracker" for the sake of clarity. Algorithms that are used in this game are given below. In this game, LevelManager (in Appendix, see Table 7, Table 8 and Table 9) script is the main controller and handles spawning of red balls and updating hand positions. It repositions hands in game space according to Kinect data, spawns a red ball above the screen when the spawn timer reaches zero and ends the game when the play time limit is reached. On the other hand, red balls also have a controller script on them, which updates their position and notifies LevelManager on miss or catch (in Appendix, see Table 10).

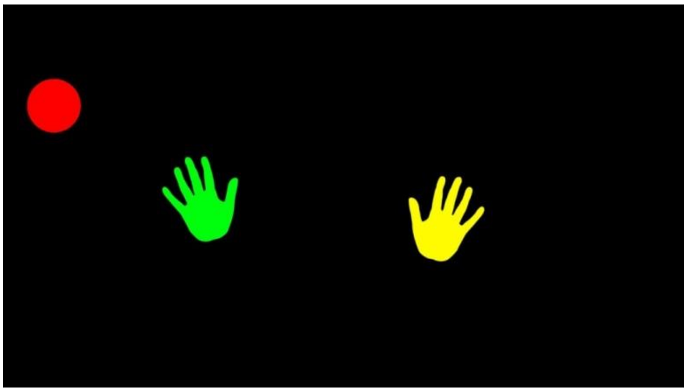


Figure 4: A screenshot from the Hand Tracker game

3.4 Study on the Game Prototype

The first study was conducted in the METU Department of Computer Education and Instructional Technology, Technology Enhanced Learning Research & Development lab. After examining the developed game with the consultants and the supervisor of the project, a meeting was held with them. In the discussion, they have stated that they observed two main issues. First issue was that the game required a precision with little hand movement. This was considered a problem, since most of the visually impaired children keep their hands to themselves and do not extend them often. Consultants suggested developing a game which requires more hand movement with less precision; a game with a wave-free environment. The other issue was the Kinect's near tracking limits. It was thought that it might be far for some of the visually impaired children that the consultants work with. However, this problem had incomplete and temporary solutions since the current Kinect technology was not able to offer more. Solutions that are suggested for this problem in this project are given in the Results section.

3.5 Additional Game Development

In order to address the issues that were found in the study on the prototype, three additional games were developed. This process took about four months.

3.5.1 Game Ideas

Since the "Hand Tracker" game provided valuable data, it is decided that this game should be left as it is. Only the red balls' speeds can be reduced and time intervals between spawns can be increased so that the general difficulty level of the game matches better to children's skill level. However, the same game could be cloned to develop a "Body Tracker" game in which the Kinect tracks players' bodies.

Seeing that the “Hand Tracker” game is a very simple game which offers a minimum amount of “fun factor”, it was considered that it might be a good idea to develop a more fun game. A classic “Breakout” or “Arkanoid” game where the players control a paddle to direct a ball towards a set of bricks and break them could produce this missing fun factor. This game could use the same input mechanism as the “Body Tracker”.

In order to provide the players a “wave-free” environment, consultants suggested that a game should be developed which requires waving. A game in which the players clean a dirty screen or paint a wall would perfectly match this criterion. This game would also address the third item of module 1; “reaches out in variable directions”.

3.5.2 Game Development

In the meeting on the prototype, “Hand Tracker” was decided to be left as it is, without any major modifications. However, a couple of addition was made without altering the gameplay. Players were asked to enter their names at the beginning of the game. This information was used in a system which stored player’s hand positions in order to acquire quantitative data about the performance of players. This system simply saved the positions of player’s hands and red balls for every single update and exported this data as an XML file at the end of the game. An example from the XML file is given in Appendix (see Table 11).

In order to overcome the issue of players’ inability to use their hands, the “Hand Tracker” game was modified to track players’ body, instead of hands. Kinect skeleton tracker was assigned to track the “spine joint” and no other feature was modified. Player was represented by a green stick man on the screen (see Figure 5). This game is named “Body Tracker” and required players to move only sideways to collect the red balls. Algorithms of this game are exactly the same of the “Hand Tracker”, hence they are not provided here.

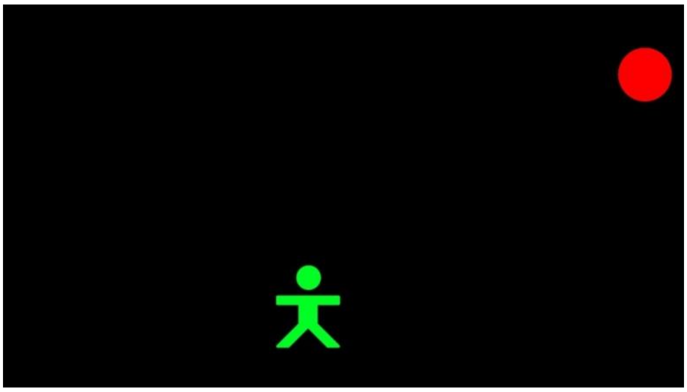


Figure 5: A screenshot from the Body Tracker game

In order to provide a little bit more fun, and to observe the reaction of the visually impaired to the conventional games, a Breakout style game was developed. Breakout is an arcade game developed and published by Atari, Inc. in April 1976 [31]. In the game, there are a number of rows at the top of the screen, formed by bricks. Players control a paddle to bounce a ball upwards to prevent it touching the bottom of the screen, which causes the player to lose a turn. However, since this game provides some kind of a challenge to the player, it was decided to drop the "losing a turn when the ball touches the bottom of the screen" feature, and leave player a safer and less challenging environment to play in. All the player needs to do is to direct the ball in the correct direction. In this game, time to complete a level, positions of the paddle and the ball was recorded to an XML file. An example from the XML file and algorithms are provided in the Appendix (see Table 12-15), and a screenshot from the game is given below.

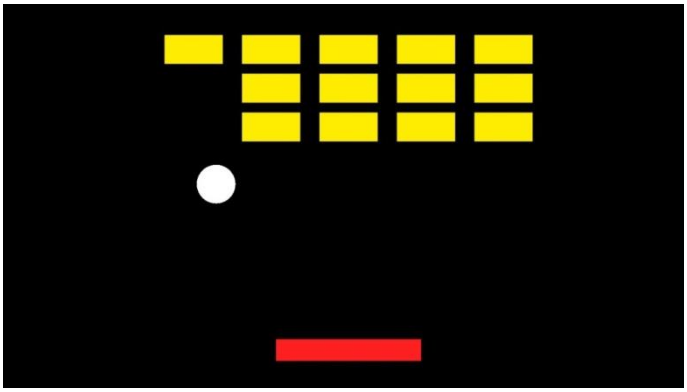


Figure 6: A screenshot from the Breakout game

In this game LevelManager updates the paddle position to match it to player's body and ends the game when there are no bricks left. Most of the game logic is handled by BallController, which moves the ball, changes its direction on collision with paddle, walls or bricks, removes bricks on collision with bricks and increases score.

