Motion-Based Navigation Interaction Performance in Visual Search Task

Using mobile augmented reality as a control mode for motion-based navigation in a large two-dimensional information space

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Abstract

This thesis explores motion-based navigation model of interaction, where the user of a mobile device, uses the motion of the mobile device to provide navigation inside the virtual environment. This was achieved using a computer vision technique through augmented reality to provide the device tracking in the physical world. Current model most commonly used on mobile devices to navigate around large two-dimensional information spaces uses a touch-based navigation model where the participant uses touch gestures on the screen to pan and zoom. We compared the two interaction models on a sample of 20 participants using a within subject methodology to determine which model of interaction performed better at large visual search tasks, where the participants were asked to locate unique items in an array of distracting elements as quickly as possible. We also looked at the two interaction modes through self-reported user experience surveys. We were able to show that the motion-based navigation mode was slower at the visual search tasks, as well as harder to use and causing more physical fatigue than the matching touch-based interaction. We feel that further investigation is needed to find in which subset of cases each model performs better.

Keywords: Human-Computer Interaction, Visual Search, interaction models, Motion-based navigation, mobile devices, tables, Augmented Reality, computer vision

Index

1. INTRODUCTION

1.1 Search in the real world

Every time we misplace our wallets or keys, we perform a search task for the specific item of interest. We search for all the groceries we need to buy at the store, our car when we are approaching the location where we parked, and the friend we are trying to meet on a busy street. It is a task we perform daily in order to manage navigation around our world. Search has been important even to our ancestors and being good at the searching process provided an evolutionary advantage through selection of edible foods from all similar looking items that provide no nutritional value, or have even more dangerous consequences like the potential to harm the consumer [4].

This task, when performed only by our visual processes, is called a visual search task and can best be exemplified by the popular game-book by British illustrator Martin Handford, called “Where’s Wally?” [18]. In “Where’s Wally?” the objective of the participant engaged in the task is to find the location of Wally, dressed in his trademark uniform of a red and white striped shirt, matching pattern winter hat and eyeglasses, in an image crowded by a diverse set of other characters, objects and items of varying shapes, sizes and colours. The more other characters in the image, the harder it is and longer it takes to find Wally.

The visual search task of searching through large two-dimensional information spaces is of significance in the present-day as seen recently in real-world examples of the visual search task to find the location and remains of the crashed Malaysia Airlines MH370 [19], where satellite maps are analysed in order to spot a piece of the plane. Moreover this task is also present and of grave importance in airport security, where each bag is x-rayed and individually screened for dangerous items, by an operator looking at a monitor of passing bags. Qylur Security is a firm that has also recently introduced a baggage scanner that simultaneously scans 5 bags at a time, uses new advances in artificial intelligence to help screen for a preselected known threats by the operator is still presented with this information simultaneously [20], requiring even greater capability to spot targets in this larger informational space.

Figure 1 – New baggage monitoring system by Qylur Security

Air traffic and train controllers use visual search, for performing their jobs, as well as doctors. In medicine, visual search is used to find cancerous tumours in a mammogram, examining a pap smear in a cervical cancer test [6].

Visual search is also used in ocean and space exploration in looking for stars in the Milky Way, as well as navigating through media libraries, for entertainment in the form of search games, and also in the field of neuroscience for going through fMRI scans of a human brain.

1.2 Mobile devices for visual search

In the past decade there has been an immense increase in mobile device's processing power and sensor capabilities. Mobile devices today provide us with cameras, Wi-Fi and 3G connectivity, touch screens, GPS, accelerometer, gyroscope, and magnetometer sensors among others. Coming up with novel ways to utilize and interact with all these capabilities provided by devices, that are small enough to fit inside our pockets, has been the topic of current investigation, especially in the field of human-computer interaction, by researches, engineers and application developers.

The main way we interact with large two-dimensional information spaces, like images and maps, on touch screen devices in the present day has been though touch directly on the device's screen and controlled by pan and pinch gestures to provide scroll and zoom capabilities inside the informational space [36]. This is very much a device-centric way of interaction as all control is provided by gestures performed on and in respect to the device itself. We wanted to see what other affordances, within Gibson's definition for this term of actions not immediately perceived by the user, were available to be used by a mobile device and in which way we can utilize the sensors already present in the device to interact with the device in novel ways, as well as to verify if those interactions are better at a certain task, like the visual search task, than the current touch based navigation model.

The method of control we selected to test is a user-centric model of navigation. It is a motion based-navigation model where the user physically navigates around the real world environment with the device in their hands to perform navigation control in the virtual world displayed on the device. The user physically moves left and right to pan the interface in the same horizontal direction. To pan the interface in the vertical axis, the user moves the device up and down. Finally, to provide a metaphor for zooming, the user walks forwards and backwards to zoom in and out of the informational space respectively. These three degrees of freedom for motion in X (horizontal), Y (vertical), and Z (depth/zoom) axis provide us with the same functionality of special navigation allowed by the pan and pinch gestures on a touch-screen device.

In this navigation model we gain a much more fluid interface which is commonly know as a magic lens [38]. This is because in this motion-based navigation model that is relative to the body, the virtual world's control by the motion of the user provides the sensation of holding a magic window into the virtual world, and the user is able to look through this window simply by moving the device around with their hands.

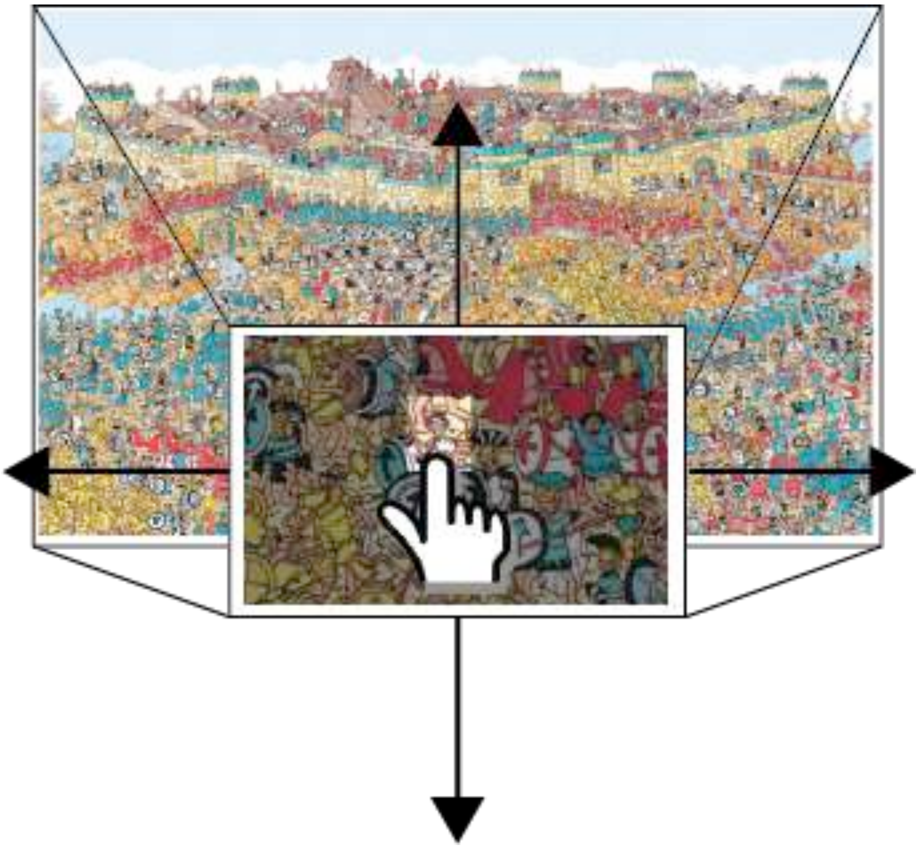

Figure 2 – "Where's Wally?" as seen through a magic lens

The objective of this work is to see whether motion-based navigation performs better than the current touch-based model in the exploration of virtual space and more specifically the selected visual search task on a mobile device we need to set the criteria for measurement and comparison.

As searching is a combination of fundamental psychological processes, [4] the visual search task is a perceptual task that deals with the study of attention in the scientific fields of psychology and cognitive science with over 40 years of research on the topic. In the task, the user looks for a specific, known, target visual stimulus among other similar looking stimuli, called the distractors as they guide the attention away from recognizing the target object and thus making it harder to locate the target. The time from the presentation of the stimuli to the time of consciously locating the target is called the search time.

The visual search is called a feature search if the target maximally varies from the distractors, which is accomplished by varying only a single property [8]. These properties include colour, shape, orientation, contrast, and completeness. In a feature search, the target creates a pop-out effect. Locating pop-outs is a pre-attentive parallel process [9] where the target pop out objects dominates the user's attention and are easily identified. This is the quickest search task and is know as an efficient search [7]. An example of a feature search is spotting a red circle in a set of black circles.

Another type of search is the conjunction search, also known as the inefficient search, where two or more properties of the target are combined to form distractors. In this search, the pop-out effect is eliminated, as the distractors are more visually similar to the target object. This is a top down, user activated search. It is a much more timeconsuming task than the feature search as each element is scanned individually in a serial process [9] and therefore requires more attention than a feature search to determine if a given object it is the target [4]. An example of a conjunction search is the location of a red circle in a field of red squares and black circles, making the task more complex as the distractors now share two properties of the target, the shape and the colour [10].

The complexity of the visual search task also varies with the set size, or the number target and distractor objects present in the visual search stimulus. Increasing the set size increases the search time of the task [37].

In all search tasks there is a second class of decisions in addition to the attention dedicated to locating the target. The decision is of the time to quit, or step out of the search task. External pressures to quit dictate this decision, and can be attributed to causes such as search fatigue or the amount of search tasks the user needs to accomplish through out the session of searching [6].

1.3 Problem statements

We focus this work on answering the following questions:

Question 1: Does motion-based interaction provide faster search times than touch-based interaction in a visual search task?

Question 2: Does motion-based interaction improve the memory of the located targets position in the virtual information space versus touch-based interaction?

Question 3: Is motion-based interaction an easier method of navigation through the virtual space than touch-based interaction?

