A technique for the measurement and possible rehabilitation of Visual Neglect using the Leap Sensor

Can Eldem

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Can Eldem

This thesis is dedicated to my parents for their love, endless support and encouragement, thank you so much. I also dedicate my work in memory of my aunt.

Declaration

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Abstract

Visual Neglect is a common neuropsychological deficit associated with a person having a Stroke [1]. This deficit is manifested by a Stroke patient's inability to notice things usually in the left hand side of their visual space. This has a serious impact on their daily lives as they fail to notice obstacles while walking or leave half of a meal uneaten because they are unaware of its existence. Currently, pen and paper-based techniques are used to assess the presence of Visual neglect in patients and there have been a number of rehabilitative programs developed to try and ameliorate the symptoms of Visual Neglect with limited success [2]. Using the Leap Sensor, this project sets out to develop a novel measurement paradigm for the detection and diagnosis of visual neglect as well as laying the ground work for developing a novel rehabilitative intervention (a means of helping stroke patients to either recover from visual neglect or make adaptations do lessen the effect of visual neglect). In addition, we replace pen and paper tests with a web based system which enables professionals to complete such assessments of visual neglect virtually and archive their results.

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Chapter 1

Introduction

1.1 Introduction

Visual Neglect[1] is a common neuropsychological deficit associated with a person having a Stroke [1]. This deficit is manifested by a Stroke patient's inability to notice things usually in the left hand side of their visual space [1]. This has a serious impact on their daily lives as they fail to notice obstacles while walking or leave half of a meal uneaten because they are unaware of its existence. Currently, pen and paper-based techniques are used to assess the presence of Visual neglect in patients and there have been a number of rehabilitative programs developed to try and ameliorate the symptoms of Visual Neglect with limited success [2]. Using the Leap Sensor and Processing programming language, this project sets out to develop a novel measurement paradigm for the detection and diagnosis of visual neglect as well as laying the ground work for developing a novel rehabilitative intervention (a means of helping stroke patients to either recover from visual neglect or make adaptations do lessen the effect of visual neglect). Measuring Visual Neglect properly depends on creating robust and dependable software because if measurement is not successfully completed it is not possible to apply correct rehabilitation to the patient. This project aims to provide certain level of dependability in order to compensate issues in previous measurement techniques.

1.2 Problem Statement

There are existing methodologies for diagnosing and rehabilitation for Visual Neglect. However, existing diagnosis methods do not give too much insight about the patient's Visual Neglect. They are mainly used as binary classifier[3] (i.e. wether or not the patient is Visually Neglected).None of the tests attempt to map specific areas of Visual Neglect. Diagnosing and measuring the performance of a patient over time is crucial because when a treatment is applied on a patient, effectiveness of treatment should be measured by simply diagnosing and measuring the patient's performance again after

[1] Neglect=Visual Neglect=Visuo Spatial Neglect=Visuoperceptual Neglect=Visual Hemineglect

treatment. If this process could not be done accurately, it is not possible to develop precise treatment for the patient.

1.3 Motivation

The project contributors are driven by the primary goal to help vulnerable people who are recovering from a debilitating a visuoperceptual problem, sometimes known as Visual perceptual or visuospatial Neglect or simply visual neglect. People suffering from this problem have limited opportunity to rehabilitate this problem, moreover failure to rehabilitate visuospatial neglect has repercussions for other problems associated with brain injury such as motor deficits resulting in problems with walking, or moving the upper limbs, or the fine motor movement of the hands. The terms for these everyday abilities is activities of daily living (ADLs) and returning to baseline or normal function is always the primary rehabilitation goal for both patients and professional staff. There are two main reasons for this problem of limited opportunity, the first one is that there are not many proven directed rehabilitative paradigms for visual neglect, and secondly the precision of assessing neglect which may be have localised specificity is limited by the availability of traditional binary classifiers (which reveal only the presence or absence of neglect and do not specify which areas in the visual field are neglected). People suffering from Visuospatial Neglect resulting from Stroke are often treated in dedicated Stroke units. It is often the case even in dedicated hospital environments such as a dedicated Stroke unit where recovering patients receiving the very best state of the art rehabilitative treatment targeting their acquired dysfunction that the time and resources focussed on Visual Neglect is limited. This is usually due to financial constraints and limited resource which are normally directed at less prosaic but extremely important deficits such as a patient's inability to perform their activities of daily living such as the ability to walk, speak, eat, read, write and manipulate objects with their hands (these attributes are usually termed activities of daily living ADLs). This investigative research, which is carried out from the assessment and rehabilitative perspectives of patient treatment, would help fill the need in a large patient population for the continuation of Visual Neglect treatment beyond that normally affordable and provide novel self-directed and readily accessible paradigms for treatment. This is done by using rapid development of state of the art and affordable mass produced consumer HCI (Human Computer Interface) technology coupled with techniques of modern open source software development. The Leap Motion Sensor (Hardware) and the processing framework (Software) provide the technological underpinnings for realising this goal. While the collaborative and interdisciplinary focus of this research leverages the essential knowledge of visual spatial perceptual and cognitive cognate discipline with exercise computer science applications.

1.4 Aims and Objectives

After series of meetings with my advisor Joseph Duffin and our research collaborator Kate Forte we came up with two main objectives for our project.

1. Develop software that will provide a new and innovative testing paradigm for Visual Neglect (problem with visual inattention suffered by Stroke patients) as well as possible means for rehabilitation. The basic idea of this system is that a patient must move a simulated object which is in their unaffected (right side) field of vision to a target location on the left side of their field of vision. The system will track how successively the patient achieves this over a number of trials (configured by the professional). This tracking information is then used to map the areas of visual neglect in the patient's left sided field of view (assessment) and will also input into the elements of the system designed to help ameliorated the effect of this neglect (rehabilitation).

2. Replicate existing pen and paper tests and create series of web applications that will allow examiners to apply these existing diagnosis methods using web browser instead of pen and paper tests.

1.5 Report Structure

This section provides information about each chapter. First chapter provides information about the problem state and gives a small definition of visual spatial hemi neglect and we describe our objectives and motivation. Second chapter, provides detailed information about spatial hemineglect and introduces diagnosis and treatment methods. Third chapter includes our solution to diagnosing and possibly treating visual neglect patients with the technologies that we use such as leap motion controller. Furthermore, it includes a study of replicating existing pen and paper diagnosis methods with a web based system. Fourth chapter provides details about evaluation of a designed system. Fifth chapter summarize our findings and mentions about future work with the development processes that is followed through the project.

Chapter 2

Related Work

In this section, we will provide information about Visual Neglect, diagnosis and treatments methods. Throughout our research we only come across with one software system that transfers the existing diagnosis techniques to a computer environment as a desktop software[3]. Therefore, we believe that we are having first steps towards creating innovative approach for diagnosing visual neglect patients. The patient fails to attend to stimuli on one side of their visual fields.

2.1 Visual Spatial Hemineglect

Spatial hemineglect (also called visual inattention [4]) refers collectively to disorders of spatial cognition, which concern specific sectors of space with reference to a given coordinate system [4]) . The word "hemi" represents a main feature of the disorder, which differentiates spatial neglect from global deficits of spatial exploration and perception[1]. In other words, only one side or one cerebral hemisphere is causing the problem of spatial perception of a patient. Following a stroke or trauma, patients who have cerebral lesions(damaged brain tissue) including the posterior-inferior parietal and the premotor cortex, most often in the right hemisphere, sometimes fail to explore the extra-personal and personal sectors of space contralateral (on the opposite side) to the side of the lesion[1], [4]. These patients, are not aware of stimuli presented in these portions of space, or may sow a lack of awareness of contralateral body parts and problems of the functioning of contralateral body parts [1], [4]. Most of the right-hemisphere stroke patients shows signs of contralateral neglect, failing to be aware of objects or people to their left in extra personal space [5]. For instance, if a patient has a lesion on his right cerebral hemisphere sometimes he will fail to explore the extra personal and personal sectors of space taking place on his left side[5]. The phenomenon whereby an injury to the right side of the brain causes problems of perceptions and movement to the left side is due to the way the brain is "wired"[6].

2.1.1 Anatomy of Neglect

As we indicated before, most of neglect patients have suffered right-hemisphere strokes but the syndrome has been more specifically associated with damage to the following regions shown in Figure-2.1;

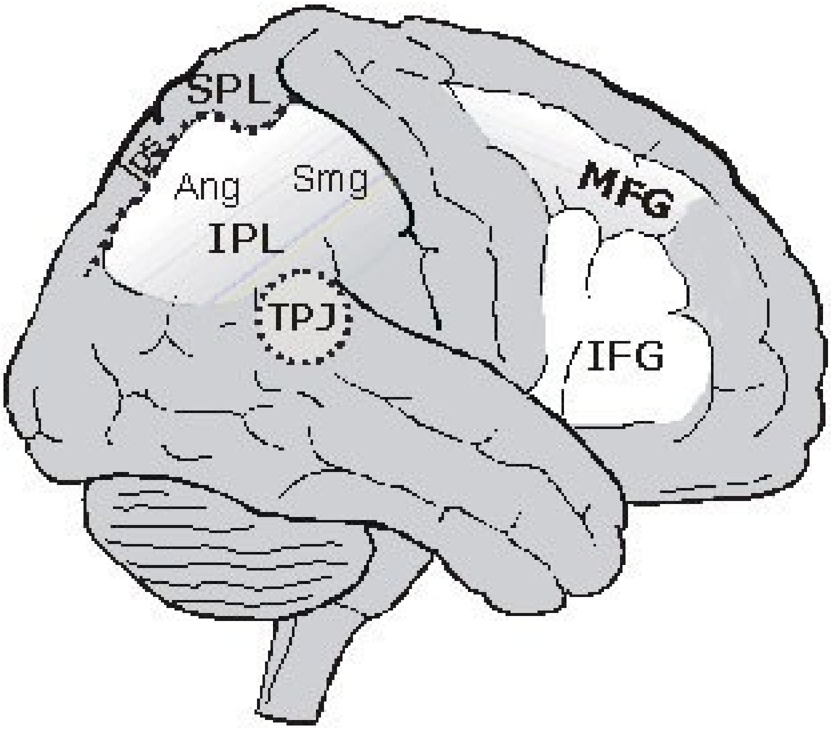

Figure 2.1: Right side of human brain indicating some areas associated with visual spatial hemineglect [7]

Abbreviations in Figure-2.1 explained below;

- IPL: inferior Parietal Lobule (IPL)
- Ang: Angular Gyrus • Smg: Supramarginal Gyrus
- TPJ: Temporoparietal Junction
- IFG: Right Inferior Frontal Gyrus
- MFG: Middle frontal Gyrus
- SPL : Superior Parietal Lobe
- IpS: Intraparietal Sulcus

There are many discussions over the mechanism involved in the problems of Spatial Hemineglect. However, there are some theories that are agreed by researchers. Visual Spatial Hemineglect has been associated with lesions of the right posterior parietal cortex, particularly the IPL or TPJ [7] . In addition to this there is agreement among researchers that Spatial Hemineglect does not come about because of a lesion on a single location, it requires the involvement of multiple areas [7]. In addition to posterior cortical areas, subcortical lesions in the absences of damge directly on the cortex can lead to neglect, although this may be via indirect effects on overlying cortical regions. Moreover, isolated lesions of the right frontal lobe may be associated with neglect, without involvement of posterior parietal or temporal regions [1], [5], [7]. Different patients have different combinations of posterior cortical, frontal, subcortical and white matter damage. This heterogeneity may be a key factor determining the diversity of functional deficits [1], [5], [7], [8] .Varieties and different deficits will be discussed in further sections. Left cerebral hemisphere maps the right side of personal space while the right cerebral hemisphere is involved in both left and right aspects of personal space [6]. Therefore, lesions on the right hemisphere are more likely to result in neglect which is more severe and long lasting then in the case of left hemisphere lesions [1], [7] .

2.2 Symptoms of Visual Spatial Hemineglect

Visual Hemineglect could occur in many different forms in patients and more importantly, many patients are unaware they have these problems. This is also known as anosognosia which is a deficit in self-awareness of a person's disability[5]. Vallar 1988,has described that the symptoms of Spatial Hemineglect could be observed under tree different categories [1];

- Extra personal space (the space outside of arm's reach)
- Peripersonal space (intermediate space between Personal and Extra Personal Space)
- Personal space (the subject's body)

2.2.1 Extra personal space (Visual and auditory objects in extra personal space)

Neglect in extra-personal space is neglect for objects or the environment outside the space that an individual can reach with their arms. For instance, patients might be unaware of large objects or people on their left side. (Considering they have lesion on their right cerebral hemisphere). Patient's drawings may not complete because they would fail to include items towards the neglected side. Figure-2.2 shows and example of this phenomenon where a patient is asked to copy, patient asked to copy drawing of the model (house) on the left side of the figure to a piece of paper. However as can be seen copied house is not complete (half of the house copied by patient). This shows how a patient perceives the outside world.

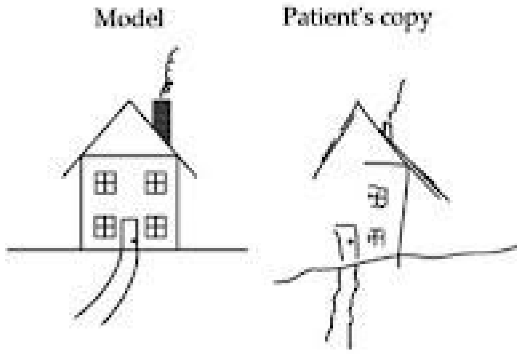

Figure 2.2: Patient ask to copy the image on the left side of the figure to piece of paper [9].

If you address these people from their left side, you will not able to interact with them as they may not be able to attend to or be aware of their left side. However, if you approach these people from their right side it is possible to interact with them [9].

2.2.2 Peripersonal Space

There is a middle ground between personal and extrapersonal space called peripersonal space. If personal space is person's body itself, peripersonal space is the space you can reach with your hands without moving so, things on your desk[1]. For instance, people who has neglect in their peripersonal space may eat from only one side of a plate and complain that they are being served inadequate portions of food[4].

2.2.3 Personal space (the subject's body)

Neglect may also extend to patient's personal space [9]. In other words, a patient may also have some perceptive issues about their own body. For instance, a patient may not wash or shave their left part of their body or woman may not apply make up to the left side of her face.[9].Actually, what happens is patient does not accept the fact that the left part of their body belongs to them [7] .Furthermore, this problem could be so profound that it could affect patients' motor skills. This is known as "motor neglect". In the case of this deficit, some patients are not able to use limbs opposite of the lesion even if they have no physical problems.

2.3 Diagnosis of Spatial Hemineglect

Severe visual neglect might be diagnosed by simple observation. For instance, patients with visual neglect might turn their gaze to the extreme right although leftward eye movements are intact on formal testing [5]. They may also fail to address those on their neglected side. There are however, simple pen and paper-based techniques which are used to assess the presence of Visual Spatial Hemi neglect in patients. These include cancellation, line bisection and drawing and copying tasks. It is recommended

Figure 2.3: A neglected person does not shave his left side. However, he considers his face is fully shaved.[9]

that, several of these paper-based assessment techniques should be used to measure spatial hemineglect because every test has some strengths and weaknesses using spatial hemineglect[5]. We will discuss the strengths and weaknesses of these tests compared to each other in following parts of this section. These pen and paper-based tests, used to assess visual spatial hemilneglect are described in the following sections .Here are the pen and paper techniques that is used to assets spatial hemineglect; These tests will also be sued to evaluate our system.

2.3.1 Line bisection

In this test the patient's task is to mark with a pencil the mid-point of six horizontal black lines (two 10 cm, two 15 cm, two 25 cm in length, 2mm in width), which are presented in a random fixed order [10]. Each line was printed on an A4 sheet, with the centre of each line being aligned with the mid-sagittal plane of the subject's body (an imaginary line running down the centre of a person's nose dividing their visual field of view equally into two halves) [10]. Patients used their right hand which is, unaffected by motor deficits in right brain damaged patients. The score on this test was measured as the deviation of the patient's mark from the objective midpoint, measured to the nearest mm; a positive score denoted a rightward displacement, a negative score a leftward displacement(see Figure-2.4) [10].

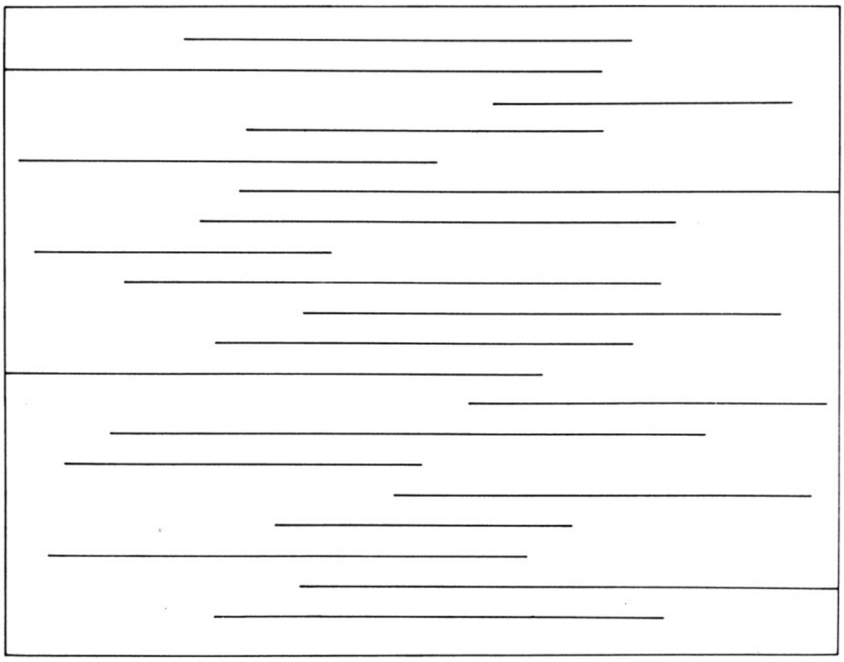

Figure 2.4: Red dots represents patient's mark green dot represents middle point of the line

The settings for the Line Bisection test can be vary. For instance, in the a multiple trial form of the method, the patient is shown a set of 20 lines of various sizes arranged so that six are centred to the left of the midline of a typewriter-paper size page, six to the right of midline, six to the centre. (See Figure-2.5)Since only the middle 18 lines are scored, 180 degrees rotation of the page produces an alternative form of the test [4]. The patient's task is the same as before. Patients who are capable take one trial with each hand, with randomized orientation of the page on first presentation and 180 degree rotation of the page on the second trial[4].

As a result two scores are obtained;

1. The number and position of unmarked lines.

2. Percent Deviation score for left right and centred lines derived by fallowing formula [4]

$$Percent\,deviation = \frac{(Measured\,Left\,Half - True\,Half)}{(True\,Half)*100}$$

The percent deviation is positive if the marks are placed right of centre and negative otherwise(left of centre).Control subjects making an average 2.9 mm deviation to the left, a right deviation cutting score of 15.3 mm indicated left hemispatial inattention [4].

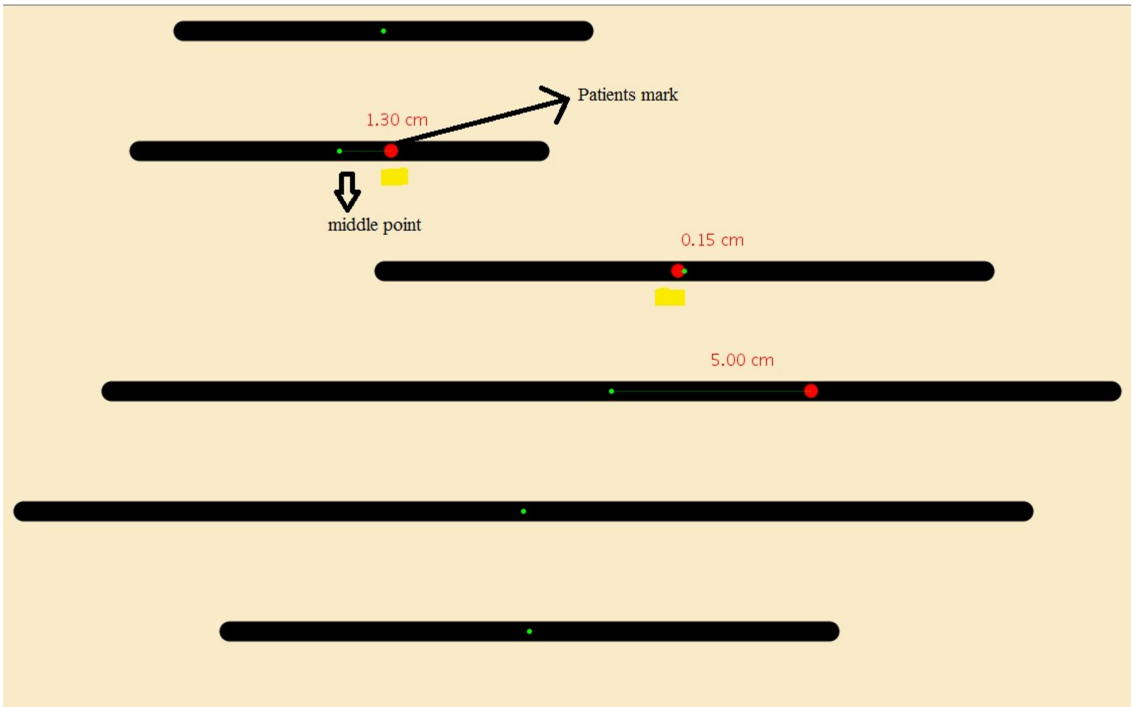

Figure 2.5: The multiple trial version of the line bisection test

2.3.1.1 Characteristics of Line Bisection over Patients

Normal subjects generally tend to mark horizontal lines to the left of centre, typically deviating one to two mms or about 1.6% [4]. In case of left handed objects the left sided deviation is more than the right handed ones. Length of the line also has an effect on accuracy of bisection for both normal and lesion subjects [4]. As it is expected short lines are less likely to elicit a deviation from centre than long ones, longer lines shows greater deviations. Most patients with right sided lesions give greater deviations to the right and most left lesioned patients move the bisection further left with increases in line length [4]. It is observed that single trial is often insufficient to detect defects. The significance of having an adequate sampling of bisection behaviour was indicated by N.V Marsh and Kersel who used four lines in their test and point out that this technique was the weakest among the ones that they tried [4].