Another game that was developed in this phase was a paint game, in which the players try to paint a section of a wall by moving their hands on the wall and change its color. Purpose of developing this game was to provide the visually impaired children an environment where they make use of moving their hands freely. Flow of this game is very simple: player moves his/her hand to paint the wall with a brush that has the same size of his/her hand, if the wall is painted "enough", it is considered to be fully painted and player starts painting the wall to a new color. Painting is only done with one hand and in this specific case, right hand. This game is named "KinectPaint". A screenshot from the game is given below (see Figure 7).

Figure 7: A screenshot from the KinectPaint game

Although the main flow was simple, the algorithm for paint was pretty complex due to Unity's handling of 2D. To draw the area to be painted, Unity's GUI.DrawTexture() method was used. A 512x512 size white colored texture was selected to be the base texture, the "canvas", and its pixel colors were modified to paint color when the player moved his/her hand. When the amount of pixels those were colored was eighty percent (%80) of the total pixels (which was 262144 for the chosen texture), the texture was painted to target color and brush color is changed to a new one. The order of paint was as follows: white canvas - black brush, black canvas - red brush, red canvas - white brush. This order was considered a single cycle and the game looped back to start after red canvas - white brush. A single script was used for this game and the algorithm along with an example from XML file is given in Appendix (see Table 17-19).

3.6 Experiment

The experiments were carried out in a 2x3 m study room of Gönül Turgut Special Education and Consultancy Center. Of the children who receive low vision training in this center, five were found to be suitable to play the games. Three of them participated in the experiment only on the first day, while the remaining two came for another session the next day. All subjects played all of the games at least once, except for subject 3, whose condition is explained below. Subjects were positioned one and a half meter in front of a 40-inch TV with a resolution of 1920x1080, while Kinect was placed 50cm from the ground level. "Hand Tracker" and "Body Tracker" games were limited to 120 seconds and "KinectPaint" was limited to 90 seconds. "Breakout" game ended when all the bricks are destroyed. In this section, the term "level" is referred to 120 seconds of gameplay in tracker games, 90 seconds of gameplay in "KinectPaint" and breaking all the bricks in "Breakout". No children were forced to play and instructed that they can stop playing immediately if they wish to.

3.6.1 Participants

Participants of the project were the students of Gönül Turgut Special Education and Consultancy Center. Aged between 5 and 11, all five of the participants were suffering from low vision due to different reasons (see: Table 1).

Table 1: List of participants

Subject	Age	Gender	Cause of Low Vision
Subject 1	5	Female	Albinism
Subject 2	7	Female	Albinism
Subject 3	9	Female	Retinitis Pigmentosa
Subject 4	8	Male	Bull’s Eye
Subject 5	11	Male	Bilateral Optic Atrophy

Figure 8: Two of the participants playing the sample Kinect game

3.6.1.1 Subject 1

Subject 1 was a 5-year-old female who was suffering from low vision due to albinism. When she learnt that she was going to play games, she expressed her joy by saying “I can’t believe that I am going to play a game”. Moreover, she was constantly moving and talking, the reason was unknown; it could be because of her excitement or because it is in her nature. She started with the “Hand Tracker” game and quickly grasped the concept of moving her hands to collect the red balls. However, it was observed that her spatial perception might be pretty low, since she tried to reach the circles by moving her hands towards the TV, instead of just sideways or up and down many times. When she finished a single level, she wanted to play another game. She spent a single level in “Body Tracker”, which was the most active gameplay of hers, which she ran from one side to another side and jumped constantly even though she was instructed that she does not need to jump to collect the red balls. Her next game was “KinectPaint” and she played four levels in this game. Even though she was not able to paint a single canvas at the first game, she wanted to play again. She said “I like this game, it is so much fun” twice, and instead of painting to move to another empty canvas, she modified the game to her liking and tried to paint an object. She stated what she is painting a few times by saying “now I am painting a bunny, “now a bug”, “it looked like a spider, isn’t it”. She expressed her unhappiness when the game was terminated due to time limit and the screen was cleared, because the game “destroyed her art”. However, this game was a little bit problematic for her, since her ~100cm height did not allow her to paint the upper parts of the canvas. Next, she played the “Breakout” game once, which proved that her spatial recognition were not that developed, since she positioned the paddle not where the ball would land, but where she saw it at that moment.

3.6.1.2 Subject 2

Subject 2 was first subject’s older sister, 7-year-old female, who suffers from low vision due to albinism, too. She seemed to be calmer than her sister at first, which was proven to be wrong they get together and played a sample Kinect game that comes bundled with Kinect SDK after the experiments. She started playing “Hand Tracker” just like her sister, however, she seemed to be more successful, since she moved her hands with more agility, and did not try to move them closer to screen to collect the red balls. She was successful in “Body Tracker”, too, which she played a single level and merely missed a few red balls. Her abilities as a gamer were also observed in “KinectPaint” game, which she grasped the concept quickly and started painting canvases one after another in two levels. After playing a single level in “Breakout”, she wanted to quit playing by saying “I don’t want to play anymore”. Her session was immediately terminated; however, when her sister came into the room, they wanted to play together. An aimless game which requires players to punch or kick shapes that are falling from top which comes bundled with Kinect

SDK to provide developers a C# sample was started for them and they have spent 15 minutes playing it.

3.6.1.3 Subject 3

Subject 3 was probably the most interesting child of them all. As a 9 year-old female subject, she was suffering from retinitis pigmentosa and her deep shyness affected the observations and led us to think that her vision loss was severe than the first two subjects. After playing a single level in "Body Tracker" which she almost stand still and scored zero, it was considered that the "Body Tracker" may not captured her attention and "KinectPaint" might crack her tough shell. However, after 10 minutes in "KinectPaint" which she barely moved and one level in "Hand Tracker" which she accidentally scored two, it was almost settled that either she was NLP (no light perception) blind, or the project was a total disaster. She was also barely talking, answering the questions with one word at a time. At this point, TA Turan Delimehmetoglu who was only observing until that moment stepped in and said that she can see and play, but she is extremely shy to strangers. He suggested to play the game himself and show it to her, which she agreed by simply nodding her head. After watching her instructor playing the game successfully, she wanted to play again. She played "Body Tracker" and this time she appeared to be more active. After five games she proved that TA Turan Delimehmetoglu was indeed correct about her.

