If Looks Could Kill – An Evaluation of Eye Tracking in Computer Games

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Abstract

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The possibility to track human eye gaze is not new. Different eye tracking devices have been available for several years. The technology has for instance been used in psychological research, usability evaluation and in equipment for disabled people. The devices have often required the user to utilize a chinrest, a bite board or other cumbersome equipment. Hence, the use of eye tracking has been limited to restricted environments.

In recent years, new non-intrusive eye tracking technology has become available. This has made it possible to use eye tracking in new, natural environments. The aim of this study was to evaluate the use of eye tracking in computer games. A literature study was made to gather information about eye tracker systems, existing eye gaze interfaces and computer games. The analysis phase included interviews with people working with human-computer interaction and game development, a focus group session and an evaluation of computer games.

The result from the analysis constituted of a summary of interaction sequences, presumable suitable to control with the eyes. Three different prototypes of eye controlled computer games were developed. The first was a shoot'em up game where the player aimed with his eyes to shoot monsters that appeared in random places. The two other prototypes were developed with the Half Life Software Development Kit. In the first Half Life prototype, the player aimed a weapon with his eyes. In the second, the view of sight was controlled with the eyes.

The different eye controlled game prototypes were evaluated in a usability study. The subjects played the different prototypes with mouse and eyes respectively. Their experience was evaluated with the thinking aloud method, questionnaires and an interview. The result showed that interaction with the eyes is very fast, easy to learn and perceived to be natural and relaxed. According to the usability study, eye control can provide a more fun and committing gaming experience than ordinary mouse control. Eye controlled computer games is a very new area that needs to be further developed and evaluated. The result of this study suggests that eye based interaction may be very successful in computer games.

Sammanfattning

Om blickar kunde döda – En utvärdering av ögonstyrning i dataspel

Möjligheten att mäta var en människa tittar är inte ny. Olika ögonspårare har funnits i många år. Tekniken har till exempel använts i psykologisk forskning, användbarhetsutvärdering och i utrustning för handikappade människor. Det har ofta krävts att användaren har ett hakstöd, en bitskena eller annan obekväm utrustning. Således har användandet av ögonspårning varit begränsat till speciella miljöer.

På senare år har ny teknik för ögonspårning blivit tillgänglig. Detta har gjort det möjligt att använda ögonspårning i nya, naturliga miljöer. Målet med denna studie var att utvärdera användandet av ögonspårning i datorspel. En litteraturstudie gjordes for att samla information om ögonspårnings-system, existerande blickbaserade gränssnitt och datorspel. Analysfasen innehöll intervjuer med människor som arbetar med människa-dator interaktion och spelutveckling, ett fokusgruppsmöte och utvärdering av datorspel.

Resultatet från analysen bestod av en summering av interaktionsmetoder som skulle vara möjliga att kontrollera med ögonen. Tre olika prototyper av ögonstyrda datorspel utvecklades. Det första var ett ”shoot’em up” spel där spelaren siktade med ögonen och sköt monster som dök upp på slumpmässiga ställen. De två andra prototyperna utvecklades med Half Life Software Development Kit. I den första Half Life prototypen siktade spelaren ett vapen med ögonen. I den andra styrdes synfältet med ögonen.

De olika ögonstyrda spelprototyperna utvärderades i en användbarhetsstudie. Försökspersonerna spelade de olika prototyperna med mus och ögon. Deras upplevelse utvärderades med ”tänka högt”-metoden, enkäter och en intervju. Resultatet visade att interaktion med ögonen är mycket snabb, lätt att lära och upplevs som naturlig och avslappnad. Enligt användbarhetsstudien kan ögonstyrning erbjuda en roligare och mer engagerande spelupplevelse än vanlig musstyrning. Ögonstyrda datorspel är ett nytt område som behöver utvecklas vidare och utvärderas. Resultatet av denna studie visar på att interaktion med ögonen kan vara framgångsrikt i datorspel.

Contents

Thanks

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Introduction

Eye tracking technology has been used for several years, for instance in psychology research, usability evaluation and in equipment for disabled people. The eye tracker devices available have often been cumbersome or required the user to sit absolutely still. Hence the use has been limited to restricted areas. Today there is eye tracking technology available that is both non-intrusive and allows head motion. This makes it possible to use and investigate eye tracking in natural, everyday environments.

Tobii Technology, a company that develops eye trackers, initiated this study to evaluate a new area for eye tracking – computer games. It was of interest to find out if eye tracking could provide value in computer games and to find game environments and interaction sequences suitable for eye tracking.

The study started with a literature study about relevant areas like human-computer interaction, eye tracker systems, eye gaze interfaces and computer games. The literature found about eye tracking was limited and no information about eye tracking and computer games was found. Hence, it was important to collect further information in some other way. This was made in the analysis phase, where some different methods were used to try to get a comprehensive picture of the area. Interviews about eye tracking, interaction and computer games were held with researchers in human-computer interaction and a game developer. A focus group session was held to gather ideas about game environments and interaction sequences presumable suitable for eye tracking. An evaluation of different computer games was made to get an understanding of different environments and how interaction is made. The result from the analysis phase was summarized as a list of different interaction sequences, presumably suitable for eye control. Three different prototypes of eye controlled computer games were developed. The prototypes covered two different gaming environments and two different interaction sequences – aiming and changing field of sight. The prototypes were evaluated in a usability study.

This thesis report is split in four parts. In the first chapter, Previous work, a summary of the information collected in the literature study is presented. The second chapter, Analysis, covers the different methods used to gather information, later used as a basis for the prototype development. Chapter three, Implementation, will describe the development of the different prototypes of eye controlled computer games. The last chapter, Evaluation, covers the setup and performance of the usability study based on the prototypes. The chapter is ended with a discussion about the result of the study.

1 Previous work

1.1 Human-Computer Interaction

Human-computer interaction (HCI) can be defined as: “A discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them” [28]. User interfaces, tools and methods for interaction are examined within this research area.

1.1.1 User interface

To be able to communicate with a computer we need some sort of tool, an input device, for transferring information. Mouse and keyboard have since the eighties been the input devices most used. There are however a large number of alternative tools that can be used for input and new technology is under development. Depending on the tool used, the interaction is made in different ways. A summary of input devices and methods used to interact with them is given in Table 1, based on [2].

	Touch	**Speech**	**Movement**	**Mind**
Tool	Keyboard Mouse Joystick Gamepad Steering wheel Light gun Light pen Trackball Touchscreen Digitalizing table Mouth mouse Foot mouse	Microphone	Camera Cyber glove Body suit Head mouse Eye tracker	Mind mouse
Method	Alfanumerical input Pointbased interaction	Speech recognition	Eye tracking Gestures with hands, body or head	Recognition of neuro-muscular signals

Table 1. Different input devices and methods.

The dialogue between human and computer is made via a user interface. Early computer user interfaces were based on communication with text commands. It was not until 1984, when Apple introduced Macintosh, that the graphical user interface (GUI) became known and used by the public. This kind of interface, often called WIMP (Windows, Icons, Menus and Pointing device), displays a graphical metaphor of a desk with windows, icons and menus. Today this is the most common used interface both for PC and Mac. An exposition of different kinds of user interfaces is given in [20]. The change, from difficult interfaces where a lot of training is needed to easy and natural ones, has made computers available to a larger group of users; a trend that can be further developed.

1.1.2 Future user interfaces

The development of new technology makes it possible to design completely new user interfaces and forms of interaction. Since computer performance improves rapidly, even cheap computers will be powerful enough to support advanced user interfaces in a few years. The next-generation user interfaces may involve features like virtual realities, speech, gesture recognition, artificial intelligence and eye tracking. According to Nielsen an important characteristic of the next-generation user interfaces may be that they become more specialized and tailored to the task they are meant for, apart from today's uniform interfaces. He splits the development of interfaces into five generations, presented in Table 2 [16].

Generation	User types	Advertising image	User interface paradigm
0 -1945, Pre-history	The inventors themselves	None	None (direct hands-on access to the hardware was the only thing that mattered)
1 1945-55, Pioneer	Experts, pioneers	Computer as calculator	Programming
2 1955-65, Historical	Technocrats, professional computerists	Computer as information processor	Command languages
3 1965-80, Traditional	Specialized groups without computer knowledge (e.g. bank tellers)	Mechanization of white-collar labor	Full screen strictly hierarchical menus and form fill-in
4 1980-95, Modern	Business professionals, hobbyists	Personal productivity (computer as a tool)	WIMP (Windows, Icons, Menus and a Pointing device)
5 1996-?, Future	Everybody	Computer as entertainment	Noncommand interfaces

Table 2. Different generations of user interfaces.

In general today's input devices are used one at a time. Future interfaces may involve multi-threaded dialogues where the user operates multiple input devices simultaneously to control different aspects of the interface. This kind of interface is usually called multimodal, since the user utilizes several modalities when interacting.

Most of the methods used for interaction today are learned and only natural for those who already are accustomed to them. The next generation interfaces can change this. With use of new technology it is possible to enable users to interact with skills already acquired – like looking, writing and grabbing. Interaction can be similar to that with the real world. If used in the right context, such interaction can decrease the user's cognitive burden and reduce the time to learn and adapt to new interfaces and interaction methods.

Jacob writes about a new style of user-computer interaction emerging; an interaction that is characterized by a change from explicit to implicit commands (non-command) as well as a change from turn-taking, single-stream dialogues to simultaneous, parallel interactions [14]. In a non-command interface the user does not make explicit commands. Instead, the computer monitors the user's behavior – for example his or hers movement of head, hands or eyes – and responds to this. The definition of a command can be somewhat vague, because even an action that the user makes unconsciously can be regarded as a command. Jacob suggests that one definition of a command is that the user has to *think* a command is made when he or she makes an action.

Nielsen describes the concept of a non-command based user interface in following way: “This term may be a somewhat negative way of characterizing a new from of interaction, but the unifying concept does seem to be exactly the abandonment of the principle underlying all earlier interaction paradigms: that a dialogue has to be controlled by specific and precise commands issued by the user and processed and replied to by the computer. The new interfaces are often not even dialogued in the traditional meaning of the word, even though they obviously can be analyzed as having some dialogue content at some level, since they do involve the exchange of information between a user and a computer” [16].

1.2 The Eye

When developing user interfaces where interaction is based on eye movements, it is important to know how the human eyes function. The characteristics of the eyes will make impact on the development of appropriate interaction methods. Some of these characteristics are beneficial for interacting with a user interface while others can cause trouble.

1.2.1 Eye anatomy

When looking at an eye, three parts are easily detected – the sclera, the iris and the pupil – see Figure 1 [38]. The sclera is the white part of the eye, a thick protective coat. The colored part of the eye is called the iris. In the middle of the iris there is an opening, the pupil. The iris is embedded with small muscles that can dilate or constrict the pupil size to control the amount of light that enters the eye. The cornea is the clear bulge that covers the front of the eye. It is covered with a lubricating tear film. Light rays from the environment will enter the eye through the cornea, where the majority of the refracting is made. Finishing refraction is made by the lens, which focuses the light on the retina. The lens can change shape to focus on near or distant objects. The retina, lining the back of the eye, is covered with millions of photoreceptors that convert light rays into electrical impulses. These impulses are sent via the optic nerve to the brain, where they are converted into images.