Question 4: Did motion-based interaction cause more physical demand imposed on the user than touch-based interaction?

1.4 State of the art

The current state of art encompasses research topics that can be grouped according to the following two categories:
1) Phone tracking technology
2) Mobile device interaction beyond touch and their applications

1.4.1 Phone tracking technology

For motion-based navigation to function as a tangible physical manipulator of a virtual interface, we need the computational device to be spatially aware of its actual location in relation to the physical world and to be able to track its motion in all three physical dimensions [15].

In this regard we will first introduce the latest developments in this field before presenting solutions that will be implemented for this work. First is the prototype device developed by Google, called the Google Tango [21] which uses sensor fusion along with computer vision algorithms to precisely map the whole 3D physical environment around the device and therefore it is able to be completely spatially aware of its location in relation to the physical world. The second soon-to-be-released mobile device to mention is the Amazon Fire [22] which includes 4 extra tiny cameras on the face of the device to be able to perform a depth map to the users face and be able to calculate where the phone is in relation to the user interacting with the device, therefore this device is spatially aware only in the regard to the user, which would allow for motion-based navigation only in relation to the devices motion to the user, but not the world.

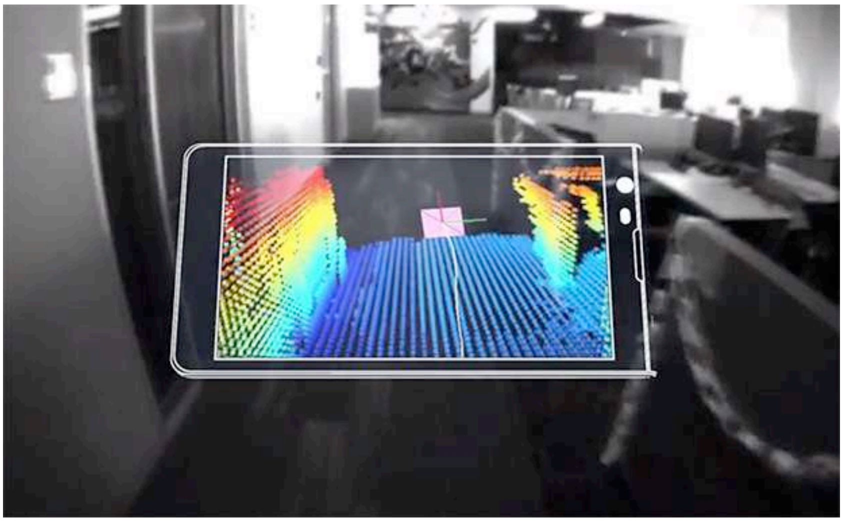

Figure 3 – Google Tango modelling the surrounding physical environment

The main two methods for tracking the devices position in relation to the physical world that are currently available are a motion-capture systems and augmented reality implementations. In motion-capture systems, the mobile device is equipped with reflective spheres, which are recorded by multiple infrared cameras position around the environment in order to capture the location and movement of these spheres. This location data is computed and sent to the mobile device for performing the matching navigation motion [35].

The augmented reality implementation used for a control method can be seen in a 2013 study on special layers and navigating through information density [1].

Augmented Reality libraries provide the device a way to overlay 3D objects over the image captured by the camera using a Computer Vision technique called marker tracking. AR is a technique to view the world through a video-capture device and virtually augment the view with additional computer-generated information. This is done using computer vision technique called marker tracking, where the device scans each frame captured by the device's camera for the set marker. Locating this marker in the frame, as well as performing calculations for it's orientation in relation to the camera, allows the device to set the same coordinates to display the computer-generated content. As performing marker tracking and calculating the position coordinates on each frame of video being captured is a computationally intensive task, a set of AR libraries exist that have these algorithms heavily optimized for best and fastest calculation of locating the marker in the image frame. We will use this marker location technique to allow the device to capture the markers coordinates and thus in-turn allow the device to know it's position to an external mark in the world so we can use it to precisely understand the devices motion throughout the physical world and map this to the control inside our interface.

There is a recent 2014 study that applies a goal-oriented visual search in a augmented reality environment along with subtle cueing towards the target on a video-see-through AR [14] but our search will be performed in a purely virtual world where navigation happens, not by augmenting the reality though video-see-through AR but using the AR technique to track the position of the device and using it as a control method to navigate through the image.

1.4.2 Mobile device interaction beyond touch and their applications

There is a multitude of examples of state of art in research literature as well as patents of methods for controlling computing devices using non-touch methods [3,11], with a special focus on physical gestures [14] as well as examples of physical manipulation games like the Neon Zone which uses gyroscope and accelerometer features of the phone for control of the gamer's movable block in attempt to solve puzzles [23] that doesn't require any touch-based interaction. Other research on controlling mobile devices without the use of touch screen focuses on finger based movement in front and behind the device which is also used for creating virtual objects inside the virtual world by tracing the shape with the finger behind the device in order to extrude and shift 3D shapes [2]. Many of the listed examples use the body motion as an interaction method and are classifiable according to the body-centric framework where the study is focused on different motions for interaction that are relative to the body [34].

There are also recent applications that use touch on the mobile device in order to extend it's interaction to control objects in the real world by using mobile devices and augmented reality such as MIT Medias Lab Reality Editor from the fluid interfaces group [16] or from the Tangible Media group the exTouch [17] which controls a robot using a interface via augmented reality on the mobile device.

2. METHODS

2.1 Design & Development criteria and strategies

a) Technical development

To address the research questions proposed by this work, the goals was to first develop a visual search task application for a mobile device that is able to take advantage of the camera information to provide information about the devices location in the physical world. The methodology for our visual search task application is modelled upon the implementation of PEBL Visual Search task [24]. The PEBL test battery provides a freely distributed library of computer-administered psychological tests used for psychological and neuropsychological research [25]. The PEBL visual search task presents the target to the user, and then shows the screen with the target and distractors for a set period of time and immediately following the timers completion it asks the user if and where they saw the target. Each experiment saves the complete data set for later analysis.

Our selected platform for this application was the iPad Mini 10" tablet as it was the device most readily available to the researchers. Therefore, the development of the application was done in the Objective-C language on the OSX platform using Apple's developmental toolkit, Xcode. The application had to be capable of storing and presenting a series of 4000x3000 pixel images that included various complexities of the visual search task. This resolution for the images was selected, as the devices screen resolution is 1024x768 pixels, so at maximum zoom of 1 for least degradation of the JPEG image quality meant that the user had a 1024x768 pixel view in a 4000x3000 pixel image that they were moving around. At minimum zoom, the 4000x3000 pixel image is scaled proportionally to fit completely on the devices screen, which shows through a simple calculation that the minimum zoom level is a scale 0.256 of the original image's size.

Each image needed to have the capability of being controlled for panning and zooming in the touch-based method that the touch-screen users are accustomed to, as well as programmatically that can be mapped to the information form the computer vision system. The navigation within the image needed to be smooth, without jerky movements that would distract the user and take away from the navigation experience, so a smoothing curve is applied to each movement of the image. As the user approaches the edge of the image or minimum and maximum zoom levels, the bounce effect needed to be disabled to minimize the distracting effects of the additional motion animation. The progression to the next stage of the experiment can only be reached by precisely locating and tapping on the target. The targets coordinates are stored for each image and are zoom dependent, so as is expected, the target's tap area is larger at greater zooms as the user is able to see the larger target, and smaller at lower zoom level to additionally avoid accidental taps on the target either from navigation or from a brute-force attempt to locate the target by tapping everywhere on the screen. In the motion-based navigation trials, the navigation is mapped to the position matrices provided by the augmented reality library.

Among the many available Augmented Reality libraries available for all platforms, Vuforia [26], shown in Figure 4, was selected for its ability to provide precise 3D object tracking using natural feature detection on it's markers and as well as performing a augmented reality visual search [27]. It is also a library that has most of the implementation open for the chosen iOS platform and the developer has direct access to all the transformation matrices [28] directly available in Objective-C. Vuforia is available for both iOS and Unity. What makes Vuforia especially useful in our case is that it doesn't require the use of C++, allowing us to stick to Objective-C.

Figure 4 – Vuforia AR platform displaying a 3D model of a teapot on top of a marker

Once we map the markers position, and it’s movement relative to the device, to the navigation of the image, we were able to provide a motion-based navigation model that allowed navigation within the image by movement of the device side to side, up and down and forwards and backwards. Special consideration was applied through trial and error to making sure that the motion of the image is as smooth and intuitive as possible.
A specially settings panel, shown in Figure 5, was implemented inside the application to allow for adjustable mapping limits for left-right, top-bottom and front-back maximum movement limits in all three axis that allows for marker readjustment in case of necessity during the experiment, as the users heights vary, therefore the maximum limits for top and bottom is readjusted to match where the appropriate level viewing the image for their height.