2.3.2 Letter cancellation

This test for visual neglect involves patients searching for and marking with a pen target items on a sheet of paper [10]. The patients' task is to cross out all of 104 H letters (53 in the left hand side, and 51 in the right hand side of the sheet), printed on an A3 sheet (See Figure-2.6), together with other letter distractors [10].

B E I F H E H F E G I C H E I C B D A C H F B E D A C D A F C I H C F E B A F E A C F C H B D C F G H E

C A H E F A C D C F E H B F C A D E H A E I E G D E G H B C A G C I E H C I E F H I C D B C G F D E B A

E B C A F C B E H F A E F E G C H G D E H B A E G D A C H E B A E D G C D A F C B I F E A D C B E A C G

C D G A C H E F B C A F E A B F C H D E F C G A C B E D C F A H E H E F D I C H B I E B C A H C D E F B

A C B C G B I E H A C A F C I C A B E G F B E F A E A B G C G F A C D B E B C H F E A D H C A I E F E G

E D H B C A D G E A D F E B E I G A C G E D A C H G E D C A B A E F B C H D A C G B E H C D F E H A I E

Figure 2.6: The patient is required to cross the letter 'H' in this task.[4]

The median omission for 13 control subjects was 1 for this test and median time taken was 100 sec on letters. Normal performance limits have been defined as 0 to 2 omission in 120 seconds [4].Comparing with patient scores with health unaffected control subjects, stroke patients with right- sided lesions were not much slower. However, they had many more omissions left side of the page and no errors.(mdn letters=34) Patients who has lesion on the left made few errors but took up to twice as long in terms of time (mdn letters time= 200 seconds) [4]. In conclusion, performance deficits appeared to be associated with spatial neglect problems with right sided strokes, whereas slowed information processing when strokes involved the left hemisphere [4].

2.3.3 Star cancellation

In this test, the patient's task is to cross out all of the 56 black small stars (30 in the left, 26 in the right side) printed on an A4 sheet (See Figure-2.7), together with distractors [10] (See Figure-2.7) .The page is arranged in columns to facilitate scoring the number of cancelled small stars.Control subjects rarely miss a star (mean score of misses for 50 control subjects was 0.28) [4].

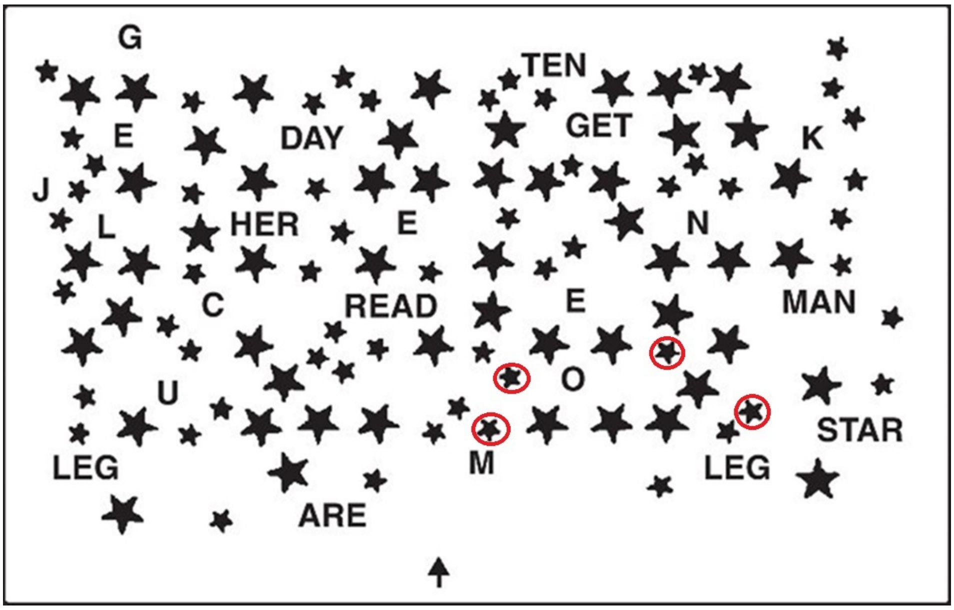

Figure 2.7: Patient is required to cross small stars

This test is designed to increase the cancellation task sensitivity to inattention by increasing it's the test difficulty [4].

2.3.4 Line cancellation

In this test, the patient's task is to cross out all of the 40 black lines printed on an A4 sheet (see Figure-2.8) without any distracting items (Unlike in Figure-2.7).

Test setting should be as follows[10] (the test setting could be vary);

- The target lines were distributed at random in the sheet (20 in the left and right side)
- Target lines were also arranged in four quadrants 13.8 cm wide and 9.5 cm high, with 10 lines per quadrant; the four quadrants were separated by a white cross-shaped area 2 cm wide.

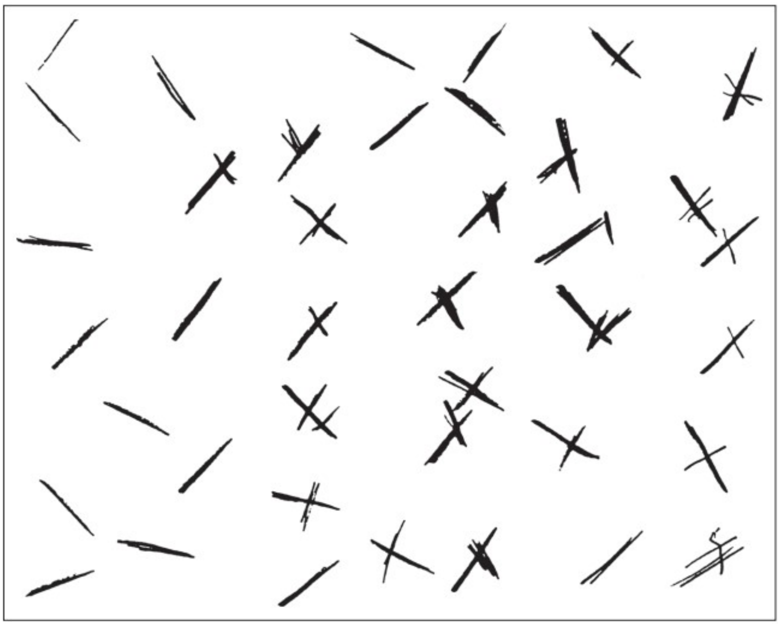

Figure 2.8: Line crossing test. Performance of a patient who has left visuospatial inattention[4]

2.3.4.1 Test results of the line cancelation test compared to the healthy control group

One or no omissions is considered a norm of normality. Only one of 40 control subjects made a right field omission and none omitted lines on the left with the inattention criterion of >=2 omissions on the three left or three right columns, unilateral inattention was identified in seven of the 40 patients [4]. Observations showed that a few patients with left-sided lesions may also display unilateral inattention in this test but those whose lesions involve the right hemisphere tend to leave many more lines uncrossed [4].

2.3.5 The Bells Test

In this test 315 objects are distributed randomly on the page among 35 bells. Construction of this test allows for the rapid visualization of the spatial distribution of the omitted targets and their quantification [11]. Objects are arranged in seven columns and every column has five bells. The patient's task is to simply circle the bells on the page. While the patient is circling the bells the examiner notes by the number of bells circled on a diagrammed page also the order in which the subject finds the bells. The purpose of this is to analyse the patient's scanning strategy [4]. The maximum score that a patient can possibly score in this test is 35. The examiner can observe the spatial distribution of the omitted targets and evaluate the severity of the visual neglect. In the bells test completion time is not a valuable indicator of success or neglect [11]. Generally patients who have visual neglect start cancelling bells from right side whereas healthy subjects start from left [7].

Figure 2.9: The Bells cancellation task, here the patient is required to circle each of the bells interspersed among other objects

Comparing with other tests which mentioned above, The Bells tests has an certain advantage which is that the performance of the subject can be evaluated qualitatively in addition to quantitatively [11].

2.3.6 Object copying Tasks

As the name implies these tasks involves copying the given objects to a piece of paper (See Figure-2.10). For instance, the patient is given a cube and he/she is asked to copy this to another paper [7].

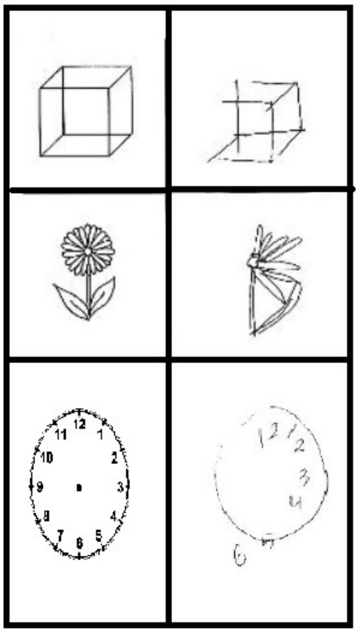

Figure 2.10: Copying tasks, here patients asked to copy given pictures on the left side of the figure. Patients who has spatial hemi neglect are not fully able to copy the given drawing

A Characteristics of the given images is their bilateral nature. Many are bilaterally symmetrical images (See Figure-2.10). This ensures that left and right side of the image contain the same amount of details. Patients might also be asked to recall an object in their memory and draw it on a piece of paper. For instance, patient might asked to draw a clock to a piece of paper without showing any picture of clock to a patient. Although object copying tasks are practical way to detect visual neglect many researchers believe that they are less sensitive form of eliciting visual neglect comparing with cancelation tasks especially when they are used alone [4], [5].

2.3.7 Conclusion

A variety of diagnostic tests for visual neglect were described, and their strengths and weaknesses were discussed [1], [7]. The reason why various types of tests exist is because no single test alone is able to spot neglect in all patients. Moreover, there are many journals pointing out that some patients could show neglect on certain task but not on others [1], [7]. For instance, a patient could display signs of visual neglect in the line bisection test but he might not show visual neglect on the star cancellation test. Nevertheless, some tests are more superior to the others, for example one study showed that the line bisection test missed 40% of the test subjects who have visual neglect. Whereas the letter cancellation and bells tests each missed only 6% of these cases [12].

These tests are generally used to identify the presence or absence of spatial neglect [3]. In other words, these tests do not provide much detail about patient's neglect to examiner such as where exactly in the left hemi field the patient is neglecting to attend to. These tests are just used to verify existence of visual neglect but neglect could be exists for certain parts of spatial area of a patient rather than for the whole left side or for the whole right side of a patient [1]. It can also exist in different levels of space; peripersonal but not extrapersonal or personal etc.

2.3.8 Treatment of Spatial Neglect

The human brain has an incredible capacity to heal itself in certain situations. After a stroke, the brain tries to recover from the damages which resulted in the deficit of spatial hemi neglect. However, it is not possible for brain to recovery fully and reach the same state before the stroke. Therefore, a primary goal of any treatment is to minimise the effect of visual spatial hemi neglect. Different techniques, such scanning therapy and hemianopic patching, prism adaptation, transcutaneous electrical nerve stimulation (TENS) and neck muscle vibration have been shown to alleviate neglect with varying degrees of success. However, there is no evidence found that existing treatment methodologies eradicate effects of spatial neglect 100% [2]. Different treatments could often use in combination with each other [13]. The following section gives a brief overview of some of the major treatment methods that are used to ameliorate the symptoms of visual hemi-neglect.

2.3.8.1 Scanning therapy and hemianopic patching

Scanning therapy is a conventional treatment for visual neglect. This method basically aims to train patients to direct their look towards contralesional space or spare affected by Visual Neglect [7]. For instance, in the case of visual neglect on the left side, the patient is encouraged to look leftwards. Scanning therapy could be applied to a patient in different ways. In one type of scanning therapy the patient is required to detect digits appearing to detect digits appearing in sequence on a large screen (2X3m) in 48 different positions. In the early sessions, the digits were presented in a linear sequence and the patient had to press a keypad and read each stimulus aloud as quickly as possible. As the patient's scanning abilities improved, nonlinear and less predictable presentation sequences were used. Both response time and number of omissions were recorded [14].

Even though these methods showed some success, patients were not able to reflect these improvements to tasks outside of the training environment [7]. The reason why patients very often fail outside of the rehabilitation environment is that, the rehabilitation environment deliberately remoulds and modifies the patient's behaviour. However, once the patient is outside of the rehabilitation environment he/she does not have a chance to receiver reminders. Therefore, most of the patients fails outside of the rehabilitation environment [7]. Another method involve using special spectacles that obstruct the non-neglected side of vision in each eye, effectively obliging neglect patients to direct their look to their opposite side of the lesion [7]. However, there are some issues reported by A Parton, P Malhotra, M Husain with this kind of spectacles. "Many patients do not tolerate these spectacles well, because their natural inclination is to gaze towards the now occluded ipsilesional visual field, and, in our limited experience with this technique, compliance is not optimal [7] ."

2.3.8.2 Limb activation

This method basically encourages patients who suffer from neglect to use their motor skills contralateral (on the opposite side) to the side of their brain lesion.[15]. For example, the paper by Robertson, North, Geggie's which describes a case study of a person who is diagnosed with spatial hemi neglect who is trained to always place and hold his left arm that is, locate it visually before beginning a motor task (e.g washing, eating, reading etc.). After intensive therapy sessions with a therapist, the patient became able to complete these tasks with his left arm. Moreover, after this period the same test is applied to the subject which is used to diagnose his spatial hemi neglect in first place. Results of the diagnosis tests (e.g. line bisection, start cancellation) showed that subject's scores have improved approaching normality. Robertson et al (1992) reported that the letter cancellation performance improved from a mean (SD) of 16-3 (2 4) correctly cancelled letters before treatment to a mean of 47.5 (8d1) during training ($p < 0\text{-}001$). The prose reading performance also improved from 52% (18%) accuracy during baseline to a mean of 93% (7%) accuracy during training [15].

2.3.8.3 Prism adaptation

One of the most convenient and promising treatment methodologies of visual spatial hemineglect is prism adaptation. This method is mostly preferred because it is cheap, easy to implement and some studies showed that it has long term amelioration on patients [5], [7], [16]. Prism adaptation is simply shifting a visual field of a patient using prisms. For visual hemispatial neglect the patient's visual field generally (See Figure-2.11) shifted 10 $^\circ$ rightward [16]. This helps patients to alter their manual body-midline and improve their results on classical neuropsychological tests [17].

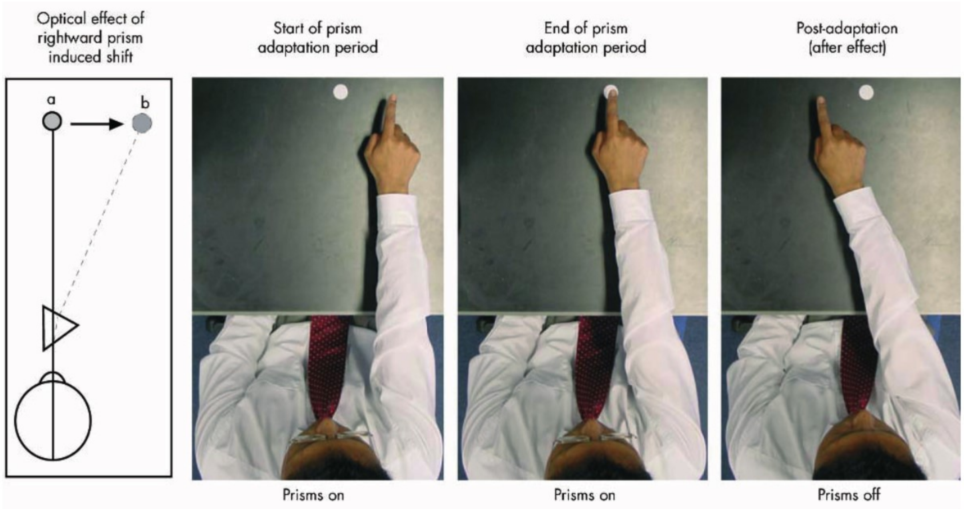

Figure 2.11: Using the prism a patient's visual filed is shifted to rightwards. As it is seen from the figure, the patient is able to point out the objects after therapy [7].

As we indicated before it has been shown that prism adaptation is a an effective way of achieving long-lasting improvements in the treatment of neglect [5], [7], [16].

2.3.8.4 Neck muscle vibration

The starting point of using mechanical vibration for spatial hemineglect is based on anatomical studies in humans and neurophysiological work on the primate brain [18]. One model how spatial representation is achieved links the phenomenon of neglect to damage to a sensory integration area where the inputs of peripheral sensory and motor related signals become integrated into an egocentric coordinate. Egocentric coordinate system is in authority for the localisation of the body in space, and of object position relative to the body [18]. According to this model the peripheral sensory representation systems in the brain are assumed largely intact and function as normal. It is in the more executive system where the problem is observed. This central system is involved in the transformation of the sensory information from the peripheral networks and integration of it into a high level, multi-modal representation (representation using information from many senses). This model suggests that this system is therefore subject to an extreme rightward orientation bias which shifts attention towards the right and away from the left in patients with left sided neglect [18].

Neck Muscle Vibration attempts to realign the coordinate system and a centring of the body's midline. First of all, a small mechanical vibrator is attached to a patient's contralesional posterior neck muscles (See Figure- 2.12). Then, the patient is asked to do a visual exploration training(see Scanning therapy) whilst the patient completing the given task, the contralesional posterior neck muscles are then vibrated [18].

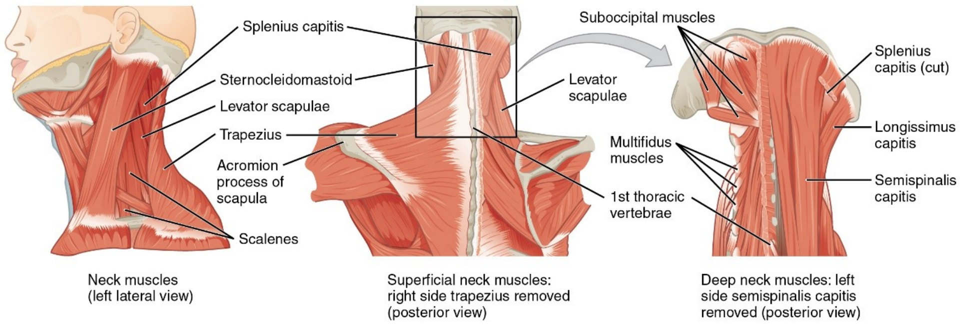

Figure 2.12: Figure shows posterior neck muscles

There is some evidence indicating that this treatment methodology also has long lasting effects similar to prism adaptation [18].

2.3.8.5 Transcutaneous electrical nerve stimulation (TENS)

Transcutaneous electrical nerve stimulation (TENS) is a form of low-voltage stimulation historically used for therapeutic purposes. TENS is also used for treatment of spatial hemineglect [19]. Similar to neck muscle vibration therapy, the contralesional side of the patient's body is simulated using electricity, typically on the left neck muscles, but also on the left hand (See Figure-2.13).

Figure 2.13: TENS applied to a woman who has visual spatial neglect

The effects of the TENS treatment could be vary. Result of a study conducted by Sabrina Pitzalis, Donatella Spinelli, Giuseppe Vallar and Francesco Di Russo showed that when they applied TENS treatment to patients (14 people in total) they observed 93% of improvement in patient's neglect in a positive way (93% patients improved the deficit). However, the same treatment method did not show the same amount of success of patients who has visual neglect on their right side in fact, their performance worsened (When the treatment was applied on 9 patients only 64% of patients improved their deficits) [19].

Chapter 3

Solution

In this chapter we will propose our solution for measurement and possible rehabilitation of Visual Neglect. Moreover, this chapter aims to provide insights of technologies that is used in our solution such as leap motion controller, processing programming language.

3.0.9 Background Information

This section aims to introduce the technologies that is used in our solution (implementation) and explains why these technologies are chosen among other alternatives.

3.0.9.1 The Leap Motion Controller

The San Francisco start up Leap Motion has developed a device size of a pack of chewing gum (7.62 x 3.048 x 1.27 cm) called The Leap Motion Controller. This device is plugged in to the computer via usb cable that enables people to interact with the computer using hand and finger movements [20]. The controller is able to reach the hand gestures via two camera sensors and three infrared LEDs (See Figure-3.1). Unlike a Kinect device, it is only able to detect hands and predefined objects such as pen. The controller can detect at most two hands and 10 fingers. The Leap Motion Controller claimed to be really accurate about detecting fingers (track finger movement within 0.01mm) and complex hand gestures such as clutching hands [21].