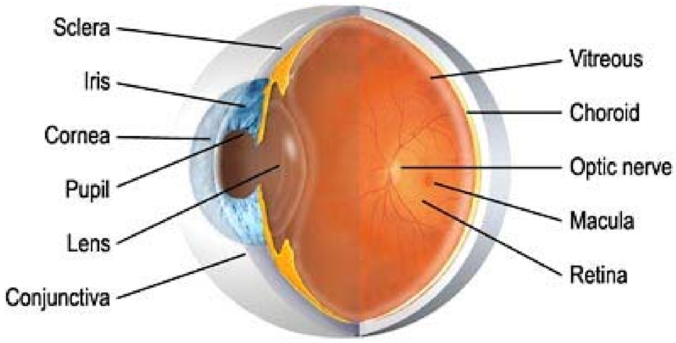

Figure 1. Picture of the human eye.

The fovea, located near the centre of the retina, is more densely covered with receptors than the surrounding area. This will make images focused on the fovea seen with higher acuity. The fovea covers approximately a one-degree field of view (a one-degree angle with its vertex at the eye, extending out into space). Outside the fovea the acuity is only 15 to 50 per cent of that of the fovea. To be able to see an object clear, the eyeball must be placed in a position where the object appears directly on the fovea. An image can be seen sharply anywhere within the area of the fovea, which implies that it is not possible to decide where within a one-degree circle a person is looking [11]. When using eye tracking, accuracy of the eye is often measured in degrees. If the user sits 50 cm from the computer, one degree corresponds to accuracy about one centimeter.

1.2.2 Eye movements

Eyes are moving all the time, but not smooth and even over the visual field, as it could feel. Instead the eyes make specific motions. The most common movement is the saccade, a fast and sudden jump. A saccade can cover from 1 to 40 degrees, where a typical saccade covers 15 to 20 degrees and lasts for 30 to 120 ms. The visual system is greatly suppressed during a saccade. After a saccade, there is a delay of at least 100 to 200 ms, before it is possible to make another one. Usually, a saccade is followed by a fixation. During this period the eyes remain fairly still and an object can be viewed. Even if it feels like the eyes are completely fixated, small, jittery motions will take place. A fixation typically lasts between 200 and 600 ms and then a new saccade will occur [12].

1.3 The Eye Tracker System

There are several different techniques that can be used to track eyes. Some eye trackers are mainly used in controlled settings e.g. in laboratory experiments, while others are suitable for everyday use. The technology used in different eye trackers differs in price, where a lower priced system probably has reduced accuracy or less tolerance to head-motion. Many earlier eye trackers require the user to wear helmets or glasses with built-in cameras or to fixate the head in a chinrest. An eye tracker of this kind will of course limit and restrain the usability. Recently new, contact free eye tracking technology has become available. In this study an eye tracker of this kind, the Tobii ET-17, was used.

1.3.1 Eye tracking technologies

The use of Electro-Oculography (EOG) is an inexpensive and simple way to track eyes. The technology is based on electrical measurement of the potential difference between the cornea and the retina. When the eyeballs rotate, electrical changes will occur. The electrical field is measured with skin electrodes placed around the eye socket. This method is more suitable for measuring relative eye movement than absolute position. The accuracy is poor and due to the electrodes the technique is cumbersome for the user. Hence this form of eye tracking is limited to special environments. Another method, very accurate but uncomfortable, is to use a non-slipping lens with magnetic coil or a mirror. The lens is placed over the corneal bulge and is then possible to track reliably.

Probably the most common technology used for eye tracking is a camera observing the user in combination with image processing techniques. The position of the eyeball can be measured by tracking features of the eye; e.g. the boundary between pupil and iris or the outer line of iris. Near infrared light is often used to illuminate the eyes. If the light is placed coaxial with the camera, the pupil will appear as a bright circle. This will make it easy to distinguish the pupil from its surroundings.

If the eye tracker detects a motion of the pupil, it could be either that the user’s head moved and the point of gaze remained still or that the eye moved, thus a change of gaze focus. In a human-computer dialogue it is necessary to be able to determine which of the events that took place. One solution is to keep the head absolutely still. This could be achieved by using a bite board or a chinrest, but is obviously not a very convenient solution for the user.

Another solution is to shine infrared light at the eyeball, to produce a corneal reflection – a glint. The point of gaze can then be calculated from the relationship between the centre of the pupil and the centre of the glint [12]. This method provides contact free eye tracking, which makes it appropriate for normal computer users. A similar technique, with a small camera mounted in a head-mounted display or in a pair of glasses, can be used. This could enhance the accuracy but is not a good option for everyday use. However, in situations where the user already wears equipment, like in virtual environments, there will be little extra effort to integrate a camera.

1.3.2 User interface software

The user interface software is a layer between the eye tracker and the applications that the user runs. It transforms data from the eye tracker into meaningful information that can be used in the human-computer dialogue. At the time of this study there was no user interface software developed that worked with the Tobii ET-17. Instead, a description of user interface software developed by Jacob et al. is given [11].

Raw data from an eye tracker do not describe a user’s intentions. When thinking that you are only looking at a few points on a screen, your eyes will in fact make a lot of small jittery motions, which will result in erratic data from the eye tracker. The user interface software transforms the raw data from the eye tracker into tokens that represent events. Each token reports start, continuation and end of a fixation. If more than 50 ms of position data lying outside one degree of the current fixation is received, the fixation is regarded as terminated. Jacob et al. write: “First we process the raw data from the eye tracker in order to filter noise, recognize fixations, compensate for local calibration errors and other characteristics and imperfections of the eye tracking hardware, and generally try to reconstruct the users more conscious intentions from the available information”.

It is essential that the interface interpret eye gaze data correctly so that the things the user thinks he is doing will happen. While a user looks at one object, the eyes can in fact make several fixations, all in the area of the object. If the user thinks that he only watches one object, the interface should interpret the fixations as one fixation.

1.3.3 Calibration

The features of the eyes differ from person to person. Before using an eye tracker, a personal calibration has to be done. The calibration maps the user’s point of gaze to a corresponding point on the screen. The process of calibration is made in different ways, depending on the eye tracker used. To calibrate the Tobii ET-17, the user looks at a number of points appearing randomly on the screen. The number of points can be chosen freely. When using several points, the calibration will be more accurate. In this study a calibration with 16 points, evenly distributed over the screen, were used. The accuracy of the eye tracking will depend on the quality of the calibration.

1.3.4 Tobii ET-17

In this study an eye tracker system developed by Tobii Technology, was used. Unfortunately there was no possibility to try any other eye tracker within the limits of this work. During this project, the eye tracker was a prototype still under development. This made the performance and characteristics of the eye tracking a bit uncertain. Today the eye tracker is a finished product called Tobii ET-17, see Figure 2. The technique used is similar to that earlier described, where near infrared light is used combined with a camera that records the pupil and the glint. The eye tracker consists of a camera mounted underneath the computer display, near infrared light emitting diodes placed next to the camera and above the display and a processing unit with image processing and other mathematical calculations.

Figure 2. Tobii Technology ET-17.

1.4 The Eye Gaze Interface

There is not yet a standard for the best way to interact with eye gaze interfaces. Researchers in the area propose different techniques for using the gaze for interaction. The eye gaze interfaces can on basis of how interaction is made with them be divided in two main categories, gaze based and gaze added interfaces.

Gaze based interface – Only the user's eyes controls the GUI, no extra input device is used.
Gaze added interface – The eye tracker is combined with other input devices.

Interaction with an eye gaze interface can be made in a command or non-command based way. In the command based interface the gaze is used for object selection in the same way as with traditional pointing devices like the mouse. In the non-command based interface the user's gaze is registered and analyzed to find out where the user's attention is. The eye movements used to operate the interface can be "natural" or "unnatural". In the latter case the user has to learn to do specific commands with his eyes, e.g. winks.

1.4.1 Midas touch problem

There are difficulties with using eye movements in a human-computer dialogue. The physics of the eye makes it unsuitable to replace manual input devices directly with an eye tracker. One characteristic of eye movements is that they are both controlled consciously and affected by external events. When using eyes to interact with a computer, the input is continuous; the eyes are always "on". This is different compared to manual input devices, which are active when the user choose them to be. These characteristics make it impossible for the computer to interpret the user's intentions only from gaze focus. All gaze fixations made by the user cannot be regarded as commands; a difficulty called the Midas touch problem. There need to be a way for the user to confirm that a command should be executed on the object he is looking at. To avoid Midas touch problem it is possible to use one of three following techniques:

- Dwell time
- Winks
- Extra input device

With dwell time, a selection is confirmed after the user has looked at an object a certain amount of time. When using dwell time it is important that the response time is sufficient. If the dwell time is too short, wrong selection may be made and if it is too long, the user gets frustrated. If a wink is used the interface must know if it is intentional or not. The use of a combination of eye and hand for controlling a user interface may be the best option in most situations. This makes the use of an extra input device necessary and thus the technique is not an option in a purely gaze based interface.

1.4.2 Cursor

An important aspect when developing an eye gaze interface is if the interface should include a cursor that follows the user's gaze focus. If calibration, accuracy and speed of the eye tracker would be perfect, no feedback would be needed, since the user knows where he is looking. The eye tracking technique of today is not that precise. A cursor is a way of feedback; it shows the user where his gaze focus is, according to the computers interpretations. But there are also disadvantages with the use of a cursor in an eye gaze interface. If there is a flaw in the calibration, the cursor will be shown displaced from the user's real gaze focus. The user's gaze will then be drawn to the cursor, which becomes further displaced. An alternative to the use of a cursor is to highlight the items that the user is focusing on.

1.4.3 Gaze based interfaces

In a gaze based interface the user does not need to use his hands to interact with the computer. The only input device used is an eye tracker and solely the user's eyes control the GUI. This kind of interface is suitable for people with physical disability that prevents them from interacting with their hands. It is also a good option if the space available does not allow a keyboard or mouse to be used. Instead of using a keyboard the user can write by using an eye controlled graphical keyboard displayed on the screen.

Command based interfaces

In a command based interface the gaze is used to perform commands, e.g. object selection, in the same way as with traditional pointing devices like the mouse. To avoid Midas touch problem, winks or dwell time are used to confirm a command. Special methods and user interfaces have been developed to make the interaction with dwell time easy and convenient, for example the Quick Glance Selection Method [17] and EyeCon [10].

Wink

The research of Bernard D Shaviv has a focus of making equipment for severely handicapped people, for whom the eyes are the only way to interact with a user interface [19]. He proposes that a wink with one eye can be used to confirm an object selection. A wink with one eye is used to make it possible to separate the intentional blinks from the unintentional, which always are made simultaneous with both eyes. When the user looks at an object on the screen, the object becomes highlighted. No action is performed until the user winks with one eye – then a command is executed. Several winks can be joined to make a special command. For example a wink with left eye followed by a wink with right eye can imply "page up" in a word processor.

Dwell time

Dwell time is best suited for situations where the result of selecting the wrong object easily can be undone – then the response time can be kept short. Jacob et al. have in experiments used a dwell time of 150-250 ms with good results. Their results show that a short dwell time is preferred instead of using a button for confirmation since it is more convenient. In cases where it is difficult to undo an object selection a button is used rather than dwell time. Jacob et al. do not recommend the use of a longer dwell time, since staring is not a natural eye movement and the slow response time can make the user thinks the system has crashed [11].

Glenstrup and Engell-Nielsen has developed a graphical user interface where the buttons, called EyeCon, provides visual feedback, see Figure 3 [10]. When the user fixates a button an animation of an eye, gradual closing, is showed. The user knows that he has the possibility to cancel the action as long as the eye is not completely closed. In the GUI the buttons were placed right beside the objects to be selected. That made it possible for the users to examine the objects in peace, without bothering that a wrong selection was made.