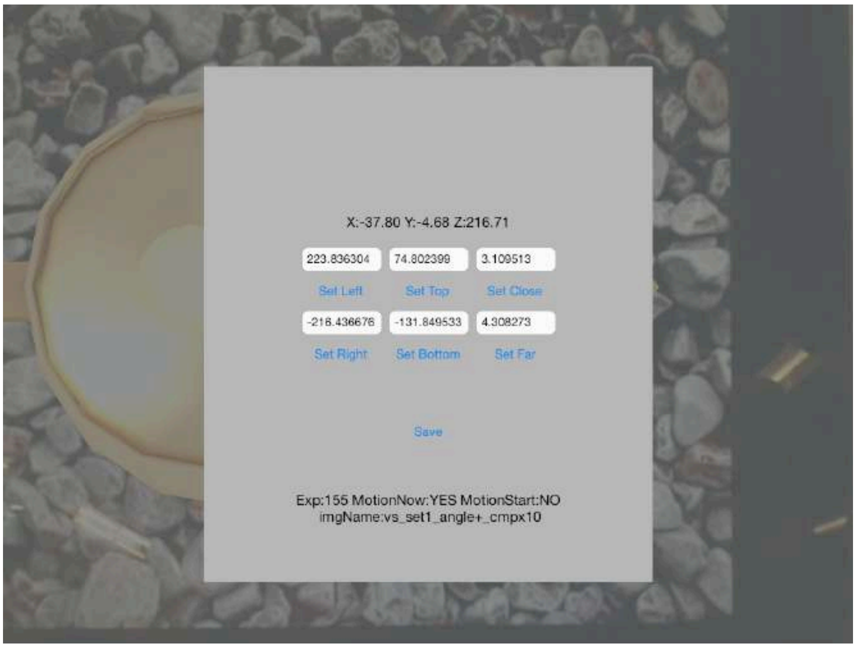

Figure 5 – Settings panel inside our Visual Search application for configuring the mapping

One of the major problems that arise in this situation is the loss of marker tracking by stepping outside of the range where the camera is able to see the marker. In this scenario we place the image at the minimum zoom level, so the whole image is visible and place a red X mark in the corner of the screen letting the user know that the system has lost tracking capability and they need to return to the reset position marked on the floor for the device to detect the marker and allow navigation. In the case that the marker does lose tracking, we still enable for the target to be selected if previously seen. As the motion-based navigation is slightly less stable than touch-based navigation due to the fact that the device is never held perfectly still due to muscle strain and anatomy, so a margin of two times the width and height of the target is added to the target hit area making it easier to hit the target even if in slight motion. Vuforia provides markers that include the best possible conditions for the computer vision to minimize the loss of marker tracking, so the two recommended images are full of natural features, rich in detail, have good contrast and have no repetitive patterns allowing for smooth tracking. The marker used can be seen in Figure 6. Natural features are sharp contrasting elements inside the marker image. A simple square has 4 natural features, one at each corner however the selected stones image has hundreds included. The only processing performed on the marker image is desaturation of colour as to least distract the attention of the user that it looking for colour patterns inside the visual search task [29,30,31]. An additional feature provided by Vuforia that would provide usefully functionality to the application is the use of extended tracking. Extended tracking uses a fusion of the devices sensors as well as the surroundings around the actual marker as references for tracking in the case that the actual marker is lost from sight, but extended tracking could not be reliably turned on for all tasks as we switch between motion and touch trials so extended tracking was completely turned off.

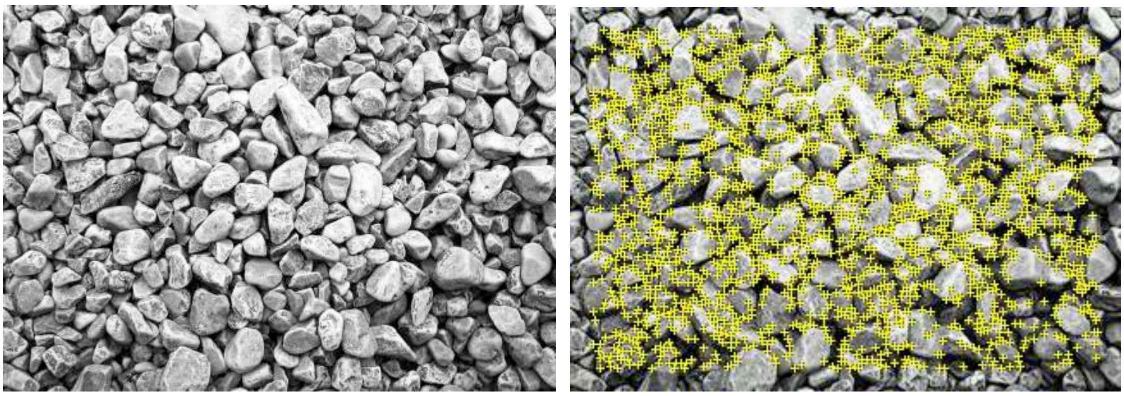

Figure 6 – Select Vuforia stones marker and all of it the natural features shown highlighted

b) Experiment control

If at any time the participant feels frustrated or the complexity of the task is too high, they have the ability to skip the trial by swiping with four fingers on the screen to the left. The device records both the time it took to finish the trial and whether it was a tutorial trial, a touch-based navigation or motion-based navigation trial, and whether it was skipped.

After the termination of the trial, we present a screen with a blank visual map of the whole image and instruct the user to select approximately where they thought the image was located. We record this tap point coordinate as well as the actual target coordinate in the log file and we visually display the answer by showing two circles on the screen, a small green circle representing where the user tapped their best guess, as well as a larger blue circle cantered around the location of where the target was actually located.

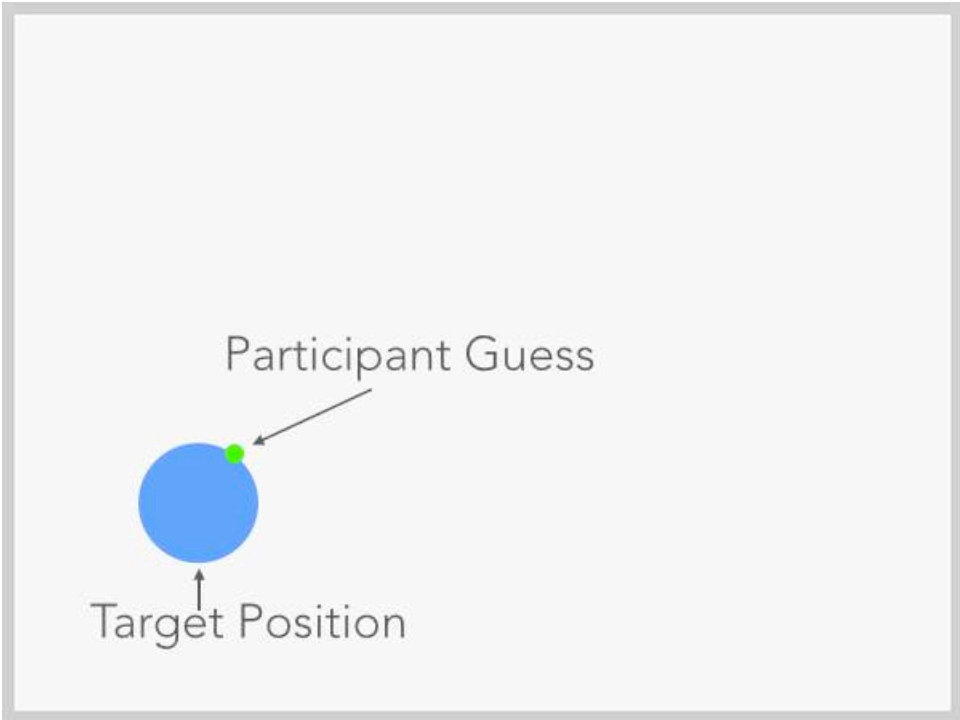

Figure 7 – Memory of target location feedback displayed on a blank results image

After a two second timer of showing the results of the memory guess of the targets location, we present a info screen letting the user know which navigation mode and which target they will be looking for in the next trial.

There is also a global 20 minute timer implemented that upon it's expiration as well as the completion of the current trial presented to the user, shows an info screen letting them know that the experiment is over.

The greatest problems in the development of the actual app arose from the limited memory available on the device it self, as reported by other studies as well [35]. Since we are continuously switching between presentation of large resolution images, most of which the iOS operating system systematically caches in case they need to be used again, special methods of memory allocation and deallocation needed to be implemented in order to avoid crashing the application during the experiment due to memory pressure.

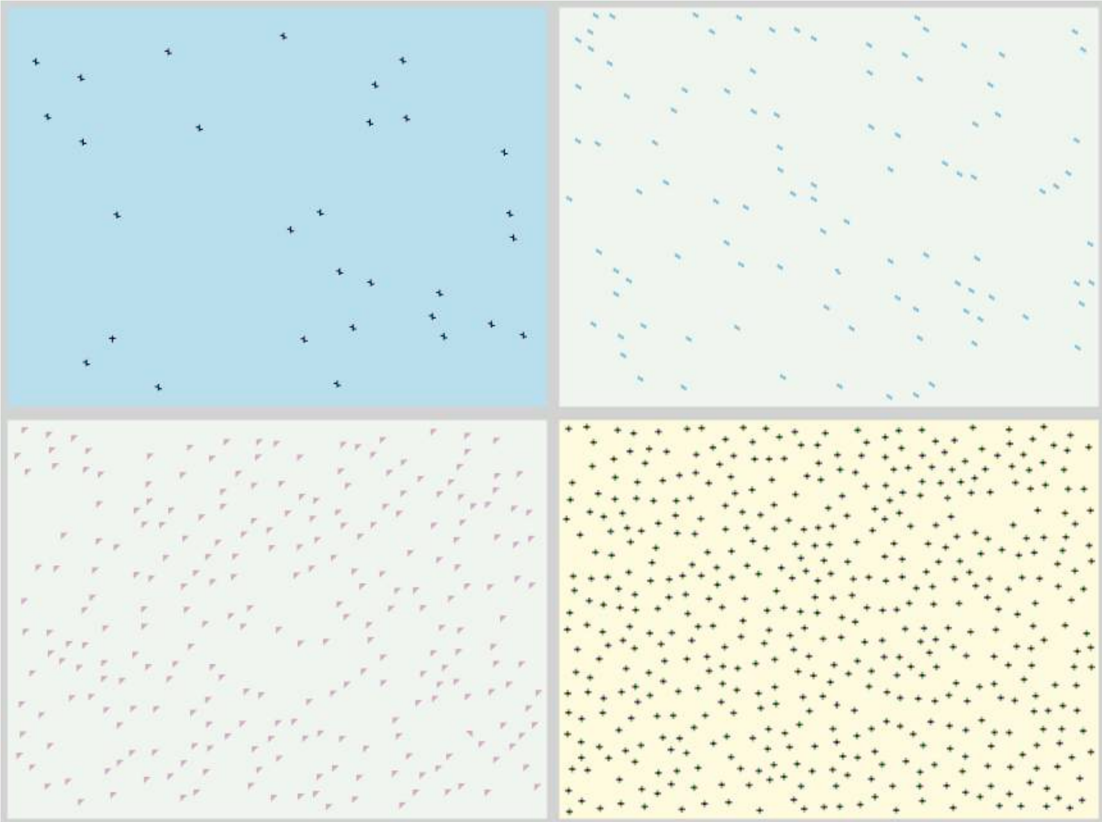

Figure 8 – Generated images at various set sizes (30, 100, 200, 500)

c) Target images generation

To make the 4000x3000 target images we also developed a random visual search task image generator. It is coded in Processing, as all the images are pre-generated to be used for the trials. Very much like “Where’s Wally?” [18], our objective was to randomly distribute the location of the target, without clustering it specifically around points that the search inherently begins with, the edges or the centre of the image. First attempts were used with generating target placement using a Halton Sequence, which provides more even distribution of objects than a simple pseudo-random generated sequence [32]. However, the Halton sequences are inherently deterministic so a more brute force algorithm was developed in part using the Circle Packing in a square methodology [33] where each target has a defining radius around it and the algorithm attempts to place objects and a single target in the picture until there a overlap between two object's radiuses, in which case a new location is generated until there is no overlap collision between the newly placed object and all the other previously placed in the image. We also made sure that between images, the target is distributed around all parts of the image as to not form clusters where the targets may have been more easily in following trials.