3.6.1.4 Subject 4 and Subject 5

Subject 4 and subject 5 were brothers aged 8 and 11 respectively. It was their second week at a low vision training center. Up until that, they have only received blind education. Subject 4 agreed to participate in experiments first while his brother attended another class. His first impression about the "Body Tracker" was positive; he said "I like this game". He played three levels and his score improved in each of them. However, he often rotated his direction, causing him to move towards the screen instead of just going sideways. On the other hand, his reaction to "Hand Tracker" was a definite negative; he stated that he did not like the game and refused to play another level. He was furious about the game and said "am I going to look at the screen or my hands? I did not enjoy this game". His experience with "KinectPaint" was not different and after scoring zero, he asked to play another game. He did not enjoy "Breakout" either, as he stated that it was hard. After playing a single level in this game he wanted to quit playing.

As he quit playing, his brother, subject 5 came into the room and asked if it is his turn to play. He started playing "Body Tracker" and completed a level with a good score. He did not have issues moving towards the screen, and observed to be more successful in moving sideways. However, he was not attracted to "Hand Tracker" just like his brother, and preferred to keep his hands close to him. After playing one level in this game, he failed to complete a level in “KinectPaint”. Failure seemed to increase his ambitious as he wanted to have another try, which also failed. At this point, subject 5 offered to play in dark, suggesting that he could see better. Lights were turned off and he played three levels in “Breakout”. Although his completion time was increased at each level, he seemed to response better to the ball’s movement. During his session, he was observed to be driven by ambition, as he made statements like “I can do this”, “I am going to do this”, “this time I will be more successful”. First day of the experiments was completed after about four hours.

On the second day, subject 4 and subject 5 came back to the education center for their trainings and they wanted to play more. This time subject 5 started first and he seemed to be more ambitious than the previous day, as he said “today, I am going to ace all of them, start me a game”. He was indeed hesitant to play, as he played four levels in “Body Tracker”, two levels in “Hand Tracker” and two levels in “Breakout”, and completed them with very few mistakes. On the other hand, at the end of his session, he still did not like “Hand Tracker”.

Subject 4 started playing “Body Tracker” as subject 5 left the room. After playing two levels and expressed his boredom quickly by asking if there are other games to play. Over his question, he was requested to play “Hand Tracker”, which he agreed unwillingly, but completed four levels with few mistakes and a number of catches. When he asked whether he can quit, his session along with the experiments were terminated.

CHAPTER 4

RESULTS

In this chapter, results of the study on the game prototype phase and the experiment phase are demonstrated separately.

4.1 Results of the Study on the Game Prototype

Study on the game prototype was conducted in order to provide insight for the experiment phase and it was successful in that manner. Firstly, due to visually impaired children are thought to keep their hands close to their bodies not to break anything or hurt themselves, consultants stated that they were reluctant to use their hands freely. Moreover, since it is already a life-long learning process to develop hand-eye coordination for the good-sighted, it is surely expected that they would have issues moving their hands. In order to overcome this complication, it is suggested that the same game could be developed to track players' bodies instead of their hands. With body tracking, this game would also address some of the items in module 1 – movements that require physical coordination and module 3 – movements that require large and small muscles. Another suggestion was to develop a game where not only the children could wave their hands freely, but it is also encouraged and necessary to complete a level. This way, children might find out that it is perfectly acceptable to "go crazy" once in a while and they might be more willing to extend their hands.

Secondly, games should be developed in a way that Kinect can be placed on lower heights so that the children stand closer to the screen. Kinect has a constraint in far and near range, and can detect motions safely between 80cm and 4m away from the camera, 2m being the suggested play distance. It also has a special mode called "near mode" which allows players to play from 50cm, but lowers the far range to 3.5m and was not available on the camera that the experiment was conducted with. If the camera is placed lower and its "head" (the part in which the sensors reside) tilted back, children might be able to play closer.

Thirdly, games should include a tutorial level which should instruct the players on how to use their hands in order to play the game. A tutorial level should provide step-by-step instructions on how to move hands in order to collect items.

4.2 Results of the Experiment

Results of the experiment are examined under two sub-sections: quantitative results and qualitative results.

4.2.1 Quantitative Results

The position saving system that was implemented in the games allowed us to gather quantitative data. Players' hand positions, positions of collectible items and completion times were collected. In this subsection, results of the subjects will be given per-subject basis. Subjects were scored "1" for each red ball they caught in "Hand Tracker" and "Body Tracker" games, and again "1" for each canvas they completed in "KinectPaint". The time that took to complete canvas in "KinectPaint" and finish a level in "Breakout" by breaking all the bricks was also measured. Scores were given as tables at the end of the chapter per-game basis.

4.2.1.1 Subject 1

Subject 1 started her session with "Hand Tracker" and finished it with "Breakout". Her "Hand Tracker" score was 10, which she improved in "Body Tracker" with a score of 11. Her first experience with "KinectPaint" was unsuccessful and she scored zero by not being able to paint a single canvas. However, since she liked the game and asked to play again, she tried her chances three more times. On the first one, she was able to paint a canvas in 61.496 seconds and could not complete another in time. On the second try she painted two canvases, first one in 61.449 seconds which was very close to her first time and the second one was in 26.838 seconds which was a huge improvement. On her third try, she completed three canvases, with times 36.615, 17.582 and 12.147 seconds. After this point, she started painting shapes as she liked and did not paint another. She was one of the two who were successful in playing this game. Although she completed her single level in "Breakout" in 82.126 seconds, it was observed that it was not due to her skill, but the game's forgiving nature.

4.2.1.2 Subject 2

Subject 2 played single levels on "Hand Tracker" and "Body Tracker", then two levels in "KinectPaint" and a single level in "Breakout". When she finished with this cycle, she wanted to play more and chose to play one more level in “Hand Tracker” and another level in “Body Tracker”. On her first level in “Hand Tracker” she scored 14 and on the second level she scored 17. Her scores in two levels in “Body Tracker” were 15 and 17 respectively. She was the most successful “KinectPaint” player, in which she scored 5 on her first try and scored 4 on the second. Her completion times on the first try were 32.399, 17.142, 13.890, 8.387 and 8.876 seconds respectively. Completion times on her second try were 27.883, 26.941, 14.910 and 15.228 seconds. She destroyed all the bricks in “Breakout” game in 117.171 seconds.