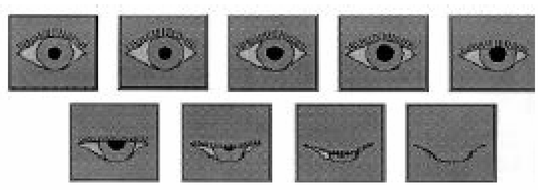

Figure 3. EyeCon – a gaze controlled button.

Takehiko Ohno suggests a method for eye controlled selection, the Quick Glance Selection Method [17]. A special graphical user interface has been developed, where the objects are divided in two separate parts – command name and selection area. If the user looks at the command name, a mark appears as visual feedback in the selection area. When the user looks at the mark, the selection is performed. If the user knows how the information is structured, he can look directly at the selection area.

Evaluation

Sibert et al. have performed several experiments to investigate the possibilities of using eye tracking as a form of human-computer interaction. The time it takes to choose a randomly highlighted item, with mouse and dwell time respectively, was investigated in one experiment. According to the results, interacting with the eyes is significantly faster than with the mouse [21]. One subject reported that it was so fast and easy to use the eyes that – "it almost felt like watching a moving target, rather than actively selecting it". Sibert et al. write: "When all is performing well, eye gaze interaction can give a subjective feeling of a highly responsive system, almost as though the system is executing the user's intentions before he or she expresses them". Data from the experiment has been used to investigate the performance of eye tracking, with respect to Fitts law [20]. The research findings indicate that the time to move the gaze is only marginally related to the distance moved. This makes eye controlled interaction especially suitable for large screens, systems with several screens and virtual reality, where the distances are large. Since the time it takes to move gaze focus is nearly constant, the benefit of eye tracking becomes greater the larger the distance to be moved is.

Non-command based interfaces

In the non-command based interface the user's gaze is registered and analyzed to find out where his attention is. The user does not make any explicit commands. This kind of interaction can be used in different ways.

Interest and Emotion Sensitive media

The term "Interest and Emotion Sensitive media" (IES) is used by Hansen et al. to describe a non-command interaction that is based on accumulated data of the user's eye movements [6]. The user's interest is measured by recording areas where he focuses his gaze. Even emotional reactions can be registered by measuring frequency of winks and the size of the user's pupils. This information can be used to affect and change events or environments in digital media.

The Little Prince – an application based on the children's book with the same name – is a way to implement the ideas of IES [11]. A graphical model of the planet where the prince lives is displayed. Simultaneously a digital voice tells the story about the prince. If the user's gaze is wandering about the environment, the story will be about the planet as a whole. If the user's attention is directed at specific parts of the planet, the story will tell about details of those parts.

Image viewer

Stiefelhagen et al. have developed a multimodal interface for controlling a panorama image viewer [22]. A 360-degree panorama image is scrolled on the basis of where the user looks. In this case the user's gaze controls the interface in a non-command style. Voice commands are used for zooming.

1.4.4 Gaze added interfaces

In a gaze added interface, the eye tracker is used as a complement to manual input devices like mouse or keyboard. In this kind of interface, the problems with gaze accuracy and Midas touch can be solved in different ways.

Gaze-button

In a gaze added interface there is the possibility to use manual input devices, e.g. keyboard and mouse, as a complement to the eye tracker. A command can be confirmed by pressing a button. A button on the keyboard or one of the mouse-buttons, called "the gaze-button", can be used for this purpose. In the gaze added interface developed by Jacob et al. both dwell time and a gaze-button are implemented parallel [14]. The user can then choose the interaction technique that he prefers. If interaction with dwell time is regarded too slow, a command can instead be executed by pressing the gaze-button.

MAGIC pointing

Zhai et al. have argued that using solely the eyes for interacting with a computer is unnatural for the user. They consider that the human visual perception channel should not be loaded with a motor control task, like selecting or moving an object. To solve this problem they developed a method called MAGIC pointing – Manual And Gaze Input Cascaded pointing [26]. The technique is based on the idea that pointing and selecting should be manual tasks; while at the same time make use of the benefits with eye control. The speed of the eye makes it appropriate to use for fast movement of the pointer. In this interface the pointer is "warped" to where the user fixates his gaze. If the fixation is close to an object, fine adjustment is made with a manual input device. A gaze-button is used to confirm a selection. In this way the distance the pointer is moved by hand becomes small. There are two different approaches, the liberal and the conservative approach.

Liberal approach

With the liberal approach the pointer is moved to every new object that the user looks at. If the pointer is not directly on the object, the hand is used to adjust the pointer. The user interface interprets the user's gaze as he is watching a new object if the distance from the pointers position is at least 120 pixels. If the distance is less, the pointer remains still and jittery movements are avoided.

Conservative approach

With the conservative approach the pointer is not moved to an object until the manual input device is activated. When the user touches the manual input device the pointer appears "out of the blue" in the gaze area of the object. Adjustment can then be made manually.

Evaluation

Zhai et al. have investigated the different techniques of MAGIC pointing [26]. Subjects in an experiment were asked to point and click on objects that appeared randomly on a screen. Three different techniques were used – manual input, the liberal approach and the conservative approach. The result showed that the fastest interaction was made with the liberal approach. With the conservative approach the users improved their performance more than with the other techniques. This indicates that the same effectiveness can be achieved with this method as with the others after some training. The size of the objects and the distances between them had impact on the time it took to perform the task. The small objects were more often missed than the bigger. Interestingly, the users did not make more mistakes when using MAGIC pointing than manual input. Overall test subjects liked the liberal technique better for its responsiveness. Some users acted more slowly with MAGIC pointing, but their subjective impression was that they performed faster with MAGIC pointing than with manual input.

Combination and adjustment technique

Yamamoto et al. suggest different techniques for interaction with gaze added interfaces, where both eyes and hand are used [25]. The methods are similar to them previously described, but are here briefly presented.

Combination technique

The Combination technique uses a combination of eye and hand. The gaze is used to move a pointer on the screen and the hand is used for confirmation. To make a selection, the user looks at an object and then pushes the mouse-button. This way of interaction is previously described in the Gaze-button chapter of this report.

Adjustment technique

The Adjustment technique enhances precision and efficiency of an interface with an eye controlled pointer. Two different adjustment techniques are suggested – automatic and manual adjustment. With automatic adjustment, the pointer is automatically moved to the closest GUI object when the user pushes the mouse-button. With manual adjustment, the user's gaze controls the pointer and fine adjustment is made with the mouse. When the user touches the mouse, it becomes the current input device.

Evaluation

Yamamoto et al. tested their two different techniques – combination and adjustment – in an experiment [25]. They performed a test with buttons in ten different layouts: 5 different sizes (1 to 5 cm^2) and two different distances (1 and 5 cm). The result showed that the manual adjustment technique was more precise and efficient than standard mouse input, even in a GUI environment with many small objects placed close together.

The IGO interface

Salvucci et al. have developed an "intelligent" gaze added interface, which utilizes a probabilistic algorithm and user model to interpret gaze focus [18]. The interface is called IGO, "the intelligent gaze-added operating-system interface". The appearance of the interface resembles Microsoft Windows, except the icons are larger. Interaction with the interface is made in a standard way with a manual input device. As a complement the possibility to utilize the eyes as an extra input is given. When the user looks at an object it becomes highlighted and to execute a command, a gaze-button is pushed. The purpose of the gaze interpretation algorithm is to map the gaze to the item that the user is looking at. The simplest method is to map the gaze focus to the closest item, but that is not always proper. Salvucci et al. propose an "intelligent" algorithm, based on the position of gaze focus and the current task context.

Evaluation

In user tests with the IGO interface, participants were told to perform five different tasks and to do it as fast and precise as possible [18]. The tasks involved common elements of interaction with WIMP interfaces – moving a file, creating a folder, copying a file, renaming a file and dragging a file to the trash. To find out if the "intelligent" algorithm had any impact on the result, collected eye tracking data from user tests were executed with simpler algorithms. It became clear that the "intelligent" algorithm had a great impact on the result – 83 % of the interpretations were accurate compared to 17 % with a basic algorithm (gazes directly over a target is assigned to the target).

The result of the user tests shows that the users made more mistakes when interacting with the eyes than with the mouse. A specific error, called "leave-before-click" error by the authors, was common among users. The user looked at an object and tried to press the gaze-button but looked away before the button was completely pressed down. This error became more common when the users got used to the interface, since the interaction then became faster. Adding a delay, so that the gaze focus remains on an item some time after the gaze has left it, could solve this problem. Following were observed during the tests:

- The users had some problem with having two foci, gaze and mouse. They sometimes used wrong button, e.g. mouse-button instead of gaze-button when an object had gaze focus.
- Users showed a tendency to prefer eye tracking for simpler tasks and the mouse for more complex tasks.
- Many choose to use eye tracking after using keyboard to avoid movement of the hand from keyboard to mouse.
- The users utilized the eye tracking until any problem appeared. Then they used the mouse and after a short while returned to the eye tracking

1.4.5 Eye tracking in virtual reality

The virtual reality environments of today can display realistic and immersive graphical worlds. One benefit of using eye tracking in VR is that the environment can be rendered with regard to the user's point of gaze, which will save a lot of computer power. If a head-mounted display is used, a very robust eye tracking can be achieved by including an eye tracker in the display.

Often a manual handheld device is used to interact, point and execute commands. There can be difficulties interacting with this kind of environment, since it lacks haptic feedback to guide the hand and to support it in space. Tanriverdi et al. write: “We thus require new interaction techniques to provide users with easy and natural ways of interacting in virtual environments” [23]. They have performed studies where subjects used partly eyes partly a handheld yardstick to interact with a virtual reality [23]. The performance was considerable better with eyes than with hand when the virtual environment was distant. For interaction with closer environments, the performance was not significant different. The user’s spatial memory was less after interacting with eyes. One explanation could be that no extra effort was necessary when using eyes to locate and manipulate objects. Of the 24 participants, 18 preferred to use the eye tracker since they thought the eye tracking was natural, easy, fast and less tiring than the yardstick. The researchers write that the findings “suggest that eye movement-based interactions could become a viable interaction type in virtual environment provided that proper interaction techniques are developed”.

1.4.6 Characteristics of eye tracking

There are many ways to design methods for using eye movements as input in a human-computer dialogue. Special interfaces and applications have been developed where interaction is made solely or partly with the user’s gaze; some are described in this chapter. Clearly there are both benefits and some problems with eye tracking, depending on the interface used. A summary of some general characteristics of eye based interaction is given in Table 3.

Characteristics of eye tracking	
Fast	The eyes move very fast. If the user wants to operate an object in the interface, he looks at it and then uses an input device. Hence, the eyes will provide input faster than any other input device.
Easy	Previous studies suggest that interacting with the eyes can be intuitive, natural and easy to learn.
Reveal attention	By calculating the user’s point of gaze, the computer could reveal where his attention is.
Midas touch	The Midas touch problem has been discussed earlier. The eyes lack equivalence to the mouse buttons and hence there has to be another way to confirm actions. Dwell time, winks or a gaze-button can be used.
Always “on”	The eyes are always “on”, the input is continuous unlike manual input devices that are active when the user chooses. It is important to regard this when designing eye gaze interfaces and interaction techniques.
Contact free	Point of gaze can be detected without physical contact. The user can interact with a computer even if he can’t use his hands. It could be that they are occupied or due to disability. To use gaze as an input is also a good option if the space available is not enough to use keyboard and mouse.
Extra input	If both hands are used for input, the use of eyes can offer a “third hand”. The use of several inputs and modalities can be used to enhance interactivity.
Reduce fatigue	If eyes are used as input instead of a manual input device, arm- and hand-movements will be diminished. This can reduce fatigue and prevents injuries like Repetitive Strain Injuries (RSI).