There are countless devices on the market available for motion technology such as Oblong's main product is g-speak, Microsoft Kinect, Primesense camera, intel interactive gesture camera and many others [22]. We choose to use leap motion controller although there are some problems (see limitations part) because it is cheap, accurate enough for our purposes, easy to deploy and it is a compact device.

The controller is highly responsive to movement of user hands and fingers. However, when we tested few applications from the Leap Motion app store, we realized that for some of the applications are not working smoothly as the leap motion controller is advertised. For instance, we tried a simple game called Duck"n" Kill. In this game the user tries to shoot ducks using their index finger. Although it does not require the tracking of complex hand gestures, the controller sometimes is not able to track finger position and this is resulted in the disappearance of the cursor during the playtime. We believe that the source of the issue is mostly hardware rather than a poorly written algorithm. These issues will be discussed in further sections.

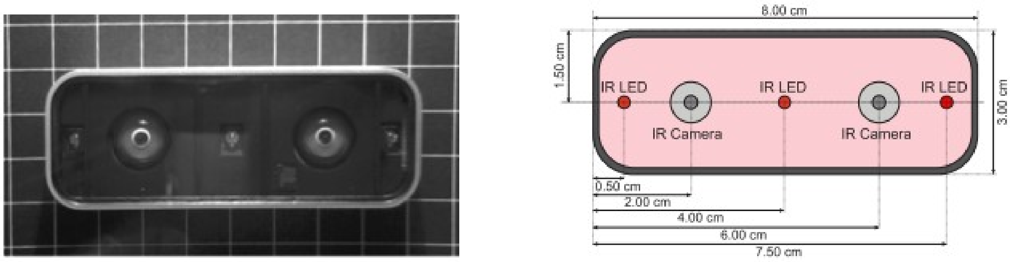

Figure 3.1: The leap motion controller which has its lid is removed to demonstrate the sensors on it [23]

3.0.9.2 Applications

The Leap Motion Company created a platform called "Leap Motion AirSpace" for software developers, for the purposes of presenting applications which had been developed using the leap-motion controller technology. There are various types of applications available in Leap Motion AirSpace at the moment. For instance, there is an application that allows users to do paintings, applications related to astronomy, Google Earth has an application that allows users to navigate on map with gestures, with application called Frog Dissection, user can open up a frog as he would in high school biology class and examine each organ and many others [24]. Moreover, there are enterprise applications being developed in the field of security, automotive, defence and medicine. We will mention few of the applications related with medicine which is having a benefit from leap motion technology.

Strabismus is a visual disorder in which the two eyes do not line up in the same direction, because of the problems related with muscles around the eyes and consequently the eyes do not look at the same object at the same time (see Figure-3.2). This disorder is also known as "crossed eyes". Strabismus results is loss of vision because brain receives conflicting information from eyes thus loos of depth perception and 3D vision [25].

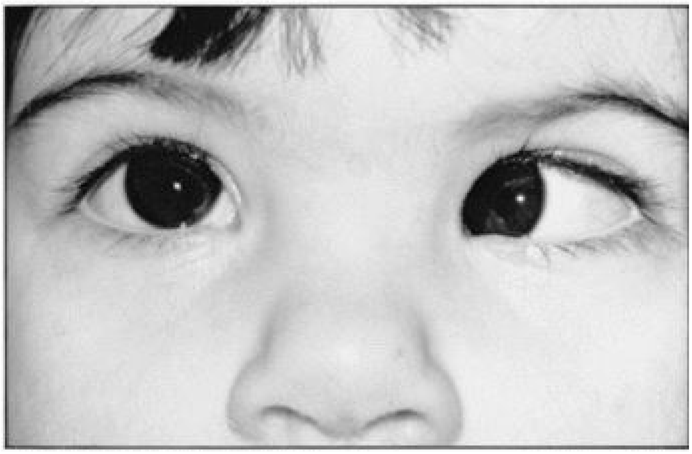

Figure 3.2: Strabismus which causes visual loss. Image is taken from http://www.cecraleigh.com/strabismussurgery.htm

James Blaha, developed a game called, Diplopia using oculus rift[1] and the leap motion controller in an attempt to develop a treatment for strabismus (See Figure-3.3).

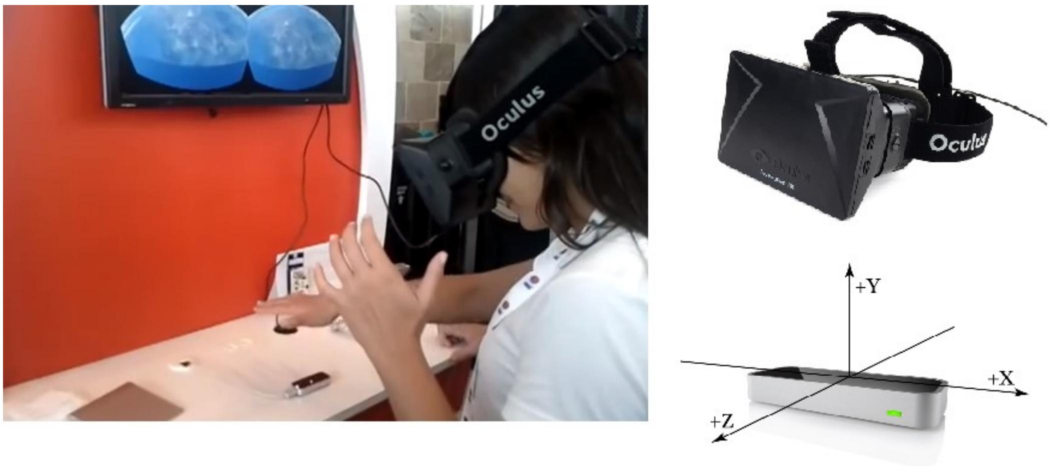

Figure 3.3: Combination of the leap motion controller and Oculus Rift technology could allow developers to create amazing virtual reality applications

The game is about controlling the bounce of a ball around a room with a paddle to destroy blocks, unlocking power ups.

The logic behind the Diplopia project according to Blaha is that, certain kinds of therapies (including video games) can actually treat amblyopia even when the affected person is beyond adolescence, allowing for the possibility of restoring 3D

[1] "The Oculus Rift is an upcoming virtual reality head-mounted display. It is being developed by Oculus VR, which has raised US $91 million, of which $2.4 million was raised with crowd funding via Kickstarter. The company was founded by Palmer Luckey and Scaleform co-founders Brendan Iribe and Michael Antonov, as well as Nate Mitchell. id Software co-founder John Carmack was later hired as its Chief Technology Officer (Wikipedia)."

vision in adults. Moreover, he claims that he had some positive feedback from doctors considering improvements of patient's 3D visions[2].

Another application was developed by César Augusto Cardoso Rodrigues; which aims to aid medical examiners with one of their most complicated tasks which is the preparing for and carrying out of the authopsy. This activity is currently inconvinient for the coroner because he/she has to examine the body and also operate a computer for the purpose of constructing the authopsy report. However, with the help of the leap motion technology second part of the interaction could be omitted [26].

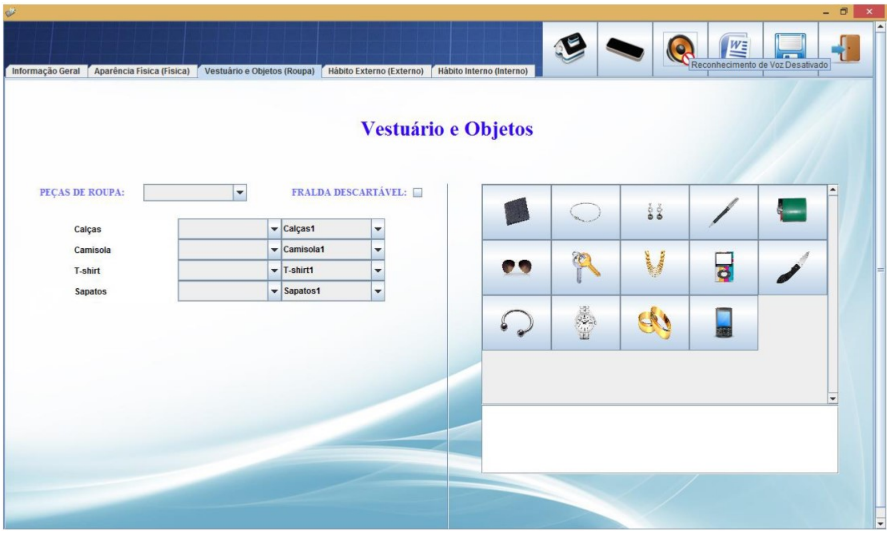

Figure 3.4: Interface of a touches autopsy report application

3.0.9.3 Analysis and Limitations of Leap Motion Controller

In this part, we will provide details about the controller, how it is working in terms of software, analysis of accuracy and limitations that we encounter during development of our application. We were not able to obtain information about the insight mechanism of the leap motion controller due to current patent problems. However, there are some documents providing some information. Most of the information is provided from SDK document prepared by Leap Motion Company.

3.0.9.4 Coordinate System of Leap Motion Controller

The Leap employs a coordinate system which most people are familiar with from primary school. Values described are in units of real world millimetres[27]. This is because of the way a points represented by the controller may be different to the way it is represented in the programming environment. This will be explained in later sections. The origin is centred at the middle of the Leap Motion Controller. The y-axis is vertical, with positive values growing upwards unlike most computer systems.

[2] More details could be found http://diplopiagame.com/

The z-axis has positive values increasing further than the computer display and x-axis values are increasing towards right side(See Figure-3.5)[27].

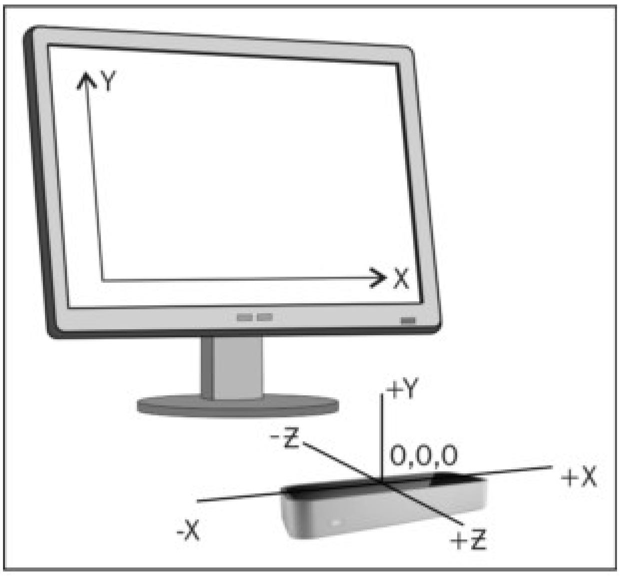

Figure 3.5: Coordinate system of the controller[27]

3.0.9.5 Motion tracking data

As we mentioned before, the controller tracks hands, fingers, and tools (i.e. pen) in its field of view. During tracking, the controller provides information as a set, or frame of data. Each frame contains detailed data of a tracked object. (i.e. x, y, z position of a finger, length of a finger etc.) and also lists of the basic tracking data, such as well recognized gestures and factors describing the overall motion in the scene[28]. When the controller detects a hand, finger, tool, or gesture the controller assigns a unique ID to the detected object. The ID remains the same as long as that entity remains visible within the device's field of view. For instance, if a user puts his hand in the field of the controller, controller creates a frame, and assigns an ID to the user's fist and his fingers (separate ID for each the finger) as long as the user holds his hand in the field of the controller. Whenever user pull his hand from the view of the controller, the frame and ID which is assigned to it is removed. Thus, the software may not know that the hand or finger is the same as the one visible earlier [28].

3.0.9.6 Hand Model

The hand model makes data available about the position, characteristics, and movement of a detected hand along with lists of the fingers and tools linked with the hand[28].

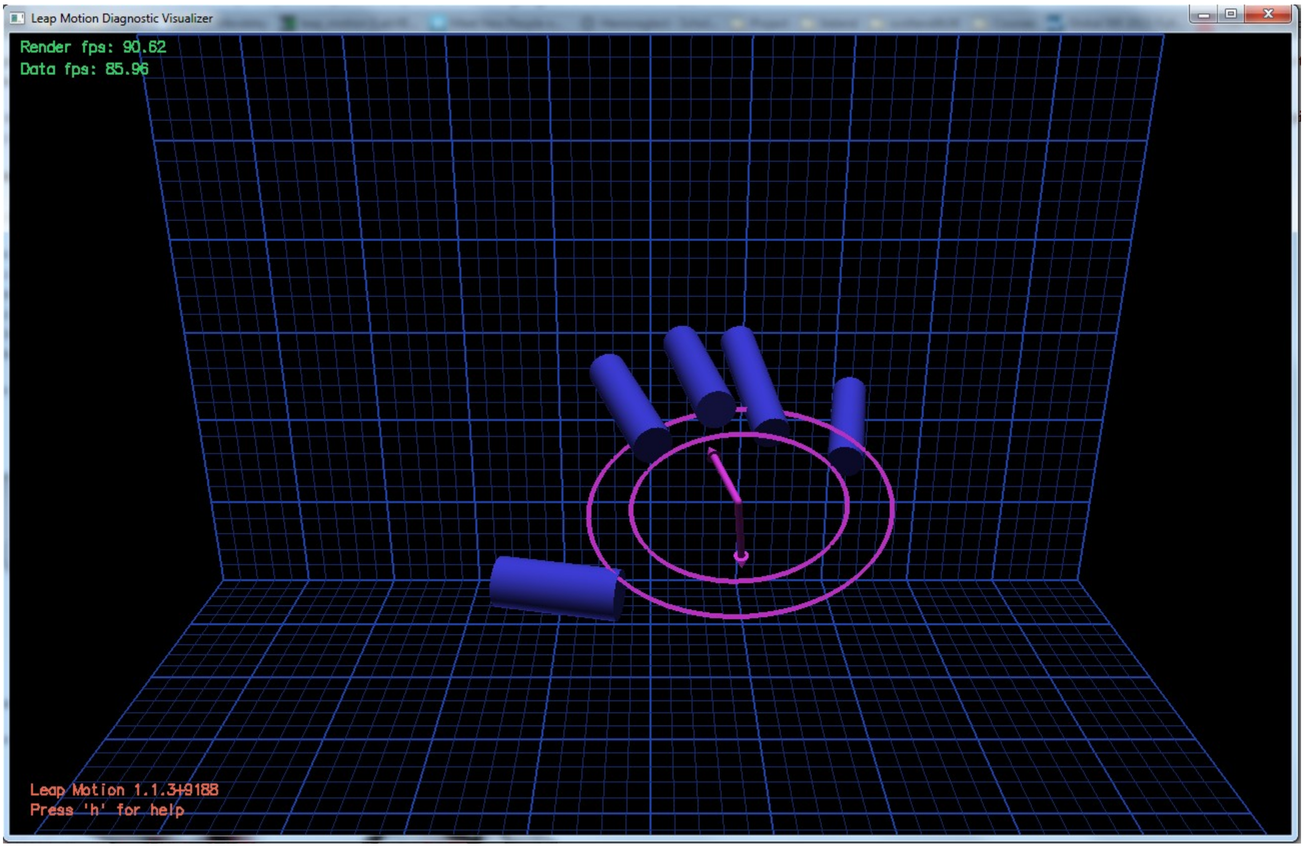

Figure 3.6: Screen capture obtained by using visualizer software provided by Leap Motion. As it is seen from the capture the controller provides us information about the hand in its view

Although the API delivers detailed data about a hand, it is not possible to obtain all the details. For instance, the controller does not able to decide whether a hand is a left or right hand by default[28]. Some algorithms could be developed to overcome this issue for certain conditions by developers. For instance, if there are two hand in the vision of the controller, hand appearing on the right most position could be aligned as right hand or an algorithm could be implemented to detect whether a hand is left or right depending on the vectorial direction of a thumb.

The controller is able to provide several attributes [28] of detected hand object these are;

- Position of the palm
- Velocity of the palm
- Direction of the palm
- The centre of a circle fit to the arch of the hand (see Figure-3.7)
- The radius of a circle fit to the curving of the hand. The radius changes according to shape of the hand (see Figure-3.7)

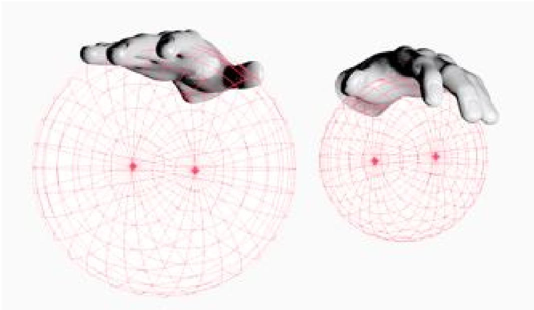

Figure 3.7: Palm is detected by the controller[28]

3.0.9.7 Finger and Tool models

The controller also keeps information about fingers and tools within its field. The controller categorises finger like objects in relation to shape. For instance, a tool is different than finger because it is thinner, and straighter. In the Leap model, data related to fingers and tools are abstracted into a *Pointable* object. The controller is able to provide some details about *pointable* objects these are [28];

- Length of a point able object (visible portion)
- Width of a point able object (average width)
- Direction of a point able object (unit direction)
- Velocity of a point able object
- The location of the tip in millimetres from the Leap origin

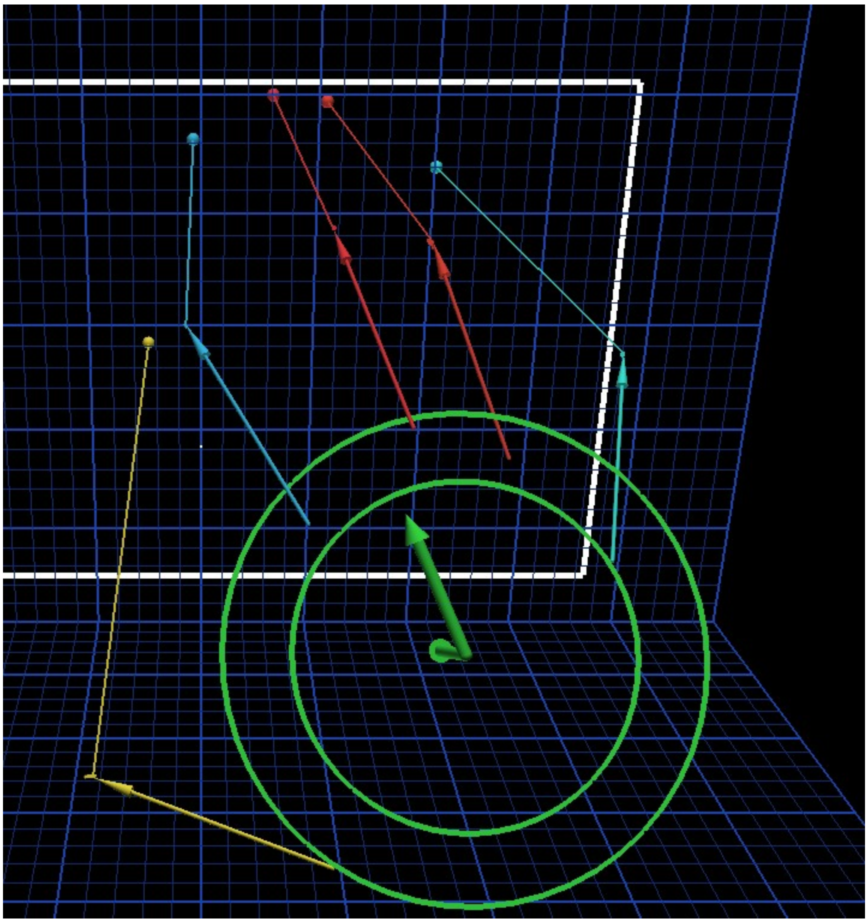

Figure 3.8: Leap Motion Controller is able to detect fingers and tools their positions directions and velocities.

3.0.9.8 Gestures

The controller recognizes certain gestures which could be used in applications in various ways.

The following gestures recognised by the controller [28];

- Circle
- Swipe
- Key Tap (a vertical tapping movement)
- Screen Tap (i.e. tapping movement towards the computer screen)

3.0.9.9 Accuracy and Robustness of the LMC

As we mentioned before there not many resources available for the leap motion controller. In this section, we will discuss the accuracy and robustness of the leap motion controller based on a study. The Manufacturer of the leap motion controller claims that its precision in fingertip position detection is ~0.01mm [23] A study was conducted to prove that claim of a manufacturer was correct. The research group prepared a testing environment. All conditions such as temperature (23 degree), lighting (250 lx) is stabilized. Using a robotic arm (see Figure-3.9) and reference pen, they compared the coordinate of the reference object with corresponding separate sensor measurements of the same object tip in the Cartesian coordinates of the controller [23].