4.2.1.3 Subject 3

Subject 3 did not play “Breakout” at all and were unable to paint a canvas in “KinectPaint”, hence her scores in those games were zero. However she played one level in “Hand Tracker” which she scored 2. Her scores in “Body Tracker” were more promising, in which she played 5 levels. Her scores were 5, 7, 6, 7 and 10 respectively.

4.2.1.4 Subject 4

Subject 4 played a total of 12 games in two days. On the first day, he played three levels in “Body Tracker”, one level in “Hand Tracker”, one level in “KinectPaint”, and one level in “Breakout”. On the second day, he played two levels in “Body Tracker”, and four levels in “Hand Tracker”. He scored 3 in his first level of “Body Tracker”. His scores on later levels were 9, 12, 9 and 14 respectively. In his single level in “Hand Tracker” he scored 9 on the first day, even though he refused to play in the middle of the game and lowered his hands. He agreed to play more levels in “Hand Tracker” on the second day and in his four levels, he scored 12, 11, 14 and 13. He was unable to complete a level in “KinectPaint” and scored zero, while his completion time in “Breakout” was 135.160 seconds.

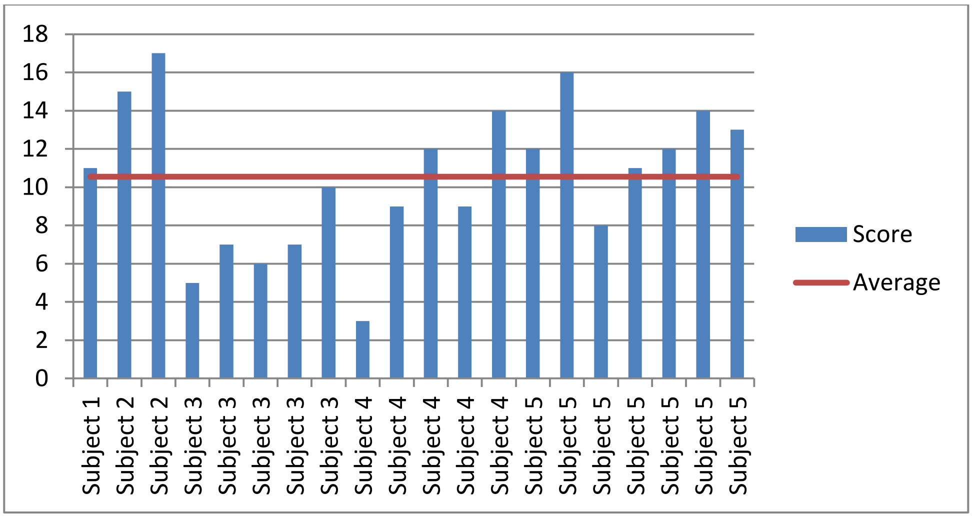
4.2.1.5 Subject 5

Subject 5 was the most active participant of the experiments with 18 games in total. In his seven levels in “Body Tracker” he scored 12, 16, 8, 11, 12, 14 and 13 respectively. His scores in “Hand Tracker” were similar and consistent, 14, 17, 17 and 17 in that order. Even though he tried his chances twice in “KinectPaint” he was unable to complete a level in both of them and scored zero. He played five levels in “Breakout” and his completion times were 86.741, 122.316, 141.895, 105.601 and 106.841.

4.2.1.6 Results

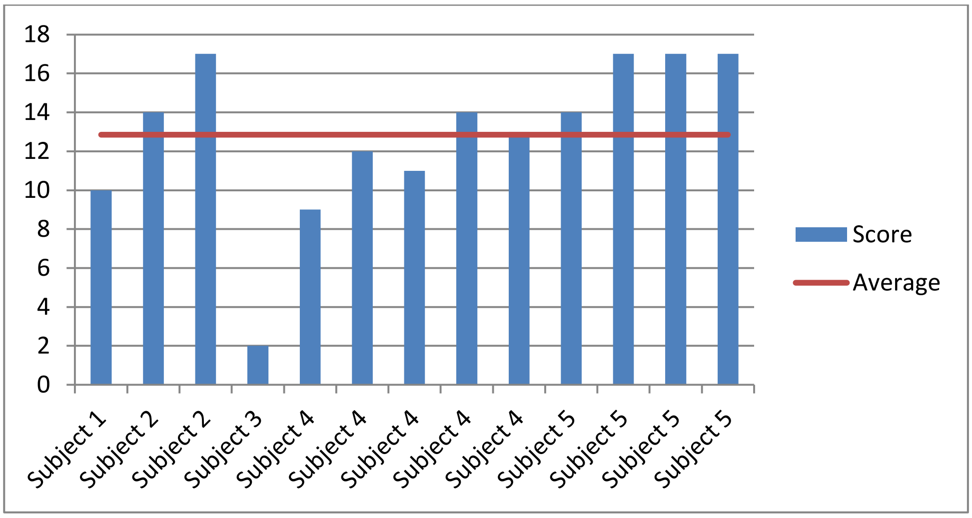
In this section, all results are given in tables and discussed. However, since the collected data is rather small, a future study should be conducted in order to create a bigger sample space.

Table 2: Scores of each games and the average of total on Body Tracker



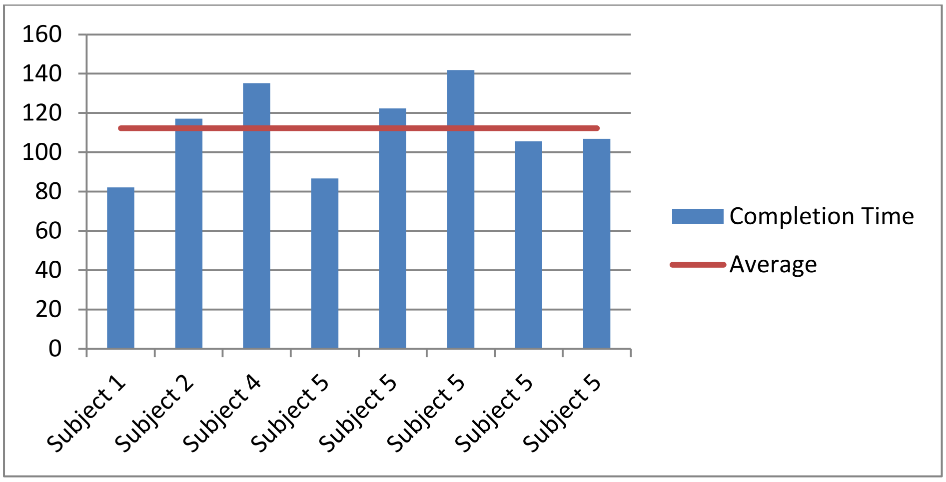
In Table 2, the improvement in the scores of the subjects is observable except for the Subject 1 who only played a single level and does not have any other data to compare. While prior scores are below average, it can be seen that later scores are above average.