Table 3. Characteristics of eye tracking.

1.5 Computer Games

To get an overview of the many kinds of computer games available, they can be divided in different genres. The division can be made in several ways; one suggestion is made in this section. The different categories constitute a basis for further work; in the analysis phase games from each category are chosen and played in order to get ideas about the use of eye tracking in different environments.

1.5.1 Computer game genres

Today there is a wide selection of different computer games. To get an overview the games can be divided into genres, but it is not possible to make a distinct division between different genres. Certain games can fit in many genres and there is also the possibility of new games that will define totally new genres. The division presented here is based on information from [5] and [9]. For each genre, examples will be given of game titles that are well-known and representative for the genre.

Action

The category of action games is an overall genre that represents different kinds of games with a common characteristic – action. In an action game the player has to act and react fast. The games often contain some sort of violence. Sub categories of action games could be defined with respect to characteristics of the game, e.g. the player's perspective – first person or third person, or to the mission of the game – shoot'em up or beat'em up.

First Person Shooter

In a First Person Shooter (FPS) game, the player views a three-dimensional world from the eyes of the gaming character, in a first-person perspective. This view gives the player a feeling of reality and makes him immersed in the game. The mission in a FPS game is often to use different weapons to defeat enemies or monsters. Interaction is usually done with keyboard and mouse, which are used to move around, change the view and shoot. The course of events is rapid; hence technical skills and good coordination between eye and hand is necessary. In the last years it has become very common to play FPS games in networks and over Internet. The enemies are in that case played by other people simultaneously. The graphics in this kind of game demands a lot of computer power. Therefore this genre was not developed until the 90's. One of the first and most famous FPS games is Doom. Later well-known titles as Quake and Half Life were released.

Third Person Game

In a third person game, the player sees his gaming character from an external camera angle. This makes it easy to get an overview of the environment and the movements of the character. The character moves around in the world and uses fists or weapons to defeat enemies. Tomb Raider, with the famous character Lara Croft, has been a very popular game in this genre.

Shoot'em up

The purpose of a shoot'em up game is to get as many points as possible by shooting objects, e.g. monsters, spaceships or enemies that appear randomly on the screen. The game scene is typically static and the player controls a weapon of some kind. Since this is a pretty simple kind of game, it was more common before the development of more advanced computer games. One of the first games in this genre was the arcade game Space Invaders. In arcade games it is common with games that represent a merge between a FPS and a shoot'em up game. Some of these games are remade for PC, e.g. House of the dead. The player has a first person perspective but has no control over movements in the environment; the character follows a predefined path and the view is changed automatically.

Beat'em up

In this kind of game, the player will beat his enemies up instead of shooting them. The player chooses a character with certain strengths and weaknesses and fight in a battle by directing the character's kicks and knocks. The competitor is played by the computer or another player. Beat'em up games is most common as console games or arcade games. One reason is that interaction usually is done with a game pad, an input device not often used with a PC. Another reason could be that it is more fun to play this kind of game together, in front of the TV instead of the computer screen. Tekken and Mortal Kombat are well-known titles in this category.

Racing

In racing games, the player drives some kind of vehicle, e.g. a rally car, motorbike or motorboat. The aim of the game is typically to drive a track as fast as possible or to win a race. The player is often able to compete with the computer or another player. This kind of game is common both as arcade games, PC games and console games. The interaction is preferably made with a steering wheel and pedals. Popular game titles are Colin McRae Rally and Gran Turismo.

Sport

Within the category of sport games there are several different sports represented; team sports as football, ice hockey, basket and individual sports like tennis, golf and snowboard. A less common theme is hunting, where the player's mission is to shoot wild animals. The EA FIFA series and EA sports NHL series are typical games of this genre.

Strategy

Common for strategy games are that they offer intellectual challenges. The player has to think, plan and create a strategy for his actions. The mission could be to wage war with armies, build cities or to create a whole world. The playing is calm and methodical and does not demand fast interaction. Strategy games are mainly developed for the PC. Mouse and keyboard are excellent tools to interact with the gaming environment's small items. The development of strategy games has led to a new genre – the Real Time Strategy games (RTS). In a RTS game the interaction is not turn based as in ordinary strategy games; actions will occur regardless of the player has made his turn or not. Famous game titles in this genre are Age of Empires, Warcraft and Civilization.

Simulator

In a simulator game the player is able to simulate a real world system or action. The most common theme in simulators is vehicles e.g. a combat aircraft or a helicopter. The purpose is to give the player a realistic feeling of how a vehicle is operated. There are restrictions of how realistic a digital game environment can be, but development of computer technology makes it possible to create more and more realistic simulators. It is important that the game gives the player a feeling of reality. A joystick is often used as an input device in flight simulators. The joystick is designed to look like the steering tool of a real aircraft; hence it is a more natural way to interact than with keyboard and mouse. Well-known flight simulators are European Air War, Battle of Britain and Sturmovik IL2.

Platform

In a platform game the aim is to take the character you control to the next level and get as many points as possible. Some of the characters in this kind of games has become very famous; e.g. Donkey Kong, Super Mario and Sonic the Hedgehog. The character is often able to run, climb, jump and sometimes shoot and fight. The platform games are usually not very violent. It is more common to play the platform games on consoles than on PC. A well-known title is Super Mario Brothers.

Adventure

In an adventure game the player's character is situated in an unknown environment that successively will be explored. The environment is viewed from a first person perspective or from a third person perspective, where the player is able to watch his character in the surrounding area. In some games it is possible to choose between the two different perspectives. The goal of the game is to solve a mystery or to complete a mission. Riddles, dangers or other troubles may appear during the game. It is common that different objects are placed in the environment, e.g. books, maps or keys. The player can pick these items up and use them to solve problems and make progress in the game. Interaction is often calm and methodical. Fantasy and the ability to solve problems are important characteristics for a player to complete this kind of game. Myst, with the follow-ups Riven and Myst 3: Exile, is one of the first really successful adventure games. Grim Fandango is another much liked adventure game.

Role-play

The characteristics of the role-play games are similar to that of the adventure games; the player plays the role of a gaming character that explores an environment with the aim to solve a mystery or complete a mission. Unlike in the adventure game the gaming character is not predefined, instead the player is able to choose and develop qualities and capabilities of the gaming character. During the game there will appear problems or missions to be solved. Usually the player has to defeat enemies and monsters. Diablo and Baldur's gate are titles that represent this genre. There is an increase in the interest of playing role-play games over the Internet; one example is the game Everquest that has become very popular. The gaming character participates in a virtual world together with the characters of the opponents. The characters talk, fight and help each other to solve missions. The social interaction is very important when gaming over the Internet, the players chat not only about the game.

Puzzle and board

Puzzle and board games are often computer versions of real games, e.g. card games or board games. They are often easy to understand and do not need a lot of effort to learn. One classic puzzle game is Tetris.

Edutainment

The word edutainment is a merge of the words education and entertainment. The aim of this kind of games is to educate while having fun. The target group of the games is children and the purpose of the game could be to learn languages or math.

2 Analysis

2.1 Method

After finishing a literature study about eye tracking and computer games, it was obvious that information within certain areas was difficult to find. Previous studies of eye tracking have dealt with basic interaction; no studies of eye tracking in computer games were found. It was also difficult to find studies regarding computer games, except studies of how violence in digital media affects us. Before implementing the prototypes, an analysis of the subject was made to give a comprehensive picture of how and in what gaming environments eye tracking could be useful. Several methods were used to gain further information; interviews, focus group session and evaluation of computer games.

2.1.1 Interviews

Information from the literature study was complemented by interviews with experts in the area of eye tracking, computer games and HCI. Interviews were made with:

Shumin Zhai, researcher in HCI at IBM Almaden Research Center.
Ulrik Lindahl, game developer at Liquid Media.
Peter Lönnqvist, psychologist and doctoral student in HCI at Stockholm University.

These persons were interviewed to get their opinions about eye tracking, future human-computer interaction, what makes a computer game successful and the possibilities of using eye tracking in computer games.

2.1.2 Focus group

It is important to get feedback and comments from the proposed target group in an early stage. A questionnaire was created with the intention to receive information from computer game players. There is however difficulties associated with this method, since eye tracking is such a new technique. It is hard for people to answer questions about a subject that they are not familiar with. In this case the participants would have had to imagine the functionality and performance of a new interaction method; which is clearly a difficult task. To solve this problem, a focus group session was held where it was possible to demonstrate the eye tracker and interaction with eye tracking [40].

2.1.3 Evaluate computer games

Several computer games from different genres were played to get an understanding of the different environments and how interaction is made. Then an analysis of how eye tracking could be used as a substitute or complement to mouse input was made. The main focus was on PC games but a short study of arcade games was also made. Console games were not regarded due to the lack of access to a console. There was also no possibility to develop prototype games for arcade or console within this study.

2.2 Interview with Shumin Zhai

Shumin Zhai works as a researcher at the IBM Almaden Research Center. His research interest is in human-computer interaction. According to Zhai's homepage, he is particularly interested in researching novel interaction techniques and devices based on human performance insights and experimentation [29].

2.2.1 Eye tracking

Zhai was at first very skeptical about eye tracking. "The reason was the fact that the eye is sometimes controlled by will and sometimes by extern events", explains Zhai. Another problem of eye tracking is the limitations of accuracy. With the aim to solve these problems, Zhai participated in the development of a new interaction method called MAGIC pointing [26]. "It is not appropriate to replace the mouse directly with eye tracking", says Zhai. He regards the use of dwell time not to be realistic in general user interfaces. Only in special cases, when the user can't utilize both hands, dwell time could be a good option. The ability to interact with a user interface will then compensate for the limitations of a solely gaze based interaction. Usability studies are another area where eye tracking is used without other input. In that case the eye tracker is only monitoring the user's gaze and no interaction is performed with the eyes.

For eye tracking to be successful the interaction has to, according to Zhai, be made with a combination of eye and hand, for example like MAGIC pointing. The interaction must be implicit instead of explicit; the user should not have to think about how he uses his eyes. Zhai regards eye tracking to be very suitable for moving large distances and for interaction with larger objects. For eye tracking to have sufficient performance and get a break through as an interaction method following requirements must, according to Zhai, be fulfilled:

- No personal calibration.
- Allow user movements.
- Good accuracy.
- Fast, at least 30 Hz.

2.2.2 Eye tracking and computer games

Zhai has not heard of any research about eye tracking in computer games. The research so far has been about basic interaction, like to point or move a cursor. Investigations have focused on quantitative data, e.g. how long time it takes to perform a task or how many mistakes that is made. Evaluation of interaction in a computer game is a more complex and abstract task. Instead of getting quantitative data the main purpose is to find qualitative data, how the user experience the use of eye tracking. The basic elements of interaction – like pointing, choosing, marking – are also used in computer games, but there can also be other forms of interaction, apart from those.