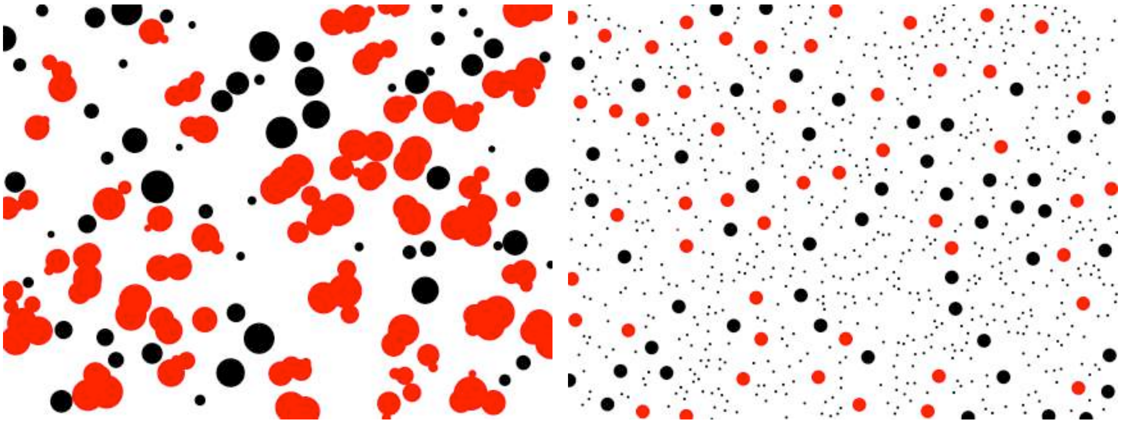

Figure 9 – Random object placement without and then with dispersion

We selected four different target-distractor pair examples [5,12] that for the basis for the visual search in order to provide variety so the user doesn't feel fatigued and is presented with an unexpected target to find in each following trial. The generator uses each one of the target-distractor pairs to generate a varying complexity by incrementing the set size, or the number of distractors present between each image.

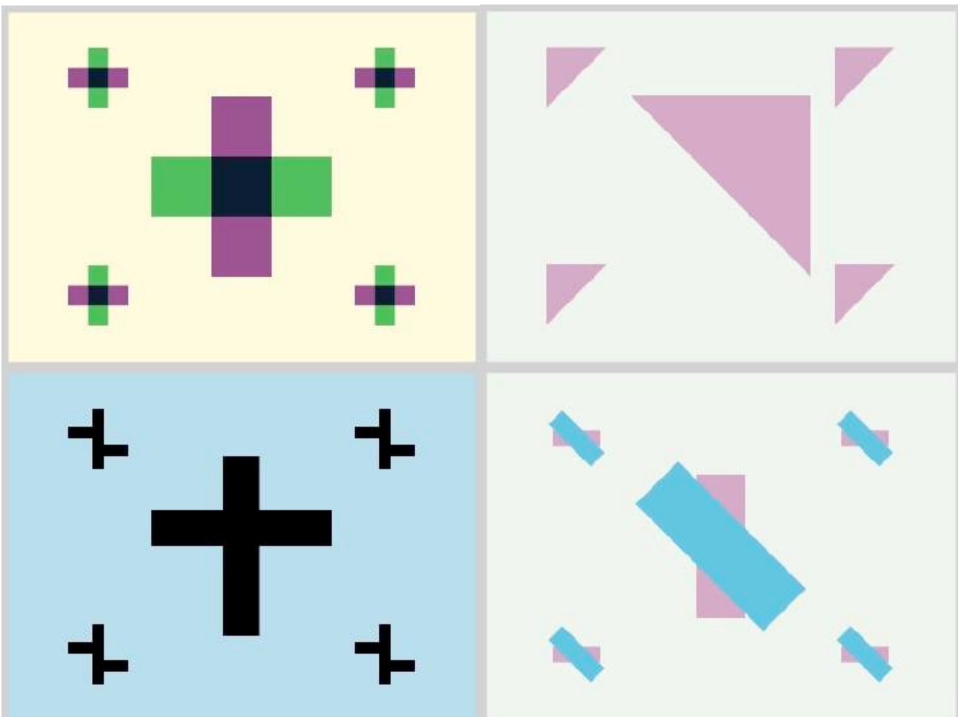

Figure 10 – Different targets shown to the participant surrounded by four smaller distractors

2.2 Experimental design and set-up

The experimental design consists of three stages. The first is pre-experimental phase and the tutorial phase (with verification). Following that is the experimental phase. Finishing with a post-questionnaire. Before any of these stages, the iPad mobile device is prepared by cleaning the oils from the screen, disabling all network activity by putting the iPad in Airport Mode and all notifications are turned off. All applications are closed to release all possible memory and remove the off chance of the experiment application crashing due to a lack of memory. Once the Visual Search Task application is turned on, the device is put in the Guided Access mode that keeps the iPad in the single application and disallowing the participant from accidentally exiting the application by hitting the home button on the iPad. The final step to end the preparation, at the beginning of the applications, the experimenter selects by random selection whether the participant will start the experiment with motion-based navigation or touch-based navigation thus setting up the experiment in the a ABAB and BABA conditions as after each trial the navigation mode switches conditions.

The location of the experiment is a quiet room with consistent and solid ambient lighting to best allow the iPad's camera to track and recognize the marker. As the new participant enters the experimentation location they informed of all the steps that will take place, in order to know what to expect and the time duration allocated for the experiment. In the pre-experimental phase, we first ask the participant to fill out a pre-questionnaire and a standard consent form [Appendix A]. For the consent form, the participant is let know of the purpose of the experiment, as well of what is being collected and informed of their right to stop their participation in the experiment without prejudice and at which point all records made up to that point, both in paper and digital will be erased. In the pre-questionnaire we ask the participant to fill in basic, general information like their name, age and sex, and state whether they use touch-screen devices on a regular basis in order to determine afterwards any variability in the participants that are not sufficiently accustomed to the touch-based interaction mode. We also present in the pre-questionnaire a four part section of the Ishihara Colour Vision Test to check for colour blindness as many of the visual search tasks are colour dependent in order to complete the task. We then proceed to the tutorial phase where we as the experimenter show the participant the two interaction methods that will be used, lets the participant play around freely with both interactions until they get comfortable using both, and then run 8 tutorial stages of simple search task at very low complexity to verify that their level of performance and comfort using the interactions is at an adequate level for running the experiment.

In the tutorial stage, participants are explained of the initial position they need to take in the marking on the floor and the range of motion they have within the trapezoid shape outlined on the floor. There is also a predefined reset position marked in case the camera loses track of the marker and they see the red X in the corner of their screen. They are told that the image they are navigating is a two dimensional image in front of them like a wall and they are to scan by holding the iPad in the vertical position, as well as how to skip trials that are for any reason too complex and they feel like they are wasting too much time on them. They are pointed out the grey border around the image for two reasons, to know when they reached the limit of their movement and to understand how to better locate the target in the memory of location segment where they are presented the same grey border. They locate and tap on the target and move to the memory of target location section where they are asked to approximately select where they thought they found the target, and are explained what the two circles that show up mean (the guess point and the target location).

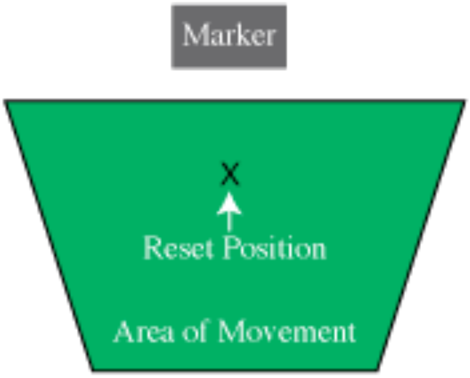

Figure 11 – Marking on the floor indicating the area of movement and reset position in relation to the marker which also signifies the direction of the image.

In the experiment we use the generated images for the visual search task using both colour and orientation searches [5]. Before the presentation of the trial, participants see the mode that they will use and the target surrounded by distractors to know what they will be looking for. Each method of interaction, touch-based and motion-based is performed for each complexity level (determined by the set size of the image), before incrementing the level for the following trial. As the experiment progresses, participants enter stages of increasing followed by decreasing complexity levels of the visual task images. The targets in the images are intentionally made small at the minimum zoom level to make it as difficult as possible to spot them from this global overview and force the user to start exploring the space using the given interaction mode.

The experiment runs for 20 minutes, as this is the maximum time determined in the testing stage of design before fatigue and loss of attention occur. At the 20-minute mark, the application allows the participant to finish the trial they are currently being presented with before showing a end of experiment message. The participant hands back the iPad to the experimenter, who notes down the experiment number shown inside the application on the pre-questionnaire form.