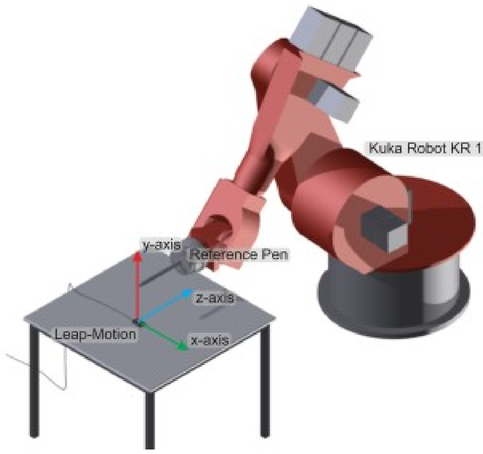

Figure 3.9: Robot setup that is used to measure accuracy of leap motion controller

Two types of measurement were made,

1. Static measurement with the reference pen held in certain position and the coordinates are compared.
2. Dynamic measurement in which the reference path is moved in a random path and measurements are then made.

In static setups, an axis- free deviation among a desired 3D position and the measured positions less than 0.2mm has been attained [23]. For the evaluation for dynamic situations was performed, an accuracy of below 2.5 mm could be obtained (average of 1.2mm). The repeatability had a mean of less than 0.17 mm. While moving to separate positions on a path, the SD[3] was less than 0.7 mm per axis [23]. This study indicated that it was not possible to achieve the theoretical accuracy of 0.01mm under real conditions. However, the leap motion controller still provides high precision compared with other similar products in the same price range on the market. For instance, one of the well-known products called the Microsoft Kinect camera is not able to achieve this level of accuracy. The Kinect is more expensive than the leap motion controller (USA price of Kinect Camera is $249 meanwhile USA price of and the leap motion controller is $80).

[3] Standard deviation

3.0.9.10 Limitations

The software that is provided by the leap motion controller is called as diagnostic visualizer and it was used in order to observe the functionality of the controller. In tests it was observed that the controller had difficulty to sense four or five fingers. The controller did not pick up all four or five fingers at a time especially when fingers were close to each other or even though the controller was able to detect 4 or 5 fingers at the same time it quite readily lost track of the fingers from time to time. Moreover, it was observed that the controller was sometimes not able to detect some pointable objects such as a pen and the hand control was clumsy. Another critical issue was that the LMC behaved erratically with different lighting conditions especially with fluorescent light which is generally used in clinical environments and hospitals. Since the controller is using the infrared spectrum, the lighting conditions in which the device is used appear to be affecting the way it works. Moreover, even the reflecting surfaces (i.e. ceiling of a room covered with reflective material) in the environment could affect the device. Therefore, in order to get optimum results from the device suitable specific lighting conditions should be proscribed during the operation of the Leap controller ViNAR system.

3.0.10 Selection of a Framework or Programming Language

Our project requires us to work with a graphical environment. We examined many different frameworks and programming languages such as Java Graphics library, Piccolo2D, G graphic library, Slick2D and OpenGL. We decided on Processing Programming Language because it is easy to learn, allowing programmer to work with many different devices including Leap Motion and it is possible to create web applications as well as desktop software. Moreover, Processing allow developers to work on three dimensional environment with different graphics engine (i.e. programmer can work with OpenGL or Java2D libraries).

3.1 Processing Framework

Processing is an open source programming language mainly built on Java which aims to teach fundamentals of computer programming to new media art and visual design societies and provides easier way to work with graphics for technical students [29]. Processing was first developed in 2001 at MIT, it has grown up within a set of other institutions including UCLA, the Interaction Design Institute Ivrea, the Broad Institute, and Carnegie Mellon [29].

Although it was initially developed to teach the fundamentals of computer programming for certain type of users, we believe that Processing provides sufficient functionality to support the ViNAR system. There are various types of libraries developed for Processing that allows advance developers to create complex graphical programs. For example, we come across homemade small radar system that is programmed using processing language(http://www.grook.net/how-to-make-radar-using-arduino-uno). Moreover, processing works with many different devices such as Ardunio, Android, Leap Motion, Kinect etc. Many other processing projects are presented with their source code at http://www.openprocessing.org/.

3.1.0.1 Processing Environment

The Processing includes an IDE. However, the provided IDE comes with a very limited set of features. Since Processing is built on top of the Java programming language it allows the use of all the Java features. In fact every Processing sketch is actually a subclass of the PApplet Java class which implements most of the Processing language's features. Moreover, it can be used in Eclipse(IDE) environment easily with the help of a plug-in called proclipsing. (https://code.google.com/p/proclipsing/)

```
void setup() {
  size(400, 400);
  text("DESEM", 200, 200);
}
```

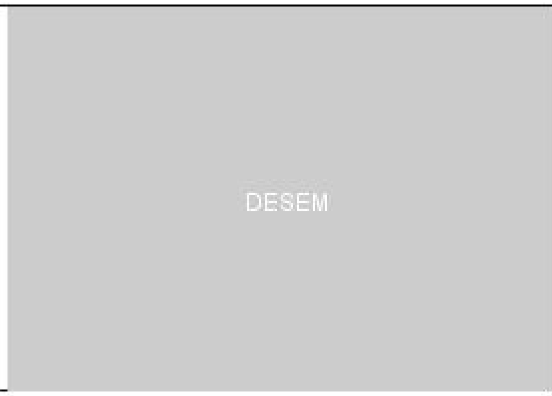

Figure 3.10: Small sketch created using the IDE provided by Processing. The Syntax of processing language is identical to Java with a few modifications.

There are two main methods used to create a processing sketch. One of them is ***setup( )*** block which runs once, and the ***draw( )*** block runs repeatedly like an infinite loop. ***setup( )*** is generally used for any initialization ;i.e. setting the screen size, changing background colour, and setting the stroke colour to red. The ***draw( )*** block is used to handle dynamic actions during the runtime such as animation [30].

3.1.0.2 Processing Coordinate System

Processing programs are able to manipulate all or a subset of the screen's pixels. When the programmer wants to create a sketch, one of the first things that a programmers is required to do is to invoke the ***size( )*** method and assign pixels for a processing program by invoking the ***size( )*** method. (i.e size(width, height), size (400,400) processing sketch will work on 400 to 400 pixel area. This might change depending on computer screen because every screen has a different resolution; in other words, different number of pixel for each inch on the screen.) Each pixel of the screen is a coordinate - two numbers, an "x" (horizontal) and a "y" (vertical) - that determines the location of a point in space. It is crucial to understand the system in order to create visual objects in the sketch. Unlike the coordinate system that is taught in secondary schools Processing uses a different coordinate system. The origin is considered to be in the upper-left corner of the display window and coordinate values increase down and to the right (See Figure-3.11)[29].

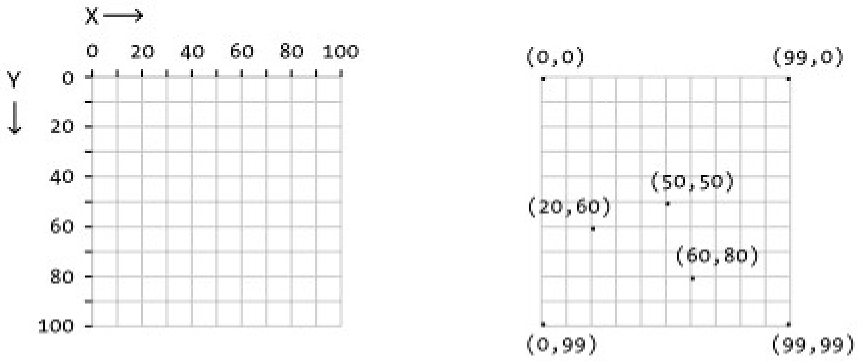

Figure 3.11: Coordinate System of Processing [29]

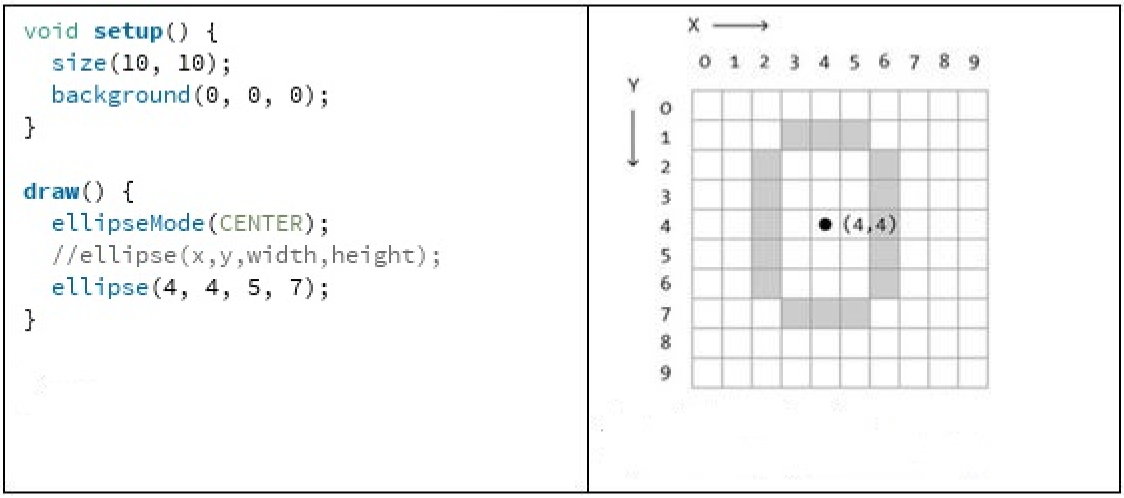

Figure 3.12: Example shows how items are placed to sketch using coordinate system logic.Image adapted from processing.org

3.2 ViNAR (Visual Neglect Assessment and Rehabilitation)

After a series of design meetings with Joseph Duffin and our research collaborator Kate Forte we outlined our system which will help professionals to measure diagnose visual neglect patients.

The overall, ViNAR system uses the Leap Controller, Leap Controller SDK, and the processing programming language in conjunction with a standard laptop to provide a testing paradigm for Visual Neglect. (In the future it will be also act as a rehabilitation paradigm for Visual Neglect). The basic idea of this system is that a patient must move a simulated object from their unaffected (right side) field of vision to a target location on the left side of their field of vision (see the paper prototype screenshots in Figure-3.13 below). The system will track how successfully the patient achieves this over a number of trials (configured by the testing professional). This tracking information is then used to map the areas of visual neglect in the patient's left sided field of view (assessment) and will also input into the elements of the system designed to help ameliorated the effect of this neglect (rehabilitation). The results for each patient are displayed as bar graphs, displayed in a heat map and exported by the system in various formats. (i.e. excel file, for graphics .jpg). The following is a description of each of the main software components and libraries used in the ViNAR software.

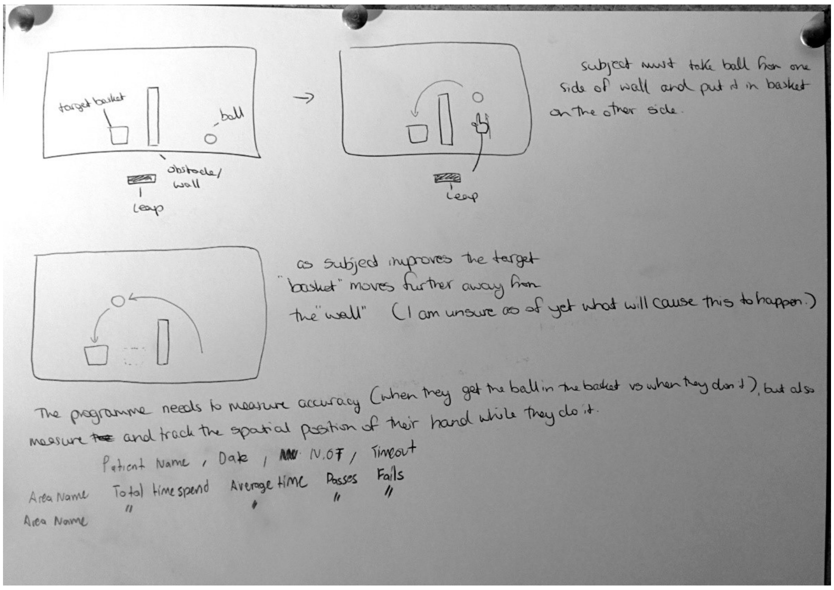

Figure 3.13: Paper prototype drawn by Kate Forte

3.2.1 Overall Design

Figure-3.14 shows components in ViNAR and its surrounding environment. Each of those components will be described the following sectors;

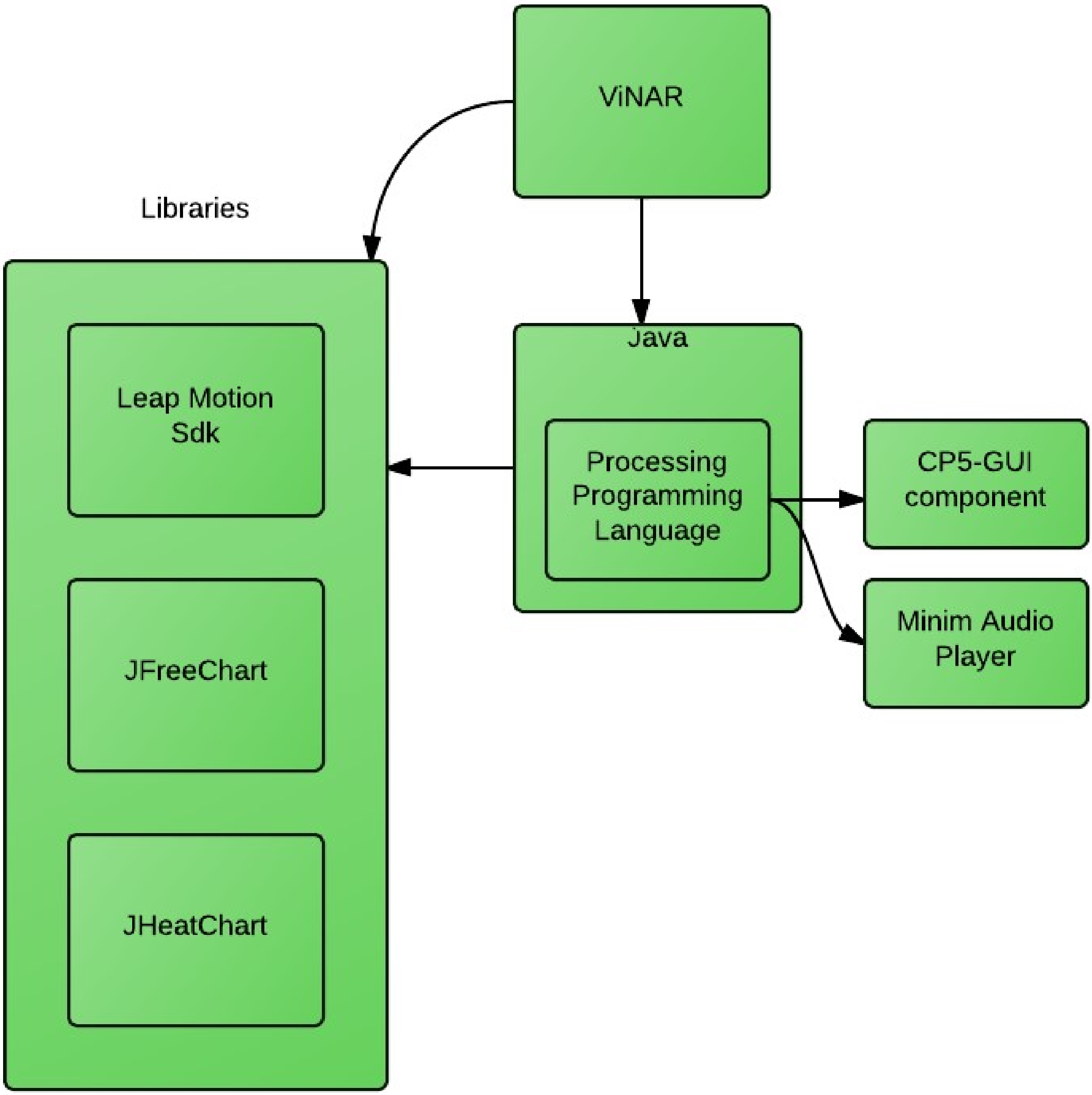

Figure 3.14: ViNAR software components

- **Leap Motion Sdk:** Enables developers to interpret the data which is obtained from the leap motion controller.
- **JfreeChart:JfreeChart:** JFreeChart is Java library which helps developers to create various types of diagrams easily on Java swing components.
- **JheatChart:** JHeatChart is a minimalistic Java library for generating heat

map charts and export in various formats.

- **Processing programming language:** Will be explained in following section.
- **CP5:** Cp5 is a library for processing programming language which enables the creation of simple GUI elements on the processing sketch
- **Minim:** Minim is a library for the Processing programming language which plays various audio formats for processing programs. ViNAR uses the Minim library to provide sound feedback to the patient since their visual field may be neglected. For instance, whenever the stimulated object hits the obstacle a warning audio is played using the Minim library and ViNAR will give feedback to the patient.

3.2.1.1 Object Design

ViNAR is designed is an object oriented fashion. Every item on a processing sketch is represented by an object and all related information such as the state of an item, actions etc. are embedded to class structure. (See Appendix A) For instance, considering the ball (stimulated object) on ViNAR's test environment. A class representation for this build is as fallows;

```java
public class Ball {
  int ball_diameter = 70;
  public int ball_radious = ball_diameter / 2;
  Color ball_color;
  Color selected_ball_color;
  Color ball_sroke_color;
  public Vec2D ball_position;
  public Vec2D initial_ball_position;
  MainScreen main_screen; //access main screen for drawing
  public Ball(MainScreen _main_screen) {
    //constructor
  }
  public void Display() {
    //display a circle according to values on class attributes
  }
  public Boolean isIntersectWithCursor() {
    //perform designed action
  }
  public Vec2D[] pointsOnCircle() {
    //return points on circle of collision method
  }
}
```

3.2.1.2 Adjusting Coordinate System for the Processing programming language and Leap Motion Controller

Unlike the standard input devices such as mouse, some of the interactions in ViNAR will require to use leap motion controller. For instance, the cursor (the red circle in Figure-3.16) is designed to move according to input parameters (x,y coordinates) obtained from the leap motion controller. However, the leap motion controller and processing programming language are using different coordinate system as we indicated in previous sections. Therefore, some mathematical adjustments were required. There three main steps should be followed in order to adjust the coordinate system of leap motion controller to the processing coordinate system;

1. Create interaction box
2. Normalize vector position of hand and fingers
3. Mathematical adjustment

Interaction Box

Interaction box represents a box shaped region completely within the field of view of the Leap Motion controller(see Figure-3.15) [28].

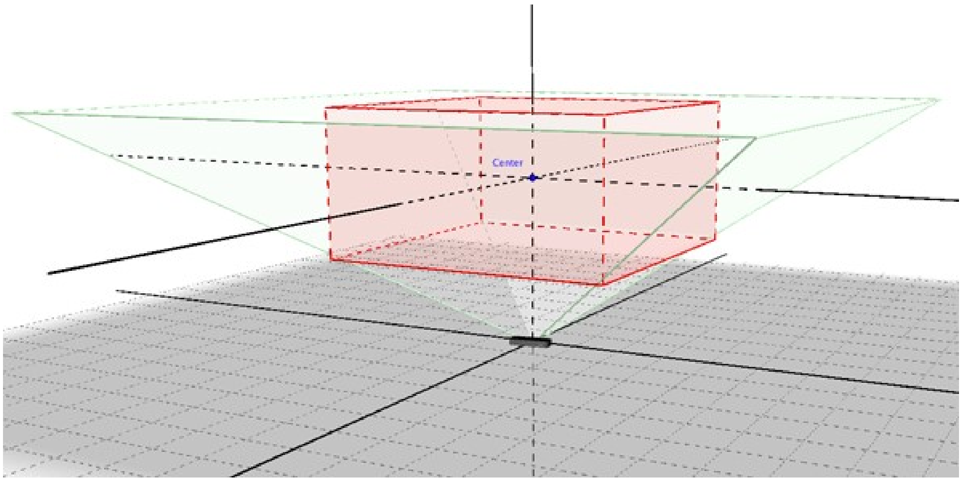

Figure 3.15: Interaction box

The interaction box provides normalized coordinates for hands, fingers, and tools within its borders. It helps to map positions in the Leap Motion coordinate system to 2D or 3D coordinate systems used for graphical applications[28].

Normalize vector position of hand and fingers

The position data (vector) received from the LMC should be normalized in order complete the conversion process. After the normalization process, the coordinates from the LMC frame of reference are converted to a range of [0..1] such that the minimum value in the interaction box maps to 0 and the maximum value in the interaction box maps to 1. [28]. This normalization supports the conversion of positions to the processing coordinate system. It would be possible to complete this conversion without normalizing the received vector data however, it would be difficult in terms composing appropriate mathematical functions and that method may not be robust.

Mathematical adjustment

The final step is adjusting the normalized vector data according to the size of the processing sketch. This has two steps.

1 Converting the x-axis: is simply multiplying the normalized vector's x-axis with the screen width because normalized data is between *[0..1]* and the processing coordinate system also increasing towards the left side;

$$x^1 = x * w$$

[4]

2 **Converting the y-axis:** this process is slightly different from converting the x-axis because although the data is normalized, the y-axis value increasing to the opposite side of the leap device however, in the processing coordinate system the y-axis increases in the opposite way. Therefore, following formula should be applied;

$$y^1 = wh - (y * wh)$$

[5]

3.2.2 Developing Gesture Models

The user has to complete the test by simply moving the ball into target area while avoiding the obstacle barrier using the cursor controlled by the leap motion controller (see Figure-3.16).