2.2.3 Interaction in the future

The development of new methods for interaction is urged by the change of the way computers are used. "If computers in the future will be used for the same tasks as today, the mouse and keyboard will remain the main input devices. Maybe in combination with MAGIC pointing", says Zhai. If computers will be used for different purposes than today, the interaction methods will be adapted to that. A clear change in the use of computers is connectivity – the access to fast communication and large amounts of information over the Internet. According to Zhai, an enhanced connectivity may change the way we use computers.

The way we use computers has already changed a lot during the last years. The command based user interfaces have been replaced by graphical user interfaces. This development is based on a change of the purpose of computer use. Earlier, very specific applications were used and a command based interface was appropriate. Today more general applications are used, a fact that has made it necessary to have an interface where it is possible to interact with different applications, but in the same way. Command based interfaces are still used in computer environments where only specific applications are used, e.g. in airports, since it is the most effective.

Input devices

Interaction with computers is today almost exclusively done with mouse and keyboard. For certain use, e.g. computer gaming, joysticks and other input devices are utilized. Zhai believes that the mouse has got such a great impact owing to its good performance and the fact that it is easy and cheap to manufacture. When the mouse is released, the pointer will remain in the same position. This makes it easy to find it even after looking away. The mouse also has a good integration of movement and button in the same device. It is possible to simulate forces in both horizontal and vertical direction. This is suitable for moving objects on the screen – drag and drop; one vertical force holds the object down and one horizontal force moves the object.

The digital pen is, according to Zhai, a competitor to the mouse. An advantage of the pen is the possibility to write with it, something that is hardly done with a mouse. A problem is that the pointer does not remain in the same position when the pen is released. This makes it difficult to find the pointer when the pen is picked up again. This is, according to Zhai, the reason that the pen has not been a success. A head tracker is another input device, tried by Zhai. He regards the accuracy of head tracking to be to poor; the neck not flexible enough and that it easily cause tensions.

“I am confident in the future of eye tracking”, says Zhai. Eye tracking will not only be used in specific applications but in general, in all computer environments. If the equipment used becomes cheap there will be a mass-market, since eye tracking is a very good and appealing interaction method.

2.3 Interview with Ulrik Lindahl

Liquid Media is a game development company situated in Stockholm. The company was founded in 1995 and has 15 employees. According to their homepage they "create games and interactive entertainment for the major platforms with game play as our guiding light" [34]. Ulrik Lindahl is one of the owners of the company, game developer and CTO.

2.3.1 Computer games in the future

"There are really no limitations of computer games in the future", says Lindahl. Since the 80's there has been eight different genres of computer games and he does not think that there will be a new genre in the future. Instead there will probably be new kinds of games where different genres are combined. Lindahl thinks that future interaction with computer games will be made via several channels, so called multimodal interaction. Liquid Media runs together with other companies and universities an EU sponsored project about multimodal interaction. The aim is to develop a "social" system where the user is able to interact with gestures, face and voice.

In the 80's, the soundcard became common as a computer accessory. Today a soundcard and also a 3D card are regarded as standard and a part of the system requirements for most computer games. The same development will, according to Lindahl, take place for hardware devices for multimodal interaction; they will gradually become common and hence regarded as system requirements. Lindahl also believes that computer games in the future will be based on the use of several different media, which will make the player immersed in the game. An example is the game Majestic, where the gaming is done via fax, e-mail and cell phone instead of in front of the computer.

2.3.2 Successful computer games

What is necessary to make a computer game successful? "Gameplay – the feeling is most important", answers Lindahl. He believes that the use of several modalities, for example eye tracking, contributes to the gameplay. When the first FPS game was released, a new form of gameplay was offered. The player views the environment from his own perspective and becomes immersed in the game, in a way not possible to accomplish before. "Point counting also enhances the gameplay – it is easy to get caught by very simple games, just to exceed your old score", says Lindahl. Tetris is a good example of a computer game without fancy graphics or other features, which yet has a great gameplay. This shows how difficult it is to know what features that will make a game successful.

2.3.3 Eye tracking in computer games

"There can definitely be a use of eye tracking in computer games. Eye tracking could contribute to a better gameplay", says Lindahl. The use of an extra modality can make the player immersed in the game in a new way. Lindahl believes that eye tracking is suitable in games with a lot of action and for situations where the user's hands are busy. He regards the area of Interest Emotion Sensitive media to be very interesting. With eye tracking it is possible to design a computer game that considers the player's interest in different objects. "When using eye tracking in this way, it will give a new dimension to the game; more than a substitute for the mouse", says Lindahl. He suggests that the level of horror in a game could be adjusted depending on flickering eye movements or other signs of fear. Other suggestions are to aim with the eyes or to create eye contact with other people in an online game.

2.4 Interview with Peter Lönnqvist

Peter Lönnqvist is a psychologist and doctoral student at the Department of Computer and Systems sciences (DSV), Stockholm University. His research interest is in human-computer interaction. He works as an instructor in the course “Intelligent interfaces” hold by DSV. Multimodal interfaces is one of the subjects in the course. When Lönnqvist was told that this project was about eye tracking in computer games, his first reaction was: “Then you could aim in Half Life!”

Peter Lönnqvist was asked what he thinks about human-computer interaction in the future. In what ways will humans interact with computers in about ten years? His spontaneous reaction is – “it can happen unbelievable much!” Lönnqvist thinks that a lot of interaction will still be made with our hands, via e.g. a mouse or a pen. Our hands interact with the surroundings all the time and they are also suitable for interaction with computers. The hand is strong, flexible and has good accuracy. We will not use devices that we have to wear, at least not if they are bigger than the size of a ring or watch. VR equipments were, according to Lönnqvist, no success due to being too heavy and bulky.

Future devices may even be integrated in the human body. “In 20 years it is likely that we have input devices operated into our bodies”, says Lönnqvist. There is a nasty feeling about implants, but attitudes are changed over time. Lönnqvist makes a comparison with lens implants; an operation earlier sawn negative, that today is very common. He mentions Kevin Warwick, Professor of Cybernetics at the University of Reading, who has had digital chips inserted into his body. Augmented reality is another area that, according to Lönnqvist, will be further developed in the future. Augmented reality is about “seeing more of the world”. He tells about a project at the Swedish Institute of Computer Science (SICS) called GeoNotes, based on positioning technology. The user is able to attach virtual notes to real world locations. For example, after being at a nice restaurant, the user could write this down on his device. When a friend later walks by this restaurant, this information will appear on his device.

Lönnqvist’s main research area is ubiquitous computing. This research is about another tendency of the future use of computers; computers will be everywhere – integrated in walls, clothes and furniture. “I am interested in how to define interaction methods when traditional interfaces are missing”, says Lönnqvist. He concludes, “In the future you will be able to access devices everywhere. You can pick them up, identify yourself with fingerprints or iris recognition and get access to your personal account with information.” Multimodal interaction will, according to Lönnqvist, be more common; interaction will be made with voice, lips and eyes. Following list is a summary of his ideas of how future human-computer interaction will be made:

- Hands.
- Body-integrated devices.
- Augmented reality.
- Multimodal – voice, lips and eyes.
- Ubiquitous computing.

2.5 Focus Group

The focus group participants were all from Medieskolan – eight students and one teacher. Medieskolan is situated in Stockholm and offers courses in multimedia-, web- and TV-production. The focus group session was held in the premises of Tobii Technology. Some of the participants had heard about the use of eye tracking before. They mentioned cameras and combat helicopters. None of them had tried eye tracking themselves or seen it been used. The discussion with the focus group roughly followed this plan:

- Introduction of the focus group members.
- Discussion about computer games and playing habits.
- Demonstration of the eye tracker.
- Discussion about ideas for eye tracking in computer games.

2.5.1 Computer games and playing habits

Three of the participants play computer games as often as possible, almost every day. Another three play some times a month and the remaining three do not play computer games. Two of these are however parents and they sit beside when their children play. The ones who do not play computer games explained that it is due to that they work in front of a computer all day long. When they get home, they want to do something else than using the computer again. “I can’t see the point with computer games”, one of the participants said. The gamers explained that they want to win over themselves, perform better and get higher scores than the last time they played.

The participants that play computer games use PC, Mac or Playstation and they most often play at home. The ones that play with their children use joystick and gamepad, the others only use mouse and keyboard. The gamers play a variety of different games – FPS, strategy, simulators, sport and children’s games. We discussed characteristics that make a computer game successful. The participants had following suggestions:

- Excellent graphics, sound and character animation.
- Several levels of difficulty.
- Network gaming.
- Possibility to create your own levels .
- Feeling of reality.

2.5.2 Eye tracking in computer games

A demonstration of the eye tracker and how eye tracking could be used to aim in a shoot’em up game was held for the participants; the eyes were used to aim and a button to shoot. Afterwards a discussion about eye tracking and how it could be used in computer games followed.

According to the focus group members it is important that the eye tracker is fast and that the precision is good. They also meant that the device should not be noticeable. Someone suggested that the camera could be built into the screen. When this workshop was held, the eye tracker was still a prototype; today the camera is built into the screen. They also mentioned that the calibration process should be easy and fast. One of the participants pointed out that he had a joystick that had to be re-calibrated too often. He thought it was a cumbersome process and for that reason he never used it. Below is a list that sum up the participants requirements for the eye tracker:

- Fast.
- Accurate.
- Device should not be noticeable.
- Easy to calibrate.

One of the participants asked how long time it will take to get used to eye tracking, if a period of learning is needed. The discussion about how eye tracking could be used in computer games yielded several ideas and suggestions. To get an overview they are categorized by the action that is performed.

Aim/shoot

The player could aim with the eyes and then shoot by pushing a button. One of the participants commented that it could be weird and dizzy if many objects are approaching you from different directions, and you want to look at all of them.

Mark/choose

The user could mark an object by looking at it. A mouse-button or gaze-button could be used to confirm the choice. One of the participants suggested that a foot-pedal could be an alternative – when it is pushed, the choice is confirmed. This would make both hands available for the user to perform other tasks in the game. An alternative is to use dwell time; the object will be marked when the user looks at it and after a certain delay it will be chosen. These interaction methods could be used to choose active player in e.g. a sport game or to choose a weapon or tool.

Change view/scroll

Eye tracking could be used to rotate a virtual environment on the basis of the player's gaze focus, a kind of scrolling in a 3D environment. In many flight simulators there is the possibility of a "Virtual cockpit"; the player uses the mouse to change the view in a continuous way instead of changing between static views by pushing a button. The participants believed this to be a function suitable to operate with the eyes. Another suggestion was to use the eyes for scrolling large 2D environments, where all information can't be shown at the screen. This form of interaction could be suitable in strategy games where it is common with large map images. One participant suggested that a frame could be placed in the outer edge of the screen; when the user looks at the frame, the map will be scrolled.

Zoom

One of the participants suggested that eye tracking could be used for zooming. An object could be zoomed in after a certain dwell time or if the user leans forward and looks at it.

2.6 Evaluate Computer Games

Several computer games from different genres were tested to find interaction sequences that could be appropriate to control with eye tracking. The games were chosen due to being well-known, representative for the genre or high valued in reviews. Demos of the chosen games were downloaded from game sites on the Internet and later the most interesting games with regard to the study were bought. The games were played with the information received from the literature study, interviews and the focus group session in mind.

2.6.1 PC Games

A summary of ideas and concepts for eye tracking in computer games are given here. The same basic interaction sequences e.g. aiming, running or changing field of view, will often appear in different kinds of computer games. To control these actions, eye tracking could be suitable in some environments and less desirable in others. The summary constituted a basis for the further prototype development. All suggestions may not be appropriate when implemented in reality; they are only ideas that need to be evaluated. Within this study the possibility to implement ideas as prototypes and evaluate them was restricted.