Figure 12 – Symbols shown to the users to indicate which navigation mode, touch-based or motion-based navigation, will be used in the following trial

In the final part of the experimental design we present the participant with a post questionnaire. Both the pre and the post-questionnaire are filled out on paper to keep the interaction with the iPad separate from the questionnaire form methodology.
The post-questionnaire addresses the ease and efficiency of use, as well as physical demand in terms of self reported user experience with the newer, motion-based navigation model. As the participant finishes the post-questionnaire, the experiment number is also written on this sheet of paper. The participant is explained any questions they might have about the experiment before thanking and concluding the participant's experiment.

2.3 Procedures used to obtain data and results

The intended sample size of the experiment is 20 participants with an equal mix of both males and females. Both the pre and post-questionnaires, which are filled out on paper, are entered into a computer Excel table. For the pre-questionnaire, the basic information for name, age and sex as well as the question on whether or not they regularly use touch-screen devices is entered as is. For the colour test selected from the Ishihara Colour Vision Test [Appendix D], if the participant is not able to determine the given number or writes the wrong number, especially the one corresponding to the number seen by participants with red-green deficiency, they are marked as having failed the colour vision test inside the Excel table.

In explicit terms the independent variable of the study is the interaction method and dependant variables are search time, and memory of target's location. Therefore inside the application, after each trial a line is added to the results file kept on the device itself.
Each line of the comma-separated value (CVS) file corresponds to a single trial and it keeps track of the values corresponding to the experiment number assigned to the participant for the study, the trial number of which trial is currently being presented, whether the participant is in the group that starts their first trial with motion or touch-based navigation, whether motion-based navigation is enabled for the current trial, whether the trial is a tutorial trail, whether the trial has been skipped, the time to find the target, the final zoom level at which the target was located, the X and Y coordinates of the target and the X and Y coordinates of the guess point selected by the participant. The time to find the target and the X and Y coordinates of the guess point correspond to our dependant variables for the study of search time and memory of targets location. The search time is measured in seconds, but has millisecond precision. The timer for the search time starts the moment the participant is presented with the visual stimulus of the trial and ends with the selection of the target on the device. The quantity of the participant's memory for the targets location is measured as the difference, and more specifically the Euclidian distance, between the targets actual coordinates and the coordinates of the participant's guess. The results file is offloaded from the device after each participant finishes his or her experiment and is immediately backed up to an separate encrypted hard drive for safeguarding along with the excel file with the information entered from the questionnaires. The post-questionnaire asks 6 questions in a reverse order matched-pair fashion with each question using the 5-point Likert Scale, ranging from Strongly Disagree to Strongly Agree with the centre point set at neutral with Neither Agree nor Disagree. As the participant is presented with only word answers, the responses from these questions are entered in the excel table with the number from 1-5 corresponding to the answer selected by the participant.

3. RESULTS

3.1 Key results obtained in the study

The total sample consisted of 20 participants with 11 males and 9 females. The minimum age of the participant was 22 and the maximum was 67 with a mean age of 30.85 (Std.Dev. 10.6) for the sample. Because of two outliers, this distribution of ages can be best visualized in the Figure 13.

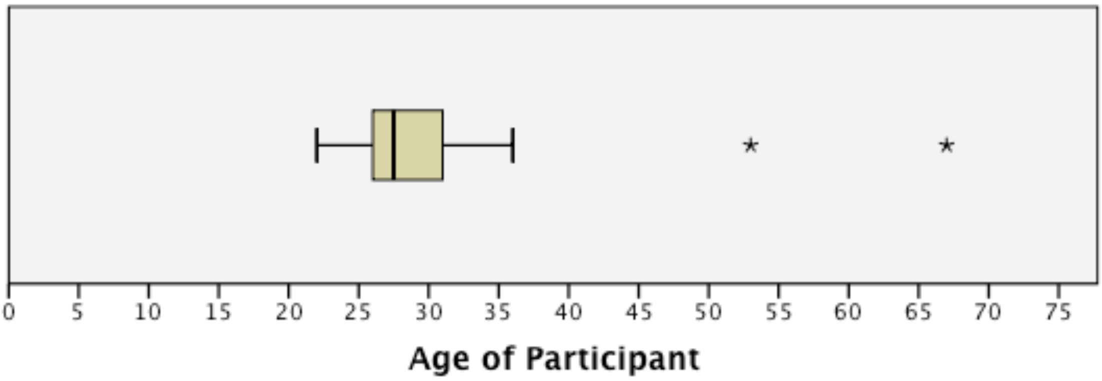

Figure 13 – Box plot displaying the distribution of Participant Ages with outliers

Two participants failed the colour vision test, but this did not seem to have problems in participating in all trials as they reported that they were able to see the differences in all the specific colours pairs used for the targets and distractors in the visual search task experiment. Three participants reported that they do not regularly use a touch-screen device, with the remaining 17 stating that they do.

Number of trials per participant varied between 16 to 83, as was expected, since all participants had 20 minutes to complete the experiment, and the number of trials presented depended on how fast the participant was moving through all the trials. The distribution of the numbers of trials performed per participant can be seen in Table 1.

	N	Minimum	Maximum	Mean	Std. Deviation
Number of Successful Trials Performed per Participant	20	16	83	30.00	14.338
Number of Trials Skipped per Participant	20	0	11	3.25	2.954
Valid N (listwise)	20				

Table 1 – Distribution of the number of successfully completed trials and number of skipped trials per participant

We will at this point address each of the research questions proposed by this thesis work.

Question 1: Does motion-based interaction provide faster search times than touch-based interaction in a visual search task?

Looking at the range of search time values as seen in Table 2, we see that the response times for all visual search task varied between 1.447 seconds and 569.086 second. However, as the experiment lasts 20 minutes, no individual task should take over 5 minutes to complete, nor are they at a sufficient complexity to require that much time commitment. So as we take a look at the Figure 14 and the box plot of these times, we see that only a handful of outliers for 433 valid trials took considerable more amount of time to complete. This is due to the fact that at a certain point some of the participants simply got stuck on a certain trial but decided against skipping the trial, even as this pressure to quit has been stressed during the instructions for the experiment. In retrospect, an additional trial timer should have been implemented to automatically skip the trial after an appropriate period, but since this values are much greater then all the other trials' search times and therefore will have a measurable effect on the statistics, we choose to introduce a cut-off where all trials over 200 seconds are discarded.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Search Time (seconds)	433	1.447	569.086	32.29220	46.220097
Valid N (listwise)	433				

Table 2 – Search time distribution of all the samples shown with minimum, maximum and mean values

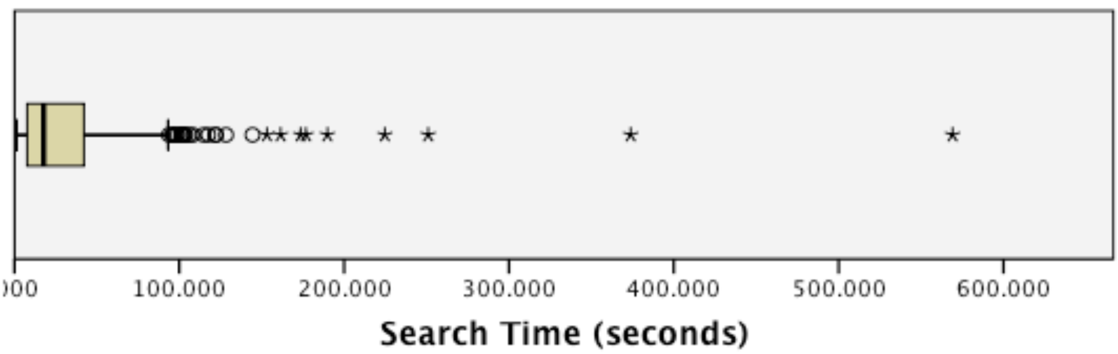

Figure 14 – Search Time distribution of all the samples visualized in a box plot

After performing a Test of Normality, as shown in Table 3, in order to determine whether we can use parametric or non-parametric test on search times with respect to Motion-based navigation being used or not, as in the trials that we are not using Motion-based navigation are in fact touch-based navigation trials. The distributions, in both cases, vary significantly ($p<<0.05$) from a normal distribution. Therefore we will continue our analysis by using non-parametric test.

Tests of Normality

	Motion-Based Navigation	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Search Time (seconds)	NO	.294	225	.000	.481	225	.000
	YES	.191	208	.000	.810	208	.000

a. Lilliefors Significance Correction

Table 3 – Tests of Normality for Search Time in Touch Based vs. Motion-Based Navigation (where NO on motion-based indication is corresponding to touch-based interaction)

It is important to note that the discrepancy in the degrees of freedom for the two navigation modes in each arise due to two factors, one from skipped trials as performed by the participant in the study. Second factor is from the fact that participants overwhelmingly reported and intrinsic easiness in finding one type of target (triangle rotation). Upon review we decided that it does not match the complexity of the other target items, as it seems to be easily discoverable at most set sizes, no matter how small or large the set size, thus indicating might be a simple feature search. Therefore we chose to remove all triangle trials from our statistical calculations.

The results of the non-parametric, Independent-Samples Mann-Whitney U Test, as seen in Figure 15, shows a significant result with $p<<0.05$. This allows us to reject the null hypothesis that the distributions of search times between touch-based navigation and motion-based navigation trials are the same.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Search Time (seconds) is the same across categories of Motion-Based Navigation.	Independent-Samples Mann-Whitney U Test	.004	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 15 – Results of the Mann-Whitney U Test on Search Times across the two interaction modes (touch-based interaction vs. motion-based interaction)

When we plot these distributions on a box plot in Figure 16, we are able to see a difference in search times between the two interaction modes.