Table 3: Scores of each games on Hand Tracker



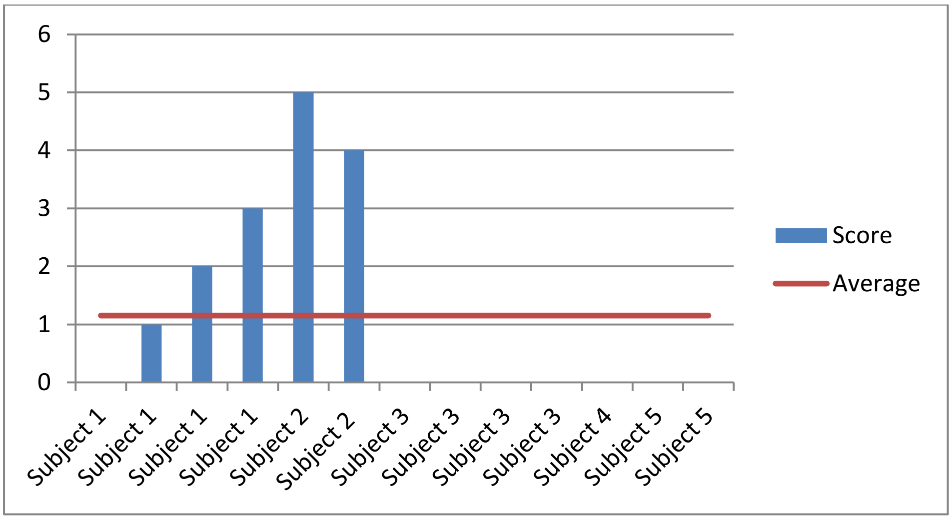
Results of the Hand Tracker (Table 3) game are similar to Body Tracker game's results. It can be observed that the latter scores are above the former scores.

Table 4: Completion times in seconds in Breakout



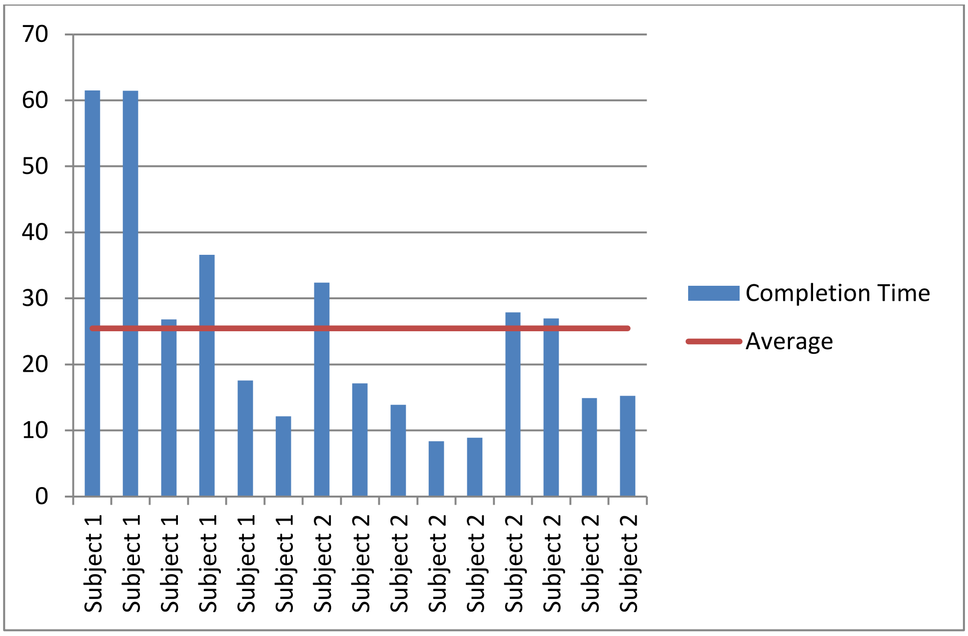
Results of the Breakout (Table 4) are mixed and it is rather hard to comment. It can be seen that many of the results are near average, however the reason is unclear and the data set is very small to make an inference.

Table 5: Scores of each games in KinectPaint



Scoring of the KinectPaint (Table 5) proposes similar results to Breakout, offering very little to comment on. However Table 6, which shows the completion times of canvases in KinectPaint, offers more. It is observable that the completion times get better and better.

Table 6: Completion times in seconds in KinectPaint (smaller is better)



These results demonstrate that "KinectPaint" and "Breakout" might have been more unsuccessful than "HandTracker" or "BodyTracker". One of the reasons might be that both "KinectPaint" and "Breakout" were not received well, and they do not offer a complete set of results from all the participants. Moreover, "Breakout" game seemed to require more luck than skill; it was observed that it was not skilled paddle control that led the ball towards bricks, but the forgiving nature of the game, which did not allow the player to lose a hand and reflected the ball when it reached to the bottom of the screen, where it should have been lost. However, for subject 1 and subject 2, who appeared to love and enjoy the "KinectPaint" game, results suggest that this game might improve their eye-hand coordination, since their scores increased significantly in their latter games.

On the other hand, results of "Hand Tracker" and "Body Tracker" are more promising. All players, with the exception of subject 3, who did not want to play the "Hand Tracker" game, either had at least one game that was above the average or very close to it. A comparison between first games and last games suggest that there is an improvement in the scores.

4.2.2 Qualitative Results

In this section, observed results will be given as a whole, not per-subject basis.

One of the first and foremost issues with players was the constant change in their movement direction. Some of the subjects stated that they could see when they tilt their head. This tilting gesture caused them to lose track of sideways axis, and resulted in a crosswise movement, which in return led them to move towards or away from the TV.

Another issue in movement was the limitations of the room. Since games required larger space than the room offered, subjects missed some red balls due to not being able to move further. Two of the participants, subject 2 and subject 5 discovered a solution on their own and resolved this issue by moving closer or further when it was necessary. However, remaining subjects had difficulties in collecting items that are coming down from furthermost sides.