Control field of view

The field of view could be changed according to the user's gaze focus. The ability to change the field of view is common in several different kinds of computer games with 3D graphics. The user often utilizes the keyboard to move around in the environment and the mouse to change the field of view.
The view could be changed in two ways; either continuous when the mouse is moved or only when the mouse focus is moved to the outer edge of the screen. In the latter case the environment is static until the mouse focus is in the outer edge of the screen and then it starts scrolling. Similar interaction could be achieved with eye tracking in two ways:

- The area that the user looks at is continuously centered on the screen.
- The environment starts to scroll when the user looks in the outer edge of the screen.

These interaction forms could be used to change the field of view in a flight simulator, equivalent to the "Virtual cockpit" where the mouse is used to get a smooth change of the view. In FPS games the view is related to the sight of the weapon; the player always aims in the middle of the screen – when the field of view changes the target area will change. The view is usually controlled in the way described in the first alternative. If mouse input is replaced with eye tracking in this environment, the player will aim and change the view simultaneously with his eye movements. Other applications where eye tracking presumably is suitable are adventure and role-play games with a first person perspective.

The use of eye tracking for controlling the field of view will free the hand previously used for interaction with the mouse. The possibility of a "third hand" opens up for new ideas and concepts of interaction. The player could for example use a light-gun to aim, a pedal to move in the environment and eye tracking to control the field of view.

Aim

The eyes could be used for aiming a weapon in e.g. a FPS, shoot'em up game or flight simulator. The weapon can be fired by pushing a button. When using the eyes for aiming it is possible to separate the weapon sight from the field of view; the view is controlled with the mouse and the weapon sight with the eyes. This makes the player able to aim anywhere on the screen without changing the field of view. Other applications for eye controlled aiming are sport and beat'em up games; ideas are to aim the direction of a ball or the punches in a fight.

Select an object

To select an object the user looks at it and confirms by pushing a button. One example of a more unconscious selection is to present information about objects after a certain dwell time. The player may explore an environment in e.g. an adventure game; information about an object will be presented after showing interest in it. Selectable objects are common in all kinds of games; for instance an active player in a sport game, weapons in a FPS or tools in a strategy game. Hence this is an interaction technique that probably could be widely used. The use of eye controlled selection could increase the speed of interaction and reduce the physical strains of repetitive movements of arm and hand between keyboard and mouse.

Zoom

Zoom functionality could be achieved with eye tracking. The user could zoom in an area or an object by looking at it and then confirming with dwell time, a gaze-button or by leaning forward to the screen.

Scroll

Changing the field of view is a sort of scrolling of a 3D environment. The same functionality could be achieved in a 2D environment. Preferably the scrolling starts when the player looks in the outer edge of the screen or on a frame surrounding the game. Especially in strategy and role-play games it is common with large maps, which could be scrolled in this way.

Dodge

Since the eye tracker records the eye position of the player, it is possible to decide if the player is moving or dodging. This feature could be useful in arcade games, where the player often has less restrictions on moving, due to standing up while playing. Some arcade games, e.g. Time Crisis, utilize a pedal to operate a dodge command. When using eye tracking the pedal could be used for other input e.g. moving forward in the environment.

Move an object

The gaze focus moves very fast; hence the use of eye tracking speeds up interaction when moving objects large distances. Strategy games are a category where troops and items often are moved large distances in the environment or on a graphical map. The repetitive movements of arm and hand between the keyboard and mouse could be reduced if using eye tracking.

Unexpected events

Eye tracking offers the possibility to calculate the player's gaze focus; hence it is possible to interpret where his attention is. This information could be used to create unexpected events, to surprise the player – for instance monsters or enemies could appear from the opposite direction of the player's attention.

Change storyline and events

The game storyline could be altered based on an eye tracker record of the player's attention. It is also possible to make the story evolve on the basis of what objects the player has seen or which characters he has encountered. One previously mentioned example where the storyline is changed based on the player's interest is the application Little Prince [11].

Eye contact

With eye tracking it is possible to create eye contact with other game characters in a computer game. The characters could also react when the player looks at them, e.g. start to speak or smile. Game characters could be computer controlled or played by other people in an online game. In the article "The Cabal: Valve's Design Process For Creating Half-Life", the "theory of player acknowledgement" is explained to be one of the features that makes a game fun [4]. The theory states that the game world must acknowledge the players when they perform an action; it could be that things move when the player pushes them or that feedback from shooting is shown as marks on walls. Feedback should also be received when interacting with other game characters; "If the players walk into a room with other characters, those characters should acknowledge them by at least looking at them, if not calling out their name. Our basic theory was that if the world ignores the player, the player wouldn't care about the world".

The use of eye tracking offers the possibility to create eye contact and acknowledgement from characters, for instance other players in an on-line game; features that could increase interactivity and give the player an immersive feeling, hence presumably improve the gameplay of a computer game.

2.6.2 Arcade games

Arcade games are an interesting application for the use of eye tracking. The hardware used in an arcade game could be custom made in a way not possible for PC games. Most arcade games available have special input devices like guns, pedals or wheels. The demands on an eye tracker will be very high when used in an arcade game; it must be robust, function for near all people and has a limited calibration process. Different arcade games were tested and some ideas on how eye tracking could be used in different environments are suggested. It is important to notice that there obviously are great possibilities to develop totally new gaming concepts based on interaction with eye tracking.

In the action arcade game Time Crisis 2 the mission is to rescue the president's daughter from terrorist kidnappers before the time available elapses. The game is played by two persons standing next to each other, in front of two big screens. The player uses a pedal to dodge and a gun to shoot. The environment is displayed in a first person perspective and the game character moves along a predefined path while the field of view is changed automatically. House of the dead is an arcade game with similar characteristics to Time Crisis 2 except the lack of a pedal. The player uses a gun to defeat monsters that appear from all directions.

Interaction with an arcade game could benefit from the use of several input devices. A review of the game Time Crisis states: "With one simple pedal, Time Crisis went beyond "point and shoot" gameplay to add a new element: dodging" [39]. The use of eye tracking could be a way to further increase the gameplay. It felt natural to use the gun for aiming; hence this function may not be suitable to control with the eyes. But eye tracking could be used to replace the predefined movements and views with the possibility to control these actions. One suggestion is to use the gun to aim and shoot, a pedal to move in the environment and eye tracking to control the field of view. The eye tracker can also be used for dodging – when the player dodges the game character will do the same. With information about the player's attention, unexpected events can be created.

3 Implementation

3.1 Background

The result from the analysis constituted of a summary of interaction sequences presumably suitable to control with the eyes. Some of these interaction sequences were to be chosen, implemented as prototypes and later evaluated in a usability study. In this pre-study, the options of implementing different interaction sequences are investigated.

Different ways to perform comparative studies were discussed with Gustav Taxén, supervisor at KTH. One alternative was to compare how the same interaction sequence, for instance to change field of view with the eyes, is experienced in two different game environments. The comparison could for example be made between a FPS and an adventure game, where interaction is made slower in the latter game environment. Another option is to use the same game environment, for instance a FPS game, and compare the player's experience when controlling an interaction sequence with mouse and eyes respectively. According to the interests of Tobii Technology, some game environments were especially interesting to evaluate: FPS, shoot'em up, flight simulators and sport games.

3.1.1 Eye tracker and computer game

The simplest way to control a computer game with the eyes is to let an eye tracker replace the functionality of the mouse. Instead of steering the pointer with the mouse, it follows the user's gaze. The eye tracker calculates the coordinates of the user's point of gaze and a pointer is displayed at that position with the Windows method SetCursor(). This option was tried by running the eye tracker and computer games simultaneously. Unfortunately, it did not work in most cases; when starting the computer game it was no longer possible to control the pointer with the eyes. The eye tracker only functioned with some simpler shoot'em up games. The reason was that new games often use DirectX.

Before DirectX was released, most PC games were developed for MS-DOS. Game developers had to spend a lot of time and effort to write hardware specific drivers to make computer games function with hardware like input devices and soundcards. When new hardware was released, new drivers had to be developed very quickly to make the new hardware function with the existing computer games. The market of hardware devices was continuously growing; hence it became an untenable situation when more time was spent on driver development than on game development.

Microsoft's Windows environment offered a solution to the problem since the programmers could utilize Windows drivers. One drawback was that most computer games got slower when played on Windows compared to MS-DOS, because of the operative system occupying most resources. Hence game development continued to be made mainly for MS-DOS. When Windows 95 was developed, Microsoft wanted to solve these problems and facilitate game development for the Windows environment. Microsoft developed a set of APIs (Application Programming Interfaces) called Game SDK (Software Development Kit), later renamed DirectX. Each API controls a set of low-level functions that provides direct access to hardware. The communication between game and hardware bypasses Windows, which provides the fast responsiveness required in games. Game developers could with DirectX access hardware specific functions without writing any hardware specific code. This made it possible for game developers to focus on game development while the drivers were developed directly by the hardware manufacturers.

The DirectInput API provides access to different input devices such as keyboard, mouse and joystick [7]. It is with regard to this project the most interesting API; it offers an explanation of why the eye tracker did not work with most computer games. All games that did not function with the eye tracker were implemented with DirectX. When the game is started, DirectInput overtakes the control and bypasses the Windows messaging system by communicating directly with hardware drivers. Hence when using Windows methods like SetCursor() to move the eye controlled pointer, nothing will happen. If the eye tracker is to function with computer games that utilize DirectX, it is necessary to have a hardware driver. At the time of this study, no driver were available that functioned with the ET-17.

To be able to use the ET-17 together with existing games that utilize DirectX, it was necessary to develop a hardware driver for the eye tracker. DirectInput has not yet any basis for communication with eye trackers. The solution is to develop an eye tracker hardware driver that communicates in a similar way to a mouse hardware driver. The prerequisites to develop a hardware driver for the ET-17 within this study were evaluated; among other things the Windows 2000 DDK (Driver Development Kit) were installed and examined. One option is to find the source code of a mouse hardware driver, get a license and modify the code.

3.1.2 Different solutions

It was desirable that as many eye controlled interaction sequences as possible were implemented and evaluated. Unfortunately, the fact that the ET-17 and computer games with DirectX were not compatible did limit the possibilities. The different alternatives available to create eye controlled interaction sequences were to use a game without DirectX, to write a hardware driver for the eye tracker, develop a computer game from scratch or to use and modify existing game code.

Game without DirectX

The simplest solution was to use a game without DirectX, which works directly with the eye tracker. It is however difficult to find more advanced computer games that do not utilize DirectX. Of the games played during the analysis, it was solely possible to eye control the simpler shoot'em up games. One great disadvantage to use a computer game directly with the eye tracker is the lack of ability to create own interaction methods.

Hardware driver for eye tracker

To make the eye tracker function with computer games that utilize DirectX, it is necessary with a hardware driver adjusted for the eye tracker. The possibility to develop this kind of driver was evaluated and discussed. With the information available it was regarded a too complex and time consuming task. If a computer game is used directly with the eye tracker, it will involve a loss of ability to modify the game, for instance separate weapon sight and field of view. These characteristics made the alternative to develop a hardware driver not favorable.