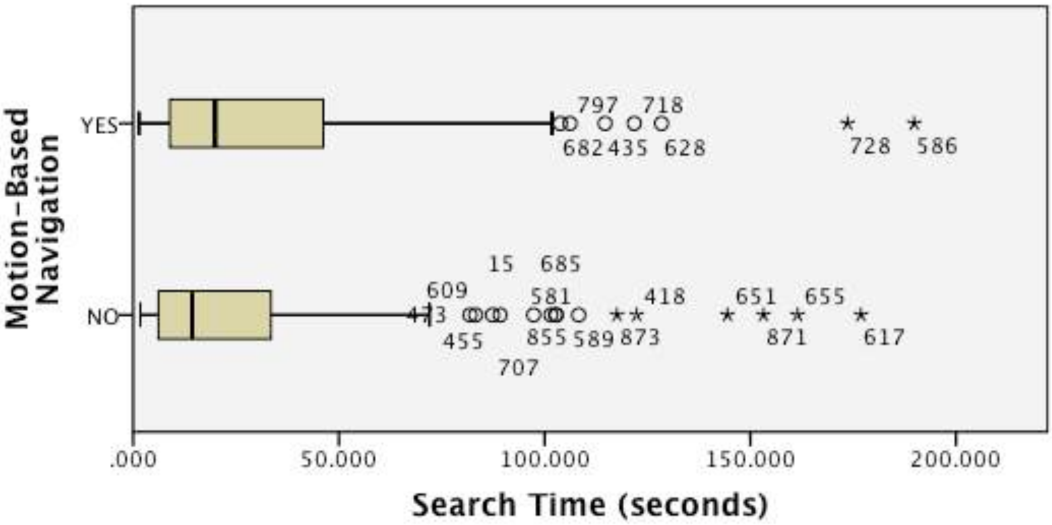

Figure 16 – Box plot distribution of search times across interaction modes (where NO on motion-based indication is corresponding to touch-based interaction)

Analysis of the bar graph, Figure 17, and the means table, Table 4, shows a considerable difference in mean search times for trials in favour of touch-based navigation. These results show that there is a mean difference of over 6 seconds between the two modes.

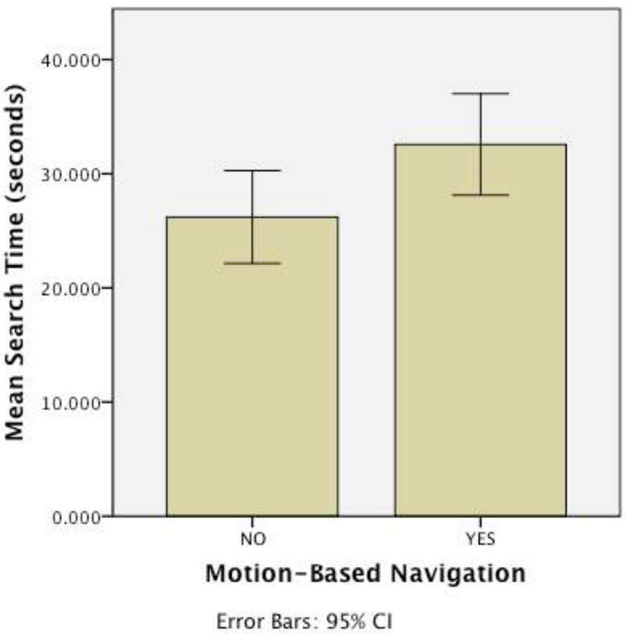

Figure 17 – Bar graph of mean search times between the two interactions (where NO on motion-based indication is corresponding to touch-based interaction)

Motion-Based Navigation				Statistic	Std. Error
Search Time (seconds)	NO	Mean		26.20765	2.061612
		95% Confidence Interval for Mean	Lower Bound	22.14461	
			Upper Bound	30.27069	
		5% Trimmed Mean		21.99357	
		Median		14.34700	
		Variance		939.304	
		Std. Deviation		30.648069	
		Minimum		1.727	
		Maximum		176.885	
		Range		175.158	
		Interquartile Range		27.430	
		Skewness		2.296	.164
		Kurtosis		6.154	.326
	YES	Mean		32.55790	2.252213
		95% Confidence Interval for Mean	Lower Bound	28.11769	
			Upper Bound	36.99812	
		5% Trimmed Mean		29.20698	
		Median		19.90400	
		Variance		1055.072	
		Std. Deviation		32.481873	
		Minimum		1.447	
		Maximum		189.838	
		Range		188.391	
		Interquartile Range		37.496	
		Skewness		1.737	.169
		Kurtosis		3.697	.336

Table 4 – Mean and related statistics for search times between the two interaction modes (where NO on motion-based indication is corresponding to touch-based interaction)

To the research question proposed, whether motion based interaction provides faster search times than touch-based interaction, we are able to show that motion-based navigation does not provide faster search times.

Question 2: Does motion-based interaction improve the memory of the located targets position in the virtual information space versus touch-based interaction?

We asked the participant to tap on a blank image where they though the target was located. The application would at that point show then two coloured circles, one small green circle representing where the guess touch occurred and a larger blue circle representing where the target was actually located, centred at the targets actual position. To measure the memory of the targets position, we will take the distance, and more specifically the Euclidian distance in a two dimensional space, between these two points for our analysis.

To analyse the difference in the Euclidian distances, we perform a Test of Normality, as shown in Table 5, in order to determine whether we can use parametric or non-parametric test on the analysis of Euclidian distances with respect to Motion-based navigation being used or not, as in the trials that we are not using Motion-based navigation are in fact touch-based navigation trials. The distributions, in both cases, vary significantly ($p<<0.05$) from a normal distribution. Therefore we will continue our analysis by using non-parametric test.

Tests of Normality

	Motion-Based Navigation	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Euclidian Distance between the memory of target guess point and target's coordinates (pixels)	NO	.183	225	.000	.754	225	.000
	YES	.234	208	.000	.663	208	.000

a. Lilliefors Significance Correction

Table 5 – Tests of Normality for Euclidian Distance in pixels between the guess point and the actual target in Touch Based vs. Motion-Based Navigation (where NO on motion-based indication is corresponding to touch-based interaction)

The results of the non-parametric, Independent-Samples Mann-Whitney U Test, as seen in Figure 18, does not show a significant result as $p>0.05$. This does not allow us to reject the null hypothesis that the distributions of Euclidian distances differ between touch-based navigation and motion-based navigation trials. However, as the significance level is 0.057 and thus close to the threshold for the accepted value of 0.05, we will continue the analysis of the Euclidian distances, to see a possible trend without accepting the results.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Euclidian Distance between the memory of target guess point and target's coordinates (pixels) is the same across categories of Motion-Based Navigation.	Independent-Samples Mann-Whitney U Test	.057	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 18 - Results of the Mann-Whitney U Test on Euclidian Distance in pixels between the guess point and the actual target across the two interaction modes (touch-based interaction vs. motion-based interaction)

Analysis of the bar graph, Figure 19, and the means table, Table 6, shows a difference in mean Euclidian distances for trials in favour of motion-based navigation.

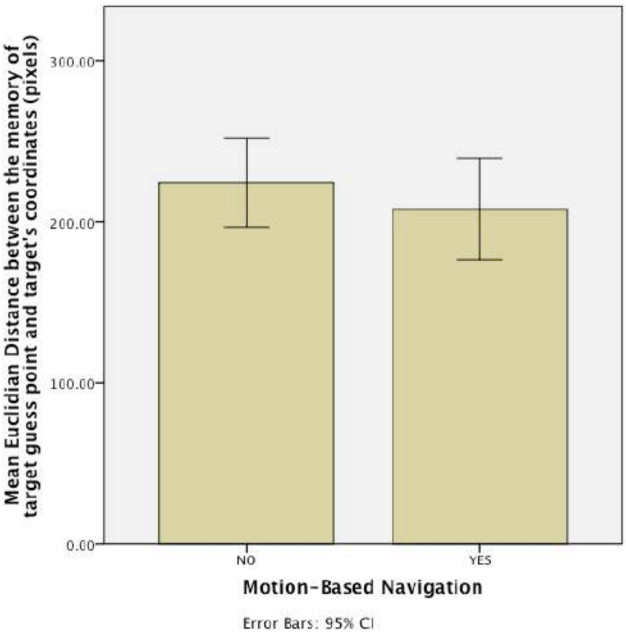

Figure 19 – Bar graph of mean Euclidian distances between the two interactions (where NO on motion-based indication is corresponding to touch-based interaction)

Motion-Based Navigation				Statistic	Std. Error
Euclidian Distance between the memory of target guess point and target's coordinates (pixels)	NO	Mean		224.3103	13.98801
		95% Confidence Interval for Mean	Lower Bound	196.7454	
			Upper Bound	251.8752	
		5% Trimmed Mean		198.7473	
		Median		157.2000	
		Variance		44024.483	
		Std. Deviation		209.82012	
		Minimum		2.00	
		Maximum		1264.42	
		Range		1262.42	
		Interquartile Range		173.88	
		Skewness		2.291	.162
		Kurtosis		6.337	.323
	YES	Mean		207.8379	15.98445
		95% Confidence Interval for Mean	Lower Bound	176.3248	
			Upper Bound	239.3511	
		5% Trimmed Mean		175.1109	
		Median		135.1900	
		Variance		53144.518	
		Std. Deviation		230.53095	
		Minimum		7.28	
		Maximum		1601.19	
		Range		1593.91	
		Interquartile Range		137.00	
		Skewness		3.088	.169
		Kurtosis		12.259	.336

Table 6 – Mean and related statistics for Euclidian Distance in pixels between the guess point and the actual target between the two interaction modes (where NO on motion-based indication is corresponding to touch-based interaction)

As the significance level is above the threshold for the rejection of the null hypothesis, we therefore do not accept this result as the answer to the research question proposed, of whether the memory of the target's location improves in one of the interaction modes. But it is note-worthy that additional participants and further collection of trials might change the significance level to the rejection of the null hypothesis below the threshold, in which case these results would show favour towards motion-based navigation in the memory of the targets location.

Question 3: Is motion-based interaction an easier method of navigation through the virtual space than touch-based interaction?

To check the user experience differences between the two interaction modes, we used a 5-point Likert scale questionnaire. As each participant was tested for both condition, by performing both interaction modes with alternation after each trial, the analysis of the central tendency best suited to the task is the most frequently occurring answer. As the answers are presented in word format to the participant, from Strongly Disagree to Strongly Agree, with the centre point staying neutral with neither agree nor disagree, we transformed the answers to a 1-5 scale, with 1 representing Strongly disagree and 5 representing Strongly Agree. The most frequent answer to the statements related to the ease of use in favour of the motion based navigation compared to the touch based navigation was "Disagree" as the single mode is 2, corresponding to general disagreement with the statement. We can see in the pie graph, shown in Figure 20, that 57.5% of the sample selected a disagreement answer, while 15% agreed that the motion-based navigation was easier to use. 27.5% selected the neutral answer.