Moreover, there was an issue that subjects' themselves created in hand tracking games. All of them hesitated to extend their arms and use their hands. Nearly all subjects tried to implement the same solution; instead of extending their arms to pick up the items or paint an area, they moved their whole body and let this motion solve the problem. In respect to this issue, "KinectPaint" ended up being the least successful game, in which only two of the participants were able to paint a complete canvas (subject 1 and subject 2), since it required players to move their hands extensively. Also, green hand avatar on a white canvas which was placed on a blue background did not help either. Most of the participants stated that they cannot see the location of their hand and unable to receive a visual feedback.

On the other hand, it was observed that all of the participants were able to play games through Kinect. After struggling a little bit, they were able to adopt themselves to the motion requirements of the games and complete them. They mostly enjoyed games, and wanted to play different ones. Subject 1 commented about it by saying to his father "daddy, when we come back next time, I want to stay longer".

CHAPTER 5

DISCUSSION AND CONCLUSION

In this chapter, results will be discussed according to research questions. Also, suggestions for the future work will be given along with the specifications on how to develop games for the visually impaired.

1- Is it possible to improve the effectiveness of the remaining vision of a person with low vision? Can they improve their eye-hand and eye-body coordination?

This study proposes a rehabilitation system through games that can be played with motion capture systems, specifically with Kinect, for the visually impaired. Results of the experiments, both qualitative and quantitative, demonstrated that games that can be played with motion capture systems might actually improve eye-body coordination which is similar to results of Rosser et al.'s research [8]. When scores of participants' first games are compared to their last games, it can be suggested that there is an improvement in the short term. This improvement can also be seen in their reluctance. Similar to increased motivation in participants in Chang et al.'s research, participants in this study who were reluctant to use their hands at first, were able to get high scores after they played a couple of levels [14]. Further studies may be carried out in order to find out if this improvement can also be seen in the long term. Games that require eye-hand coordination, such as catching objects with hands or games that require eye-body coordination, such as dodging object with the whole body should be developed, and their long term effects should be observed. Moreover, observations and comments of the participants suggested that Kinect games could be valuable in providing entertainment. Most of the participants stated that they had fun and would play if there were more games.

In conclusion, the results showed that the visually impaired can improve their eye-body and eye-hand coordination. Similar to Chang et al.'s statement that Kinect could be a valuable tool in autonomous physical rehabilitation; results of this study indicate that motion capture games could be a valuable tool in providing this development [14].

2- Are motion capture systems suitable for the visually impaired as gaming controllers? What can motion capture systems offer to the visually impaired?

Motion capture systems provide a novel way for the visually impaired to interact with technology. Since these systems see them, instead of requiring blind to see those systems, there is already an established interaction connection between the player and the game. All is left to programmers to generate feedback to keep this interaction flowing. In our study, we showed that hand or body tracking games might be beneficial to the visually impaired.

On the other hand, the system that is proposed in this research does not come without limitations. First and foremost limitation is the motion capture distance of the Kinect, not far limit, but the near limit. Due to the fact that a person with a low vision would try to come closer to the screen in order to see better, Kinect's near tracking capabilities raise an issue. Modified version of Kinect with "near mode" or the newer and improved version of Kinect which is released with Xbox One might address this issue. Using a larger screen TV could also provide a better view for the visually impaired. However, projection systems should be avoided; since they do not emit light, they are harder to be seen compared to TVs.

Relatively small viewing angle of Kinect raises another problem with the ergonomics. Even though Kinect was able to track children perfectly when they respected the near clip limit, the limitations of the room caused problems. However, this problem can easily be overcome by using large open areas.

Another limitation of the project was not about Kinect, but it was about the project itself. Since this research is a relatively new project, its scope was rather limited. A future work with more participants and a control group on a longer term would be beneficial. The data that is going to be collected would create a bigger sample space, which would provide a better understanding on the effects of rehabilitation with Kinect.

3- What kind of games can be developed for the visually impaired? What specifications should be followed along with the heuristics of game design?

This study has many aspects to improve for a future work. Games that are developed in the scope of this project forms a list for a good starting point. However, game development for the blind is not limited to this list. A precision game, which requires players to complete an action with precision, e.g. a game in which the player tries to fit a key to a keyhole, may also improve eye-hand coordination. Dancing games or exercise games might be both beneficial and fun, too. These games can also provide custom rehabilitation programs similar to Lange et al.'s study [13].

An important addition to the project would be a monitoring system. In such a system, players' data could be viewed from a web based application. Games can include a login system in which the players login to the system using their credentials. Of course, considering the visually impaired might have difficulties using keyboards, this login system should be developed so that it would not require extra effort. After completing the game collected data of the visually impaired people's gameplay could be submitted to a server with their login information where they are parsed and inserted into a database. Later on, doctors or trainers could login to this monitoring system on the web using their own credentials and list their patients or trainees and their gameplay data. This data could be served as interactive charts. For example, a chart for the "Hand Tracker" game could have a time slider and when the user moves this slider, the chart can show the position of the hands and red balls in the corresponding time interval (see Figure 9). This system would enable doctors or trainers to compare their patients' or trainees' previous games to newer ones and monitor their progress. These data could also be used as a reference for a rehabilitation program or in other researches.

Currently, games that are developed in the scope of this project require at least a sighted person even to start a game. Moreover, since those games are developed only for their gameplay, they do not include a user interface. Also, not following the heuristics of good game development, these games do not include a tutorial level either. For a better user experience, games should be easy to play, explain game mechanics to the user via a tutorial level and offer an interface that can be used with Kinect. Adding audial feedback to every single action in the game (such as catching, missing, starting, completing etc.) would also improve the user experience.

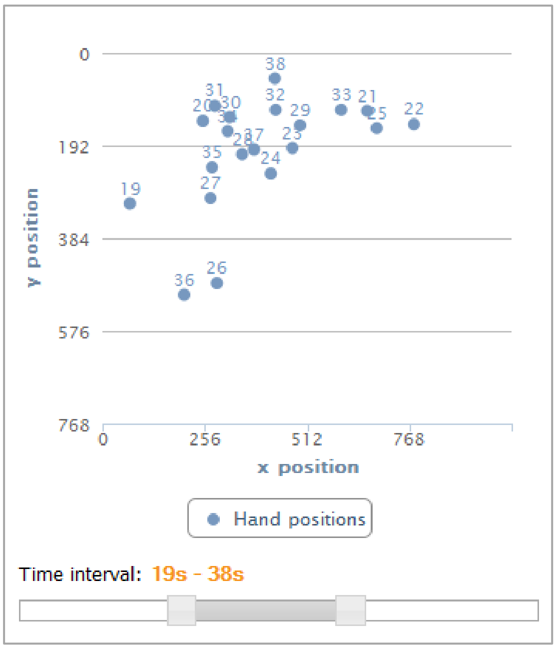


Figure 9: An example of proposed monitoring chart

In respect to these limitations, suggestions, observations during the experiments and player comments, following specifications are suggested as heuristics for Kinect game development for the visually impaired. These specifications should not be considered a replacement for other game development heuristics but an addendum to them:

1- Elements and background of the game should be colored so that the game elements can be distinguished from background easily.