---

[4] x=normalized position of x, w=window width

[5] wh= window height , y= normalized position of y

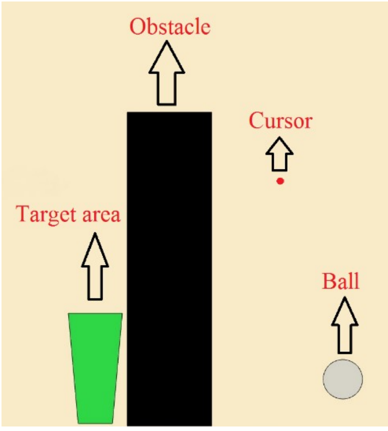

Figure 3.16: Items on the test environment for the first prototype. Colours are chosen deliberately. For instance, target area indicated with green because green is one of the most stimulating colour [31].

In order to control the objects on sketch, three different models were developed before a deciding on of the models after evaluating in terms of usability.

3.2.2.1 Palm based model

In this model, the cursor (red circle in Figure-3.17) was designed to move according to the center position of the palm of a user. The center of the palm is measured in millimeters from the LMC's origin. The user (test participant) controls the cursor, and when the cursor is on the ball the user could then stimulate the ball by performing a grabbing gesture (See Figure-3.17). The user should keep this (See Figure-3.17 right side) gesture while moving the ball.

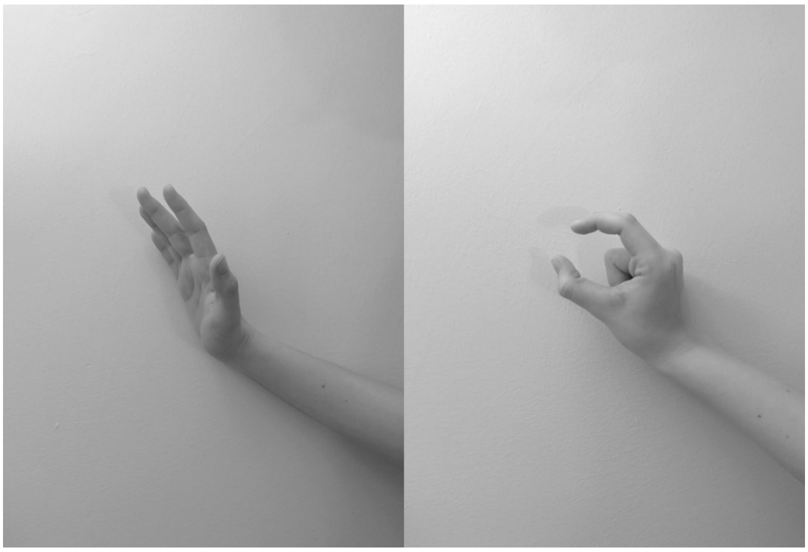

Figure 3.17: The user could move the cursor with his palm (left) and stimulate the ball by performing a grabbing movement (right)

A number of problems were identified after implementation. First of all, participants reported that it was very tiring to use their palm in order to interact with ViNAR's test environment. This may be because the whole arm has to move in order to move the palm. Secondly, an algorithm was developed for the grabbing gesture however, when the fingers are close to each other the leap motion controller is not able to detect fingers and most of the time this gesture fails. As a result the user is not able to move the ball. Therefore, this approach was abandoned in favour of simpler models.

3.2.2.2 Finger Model

This model aimed to be simpler and easy to use compared with the previous palm based model. In this model, the cursor moves according to the index point's position (See Figure-3.18). The user moves the cursor over the ball using his/her index finger and the thumb is used to stimulate the ball whilst the cursor is on it. Then using both the index finger and the thumb the user is able to move the ball towards the target area (See Figure-3.18 right side of the image).

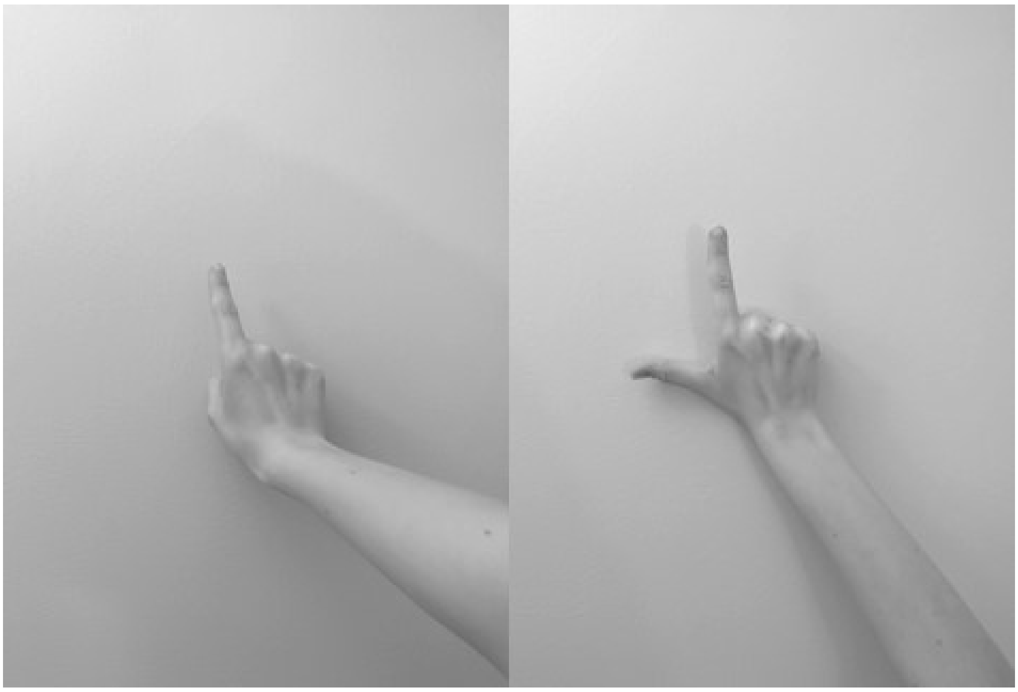

Figure 3.18: The user can move the cursor with his/her index finger and stimulate the ball using his/her thumb

Controlling the cursor with this model was shown to be easier compared with the previous one. However, when the user uses their index finger and thumb in order to move the ball the thumb disappears from the view field of the leap motion controller. This can cause some difficulties in terms of usability. Normally, this problem could be tolerated. However, since this software is designed for use with people who might have motor movement problems, a higher accuracy requirement needed to be met. Therefore, it was decided to abandon this model.

3.2.2.3 Finger and time based model

The final model that was developed has a minimalistic approach in order to have high level of accuracy. In this model, the user uses only his/her index finger in order to control the cursor. Whenever the cursor is on the ball, a countdown timer will appear above the ball (see Figure-3.19) and it will count for a second whilst the cursor is on the ball. Then, the cursor will lock the ball and the user will be able to move the ball by moving his index finger.

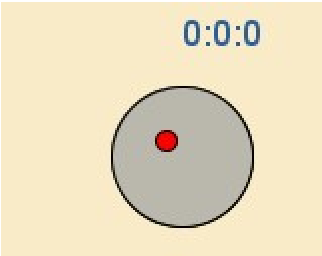

Figure 3.19: A countdown appears whilst user

This time based model proved to be quite robust and provided a high level of usability. The only thing that the leap motion controller has to monitor is the position of an index finger. All other things are handled by the algorithm. For instance, if there are extra elements in the view of the leap motion controller such as second hand. The algorithm does not allow the user to proceed until second hand disappears from the view of the leap motion controller.

3.2.3 Collision Detections

ViNAR's test environment contains geometrical objects and trough the test process these objects are interacting with each other. (i.e. ball is moving towards target area, ball hits the obstacle etc.). These objects are constantly changing their status according to interaction. For instance, when the ball hits the obstacle it changes its colour from grey to red in order to provide visual feedback to the user. All these interactions, require geometrical calculations for collision detections. There are many different ways to calculate collision detection for many different shapes [32].Moreover, many development tools and libraries helps programmers to calculate these detections. For instance, UNITY programmers can simply attach an OnCollisionEnter event to their object and determine the behaviour of and object when collision occurs.

```
void OnCollisionEnter(Collision collision)  {
  print( "Change the colour of the ball to red when hit an obstacle " );
}
```

The leap motion controller is constantly tracking information of its field of view. Thus, we observed that leap motion controller requires more computational resource than regular desktop applications. Therefore, we avoid using extra libraries for collision detection. Instead, we apply algebra for collision detection in ViNAR's test environment. We will demonstrate two examples of collisions;

3.2.3.1 Collision of Circles

In order to move the ball in ViNAR's test environment, cursor should be on the ball first. In other words, a cursor which is a ball, should intersect with the other ball.

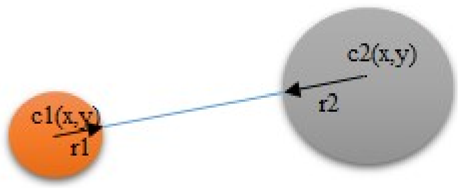

Figure 3.20: The ball(right) and cursor(left) in ViNAR's test environment

First we simply used a standard formula to calculate distance between two points (mathopenref.com) ;

$$Distance = \sqrt{(x2 - x1)^2 - (y2 - y1)^2}$$

This formula gives us a distance between c1 and c2 (see Figure-3.20).Two of the objects will intersect with each other when distance between their centre is less then sum of their radius. In other words;

$$(Distance <= r1 + r2)$$

Means two object are collide.

3.2.3.2 Collision of Target Area and Circle

As it is indicated the user (patient) has to move the ball into target area. The ball has to be totally inside of the target area otherwise user will be warned with the visual feedback (i.e. colour of the ball will be red) (See Figure- 3.21). The target area is designed to be in shape of basket at the first iterations (See Figure-3.16).However, after the first prototype we observed that placing ball into target area shaped like bin might be difficult especially for older people. Therefore the target area was change to be a square shape.

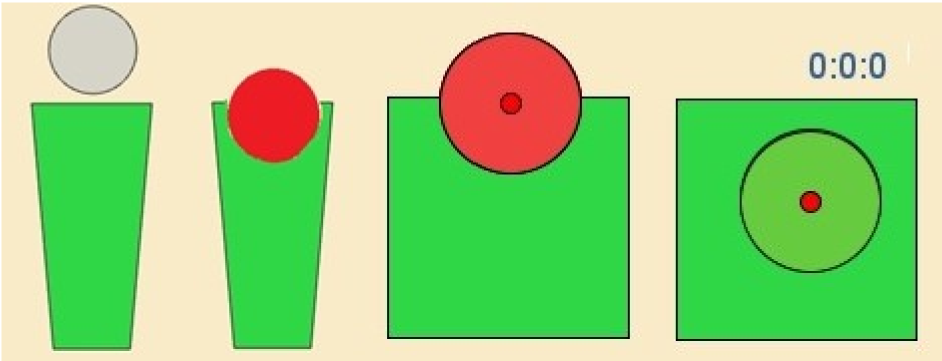

Figure 3.21: The Ball has to be inside of the target area otherwise user cannot proceed for the next level

For the collision calculation of the basket shaped target area, we obtained 20 points on the ball with 18 degree sectors. Using following the formula ;

$$x = radius * \cos t$$

$$y = radius * \sin t$$

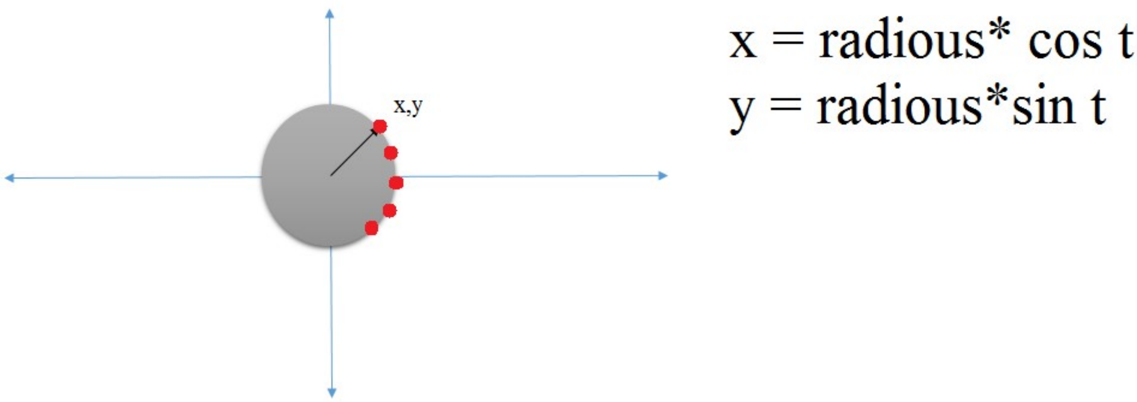

Figure 3.22: 20 points on circle obtained using formula on the left side of the image

```
public Vec2D[] pointsOnCircle() {

  Vec2D[] points = new Vec2D[number_of_points_on_ball];
  float angle = (float) ((Math.PI) * 2 / (float)number_of_points_on_ball);

  for (int i = 0; i < number_of_points_on_ball; i++) {
    int y = (int) (ball_position.y + ball_radious* Math.sin(angle * i));
    int x = (int) (ball_position.x + ball_radious* Math.cos(angle * i));
    points[i] = new Vec2D(x, y);
  }//for
  return points;
}
```

After obtaining the points on the ball, we check whether those points are inside the boundary of target area or not with following formula;

Let; M is coordinates of the point on circle.

C is centre of the square

j is the length of the square.

$$D1 = |mx - cx| \quad D2 = |my - cy|$$

If d1 or d2 is less than j/2 it means that point is inside the square. If all of the points (20 points) are in the target area it indicates that the ball is inside of the target. Otherwise, the ball is colliding with the target area but it is not fully inside of it.

3.2.4 Measuring Patient Performance

After series of meetings with Joseph Duffin and Kate Forte, we decided to use time (time to target) as a parameter to measure performance of the patient and diagnose him/her using ViNAR. The Patient's task is to move the ball into given target area.

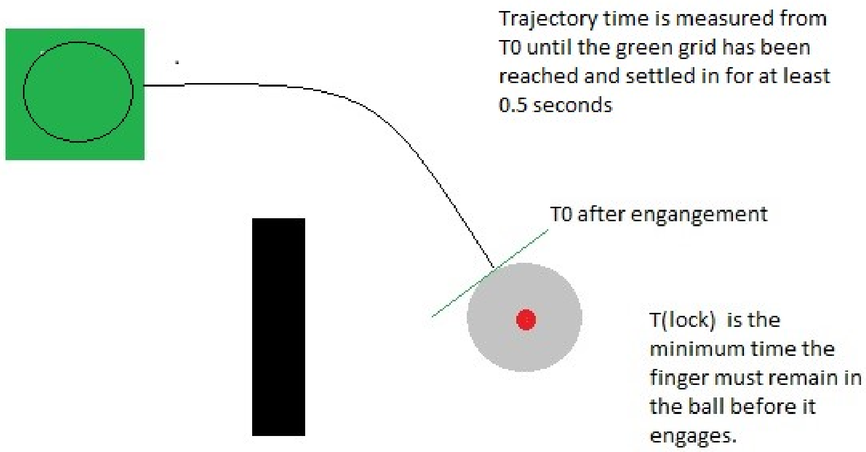

Figure 3.23: Time measurement in ViNAR (measure of performance)

The performance measure for the ViNAR assessment is the time taken for the ball to reach the target grid element on the left. More specifically, ViNAR measures the time from ***T0*** until the ball has at least settled in the box for 0.5 seconds (See Figure-3.23). A person recovering from motor paresis (whose fingers shake when they attempt to move them) may reach the box but have difficulty settling in the box and therefore record a time indicating that there is visual neglect when no neglect is present (The next iteration of ViNAR which will be implemented to include a feature to tune out this motor effect the patient results).

This timing-to-target function will timeout if the patient is not successful. For instance, at the beginning of an assessment process the clinical professional sets a timeout parameter for a patient and if the patient is not able to move the ball to target area within the time set by the professional, ViNAR saves this information and reflects this result in the patient reports. This information could indicate that the patient is unable to find the target area due to visual neglect. The timeout should be set to reasonable number depending on patient's situation. If the patient is having problem in his/her motor skills, it is better to set the timeout to be greater than 30 seconds.

We used ***millis( )*** method provided by processing programming language. The ***millis( )*** method returns milliseconds (1000 millisecond= 1 second) of runtime. This method generally used for timing events and animation sequences. There is no way to restart time obtained from ***millis( )*** method during the runtime. Luckily, CP5 library provides a custom timer to programmers which has a ***.restart ( )***. This method restarts the timing. In order to record some specific time events we are required to apply simple arithmetic operations. For instance, considering the Figure-3.23 above, in order to obtain the time for trajectory, the following simple arithmetic operation is applied;

Tlock is the time when the cursor must wait on the ball for two seconds, ***T0*** is the time after cursor is locked to the ball until the ball reaches the target area + 0.5 seconds (0.5 seconds settling time. The ball remain in the target 0.5 seconds in order to proceed with tests for different target areas).To measure the trajectory time;

$$Trajectorytime = T0 - (Tlock + 0.5)$$

This is done so that we can obtain pure time that patient spent to put the ball into target area. The Following implementation demonstrates the calculation of ***Tlock*** for the ball;

```
int locked_passed_time=0;
int lock_saved_time = 0;

if (ball_selected == true && is_locked == false) {
  locked_passed_time = millis() - lock_saved_time;
  if (locked_passed_time > 1000) {
    is_locked = true;
    lock_saved_time = millis();
  }
} else
lock_saved_time = millis();
```

In addition to the custom timer provided by the CP5 library, we used the ***TimerTask*** class provided by Java to handle scheduled tasks. For instance, whenever a time out is exceeded or a patient drops the ball into target area, ViNAR restarts the test environment and sets a new target area for patient. Restarting the test environment according to patient's action is trivial. However, restarting the test environment according to time out requires invoking certain methods with special interval. Therefore, we set tasks using the ***TimerTask*** class provided by Java. General usage of the ***TimerTask*** method is as follows;

```
1 TimerTask task = null;
2 Timer t = null;
3 task = new TimerTask() {
4   @Override
5     public void run() {
6     //do tasks
7   }
8 };
9
10 t = new Timer();
11 t.schedule(task, time_out);
```

First we defined the task, (See line 3-8 above) then with .schedule method, time is scheduled for certain interval.

3.2.4.1 Dividing Sketch to Areas

In the first versions of the ViNAR, the target areas were set to appear at a random location left side of the obstacle and the patient's performance was measured according to time that is spent to moving the ball into the target area. My advisor Joseph Duffin proposed a novel approach to measure patient's performance. Instead of placing target area into random areas, the system should be able to map the areas of visual neglect in the left hemi-field or the left side of a person's visual field with a degree of precision.

ViNAR maps the areas of visual neglect in the left hemi-field or the left side of a person's visual field with a degree of precision.(due to the presence of 36 grid targets) In that way, it will be possible to obtain more details about patient's neglect compared to the binary classification provided existing pen and paper tests. It was proposed to divide the left visual field into 36 distinct units in order to be able to map the areas of neglect for a patient (See Figure-3.24).

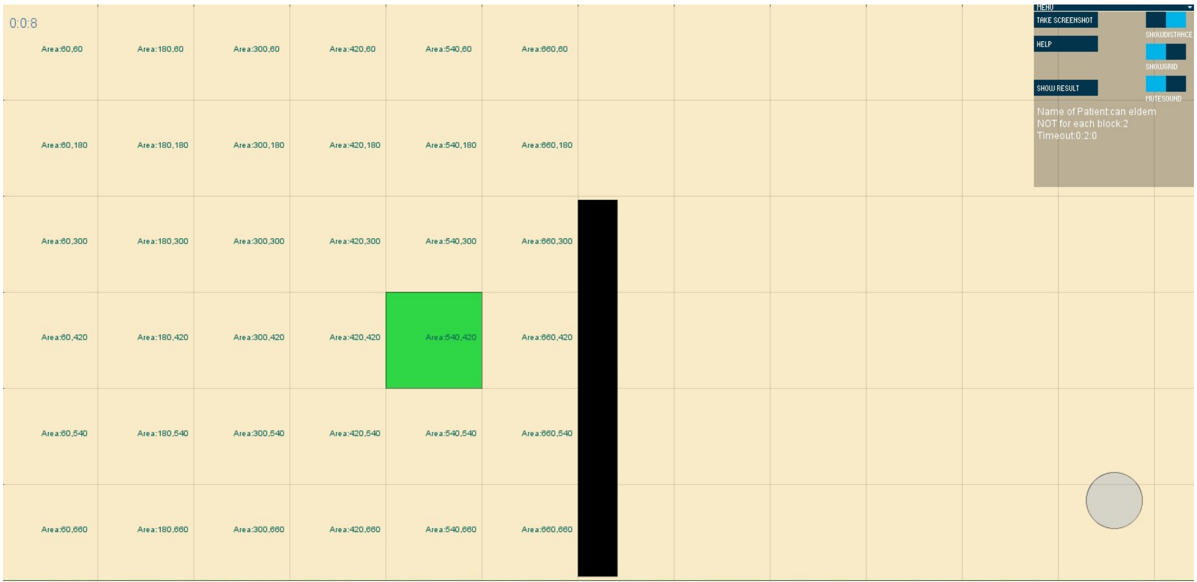

Figure 3.24: Left side of the obstacle into 36 areas to measure which areas of patient is neglected.