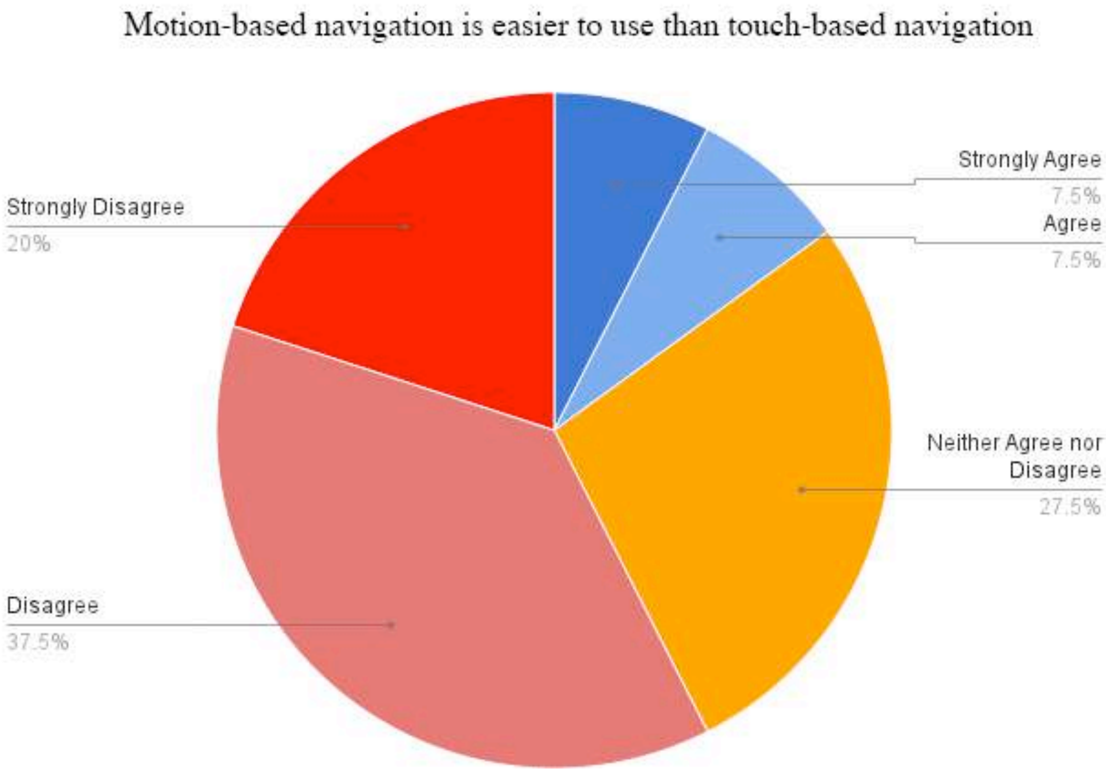

Figure 20 – Pie graph displaying the sample's answers to whether they agreed or disagreed with the statement that it was easier to use motion-based navigation in comparison to touch-based navigation

According to the results of the survey of the sample population, we show that to the motion-based navigation is not easier to use than touch-based navigation.

Question 4: Did motion-based interaction cause more physical demand imposed on the user than touch-based interaction?

To check the second quality of user experience difference between the two interaction modes, we check the answers from the 5-point Likert scale questionnaire. The most frequent answer to the statements related to the physical fatigue of use of the motion based navigation compared to the touch based navigation was "Agree" as the single mode of the corresponding value from the Likert scale was 4, corresponding to general agreement with the statement. We can see in the pie graph, shown in Figure 21, that 72.5% of the sample selected an agreement answer, while 7.5% disagreed that the motion-based navigation was easier to use. 20% selected the neutral answer.

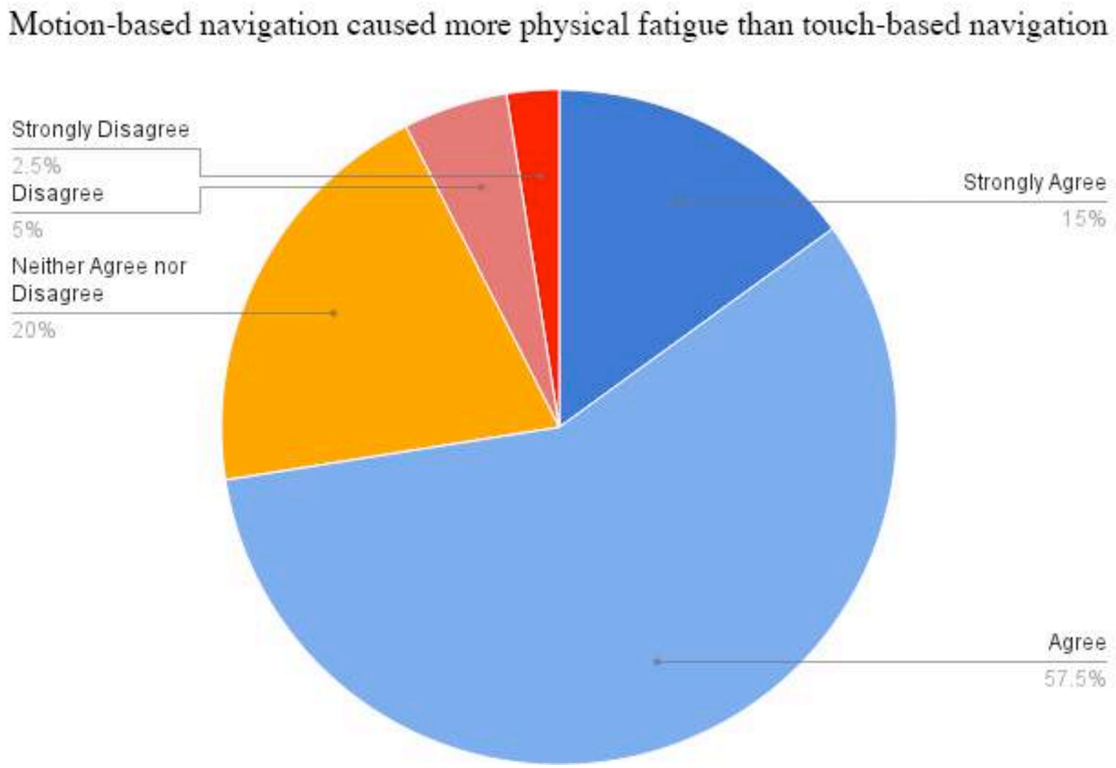

Figure 21 - Pie graph displaying the sample's answers to whether they agreed or disagreed with the statement that the use of motion-based navigation caused more physical fatigue in comparison to touch-based navigation

To answer the research question proposed, according to the results of the survey of the sample population, and according to a majority of the answers we show that motion-based navigation caused more physical fatigue than touch-based navigation.

4. DISCUSSION & CONCLUSION

4.1 How did the results address the problem defined

In the result analysis section we have answered the four main research questions defined by this thesis study. We have show that to in accordance to question 1, that motion-based navigation does not provide faster search times than touch-based interaction in a visual search task. The results of question 2, we are not able to reject the null hypothesis in order to see the effect of motion-based interaction on the memory of the targets position in the virtual information space. However the rejection of the null hypothesis is close to the threshold of $p = 0.05$, therefore we believe further collection of trials from additional participants will show an effect. The results of the user experience questions proposed by the study, we have shown that motion-based interaction is not an easier method of navigation through the virtual space in comparison to touch-based interaction and that motion-based navigation definitely caused more physical fatigue in the participants in comparison to touch-based interaction.

4.2 What are the problems faced by the study

In this thesis work, we choose to address a problem within the field of Human-Computer Interaction, and especially in the attempt to define whether the current interaction method used on touch-screen devices is the best method of navigating and searching through large informational spaces. We looked at the alternatives that a sensor-packed mobile device is able to provide in terms of navigational capability and looked at the state of art [36] to see what was possible and what to analyse. We chose a specific attention task from the field of psychology and neuropsychology, called the visual search task, which addresses visual searching a fundamental humans process. Along the way, we have faced many problems. Many of which were in the technical development of the artefact. The programming and testing of all stages of the iOS application development took considerable more time than anticipated initially. The main problems were understating and finding a way to map the information received from the Augmented Reality marker tracker to a view that controls the motion of the image presented on the screen without the use of camera video overlay. Second major problem was encountered in the memory management issue of the application development. The 4000x3000 images take considerable memory allocations to be displayed on the screen and many of the times they are automatically cached by the system because in most applications these images are used many times over. However in our application this image is displayed only once before loading another one, so finding places to release, as much memory as possible, that is not being used, was extremely important to the stability of the application. And the final technical issue requiring more time than originally anticipated is the generation of the visual search images, that would fulfil all the requirements imposed by the visual search task found in literature. From the use of this technology arose a second set of problems that comes from the Augmented Reality for tracking implementation. Participants felt frustrated as the device lost of marker tracking, causing difficulty in the participants trying to navigate the task. Lastly, the problem discovered after the experiment is that the certain target images such as the triangle were intrinsically easier to do then all other at most set sizes, which required the elimination of these trials.

4.3 Validity of the results

The major topic of discussion for the validity of the results is whether the search times to big visual search tasks in large-scale information spaces accurately describe the benefit of one interaction mode over another. The questions arise of how much does participant search techniques influence each of the trials, no matter the interaction method. This can be seen in the key results section, in the discussion on outlier trials that took over 5 minutes to complete when equivalent trials for most participants took considerable less amount of time. The question posed here is why these trials took so much time, why was the participant stuck, the role of their attention, search technique and target blindness.