2- Games should be developed to be played in a large screen and all the elements in game should be designed accordingly.

3- User interface should be minimal and easy to use. Interface should not require a mouse or a keyboard, and should be controllable with Kinect.

4- Feedback should not rely on visuals; auditory feedback and directing mechanism must be implemented in all aspects of the game (interface, success, failure, game start, game end etc.).

5- Since Kinect's tracking limitations can be problematic for the visually impaired, amount of body movements that the game requires should be measured and implemented carefully. Limitations of the rooms should also be considered when designing motion based games.

6- Games should include a tutorial level, which introduces the player to the game through audio. Since players do not know how to "see" a new game, teaching them how to play with a visual tutorial would be inefficient.

REFERENCES

[1] "WHO | Visual impairment and blindness", August, 2014, Retrieved August 10, 2014, from http://www.who.int/mediacentre/factsheets/fs282/en/

[2] (1972). *Prevention of Blindness*. World Health Organization, Geneva.

[3] "ICD-10 Version:2010", Retrieved August 10, 2014 from http://apps.who.int/classifications/icd10/browse/2010/en#/H54

[4] (2002). *Visual Standards: Aspects and Ranges of Vision Loss with Emphasis on Population Surveys*. International Council of Ophthalmology, Sydney.

[5] R Sakaguchi, S Takasu, & T Akiyama. (2000). *Study concerning the colors of tactile blocks for the visually handicapped -- Visibility for the visually handicapped and scenic congruence for those with ordinary sight and vision.*. JIPEA World Congress, Japan.

[6] "Kinect for Windows", Internet: http://www.microsoft.com/en-us/kinectforwindows/

[7] "Kinect for Windows Sensor Components", Internet: http://msdn.microsoft.com/en-us/library/jj131033.aspx

[8] Rosser, J. C., Lynch, P. J., Cuddihy, L., Gentile, D. A., Klonsky, J., & Merrell, R. (2007). *The impact of video games on training surgeons in the 21st century.* Archives of Surgery, 142(2), (p. 181-186).

[9] Green, C. S., & Bavelier, D. (2007). *Action-video-game experience alters the spatial resolution of vision.* Psychological Science, 18(1), (p. 88-94).

[10] Vanacken, L., Notelaers, S., Raymaekers, C., Coninx, K., van den Hoogen, W., Ijsselsteijn, W., & Feys, P. (2010*). Game-based collaborative training for arm rehabilitation of MS patients: A proof-of-concept game*.

[11] Deutsch, J. E., Borbely, M., Filler, J., Huhn, K., & Guarrera-Bowlby, P. (2008). *Use of a low-cost, commercially available gaming console (Wii) for rehabilitation of an adolescent with cerebral palsy.* Physical therapy, 88(10), (p. 1196-1207).

[12] Saposnik, G., Teasell, R., Mamdani, M., Hall, J., McIlroy, W., Cheung, D., Thorpe, K., Cohen, L., & Bayley, M. (2010). *Effectiveness of virtual reality using Wii gaming technology in stroke rehabilitation a pilot randomized clinical trial and proof of principle.* Stroke, 41(7), (p. 1477-1484).

[13] Lange, B., Chang, C. Y., Suma, E., Newman, B., Rizzo, A. S., & Bolas, M. (2011, August). *Development and evaluation of low cost game-based balance rehabilitation tool using the Microsoft Kinect sensor.* Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE (p. 1831-1834). IEEE.

[14] Chang, Y. J., Chen, S. F., & Huang, J. D. (2011). *A Kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities.* Research in developmental disabilities, 32(6), (p. 2566-2570).

[15] Rector, K., Bennett, C. L., & Kientz, J. A. (2013, October). *Eyes-free yoga: an exergame using depth cameras for blind & low vision exercise*. Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility (p. 12). ACM.

[16] Morelli, T., & Folmer, E. (2014). *Real-time sensory substitution to enable players who are blind to play video games using whole body gestures.* Entertainment Computing, *5*(1), (p. 83-90).

[17] Mann, S., Huang, J., Janzen, R., Lo, R., Rampersad, V., Chen, A., & Doha, T. (2011, November). *Blind navigation with a wearable range camera and vibrotactile helmet*. Proceedings of the 19th ACM international conference on Multimedia (p. 1325-1328). ACM.

[18] Shrewsbury, B. T. (2011, October). *Providing haptic feedback using the Kinect.* Proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility (p. 321-322). ACM.

[19] Zöllner, M., Huber, S., Jetter, H. C., & Reiterer, H. (2011). *NAVI–a proof-of-concept of a mobile navigational aid for visually impaired based on the Microsoft Kinect* (p. 584-587). Springer Berlin Heidelberg.

[20] Filipe, V., Fernandes, F., Fernandes, H., Sousa, A., Paredes, H., & Barroso, J. (2012). *Blind navigation support system based on Microsoft Kinect*. Procedia Computer Science, 14, (p. 94-101).

[21] "Özel Gönül Turgut Görme Engelliler Özel Eğitim Okulu", Internet: http://www.gonulturgut.com

[22] "Yeni Kurtuluş Özel Eğitim ve Rehabilitasyon Merkezi", Internet: http://kurtulusozelegitim.com

[23] "Işık Göz Merkezi", Internet: http://www.isikgoz.com.tr

[24] Ataman, A. (1984). *Kör çocuğun gelişiminde oyunun önemi* Eğitim Bilimler Fakültesi Dergisi, Ankara Üniversitesi Eğitim Bilimleri Fakültesi Yayınları, 16(2)

[25] Dal, M. (2010). *Görme Engelliler İçin Bir Mobil Yön Yardım Cihazı Tasarımı Ve Uygulaması*, Yüksek Lisans Tezi. Gazi Üniversitesi, Bilişim Enstitüsü, Elektronik-Bilgisayar Eğitimi Anabilim Dalı.

[26] Alptekin, O. (2011). *Görme Engelliler İçin Zeki Bir Öğretim Sistemi Tasarımı*. Yüksek Lisans Tezi, Beykent Üniversitesi, Fen Bilimleri Enstitüsü, Bilgisayar Mühendisliği Anabilim Dalı.