Develop computer game

Another alternative was to create a computer game from scratch; the game and the eye controlled interaction sequences could then be designed as desired. The problems of DirectX would also be avoided. The possibility to program a computer game with eye controlled interaction sequences in Wasa or Java was evaluated. Wasa is a framework for development of graphical applications. The framework is developed at the Center for User-Oriented IT Design, KTH. Gustav Taxén, supervisor at KTH, held a session about programming in Wasa. A study of information about Wasa was also made. One disadvantage with developing a computer game from scratch is that the quality of the game would not be able to compete with that of commercial computer games. If the quality of the game is lower than the player is used to, it could affect the player's experience of the game. Developing a computer game from scratch is also a very time consuming alternative, thus it was not chosen.

Use existing code

Using existing code is a good alternative that makes it possible to create new forms of interaction, for instance eye controlled interaction sequences, in an existing game. The code could be modified in any way desired and there would be no problem with DirectX. It is very difficult to find source code to commercial computer games but some games have a SDK, Software Development Kit, which makes it possible to affect certain parts of the game.

3.1.3 Extra input devices

In the usability study of this project, eye tracking will be evaluated as an interaction method of a multimodal user interface. It was of great interest to evaluate eye tracking in combination with additional input devices like speech recognizer, light-gun and head tracker. The use of several modalities could enhance interactivity and provide a more convenient user interface.

There was no possibility to utilize speech recognition, since the technology available is limited. Light-guns are often used in arcade games and consoles. However, it was difficult to find a PC compatible light-gun; Sega and different game stores were contacted with no result. Act Labs will release a light-gun, the PC USB Light Gun, which is compatible with Windows 2000 and XP. Unfortunately, it was not possible to postpone the usability study with regard to this release.

Figure 4. The TrackIR head tracker.

It was also of interest to evaluate interaction with head tracking in combination with eye tracking. Combinations of mouse, eye tracker and head tracker could provide several different interaction methods. A head tracker, TrackIR, from NaturalPoint, was purchased for this purpose [36], see Figure 4. The TrackIR uses infrared light to track the user's head movements; the light rays are reflected in a plastic dot placed at the user's forehead. With TrackIR, head movements can be used to e.g. control field of view or pointing a cursor. The TrackIR was tested with different computer games. A test subject was also invited to get opinions. Head movements seemed to be a suitable interaction method for controlling the field of view but poor for aiming a weapon.

However, the TrackIR was not utilized in the usability study since it was regarded too time consuming and confusing to evaluate head tracking and eye tracking in the same test. Head and eye interaction was also not entirely comparable due to the input devices' different control of the game environments.

3.2 Prototypes

Two of the options – to write a hardware driver for the eye tracker and to develop a computer game from scratch – were not chosen with regard to previous explanations. The remaining options were to find a computer game without DirectX or to use and modify source code of an existing game. The development of prototypes was limited to PC, due to lack of access to console or arcade development environments.

During the analysis phase some simpler shoot'em up games was found that functioned with the eye tracker, hence these could be used directly. To integrate eye tracking in the remaining interesting game environments – FPS, flight simulator and sport game – access to existing code or a SDK was required. This was necessary to get by the problem of DirectX and to be able to custom make the interaction. However, it was difficult to find existing source code and SDKs. The final decision was to use the SDK provided to the FPS game Half Life.

3.2.1 Shoot'em up

In a shoot'em up game, the player's mission is to shoot objects, e.g. monsters, when they appear on the screen. The objects could appear in a spot and then vanish or move along the screen. These different alternatives were tested in the games Sacrifice, where monsters pop up on the screen and then disappear, and Duck Hunt, where ducks fly over the screen. After testing, it was obvious that the former variant was most suitable to combine with eye tracking. If the eye tracker is a little bit too slow, it could be very frustrating to watch an object moving along the screen; the weapon sight will follow closely after the moving object. Another reason is the fact that when aiming with a manual device, the player positions the weapon sight closely in front of the object, in the direction moved. This is made to prevent the object from passing the line of fire during the delay between the bullets are fired and before it reaches the object. When aiming with the eyes the weapon sight will typically by focused on the object, hence the bullet will probably miss the target.

Figure 5. Player's view in Sacrifice.

The shoot'em up game Sacrifice was chosen as a basis for evaluation of eye controlled aiming. In this case the game did not have to be modified. The mission of the game is to shoot monsters that pop up on different locations in a static environment displayed on the screen, see Figure 5. The player aims by looking at the monsters and fires a bullet by pushing the mouse button.

3.2.2 First Person Shooter

The FPS game Half Life with the additional SDK was chosen for development of various eye controlled interaction sequences. The Half Life Full SDK 2.2 and Microsoft Visual C++ 6.0 were used for prototype development. Brief information about the directory structure and files could be found in the SDK, for more detailed information see [33]. Two interaction methods were chosen to be implemented as prototypes:

- Change field of view/aim with the eyes.
- Change field of view with the mouse and aim with the eyes.

In the FPS games of today, the weapon is always aimed in the middle of the screen, see Figure 6. When the mouse is moved the field of view is changed, hence the target area is changed, but the weapon is still aimed at the center of the screen. A similar interaction could be accomplished with eye tracking. The field of view is then changed on basis of the user's gaze; the area that the player looks at is centered on the screen and the weapon is still aimed towards the center of the screen. In this case, the mouse control is totally replaced with eye control; the user does not need to utilize the mouse at all.

In the second alternative, a separation of weapon sight and field of view is required. The field of view is changed based on mouse coordinates and the weapon sight is positioned by the player's point of gaze. This means that the view could be hold still while the player could aim anywhere on the screen by looking around. No existing game where weapon sight and field of view is controlled separately. According to several game stores that were contacted, there are no commercial computer games available with this kind of interaction. The reason is probably that common input devices involve restrictions. The player usually operates the game character's movements with the keyboard and changes the view/aims with the mouse, thus both hands are occupied. The use of eye tracking could hence provide an interaction technique not possible to achieve with traditional input devices.

Figure 6. Player's view in original Half Life.

A third option is to control the view with the eyes and aim with the mouse. It is probably a less suitable way to interact with PC games; the player's gaze focus will anyway coincide with the point that he aims at. If a player sees an enemy, he looks at it and the field of view will turn until the enemy is centered on the screen. Then the mouse is used to position the weapon sight. The effect is that weapon sight and field of view both are centered on the screen. Yet this could be an interesting way to interact with games that utilize other input devices than mouse, e.g. in arcade games where a light-gun often is used. To try this interaction form, the possibilities to acquire a PC compatible light-gun were examined, unfortunately without success.

Communication

To utilize the gaze coordinates generated by the eye tracker as a basis for interaction, it is essential with some sort of communication between computer game and eye tracker. A TCP/IP client-server was created to solve this problem. The gaze coordinate client, GC client, was written in C++ and integrated in the HL SDK. The gaze coordinate server, GC server, was written in LabView [35] and integrated in the eye tracker software.

The GC client has a method called "getCoord" that receives gaze coordinates from the GC Server. To recalculate the gaze coordinates into useful coordinates, the method takes a message – "1", "2" or "3":

1 – Get gaze coordinates recalculated to the Half Life coordinate system.
2 – Get actual gaze coordinates in screen coordinates, no recalculation needed.
3 – Get gaze coordinates recalculated for changing field of view.

The coordinate system of Half Life range from -70 to 70 in y direction and from -100 to 100 in x direction. Possible weapon angles range from approximately -10 to 20 in y direction and from 50 to -30 in x direction, see Figure 7.

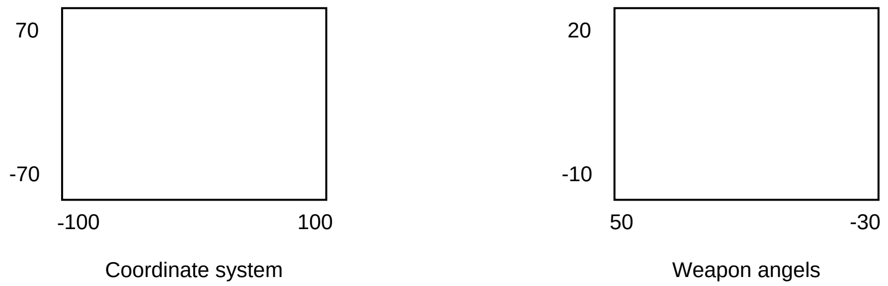

Figure 7. Different coordinate systems in Half Life.

SDK changes

To achieve the two different interaction methods wanted, changes needed to be made in the Half Life SDK. It was necessary to be able to control the change of view, aiming and shooting.

Change field of view

The field of view could either be changed with mouse coordinates or gaze coordinates. Eye control is achieved by sending "3" to the GC client and setting the cursor position to the received coordinates instead of mouse coordinates. In the prototype where field of view is changed with the eyes, the player's view will look the same as in the original Half Life game except without the crosshair, see Figure 8.

Aim and shoot

When control of view and aiming is done simultaneously with mouse or eyes, no changes in the SDK are needed to implement aiming and shooting. Separate eye controlled aiming is achieved by displaying the bullet hit and the hit mark at the user's point of gaze, for which coordinates are received from the GC server.

In the prototype where aiming and control of view are made separate, the user could aim anywhere on the screen with the environment remaining static. In this case, only the weapon sight was changing while the weapon remained in the same position. It was desired that the weapon angle should change when aiming in different directions, see Figure 9. Especially persons who watched someone play the prototype game thought that it was important, since they did not know where the player was aiming. To calculate the weapon angle, gaze coordinates are received from the GC server and recalculated as an angle.

Figure 8. Player's view in Half Life where changing field of view is done with the eyes.

In the original Half Life environment, the weapon sight is indicated by a crosshair, always focused at the centre of the screen. When aiming and change of view are made separate, the crosshair should instead follow the user's point of gaze. This can be achieved by deleting the original crosshair and displaying a new at the point of gaze focus. One drawback with this solution is that the crosshair will follow the eyes' jittery movements, which can be annoying. In the eye gaze interface developed by Jacob et al., "user interface software" is used to calculate the user's eye fixations [11]. A pointer will in that case jump between fixations instead of following eye movements. A similar solution could be utilized to control a crosshair. At the time of this project, no user interface software was available to the ET-17. The best option was to totally disregard the crosshair. In fact, if the eye tracker works with proper speed and accuracy, no pointer is needed since the user knows where he is looking.

Figure 9. Player's view in Half Life where field of view is changed with mouse and aiming is done with the eyes.

3.2.3 Summary

When finishing the development work, five different demos were available with some different interaction methods. The user interface in all of the demos is gaze added, since the eye tracking is used in addition to keyboard and/or mouse. Following demos were later used in the usability study:

Sacrifice

- Aim with mouse.
- Aim with eyes.

Half Life

- HL Mouse, change weapon sight/field of view with mouse.
- HL Eyes, change weapon sight/field of view with eyes.
- HL Combined, change weapon sight with eyes and field of view with mouse.

4 Evaluation

4.1 Usability Study

A usability study is an important process in the development of new interaction methods; it is a way to get feedback and opinions from conceivable future users. A small literature study was made on the subject of designing and performing usability studies. The usability definition of ISO 9126 is “the capability of the software to be understood, learned, used and liked by the user, when used under specified condition” [24]. Different usability attributes, for instance efficiency, reliability and flexibility, could be evaluated in a usability test; a summary of usability attributes is given in [27].

There is a lot of material available that could be used as basis in a usability test, e.g. the commercial questionnaires QUIS and SUMI [8]. This material is often designed for usability evaluation of software. The purpose of the usability study made in this project was not to evaluate the software used, Half Life and Sacrifice. The aim was rather to get a picture of how eye tracking is experienced as an interaction method and how this kind of interaction affects the user’s experience of the different computer games. Accordingly, it involved difficulties to use available questionnaires and other material in this study.