The randomness of a test is important in the process of diagnosing visual neglect. This is because be valid if a patient follows the same pattern all the time they might develop an unconscious behaviour to complete the task and the diagnosis would not valid. Therefore, ViNAR was designed so that for each of the divided areas, the target area will still be selected randomly and the professional will set how many times (trials) for each area target area will be presented. If the patient is not able to move the ball into the target area, the target area will change to another different target area (Timeout occurs).Data collected for each area are;

- How many times patient was able to reach target area
- How many times patient was not able to reach target area
- For each trial how much time patient spend to put the ball into target area.(trajectory time for each trial)
- For all trials for specific area how much time the patient takes to put the ball into target area.($\boldsymbol{t}$ for trajectory time n for number of trials for each area $\sum_{1}^{m=n} t_m$).
- How many times the ball hit the obstacle to while trying to reach target area each assessment.

3.2.5 Displaying Results

The data should be presented to the professional and stored at the end of diagnosis session. ViNAR exports all the data into an excel file for professional to evaluate later on. In order to give a better grasp to a professional about patient's situation data are also represented with graphs. Data that are obtained from ViNAR are quantitative and discrete. Bar charts are one of the most suitable way to represent quantitative and discrete data. [33]. Compared with different libraries JfreeChart is the most suitable solution to draw graphs in the Java environment, because it can be embedded in to the java swing components, easily customizable and it support various chart types[34]. Following diagram shows comparison between JfreeChart and other libraries;

	JFreeChart	JCCKit	QN Plot	OpenChart2	PtPlot	JRobin	JOpenChart	jCharts	JChart2D	Chart2D	ThunderGraph	E-Gantt	MagPlot
Licence	LGPL	LGPL	BSD	LGPL	UCB	LGPL	LGPL	BSD	LGPL	LGPL	LGPL	QPL	GPL
Features													
Size	✓	✓											
High Performance	✓		✓						✓				✓
Extendable	✓	✓			✓		✓						
Zoom support	✓		✓	✓	✓		✓		✓	✓	✓		✓
Image export	✓	✓					!		✓	✓			✓
Vector export	✓	✓	✓				!		✓				✓
Print export	✗		✓						✓				✓
Logaritmic axes	✓	✓			✓		!		✓				✓
Chart types													
Bar	✓	✓		✓	✓		✓	✓		✓			✓
Pie	✓			✓			✓	✓		✓			✓
Radar/Spider	✓			✓									
Scatter/Line	✓	✓	!	✓	✓	!	✓	✓	✓	✓	✓		✓
Gantt	✓			✗								✓	
Box/Whisker	✓							✓					
Total score	93%	50%	32%	36%	36%	4%	46%	29%	50%	36%	14%	7%	64%
	✓	!	✗	!	!	✗	!	✗	!	!	✗	✗	✓
Legend	✓	Available / Good											
	!	Planned / Semi-working / Medium											
	✗	Unavailable / Bad											
	( )	Unknown*											
	* Feature may or may not be implemented, but is not listed on the website.												

Figure 3.25: Open Source Chart Library Comparison [34]

It was decided to use Heat Maps for some parameters such as total time taken to place the ball is each target area. A heat map is a two dimensional representation of matrix data in which values are represented by shade of colours. A heat map is able to provide an immediate visual summary of information. By using heat map we could map each Area on sketch with a member of heat map's matrix data and provide a quick feedback to a professional about which areas of the patient might be neglected (by internal comparison with control data). A library called JHeatChart is used for generating heat maps. JHeatChart is a simple Java library used in Java programming language for generating heat map charts for output as image files or use in GUI components.

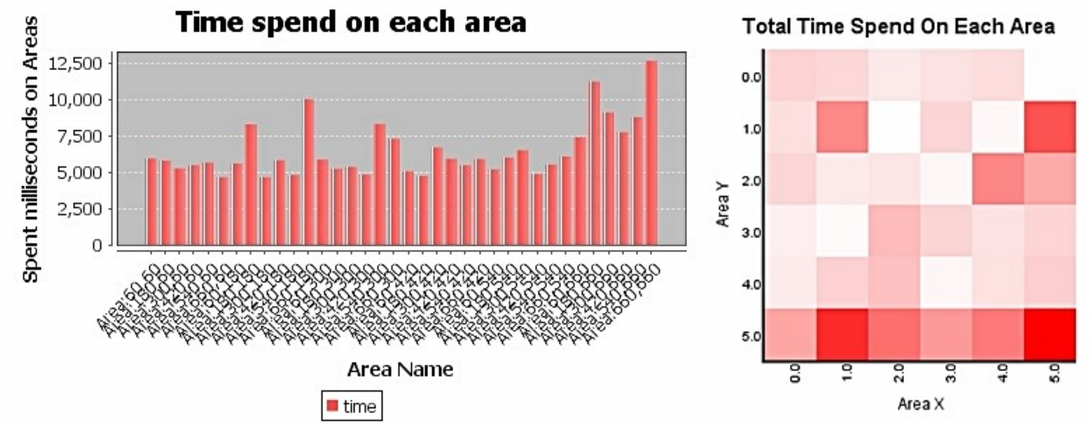

Figure 3.26: The time spent on each area represented with a bar diagram and a heat map. The Number of trials for each area was set to two for those data.

Figure-3.26 shows different graphical representations of same information obtained by ViNAR. They both represent the total time for each area that the patient spent moving the ball into the target destination. For example, for top left corner of the sketch patient spend 5400~ (5.4 seconds) milliseconds in total to put the ball into target area.(number of trials for each area set to 2 for data in Figure-3.26, exact millisecond are provided by ViNAR whenever the mouse cursor is on the bar). Figure-3.26 shows how the heat map provides an overall summary to the professional and highlight the areas which might be problematical in the patient's visual field.

3.3 Evaluating the Patient Data

The ViNAR system is a dynamic measurement system because its usefulness increases when it is loaded with normal data, or data which reflects the expected performance of people who are not suffering from visual perceptual neglect or inattention.

In order to be able to say something about a person's performance on the ViNAR we need to be able to compare their performance with the average performance of members of their peer group. In other words, if we want to evaluate or say something about the relative performance of a 40 year old male Stroke patient who has visual neglect as diagnosed by one of the standard binary classifier (such as star cancellation or line cancellations tasks), then we need to compare this man's data for completion of trials of the 36 grid ViNAR target areas with ViNAR performance data (average times and standard deviations for each grid element for the whole group) from a control group comprised of other, 35-45 year old healthy males without Neglect to determine the patient's relative performance.

The binary classifiers tests produce an indication of the presence or absence of Neglect in the form stars missed in the Star Cancellation Test or the degree to which the midpoint of a line is crossed as in Line Cancellation Tasks. This indication of performance is established after the data collected from the patient is compared to people who are healthy or have not indicators of Neglect. Usually the comparison is made between the patient's scores and the average of an appropriate group. For example, it would not be appropriate to compare the results of a 40 year old male to the average of a group comprised of women aged 75 to 85 years.

Figure 3.27: Healthy control data is collected and embedded into ViNAR to make comparison with patient's data

The Z value gives a meaningful indication about how much a piece of data, in our case the performance of a patient on reaching a particular grid element over a number of trials, is different from what could be termed the expected or normal performance for a person matching that person's profile performing on the same grid element (See the next section for a further explanation).

A number of conditions need to be met before ViNAR can be accepted as a valid assessment instrument for determining the presence or absence of visual neglect (and further determining precise areas of neglect).

The ViNAR must have access to normal performance data to compare against the assessed patient. These normal performance data are collected using the ViNAR in multiple separate test sessions on different participants making up an age matched healthy group whose members do not have neglect. It is also assumed that this performance data is normally distributed. In other words the basic ViNAR task of moving a ball from the right side of the screen to a target grid element on the left hand side when analysed statically will have the classic bell curve distribution of values either side of the mean with 68.2% of all the participants performing at a level within plus or minus one standard deviation of the mean performance score value of the group (See Figure-3.27).

These data values must be available for each of the 36 grid elements on the left hand side of the field of view. The normal performance data are comprised of the (1) average performance times using data from all group members for every grid element on the left hemifield and (2) the standard deviations values associated with each grid element from the data from all group members. (A group could be a number of participants (n = 15) whose ages range from 25-43 years).

As stated before a healthy participant is tested using the ViNAR for two trials or twice as they try to reach each of the grid 36 grid elements with the ball. The average performance for the participant is the average of the two trials for a grid element.

The group average data is calculated using data from different individuals of the overall control group by looking at their individual grid element average performance and then averaging that with all the other group members to obtain a single 36 element group average matrix. Additionally, the standard deviation measure is calculated for each of these overall 36 element group averages (means).

There are two simple reasons for gathering the group average data. Firstly we need to get a spread of the different performances for the ViNAR due to the different distances between the fixed target and the grid elements data comprises a two dimensional array of average values thus calculated. Secondly as stated above we need a way of comparing how normal the patient's performance is in relation to a group of healthy people of the same age.

With the healthy group data loaded in to the ViNAR it is possible to assess a suspected neglect patient for the presence of neglect and also to further test the efficacy of ViNAR at detecting specific areas of neglect over the left field of view.

A test patient will be first assessed on a number of different standard neuropsychological tests of cognitive status which help to determine their general intelligence (NART), their executive function or degree to which they stay on task (TMT) and a test of their everyday memory and whether or not they are prone to slips of actions of memory lapses (CFQ). The patients also needs to be assessed using the traditional tests of neglect, Star cancellation, Letter Cancellation and line bisection as a means of helping to evaluating the ViNAR's ability to detect neglect.

It is important to assess the patient's cognitive status so that it can be determine with confidence if any problem in ViNAR performance can be attributed to neglect and not to a problem with IQ (NART), executive function (TMT) or memory issues (CFQ).

Each healthy participant recruited for this research and who ultimately will have their data integrated into ViNAR must be proven to be healthy in terms of the absence of neglect as well as having cognitive status measures for their IQ, their TMT performance and their CFQ in the normal range of expected values for a person of their age. These normal data values for each of these tests can be obtained from the literature on neuropsychological testing, see [4]. In addition to the cognitive status it is recommend that each of the healthy participants be assessed on the standard traditional tests of neglect such as the cancellation and line bisection tasks.

3.3.0.1 ViNAR Evaluation with patient data and additional control data

The current version of ViNAR is integrated with data from 15 control participants (See the ViNAR MMA description and also the description of matrices [A.1] and [A.2]).

With this configuration ViNAR can be used on healthy control participants to determine if they are free of visual neglect. Part of the evaluation of ViNAR is the run a further number of healthy participants with the expectation that ViNAR will provide **true negative** results for these participants (results to say these participants do not have neglect, see table below). The data from these participants can then be reintegrated into ViNAR to add to the control group data. Each of these participants will also perform the standard pen and paper cancellation and line bisection tests for neglect as well as the cognitive status measures, the NART, CFQ and the TMT.

Table 3.1 Possible test outcomes with different types of participants evaluating ViNAR. For example, in a **True Negative test** (when a new healthy control is tested), ViNAR would be expected to give a negative result for visual neglect.

True Positive	**True Negative**	**False Positive**	**False Negative**
Patient with Neglect **Equivalent with a hit**	New Healthy control **Equivalent with correct rejection**	New Healthy Control , Motor impaired Stroke patient without neglect **Equivalent with a false alarm**	Patient with Neglect **Equivalent with a miss**

Table 3.1

The ideal situation is to begin recruiting patients with neglect in the hospital environment according to the testing guidelines presented above. These patients would have a clinical diagnosis of neglect obtained by occupational therapists or neuropsychologists using the traditional pen and paper-based neglect tests. ViNAR would be used to assess these patients by internally comparing their test data over the 36 ViNAR grid elements with the performance of the healthy aged matched healthy group which is preloaded into ViNAR.

The patient's performance will be presented both graphically using bar charts but also visually using the ViNAR's use of the heat map to show the relationship between each of the patient's grid element average scores and the data from the healthy group and this is done internally using the mean matrix algorithm (MMA).

The ViNAR mean matrix algorithm (MMA) is used to determine how a participant performs on any particular grid element compared to the mean and standard deviation values for a group of similar healthy participants on that grid element by generating a Z value as a measure of this similarity. The MMA algorithm is described in next section.

3.3.0.2 ViNAR Mean Matrix Algorithm (MMA)

The values described below are processed for each of the 36 grid elements in each of the Matrices **A** (Control data parallel arrays: (1) averages A.1, (2) std values A.2), **B** (Patient data averages) and outcome **C** (Patient assessment result, which are Z values). All of these are two dimensional arrays. [A] Input (1) is the Control group's Mean time performance for Grid element[i], (2) is the Control group's Grid element[i] standard deviation value. [B] Input is the Assessed participant's Mean time performance Grid element[i] value over two trials. [C] Output is the Z[i] value, or the number of standard deviations (or partial standard deviations) calculated by getting the difference between [A.1] and [B] and then expressing this difference in terms of multiples of [A.2].

Note 1.1: The [A.1] and [A.2] inputs are from the data compiled from participants in the control group using ViNAR and combined into two large parallel 36 element matrix data structures which are then integrated into ViNAR and used to assess a patient.

Note 1.2: The [B] data are obtained from the participant who is being assessed by ViNAR. Again this is matrix of 36 averages values.

Note 1.3: The [C] output values are stored in a 36 element matrix and represent the Z values which are calculated using [A.1], [A.2] and [B.1]. This [C] output is presented on a bar chart and also as input to the Heat Map functionality.

Note 1.4: The [C] output values represented on the Heat Map provide a visual representation method to present data in a two dimensional left sided format showing areas of normality or neglect which depends on how far the measured value [B.1] is from the mean value [A.1]] Note 1.5. The [C] output values which are the Z may be further divided by 2 so that we have a half measure of Z value allowing more display levels on the heat map. See figure below.

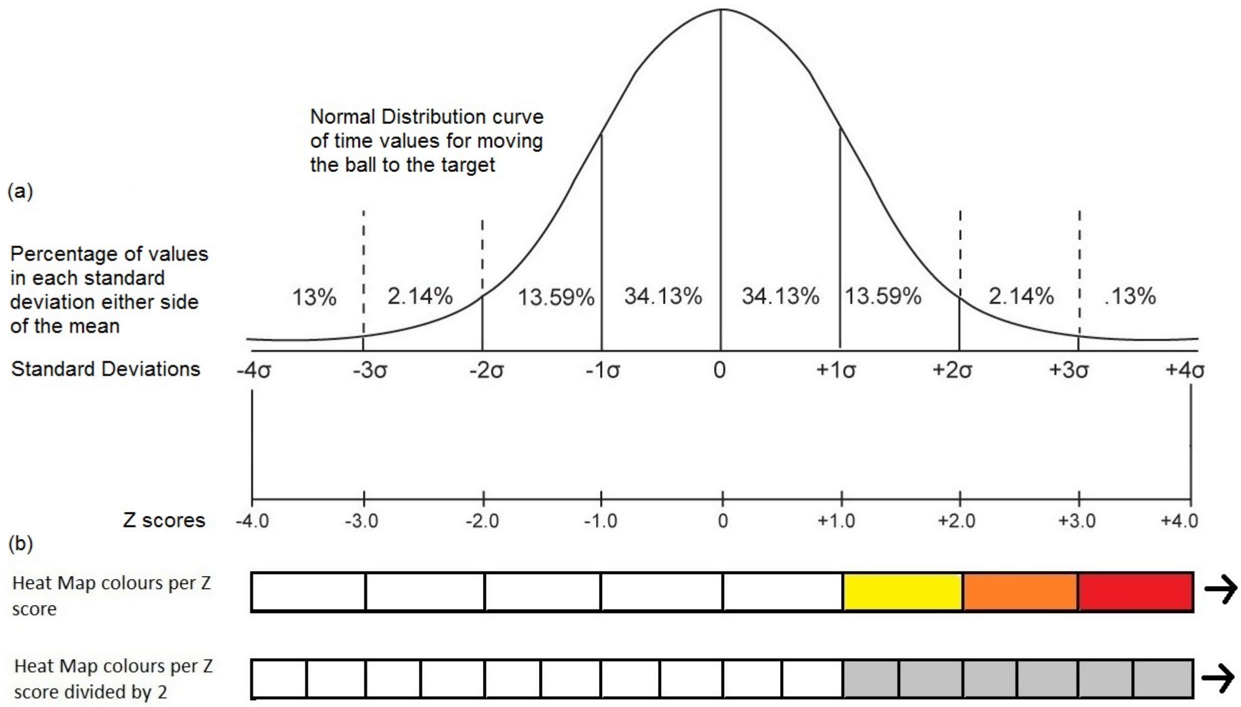

Figure 3.28: Z value heat map

The performance times for the ViNAR have been determined to be normally distributed according to (a) the standard distributions as illustrated in the curve in the picture above. The x axis of the distribution is labelled in terms of multiple standard deviations from the mean with positive values indicating scores greater than the mean and negative values indicating scores less than the mean. The Z scores are indicated below the distribution and are a measure of how many multiples of standard deviations a particular performance score deviated from the mean. For example if we calculated a a Z score of +2 for a particular patient data value this would mean that this data value is 2 standard deviations greater than the mean score for the corresponding data point (grid element) for the control group. The heat maps bars (b) illustrate the colour coding of the Z output (or Z/2) which will be presented in the heat map. It is possible to use the simple Z values or fraction of Z values as in Z/2 for presentation purposes. (Fractional Z values will yield more colours on the heat map, it depends on the distributions of the Neglect patient data as to whether Z values of fractional Z values are used. Also the Z scores can extend beyond +4 standard deviations illustrated in this diagram).

The **Z value** or the **standard score** is the (positive or negative) multiple of standard deviations that a measured data point is above or below the mean of the comparison population (The healthy control group data in this research). If the Z score is positive for a particular measured data point then this reveals the number of standard deviations the measured data point is greater than the mean value for the compared to population (health control data). It the Z score is negative then this reveals the number of standard deviation the measured data point is less than the mean value compared to the population.

The **Z score** (the calculated grid element in matrix [C]) is calculated by subtracting the population mean (data point from matrix [A.1]) from the corresponding measured datum (corresponding data grid value from matrix [B]) and then dividing the difference by the population standard deviation (corresponding control data grid standard deviation value [A.2]).

The Z score formula can be written as;

$$z = (x - \mu)/\sigma$$

Where;

μ is the mean value of the comparison population (healthy control data, matrix [A.1]) x is the data value under scrutiny (patient data, matrix [B]) σ is the standard deviation of the comparison population (healthy control data, matrix [A.2]).

The value of Z indicates the distance between the measured performance score and the mean performance score for the compared to population in terms of the standard deviations which was derived from the comparison population (healthy controls).

3.3.0.3 Control group data

Data for the healthy controls in the initial ViNAR evaluation are presented in the table below.

Participant Number	Sex	Age	Hand
kf001	F	23	R
kf002	M	29	R
kf003	M	34	R
kf004	F	23	R
kf006	F	24	R
kf007	F	23	R
kf008	M	28	R
kf009	F	25	R
kf010	M	26	R
kf011	M	43	R
kf012	F	21	R
kf013	F	20	R
kf018	M	32	R
kf019	M	24	R
kf020	M	24	R

Table 3.2: Demographic Data Table

There were 8 males and 7 females ages ranged from 20-43 (mean 28.33), all were right handed and all reported normal or corrected to normal vision.

Other Tests

- NART – National Adult Reading Test A list of 50 words arranged in two columns that participants have to read aloud. The experimenter marks yes or no whether they pronounced them correctly or incorrectly.
- CFQ – Cognitive Failures Questionnaire A 25 question questionnaire where participants have to indicate on a scale from 0-5 (never – very often) how frequently each of the 25 things listed happened to them in the last 6 months. Questions are about everyday slips and mistakes we all make like forgetting people's names and forgetting what you want to buy in the shops.
- TMT – Trail Making Task A test of motor speed and accuracy as well as the ability to switch between two tasks. Divided into two parts, A & B. In Part A participants have to join the numbered dots in ascending order as fast as they can from 1-25 (it's timed with a stopwatch). In part B they have to do something similar except this time they are alternating between numbers and letters; 1 A 2 B 3 C etc. from 1, A up to 12, L. If they make a mistake the experimenter stops them but not the stopwatch, points it out and they correct it and continue.

3.4 Rehabilitation Process

The suggested mechanism behind any rehabilitative effect of the ViNAR is similar to that seen in Limb Activation Training (LAT). LAT [15] and it involves the movement of the contralesional hand (opposite to the lesion) in the affected visual field (in this case the left). The reason the hand on the opposite side to the lesion site is used is due to the nature of the brain and the cross-wiring of the hemispheres where right hemisphere controls the left of the body and the left hemisphere the right[35][6]. For LAT to be effective these movements must be voluntary and active, rather than passive; i.e. patients must devote resources to making these movements, they cannot simply be involuntary twitches or performed by a third party (manipulation)[36]. Various experiments have shown positive results with LAT so a similar procedure was chosen for the ViNAR. The actual mechanism underlying the rehabilitative effect of LAT has been suggested to be due to a re-activation of a damaged system in the brain linked to neglect [37]. The theory, termed the attentional-motor integration theory states that neglect occurs when specific circuits in the brain responsible for the representations of space are damaged [38]. These areas exist in both hemispheres and interact both within and across-hemispheres to produce a coherent spatial reference system. This system is then used to organise and calibrate voluntary motor movements [37]. Damage to these circuits results in neglect [39]. The ViNAR makes use of LAT-type movements in the neglected hemifield and therefore LAT was chosen as the closest existing parallel treatment.