[27] Koray, G. (2012). *Görme Engelliler İçin Nesne Algılama Ve Tanımlama Sistemi. Doktora Tezi*. İstanbul Üniversitesi, Fen Bilimleri Enstitüsü, Biyomedikal Mühendisliği Anabilim Dalı.

[28] Green, C. S., & Bavelier, D. (2006). *The cognitive neuroscience of video games*. Digital media: Transformations in human communication, (p. 211-223).

[29] Rosser Jr, J. C. (2004, January). *Are Video Game Players Better at Laparoscopic Surgical Tasks?* Newport Beach, CA: Medicine Meets Virtual Reality Conference.

[30] "Unity – Game Engine", Internet: http://www.unity3d.com

[31] "Atari", Internet: http://www.atari.com

APPENDIX

ALGORITHMS AND XML SCHEMAS

Table 7: Update algorithm of the LevelManager script in Hand Tracker game

LevelManager

```
Update()
if isPlaying then
  timer ← timer - deltaTime
  playTimer ← playTimer + deltaTime
  update hand positions
  if timer <= 0 then
    SpawnRedBall()
    timer ← spawnTime
  endif
  if playTimer >= maxPlayTime then
    EndGame()
  endif
endif
```

Table 8: Score increasing algorithm of the LevelManager script in Hand Tracker game

LevelManager

```
IncreaseScore()
add one to score
add one to consecutiveCatch
if consecutiveCatch is 5 then
  decrease spawnTime
  decrease redBallSize
  increase redBallSpeed
  consecutiveCatch ← 0
endif
```

Table 9: Difficulty decreasing algorithm of the LevelManager script in Hand Tracker game

LevelManager

```
DecreaseDifficulty()
  add one to consecutiveMiss
  if consecutiveMiss == 5 then
    increase spawnTime
    decrease redBallSize
    decrease redBallSpeed
    consecutiveMiss ← 0
  endif
```

Table 10: Update algorithm of the red balls in Hand Tracker game

RedBall

```
Update()
  move the ball
  if collidedWithHand then
    IncreaseScore()
  endif
  if isOutOfScreen then
    DecreaseDifficulty()
  endif
```

Table 11: An example from the XML file of the Hand Tracker game


```
<root>
    <p time="0" l_x="0.220" l_y="1.135" l_z="-5" r_x="-
0.2201" r_y="1.001" r_z="-5" score="0">
        <e x="-0.750" y="1.948" z="-5" />
        <e x="-0.918" y="3" z="-5" />
    </p>
    <p time="0.015" l_x="-0.588" l_y="1.148" l_z="-5"
r_x="0.015" r_y="1.002" r_z="-5" score="0">
        <e x="-0.750" y="1.942" z="-5" />
        <e x="-0.918" y="2.994" z="-5" />
    </p>
    <p time="0.030" l_x="-0.589" l_y="1.151" l_z="-5"
r_x="0.01" r_y="1.009" r_z="-5" score="0">
        <e x="-0.750" y="1.938" z="-5" />
        <e x="-0.918" y="2.989" z="-5" />
    </p>
</root>
```

Table 12: An example from the XML file of Breakout game


```xml
<root time="117.171">
    <point paddle_x="0" paddle_y="-15.014" ball_x="-
12.809" ball_y="3.715" />
    <point paddle_x="-1.309" paddle_y="-15.014"
ball_x="-13.233" ball_y="4.139" />
    <point paddle_x="-1.328" paddle_y="-15.014"
ball_x="-13.55" ball_y="4.457" />
    <point paddle_x="-1.334" paddle_y="-15.014"
ball_x="-13.976" ball_y="4.210" />
    <point paddle_x="-1.389" paddle_y="-15.014"
ball_x="-14.294" ball_y="3.892" />
    <point paddle_x="-1.503" paddle_y="-15.014"
ball_x="-14.612" ball_y="3.574" />
    <point paddle_x="-1.635" paddle_y="-15.014"
ball_x="-14.930" ball_y="3.255" />
    <point paddle_x="-1.755" paddle_y="-15.014"
ball_x="-15.353" ball_y="2.831" />
    <point paddle_x="-1.875" paddle_y="-15.014"
ball_x="-15.673" ball_y="2.513" />
    <point paddle_x="-1.977" paddle_y="-15.014"
ball_x="-15.991" ball_y="2.195" />
</root>
```


Table 13: Update algorithm of BallController in Breakout game

BallController

```
FixedUpdate()
if contactPoints > 0 then
  get all contact points
  average contact points
  CheckForDirectionChange()
endif

if changeX then
  reflect ball direction on X
endif

if changeY then
  reflect ball direction on Y
endif

move the ball
```

Table 14: Collision detection of BallController in Breakout game

BallController

`OnCollisionEnter()`
if collidedObject is paddle **then**
  move the ball on x to resolve the collision
  reflect ball direction on X
endif
if collidedObject is brick **then**
  register contact points
  remove brick
  send message to LevelController to increase score
endif
if collidedObject is wall **then**
  reflect ball direction
endif

Table 15: Checking for direction change for the ball algorithm in Breakout game

BallController
`CheckForDirectionChange()` get last known ball direction calculate collision direction from contact points compare last direction to change direction calculate is changeX true calculate is changeY true

Table 16: Update algorithm of LevelManager in Breakout game

LevelManager

`Update()`
playTime ← playtime + deltaTime
update paddle position
if numberOfBricks == 0 **then**
  save positions and play time to XML file
  end game
endif
register ball position
register paddle position

Table 17: Start algorithm of the KinectPaint game

LevelManager

```
Start()
blackFill ← Color.black
redFill ← Color.red
whiteFill ← Color.white

set base texture pixels to whiteFill
set brush size
set target color to black
```

Table 18: Update algorithm of the KinectPaint game

LevelManager

```
Update()
playTime ← playTime + deltaTime

if playTime >= maxPlayTime then
  end game
endif

if hand is in paint area then
  get hand position
  calculate pixel the hand is on
  calculate pixels in a circle of brush size
  set those pixel colors to target color
endif

get number of painted pixels

if painted pixels / number of pixels >= 0.8 then
  set base texture pixels to target color
  set target color to next target color
  save paint duration and hand positions to XML file
endif
```

Table 19: An example from the XML file of KinectPaint Game

```
<paint time="36.615">
    <hand x="77" y="120" />
    <hand x="93" y="103" />
    <hand x="127" y="65" />
    <hand x="175" y="33" />
    <hand x="225" y="0" />
```

```
    <hand x="279" y="0" />
    <hand x="306" y="0" />
    <hand x="326" y="0" />
</paint>
```