The second major topic is whether the implementation of the motion-based navigation was adequate enough to provide desired navigational performance. As we have used a computer vision solution to this problem, which provided benefits in terms of costs and portability, but in turn we encounter problems that under less than ideal conditions there is loss of marker tracking, causing the experience of navigation to be abruptly disturbed. The question is that in the instances when this did happen during the experiment, whether the effect of this loss of control was large enough to be displayed in the results we concluded that motion based navigation is slower in search times than touch-based navigation.

4.4 Relevance with respect to state of the art

It is important to state here that as the study of this thesis was in the late stages of research, another study [35], was published at the CHI conference that covered the same research topics as this work. In the study they used a different implementation for device tracking as well as a different set of tasks for measurement. The results also derived from the different implementation were different from this work, as they were able to show that motion-based spatial navigation is in fact a better form of navigation in informational spaces on mobile devices. The researches of the published study felt, as we did also, that there has been an opportunity to re-evaluate and quantify the benefits of using the current interaction models versus a more spatially oriented interface using motion of the device for navigation. The conflicting results of the state of the art mean that this topic is very much implementation and experimental design dependent, and should be taken into account in all-further research on the topic.

4.5 Future steps

In the initial part of this study we believed that we would have been able to have two groups, a general public and a professional group. The professional group would perform the experiment with visual search data specific to their field, in order to see the how professionals could solve the task using the two proposed interaction models. As such, we conducted meetings with researchers at the PRBB (UPF's Biomedical Research Center) in order to find the possibilities of what kind of data would be appropriate for this search. This data was to address a biomedical problem such in the field of brain research, cancer location or molecule data visualization and see if and how the expert sample would deviate from the general population performing a regular visual search task that we currently used. The behavioural group we had been able to contact mainly used timings and images of very small size and easy to find the things they were looking. So the search for an appropriate professional group and matching data was left for future work.

The initial concept included search in 3D informational spaces, in addition to the current 2D space. The current application is able to implement, what would be considered as 2.5D as the zoom function can be mapped to change between different layered images, such as in the example of an MRI scan, where each image is a cross-section of the scan. These images were placed inside the application and we were able to move through cross-sections in a virtual foot from MRI scans. The exploration of 3D implementation was also left for future work, as the current technical artefact does not have the capability to load and navigate around 3D models.

Finally, an element of study that has been included in the experiment but not yet analysed as it has been delegated to future work is the complexity factor of images. As the participant performed trials, they encountered varying complexities through adjusted set-sizes. We want to see whether complexity of these visual search tasks play a role and change the outcome of the results, as one mode of interaction might be better then another only for a certain set of search task complexities.

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Appendix A

Consent Form

Project Title: **Device Centric Mobile Device Interaction in Visual Search Task**

Responsible Researchers:
Stefan Acin, Prof. Sergi Jorda

Contact People:

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Barcelona, Spain

PROJECT DESCRIPTION:

This study is based on researching novel interaction models in searching with a mobile device. The participant will be asked to perform searches for unique items on a tablet device using different interactions methods.

In addition to the questionnaires, the data we are collecting is time to completion of each task and memory of the targets location. The results will be kept anonymous and encrypted and will only be accessible by the researchers responsible for the study.

The experimental session will last 20 minutes and will take place at the Pompeu Fabra University campus. The techniques used are non-invasive and pose no risk to the participant.

Your participation is strictly voluntary. You are free to accept or at any point refuse to participate, without justification of motives or prejudice towards the decision. In case of refusal, all documents regarding the participation will be destroyed upon request. You are free to ask any questions in order to further clarify any element of this consent, the questionnaires or the experiments procedure.

CONSENTMENT IN THE PARTICIPATION OF THE STUDY:

I have read and understood the content of the present form. I acknowledge my voluntary and free participation in the project as well as my right to retire at anytime by verbal communication, without prejudice. I certify that I have been given sufficient time to make my decision.

____________________	____________________	____________________
Subject's Name	Signature	Date

Appendix B

Pre-Experiment Questionnaire

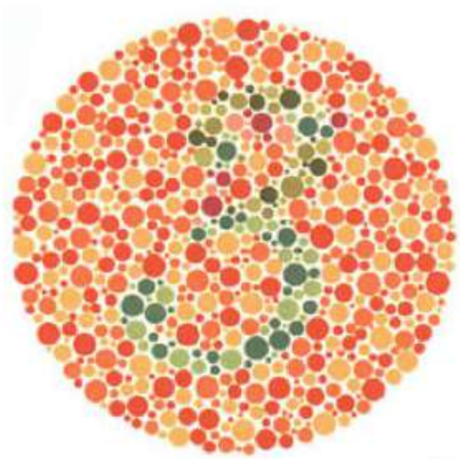
Name: ____

Age: ____________

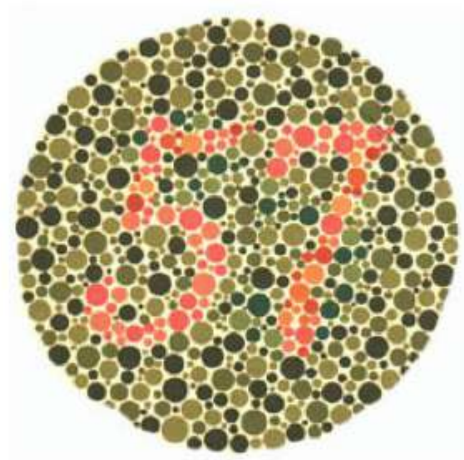
Gender: [ ] Male [ ] Female

Do you regularly use a touch-screen device? [ ] Yes [ ] No

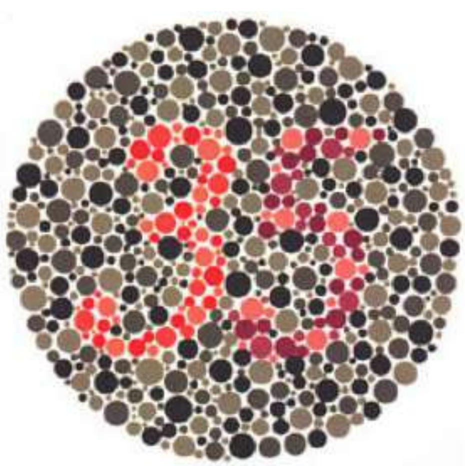
Write below which number you see in the following circles:



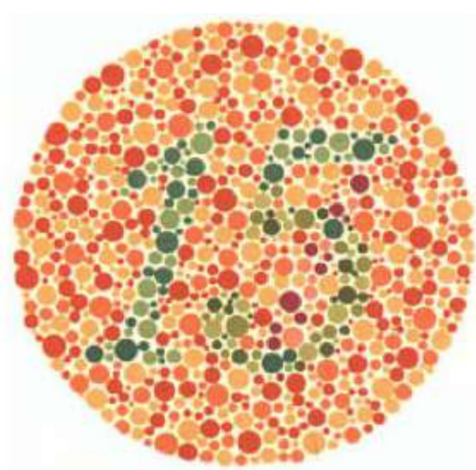
a) Number: _______



b) Number: _______



c) Number: _______



d) Number: _______

Appendix C

Post Questionnaire - Instructions
Please check only one response to whether you (Strongly Disagree), (Disagree), (Neither Agree, nor Disagree), (Agree), or (Strongly Agree) to the following statements.

1) Motion based interaction was easier to use.
[ ] Strongly Disagree
[ ] Disagree
[ ] Neither Agree, nor Disagree
[ ] Agree
[ ] Strongly Agree

2) Motion based interaction caused more fatigue.
[ ] Strongly Disagree
[ ] Disagree
[ ] Neither Agree, nor Disagree
[ ] Agree
[ ] Strongly Agree

3) It was harder to find the targets in motion based interaction.
[ ] Strongly Disagree
[ ] Disagree
[ ] Neither Agree, nor Disagree
[ ] Agree
[ ] Strongly Agree

4) Motion based interaction was less physically demanding.
[ ] Strongly Disagree
[ ] Disagree
[ ] Neither Agree, nor Disagree
[ ] Agree
[ ] Strongly Agree

5) Motion based interaction caused more frustration.
[ ] Strongly Disagree
[ ] Disagree
[ ] Neither Agree, nor Disagree
[ ] Agree
[ ] Strongly Agree

6) It was easier to remember where the target was located in motion based trials.
[ ] Strongly Disagree
[ ] Disagree
[ ] Neither Agree, nor Disagree
[ ] Agree
[ ] Strongly Agree

Appendix D: 4 Plates from the Ishihara Colour 38 Plates Set Test

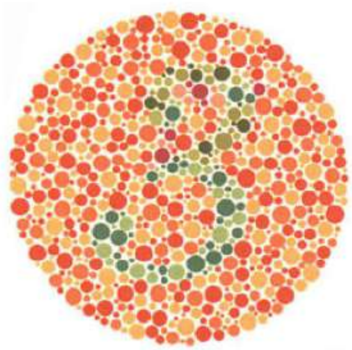


Plate 7

Normal view: 3

Red-green deficiency: 5

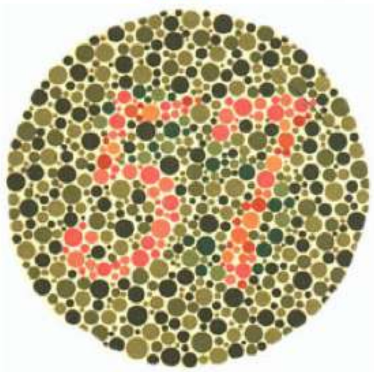


Plate 5

Normal view: 57

Red-green deficiency: 35

Plate 24

Normal view: 35

Protanopia or protanomaly: 5

Deuteranopia or deuteranomaly: 3

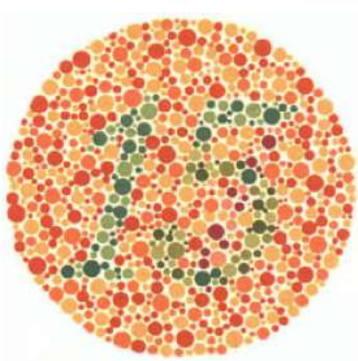


Plate 8

Normal view: 15

Red-green deficiency: 17