3.5 Web applications for paper based Tests

Our second objective was to replace existing pen and paper tests with web applications. Web platform enables professionals to reach and apply test from via the internet and reduce paper consumption. We created web applications for Letter Cancelation, Bells, Start Cancellation and Line Bisections Tests. We used two frameworks in order to create these web applications;

3.5.1 Twitter Bootstrap

Bootstrap is a free collection of tools which helps developers to create well designed, responsive (suitable for many devices such as phones, tablet pc etc.) websites and

[6] Practically speaking neglect is brought about by damage to the mentioned systems/connections. However, it has been suggested that rather than a loss of function in the right hemisphere it is actually a decrease in the ability of the right hemisphere to inhibit left hemisphere activity. The two hemispheres appear to be in a constant state of pushing against one another to achieve balanced activity levels so therefore when the right hemisphere is damaged it loses this ability to push effectively and it's inhibitory impact is decreased. This leads to over-activity of the left hemifield and results in the rightward bias of attention characteristic of neglect. Evidence to support this idea comes from experiments employing movement of both hands simultaneously. This bilateral movement cancels out any benefit of left hand only activation which follows logically from the premise of the inhibition model of activity and neglect [43].

web applications [40].

Bootstrap is library contains HTML and CSS based templates for various interface components such as typography, forms, buttons, navigation etc. Moreover, it includes JavaScript interface components and other interface components[40].

Bootstrap used by many web pages over the internet, such as NASA,MSNBS some of the UK government web pages such as visa4uk.fco.gov.uk etc. Since most of the things build in inside of the Twitter Bootstrap it is fairly easily to create smooth web interfaces. Following example shows a login screen designed using twitter bootstrap;

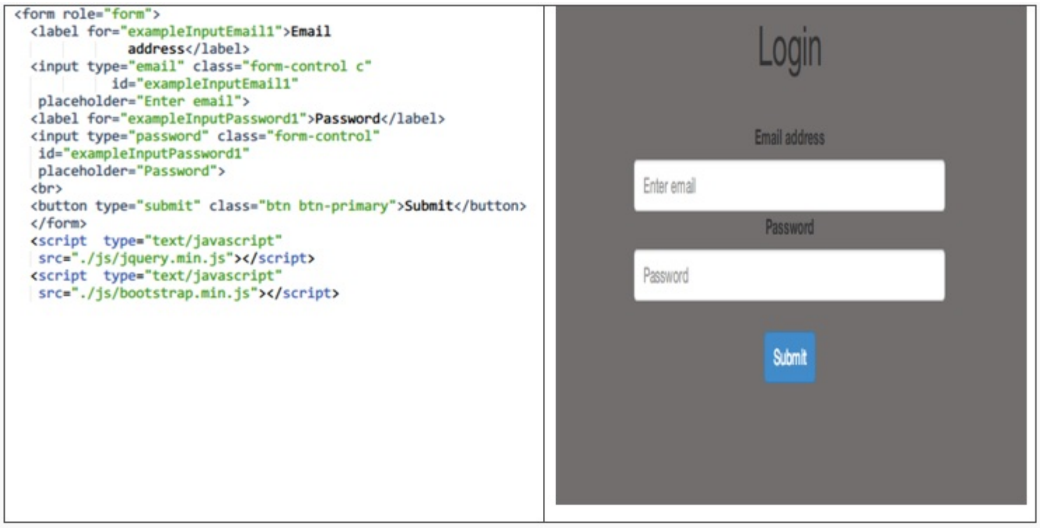

Figure 3.29: login screen designed using twitter bootstrap

We used the Twitter Bootstrap for creating websites which is connected with web applications for tests.

3.5.2 Processing.js

Processing.js library is ported version of processing visualization language to JavaScript, with the help of the HTML5 canvas technology. It enables developers to create graphical applications which works over the web. Unlike processing programming language which is built on java, Processing.js automatically downloads and converts any Processing code to JavaScript. Therefore, its capabilities are slightly different. For instance, projessing.js does not support some data types since JavaScript does not support. Therefore, programmers should mind these capabilities while designing processing applications for web environment [41].

Processing code on HTM5 canvas In order to run processing code in java two simple steps should be followed;

1. Include processing.js on an html page

2. Create a HTML5 canvas and invoke processing sketch which includes source code of main program.

```
<script src="processing-1.3.6.min.js"></script>
 <canvas data-processing-sources="desem.pde" id=hello></canvas>
```

Desem.pde includes processing source code (see Figure-3.12). Developer include this sketch into a web page (like in above code snipped). As we mentioned before Processing.js has some limitations. Only developed sketches using Processing's native ide could be included in a web page. However, the Processing's IDE does not have many features of modern IDE such as debugging, auto code competition etc. Therefore, developing processing applications using native IDE is challenging. In addition, developer is not able to combine some of the Java programming language features with processing in case it is developed with using processing native IDE. If the developer uses enumerations then, Processing's native IDE will not able to compile the code and produce error message.

3.5.3 Development of Web Applications

Considering the limitations in previous section, we developed our web applications following these steps.

1. Using processing IDE we developed sketches for these tests.
2. We invoke these sketches over the HTML5 canvas element.
3. The results of the tests .(Requires communication between Processing and JavaScript)

In order to provide better insight about these tree process we will explain development of the Letter cancelation test for this section. First of all, we implement letter cancelation test using the Processing native IDE environment according to specifications given in the literature (See letter cancelation section under related work chapter).

The software simply places letters into a sketch according to certain order and asks the patient to cancel a specific letter (E.g. circle all the capital letters "A") from the sketch by clicking on it. At the end of the test, the program displays details such as how many of the target letters have been cancelled and how long a patient spent cancelling the target letter etc. (see Figure-3.30).

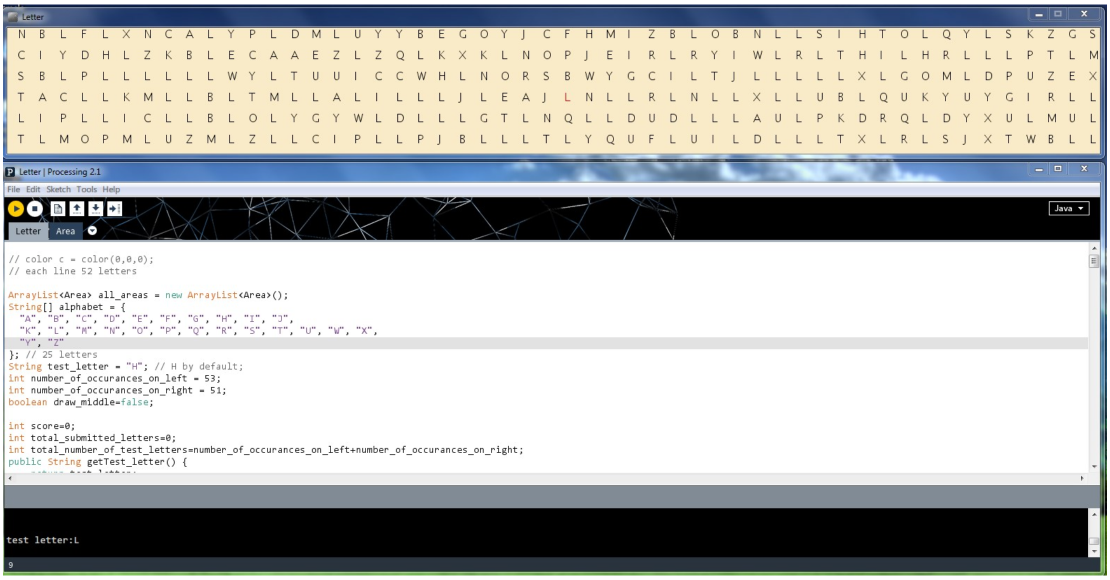

Figure 3.30: Processing native IDE (below), letter cancelation test.

Secondly, using processing.js we tried to invoke this sketch into canvas area. However, we faced several issues. As we mentioned before processing.js has some limitations and it does not support all the features of the processing programming language. For instance, we used ***Collection.shuffle( )*** for randomization, however this method is not supported by Processing.js since it is not supported by JavaScript.Therefore, we implemented our own ***shuffle( )*** method. Finally, after test is completed the results should be displayed on the HTML. Therefore, the processing sketch is required to interact with the web page via JavaScript. Fortunately, Processing.js supports this feature. In the light of information provided by Mike Kamermans on the Processing.js official web page we implemented a JavaScript function which provides communication between the processing sketch and JavaScript.

```
var psj;
 function bindJavascript() {
  pjs = Processing.getInstanceById("hello");
    if (pjs != null) {
        pjs.bindJavascript(this);
        bound = true;    }
    if (!bound)
        setTimeout(bindJavascript, 250);
 }//bindJavaScript
```

The *BindJavascript* method allows us to reach processing sketch and transfer-/retrieve data from it. Sometimes, synchronisation problem occurs between HTML page and the processing sketch. In other words, processing sketch loaded after the Javascript and HTML. Therefore *bindJavascript* method is required to be invoked automatically with in certain interval (250 millisecond) otherwise the variable psj

(See line 1 above) which yields to invoke methods within the processing source will be null and it will not be possible to communicate with the processing sketch. Line 7-8 ensures that the *bindJavascript* method is invoked every 250 millisecond until processing sketch is loaded. After initializing *psj* variable, it is possible to invoke methods from processing source code. However in order to access the variables in sketch, all variables have to be encapsulated. The Following example provides on insight of the whole procedure; This example shows a twitter bootstrap button and whenever the user clicks on this button it reads the data from processing and displays these data on a <p> element in the html page.

```html
<canvas id="loc" data-processing-sources="mysketch.pde "></canvas>
<form style="text-align:center">
<button type="button" id="results_button" class="btn btn-primary">
 See your results</button>
<p id="myresult"></p>
</form>
```

ListingHTML page

```javascript
var pjs;
bindJavascript();

function displayResults() {
  var result_message;

  result_message=pjs.getResult();

  return result_message;
}

//jquery method for button action
$(document).ready(function() {
  $('#results_button').on('click', function() {
    document.getElementById('myresult').innerHTML=displayResults();
  }
  );
}
);
```

ListingJavascript code for html page

```java
String result;
public String  getResult() {
  return result;
}
```

```
setup() {
  //initializations
}

draw() {
  //do something;
}

public void calculateResult() {
  //do something
  result=......;
}
```

ListingProcessing code (mysketch.pde)

3.5.4 Results

The section of the research project resulted in the successful replication of pen and paper visual neglect assessments using web application technology. The assessments replicated include the letter cancelation test, bells test, star cancelation test, and line bisection test; all of which have been successfully automated. The results of these tests can be seen below.

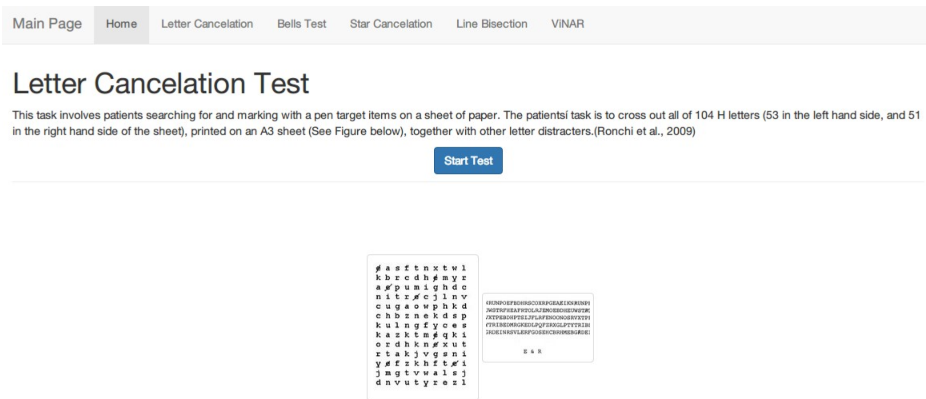

Figure 3.31: Related information provided before starting the tests. Web pages created using twitter bootstrap.

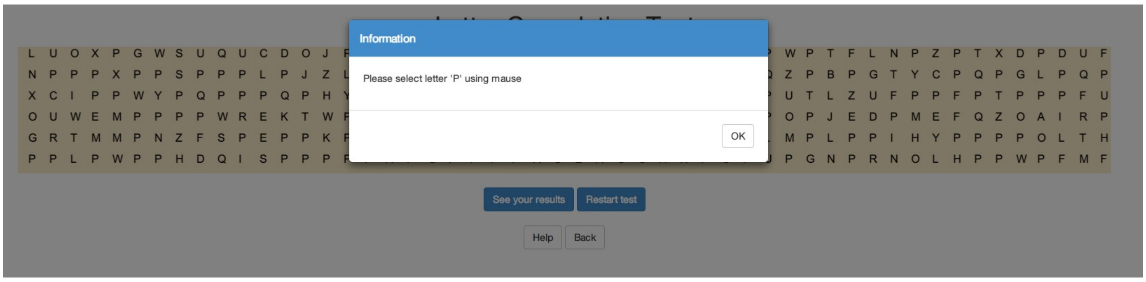

Figure 3.32: When the test starts bootstrap dialog box appear and ask user a cancel specific letter for this test.(letter cancelation) In this case patient will cancel letter P during the test session.

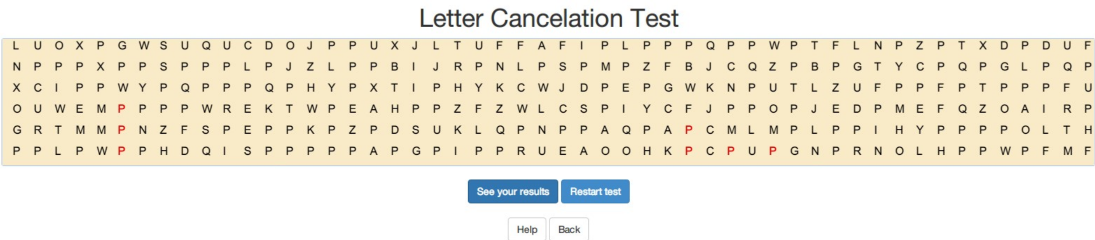

Figure 3.33: Users task is simply cancel the letter that is given at the beginning of the program cancelled letters will be in red colour.

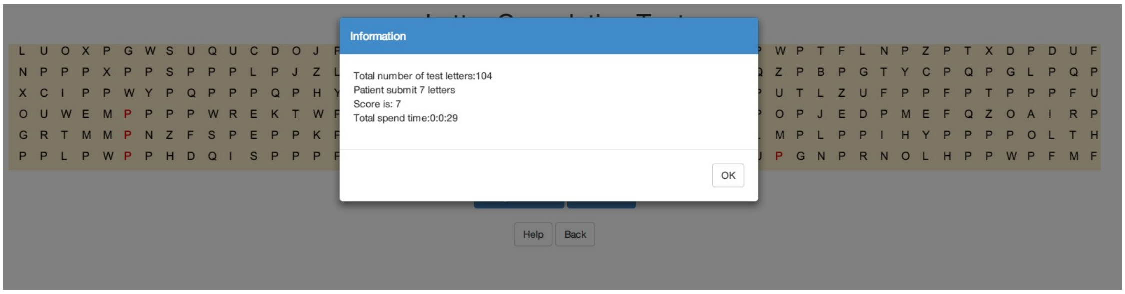

Figure 3.34: Results are displayed whenever user requests it.

3.5.5 Conclusion

The paper based tests are well known and verified ways of diagnosing visual neglect. Although verified conventional tests are replicated in web applications it is better to verify web applications against paper based tests on visual neglect patients in order to validate the system. Due to time constrains and the delay with Ms Kate Forte receiving clearance from the hospital administration as well as delays in ethical approval for this research with a patient population, we were unable to test our web system against paper based test on visual neglect patients.

Chapter 4

Evaluation of ViNAR

It is necessary to evaluate the ViNAR system against the accepted traditional visual neglect assessment techniques which are currently used in hospital and clinical environments. Each of these measures, i.e. the cancellation and line bisection tests, has been used for many years and they have generated normative data and research which supports their ability to accurately assess visual neglect in stroke and other brain injured patients [4] If ViNAR is to support the assessment and future rehabilitation of Visual Neglect then it must be proven to be an accurate measure of Visual Neglect in comparison with traditional accepted measures.

A full program of this type of evaluation of ViNAR would include it use in a hospital environment to assess visual neglect in stroke patients who carry a diagnosis of visual neglect after testing with the traditional tests of visual neglect. The ViNAR data for these patients would then be compared to the traditional assessment data to determine if ViNAR was capable of detecting visual neglect when it was identified and if it could map this neglect to specific areas in the left visual field as it is designed to do so.

Table 3.1 describes the main test conditions that ViNAR must pass to be able to successfully act as binary classifier. Ideally ViNAR should be tested with the participant categories described in this table and yield the appropriate result. For example from Table 3.1, if ViNAR is tested on Stroke Patients who have previously been diagnosed as having Visual Neglect using the standard tests (a true positive), then ViNAR should report that this person has neglect. If ViNAR is tested on a healthy control participant (true negative) then ViNAR should report that this person does NOT have visual neglect.

This research did not have access to patients to assess using ViNAR, due to time constraints and the scheduling of PhD student, Kate Forte's start in both of the hospitals in which she is planned to use the ViNAR system . In addition to this there are delays in the process of ethical approval being achieved to use ViNAR in both hospitals. In other words, it was not possible to test for true positives. However it was possible to test for true negative by testing 6 healthy participants with ViNAR (which was preloaded with control data from 15 healthy participants (See chapter 3)). This section outlines the results of testing healthy participants with ViNAR and provides an overview of the results of this evaluation. Appendix C includes the actual ViNAR

Participant Number	Sex	Age	Hand
p001	M	45	R
p002	M	47	R
p003	M	36	R
p004	F	26	R
p005	F	26	R
p006	F	23	R

Table 4.1: Demographics of 6 controls participants used to evaluate ViNAR

images, bar charts and heat maps for each of the 6 participants.

Participant Number	Letter Cancellation	Bells Cancellation	Line Bisection	ViNAR (See appendix C for details)
p001	Normal (all letters cancelled)	Normal (1 missing bell on left side)	Normal	Normal
p002	Normal (all letters cancelled)	Normal (all bells cancelled)	Normal	Normal
p003	Normal (all letters cancelled)	Normal (all bells cancelled)	Normal	Normal
p004	Normal (all letters cancelled)	Normal (1 missing bell on left side)	Normal	Normal
p005	Normal (all letters cancelled)	Normal (1 missing bell on left side)	Normal	Normal
p006	Normal (all letters cancelled)	Normal (all bells cancelled)	Normal	Normal

Table 4.2: Performance of 6 controls participants on the traditional test for visual neglect and on ViNAR

There were 3 males and 3 females ages ranged from 23-45 (mean 33.5), all were right handed and all reported normal or corrected to normal vision. Evaluation procedure progress as follows;

First of all a consent form was given to the patient and they were informed about the test session and asked to read the form and sign it [42].

Two of the paper based tests were used, which are the bells tests and letter cancelation test. In addition, the line bisection test from our web system was applied. All of the patients showed no sign of a visual neglect.

After completing the standard tests ViNAR was introduced to the participants and they were allowed to practice for 5 minutes in order to familiarize themselves with the technology. After 5 minutes, the diagnosis session was started using ViNAR. During the session the patient has to put the ball into different target locations. There are 36 individual separate target locations. Each target location must be visited at least once. The number of visits can be changed by the professional (tester) using the number of trials option in the main menu of the ViNAR. For instance, if the number of the trails set to 2 then this would yield 36*2 separate visits (2 visits for each area).

ViNAR and binary classifier tests showed that all participants are healthy. Participants ViNAR data are summarised in Appendix-C. Detailed data will be provided on request.

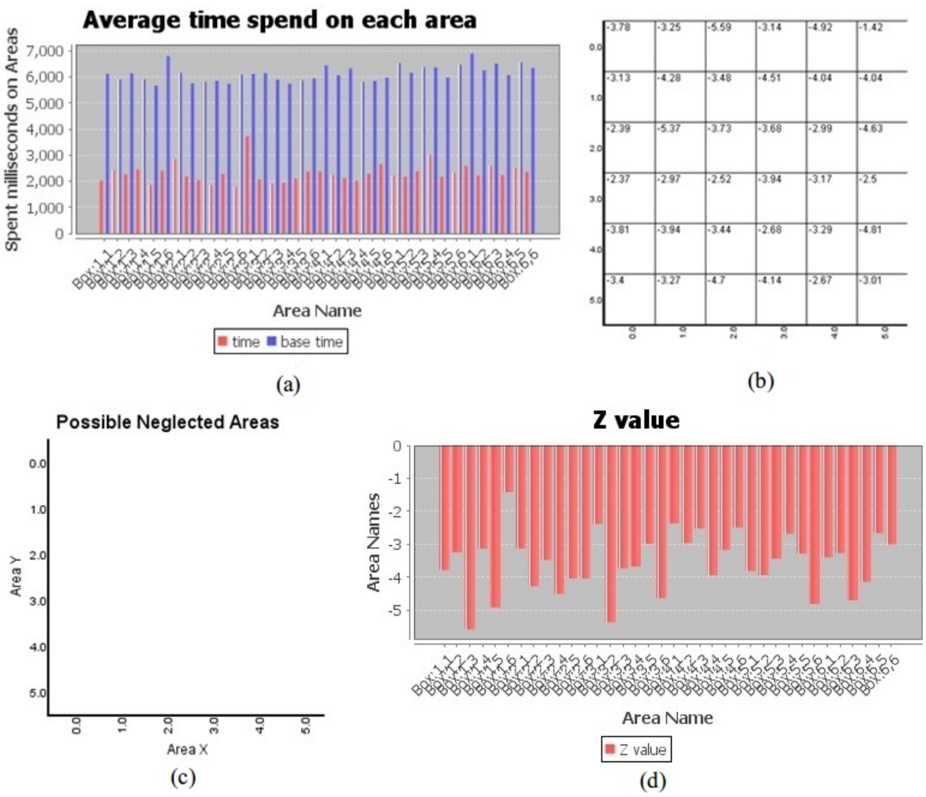

Figure 4.1: ViNAR results of a healthy participant.

Figure-4.1 shows the data of a healthy participant. The bar chart **(a)** in Figure-4.1 indicates that participant performed below the average on each of the areas. Matrix in **(b)** shows a different presentation of the z values revealing in value of the performance for each grid in terms of the z values(see Figure-3.28 for an explanation of the Z values).The heat map in **(c)** is all white since patient performed below the average. In other words, this heat map indicates that patient does not have visual neglect.

Graphs **(b)** and **(d)** in Figure-4.1 added as feature to ViNAR during evaluation session in purposes of providing details to the professional about Z-Values and patients performance.

In addition to the evaluation of ViNAR for the assessment of visual neglect, a usability issues were examined. This study resulted with small changes in ViNAR which improved the usability. For instance, the label of area names were changed to a simple and more readable form. More diagrams were also added to provide additional details to professionals. For instance, besides using a color coded heat map we provided another heat map structure with z-values instead of colours. This will make it easier for professionals to observer at a glance the patient's performance on different areas of the left visual field. Prospective professionals users (neuropsychologists, occupational therapists and doctors and nurses) of ViNAR would be expected to be very familiar with information on normal distribution of data and Z values as represented in Figure 4.1 and to be readily able to interpret the significance of positive and negative Z values.

4.1 Limitations of Heat Map Representation

During the evaluation process we realized that in heat map of participant p001 and p002 shows some areas red (see Appendix C, participants P001 and P002) although they performed well on pen and paper tests. The reason is that heat map shows the relative performance for the patient/participant on each of the areas. For instance consider a Z value matrix below;

$$z = \begin{matrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{matrix}$$

This matrix will be represented as follows even tough Z value for this red area may still be within normal bounds;

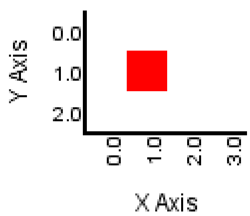

Figure 4.2: Heat map

This representation should not be interpreted as a person having visual neglect. In order to solve this confusion we should implement our own heat map algorithm which will evaluate the values independently. (i.e. 0-5 SD will be represented as yellow, 5-10 will be represented as light red etc.) However, due to time limitations we were not able to do that. Instead, we added features to ViNAR so that it will show additional information about Z value to the professional.(see Figure 4.1 (b) and (d) part for an explanation of the Z value). With the help of these additional diagrams, the professional gains insight into a patients performance and he/she can use this information through repeated testing using ViNAR to monitor the patient's progress over time.

Chapter 5

Conclusions

ViNAR is designed not only be able to act a binary classifier for the presence of absence of neglect but also to determine the spatial distribution of visual neglect in the patient's left hemifield. Once this is established, i.e. once it is determined where in the visual field a patient has visual attention difficulties, ViNAR can then be used to make the patient aware of this area of visual neglect and use this information to retrain their attentional resources to the affected areas. In addition to developing ViNAR in this research, we also provided web application versions of existing pen and paper tests. The Web platform enables professionals to access and apply tests via the internet and reduce paper consumption. We created web applications for Letter Cancelation, Bells, Start Cancellation and Line Bisections Tests. Due to time constrains and the fact that Miss Kate Forte was unable to receive ethics clearance in time from both of the intended hospitals, we were unable to test and evaluate ViNAR and the ViNAR web system against visual neglect patients but this will be addressed in the next iteration of ViNAR.

5.0.1 Future work

As the ViNAR evolves, it will be loaded with databases of different aged banded control data. This will allow meaningful comparisons with the patient's data. Specific control data will be used for comparison depending on which age bracket the patient falls within.. For instance, before patient starts to test he/she will enter his/her age into ViNAR so that ViNAR can obtain the data of healthy controls of range of patient from and integrated central database and compare the results with the patient's performance. In that way, ViNAR provides more valid assessment of a patient's performance. In addition to comparing the patient's time-to-target with healthy group which is the principle of performance measured in ViNAR, the trajectory path of the moving ball into target area could be compared and analysed. For instance, if a patient is neglected he/she will move the ball around the obstacle or other irrelevant places in test environment with a charteristic trajectory which may reveal salient information about their visual neglect or possibilities for rehabilitation. By analysing the movement paths (trajectories) of the ball as it is moved to the target and comparing with healthy control's paths we could gain additional information about a patient's pattern of visual neglect. Appendix-D which is a part of our tracking document shows other suggestions for future improvement. ViNAR will be evaluated in the hospital environment and tested with patients who have been diagnosed as suffering from visual neglect (this is done with the standard cancellation and bisection tests described earlier). It is important that the efficacy of ViNAR to detect Visual Neglect be established by testing it against patients who have a diagnosis of visuospatial neglect from traditional batteries of binary classification tests and this evaluation will be carried out beyond of the duration of this thesis .

5.0.2 Software Engineering Process

This project was developed using different aspects of a standard software development processes as well as aspects of the Agile software development process with its rapid prototyping of requirements.

After few sessions with Joseph Duffin and Kate Forte, the requirements and design documentation of ViNAR was created using a single Google document. Thus, design decisions and further requirements in every meeting is reported and tracked. Clear and understandable documentation is provided throughout the development and a user manual of the tool is provided. Different tools are present to provide documentation such as Doxygen and Active Presenter. Doxygen is a tool which generates documentation and diagrams from source code. For java projects, documentation is created from Javadoc in the source code. Created documents and diagrams are placed into an html web page which is designed to increase legibility and understandability of the written java methods.

A Version control system was used during development process. We set up a TortoiseSVN repository to a Dropbox account. Whenever we commit the changes in the project, alterations are transferred into TortoiseSVN repository system in Dropbox. Two copies of the repository are created for a computer and for a Dropbox server. Dropbox transfer changes to its private servers on the internet and these copies are synchronised with each other. This system has a certain advantage. Multiple copies of subversion system is created in different locations. Thus, TortoiseSVN is managing the versioning of the project and changes in every version are noted by me. In addition to this, we used a repository created for us by the Computer Science department at NUIM. However, there are not many versions as in our Dropbox since we started implementation before the computer science department provides us with their recommended git repository.

In order to enable users to deploy the tool developed in this project easily, the Inno Setup tool is used. Inno makes installers that work on Microsoft Windows. Inno creates a GUI for users to deploy the ViNAR application software easily into their system.

The ViNAR system software was tested throughout with the use case testing technique. We determined some test cases and executed these use cases via interacting with ViNAR. For example, to make sure ViNAR records and displays the right amount of time in order to measure patient's performance, we also measured the time with a regular clock and compared it with ViNAR's results. During the coding stage, problems in the software were reported and tracked using Google docs (See included requirements tracking document).

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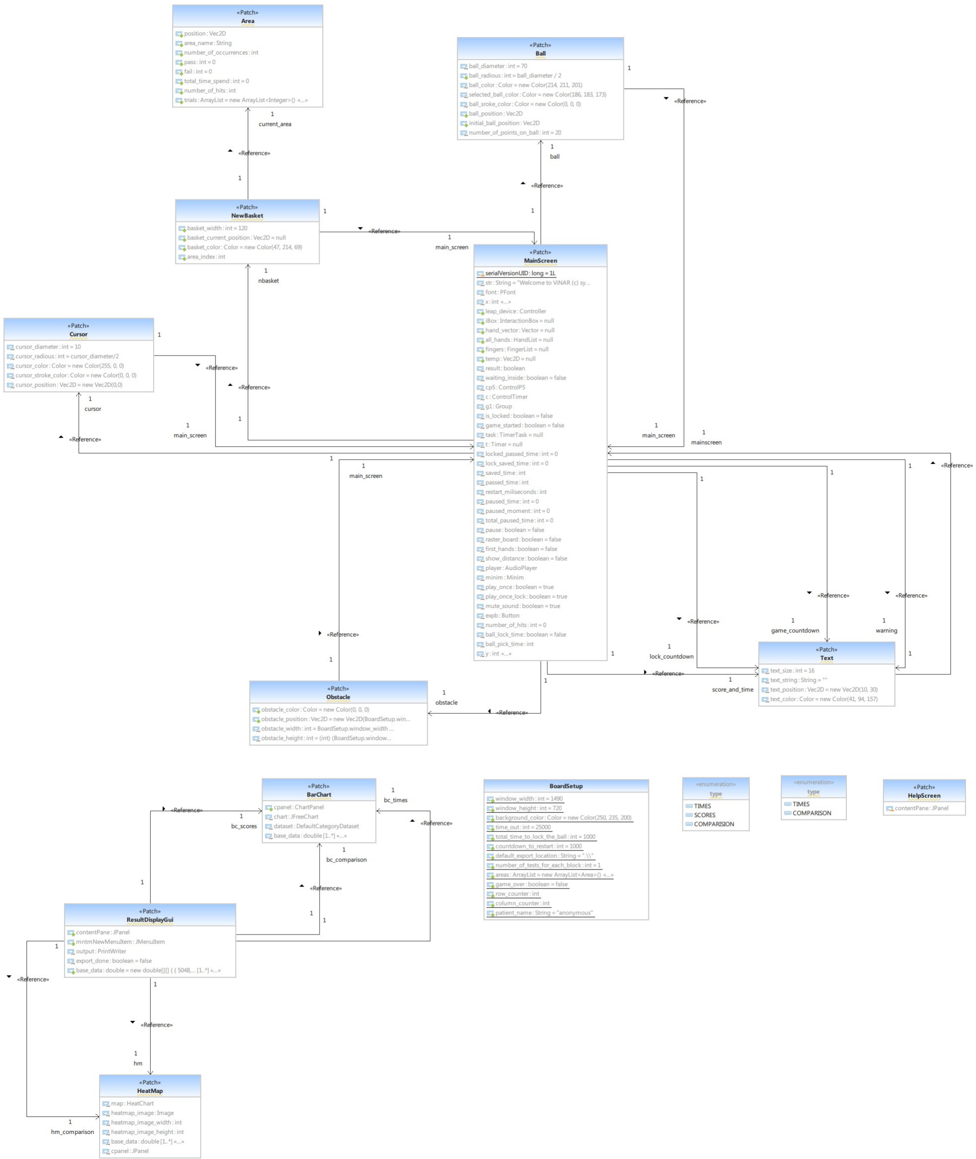
Appendix A

Class Diagram



Appendix B

Consent Form

Letter of Informed Consent for Participation in Research at the Department of Psychology and the Department of Computer Science, NUI Maynooth

Topic: Evaluation of the ViNAR (Visual Neglect Assessment and Rehabilitation) system

Researcher:Can Eldem
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Your participation is requested in an experimental study taking place in the Department of Computer Science at NUI Maynooth to help evaluate a new system for assessing Visual Neglect. Visual Neglect is a problem commonly experienced by a person after a Stroke illness. It shows up as a person not being able to pay attention or notice things usually on their left hand side even though they have normal vision. Your participation in this experiment will help evaluate a new system for Visual Neglect called ViNAR. At any time before, during or after this experiment, please feel free to ask any questions.

During the experiment you will be asked to do a number of different tasks – some will be pen and paper based, two will be on the computer, requiring you to look at the screen and using finger gestures over a new piece of sensing equipment call a Leap Motion Sensor. The Leap Sensor is able to track the movement of your fingers and draw your movement on a computer screen. The session consists of the following tasks.

1. Complete two standard pen and paper cancellation tests for Visual Neglect. (6 minutes)
2. Complete one internet based test of neglect. (The line bisection test) (2 minutes)
3. Use the Leap Motion Sensor system to test for Visual Neglect. (20 minutes)

The total time for your participation will be a maximum of 30 minutes. The specific nature of the study will be explained as soon as you have completed your session. The personal information you provide will not appear on any test sheets or publications and no participant will ever be personally identifiable from any publicly presented publications.

Any data collected over the course of the experimental process will be anonymous, identified only by a code number, assigned randomly before commencement of experimentation. Your responses will be combined with others and reported in group form in a scientific paper, your own data will remain anonymous and be available to you to look at at your discretion. You may withdraw from the study at any stage or you may withdraw your data up until the work in published.

Performance on these tasks does not provide any diagnostically relevant information. In the unlikely event that you experience any distress or discomfort as a result of participating you should contact your own GP. Please provide the following information by ticking any of them that apply to you.

[ ] Severe visual impairments
[ ] History of psychological/neurological impairments
[ ] Severe head trauma resulting in unconsciousness
[ ] History of epilepsy
[ ] Dementia/moderate to severe aphasia
[ ] Currently taking psychoactive medication
[ ] History of drug/alcohol issues
[ ] Acute mobility conditions
[ ] (i.e lower limb amputation/recent joint replacement)
[ ] Any muscular/bone problems that cause spatial ability
[ ] Impairments
[ ] Dyslexia
[ ] Normal or corrected to normal vision.
[ ] English not a first language

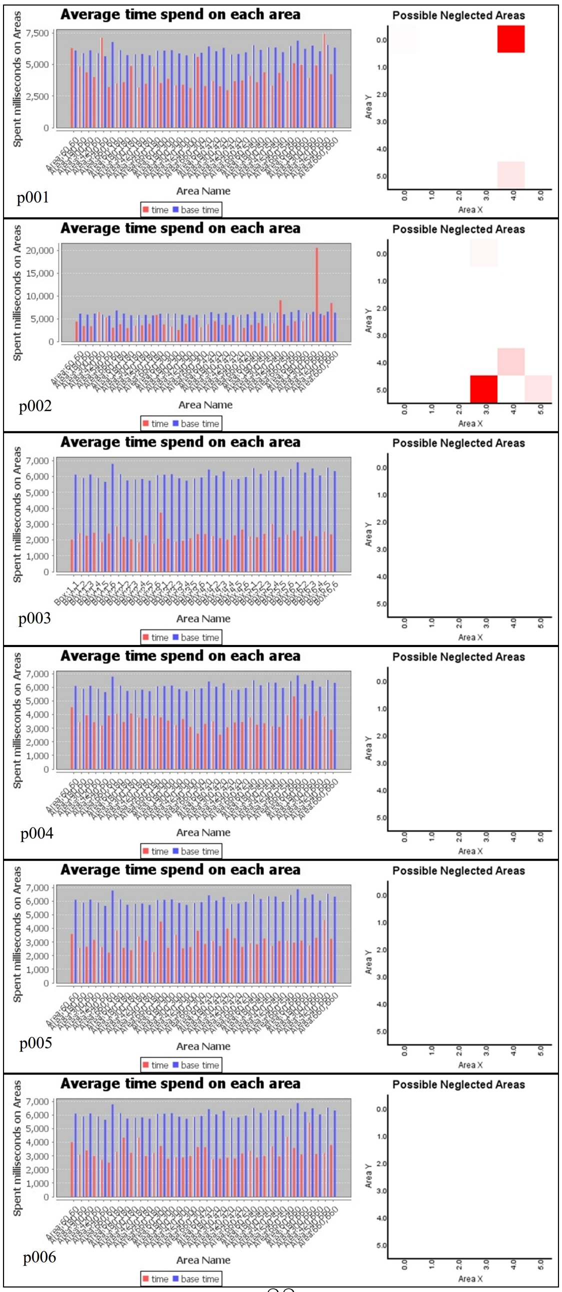
I have read the above and understand the nature of this study and agree to participate. I also understand that I have the right to refuse to participate and that my right to withdraw from participation at any time will be respected with no coercion or prejudice.

Name (Please Print Clearly): ______________________________
Handedness (left or right) ______________________________
Signed: ______________________________ Date: ________________
Date of Birth: ________________________
Signed (Researcher): ______________________ Date: ________________

This research project has been approved by the Departmental Ethics Committee If during your participation in this study you feel the information and guidelines that you were given have been neglected or disregarded in any way, or if you are unhappy about the process, please contact the Secretary of the National University of Ireland Maynooth Ethics Committee at research.ethics@nuim.ie or +353 (0)1 708 6019. Please be assured that your concerns will be dealt with in a sensitive manner

Appendix C

ViNAR Evaluation Results for 6 healthy participants



Appendix D

Future Requirements Suggestions

1. ViNAR 1.x is provided with a 36 left sided grid to provide target points for the user to reach over many trials. The results of the user's performance is presented diagrammatically in the same layout as the the assessment grid. The resolution of this performance output is 6*6 or 36 individual grid units each colour coded in terms of Z values or fraction of sStds from the mean values obtained compared to the normal data for each grid square. Instead of the coarse quantum of single grid unit presentation .

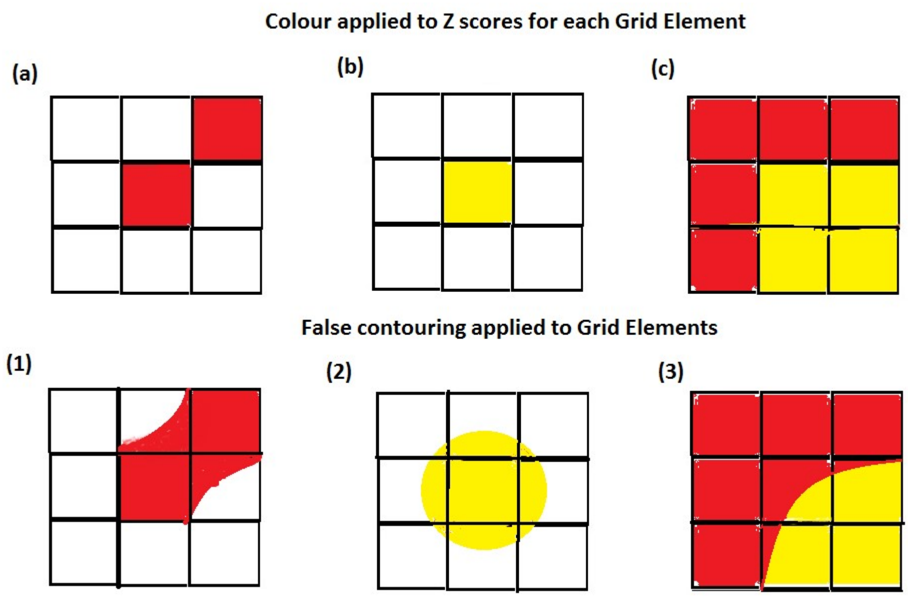


Figure D.1: Figure Illustration of calculated colour coded Z scores calculated for each Grid box (a), (b),(c) and the corresponding false contoured grid boxes below them (1), (2) & (3), such that (1) is the false contouring of (a), (2) is the false contouring of (b) and (3) is the false contouring of (c)

2. It may be beneficial to introduce a configurable practice mode which can be run by the user before the full assessment is run. This would allow user who are

patients and non-patients to get use to the system and it would allow the ViNAR system to maximise the number of complete trials once the full assessment begins after the practice test.

3. After using the ViNAR system to identify areas of left hemifield neglect, it may be useful to have an additional mode which allows the user to target the neglect area with a large number of trials towards that neglected area. (patient would have to try and get the ball into a specific sub area region of the 36x36 grid). We could then chart the patient's progress over a large number of trials and hence monitor progress and perhaps this would help rehabilitation of the patient.

4. In the Beta version which will be the release for Can's project assessment, we intend to hard code the data provided by Kate for 20 control participants into the ViNAR. This data will be used to form a control matrix and in the future, patient participants will be compared against these normal data which are built into the ViNAR. We should prioritise the addition of ViNAR functionality which will allow the user to update the Normal matrix with new control data. We should also update the ViNAR system with capability to allow the user to upload different categories of Normal data e.g (1) Health controls aged 50 to 75 years, (2) Healthy Controls aged 30 to 50 years. With this in place the user should be able to select from a number of normal control data from a selection menu. This data will be then the active data for assessing the patient's performance. So for example if the patient was a 60 year old man then the user would select the Category "Healthy Controls aged 50 to 75 years" as the normal data for the patient to be compared to.

5. The vast majority of visuoperceptual hemi neglect patients (visual neglect) have a deficit in their left visual field. Perhaps we should have the capability in ViNAR for patients with a right hemifield defect to also be assessed.