One of the main purposes of this project was to find out users’ attitude and subjective satisfaction with eye tracking; hence it was essential to perform a usability study. According to Nielsen, subjective satisfaction is especially important for non-work applications [16]. The subjective attitude is by Hix and Hartson divided in first impression and satisfaction over time respectively. Within this study it was only possible to evaluate the users’ first impressions. However it is obviously very interesting to investigate how eye tracking is experienced after long-time use.

4.1.1 Design of usability study

Above all, the purpose of this study was to receive qualitative data, how the user subjectively experienced an eye controlled interaction method. Yet also quantitative data, how the users’ performance differed when interacting with hand and eye respectively, was of interest. The design of the usability study was made in cooperation with Anders Hedman, doctoral student, and Sören Lenman, professor, at CID/KTH. Several methods were to be used to get a good description of the users’ experiences. As a preparation, I participated in a usability study about text and speech communication in web based writing, held by Mikael Andersson at the Interaction and Presentation Laboratory/KTH [1]. Some important outlines to have in mind when designing a usability study are:

- It is essential that the test participant feels relaxed during the test.
- Inform the test participant that he is anonymous and has the right to terminate the test.
- The test should be performed in an isolated room.
- The time to perform the test should not be more than one hour.

After planning the test, two pilot studies were made to see if everything functioned properly. Some changes were made due to the result from the pilot studies. A summary of the methods used in the study is given in this chapter together with the results from the pilot studies.

4.1.2 Methods

Three different methods were used in the study – questionnaire, thinking aloud and interview. The aim was to get a comprehensive picture of the users' opinions by the use of different methods that could complement each other.

Questionnaire

When arriving, the test participants answered a short questionnaire about age, computer experience and computer game habits. It was important that this questionnaire was not time consuming, therefore only two questions were open and the remaining were multiple-choice questions. More information about designing questionnaires is given in [3]. Questionnaires were also used to get rankings of the users' experiences of interaction, with eyes and mouse respectively, in the different games. Certain important aspects of their experiences were brought up and for each the user had to rank his experience on a scale ranging form one to seven. The users were also given the possibility to leave a written comment to each question.

Three game questionnaires were created with similar questions, ordered in different ways – one for Sacrifice, one for HL Mouse and HL Eyes and one for HL combined. The questions in the two first questionnaires were formulated in the same way – an example:

Estimate how natural it felt to aim/change field of view with your,

Eyes:	*Hand:*
1 2 3 4 5 6 7	*1 2 3 4 5 6 7*

Following questions were also asked in the questionnaires:

- Estimate how difficult you perceived the game when steering with,
- Indicate how engaged you felt in the game when steering with,
- Estimate how good accuracy you had when controlling the game with,
- Grade how challenging you experienced the game when steering with,
- Indicate how fun the game was when controlling the game with,
- Grade how large control you perceived when aiming/changing field of view with,
- Estimate how straining it was to steer with,
- Indicate how fast you could move the sight with, (Sacrifice)

The questions for HL Combined covered the same aspects but was formulated slightly different, without the comparative scales between eyes and hand. The reason was that interaction in HL Combined is made with both mouse and eyes.

Thinking aloud

Thinking aloud is a method that can give a lot of qualitative data from a user [41]. With this method the user is encouraged to think aloud while a task is performed. The test leader could get a comprehensive picture of the user's experience by observing the user's interaction while hearing the comments. One limitation is that many people think it is uncomfortable and unnatural to speak out their thoughts. Thinking aloud could thus affect how relaxed the user feels in the test situation. The user could also feel that it becomes harder to perform the tasks. In this study, before each game session, the test subjects were encouraged to think aloud and describe how they experience the interaction.

Interview

The test was concluded with a short structured interview [15]. The purpose of the interview was to let the test subjects describe their impression of eye tracking; if they experienced any benefits or disadvantages and if they had any ideas about the use of eye tracking in computer games. These questions require descriptive answers; hence an interview was suitable to avoid too much writing in the questionnaires.

4.1.3 Pilot study

Two pilot studies were made to get feedback on the test design and how much time it would take to perform it. Both tests took slightly less than one hour. Following changes were made to improve the design of the test:

- A schedule with the elements of the test was written to facilitate the test leader's work.
- Two keyboards were installed, thus the test leader did not have too lean over the test subject.
- One of the questions in the questionnaires was disregarded, since it was hard to understand.
- A special mouse was installed due to problems with holding the mouse still when firing.
- A chair without wheels was used instead of an office chair to make it easier for the test subject to remain still.

4.1.4 Usability test

According to the plan, the usability test was meant to take place when the prototype development was finished. Unfortunately, development work with the eye tracker system had by then resulted in a deteriorated performance of the eye tracking. The eye tracker could no longer track both eyes, solely one eye at a time. To solve the problem the eye tracker was used with an eye patch; using the eye tracker without the eye patch resulted in a very poor accuracy.

The impression of interaction with one eye was that it was very uncomfortable; not giving a good experience of eye tracking. One test subject was invited to get further opinions. He felt that interacting with only one eye was dizzying and tiring. After using both eyes for interaction, with a very poor accuracy, the test subject yet reported, "A lot better. More control, not so straining". The conclusion was that if usability tests were performed with the deteriorated eye tracker system, the result would give a very misleading picture of eye tracking. Hence a decision to reschedule the usability test, until the eye tracker was working properly again, was taken.

Material and apparatus

The hardware equipment used in the test station was a stationary computer with monitor, eye tracker, mouse, special mouse and two keyboards. The eye tracker system used consisted of a camera and diodes attached to the computer screen and software. The eye tracker system was at the time of this study a prototype. The test station was placed in an isolated room together with a desk where the test subject could answer the questionnaires.

Two different games, with various kinds of interaction, were available as a basis for the usability study. In Sacrifice, the player's mission was to get as many points as possible. Quantitative data could thus be compared between the scores yielded when interacting with mouse and eyes respectively. The different variants of Half Life constituted a basis for a solely qualitative analysis.

Written material was also included in the study, some to be handed out to the test subjects and some to be used by the test leader. An overview and short description of the documents of interest is given here, for more information see Appendix 1.

Schedule – Instructions to the test leader; a schedule of how to perform the test, step by step.
Introduction – Information pamphlet with an outline of the test.
Questionnaire, background – Questionnaire about the participant's age, computer habits etc.
Game instructions – Instructions read by the test leader before each game session.
Questionnaires, game – Three different questionnaires with rankings of the different demos.
Interview – Questions to be asked in the interview.

Subjects

Test subjects were sought by advertising at KTH. The participants were paid a movie ticket as compensation. Fourteen persons arrived to the test. Of these, eight users – two women and six men – participated successfully in the test; the remaining six could not complete the test due to poor calibrations. The users had normal vision or used contact lenses; no one used glasses during the test. All participants had a lot of computer experience and was experienced to computer games in a lesser or greater extent. A majority of the participants used mouse and keyboard when playing computer games, but some were also used to utilize a wheel, joystick or gamepad. Some of the participants had heard of eye tracking but none had any prior experience of a gaze based interface or with eye tracking equipment.

Procedure

When arriving, the test participant was greeted welcome and offered something to drink. Then the test leader and test participant continued into an isolated room, where the test station was placed. The elements of the test were:

1. Information about the outline of the test is handed out to the participant.
2. The questionnaire about the participant's background is handed out.
3. The participant sits down at the test station and a personal calibration is made.
4. Eye tracking is demonstrated with an application where a green point follows the user's gaze.
5. The user is encouraged to think aloud and Sacrifice is played with eyes and mouse, two times each. The result is noticed.
6. The questionnaire about Sacrifice is handed out.
7. The user sits down by the test station, is told to think aloud and plays Half Life with mouse. If necessary, a new personal calibration is made.
8. The user is encouraged to think aloud and plays the two eye controlled Half Life prototypes.
9. Two questionnaires about Half Life are handed out.
10. A concluding interview is made with the participant.

The Half Life questionnaires were not handed out until all three prototypes had been played. This procedure was chosen to avoid several calibrations. It would probably be more appropriate to hand the corresponding questionnaires out after each game was finished.

Sacrifice was played as the first game, since it is easier than Half Life and hence could be used to familiarize the user with eye tracking. To avoid a misleading score result in Sacrifice, every other player started to play with mouse and every other with the eyes. If all participants had used the two interaction forms in the same order, differences in the result could be ascribed to the fact that the player had tried the game a few times and hence had time to improve his skills.

4.1.5 Result

In this section the result from the usability tests is presented. A summary of the questionnaire answers – both the ranking values and comments – is made for each game environment. Some of the participants made use of the possibility to write comments in the questionnaires more than others. Also the information collected during the thinking aloud sessions are presented. There was a clear difference in how much the participants talked during these sessions. Then a summary of the concluding interviews is given. All statistics are presented in Appendix 2.

Sacrifice

Five of the test subjects experienced greater control when interacting with the eyes than with the mouse in Sacrifice. One participant commented that it was faster to find the targets with the eyes than with the mouse and one wrote that it was more intuitive to play with the eyes. Another participant wrote: "Mouse steering transfers the movements perfectly to the screen while eye tracking sometimes fails and most often is displaced a bit outside the target".

Six of the test subjects graded that they had better accuracy when interacting with the eyes than with the mouse. One person commented that the quality of the calibration was not perfect and another wrote that the accuracy was good as long as he remained in the same position as during calibration.

The game was by all participants perceived to be more fun when played with the eyes compared with the mouse; the average rate for eye tracking was 5.9 and for mouse steering 2.5, see Figure 10. One person commented in the questionnaire, "Fun with the eyes since it was so easy, new and exciting". Another test subject wrote, "A game with this low level of difficulty is probably becoming extremely boring in the long run, if there is no challenge to hit the targets". Five persons rated that they were more engaged in the game when they used eye tracking instead of mouse. The other three gave the same rating for mouse and eye tracking.

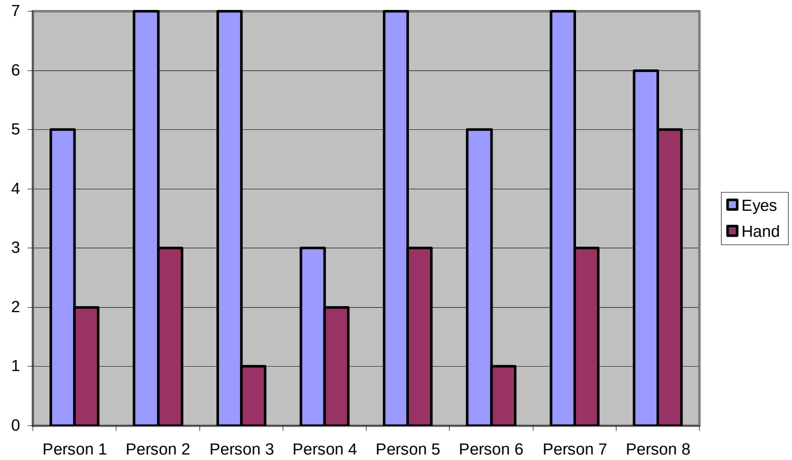

Figure 10. Sacrifice – ratings on how fun the game was perceived.

Six out of eight participants felt that it was more natural to use the eyes for interaction than the mouse. On the ranking scale for how natural the two interaction methods had been perceived, the average rate for eye tracking was 6.5 and for mouse steering 4.5. Six persons commented in the questionnaire that they graded mouse steering fairly high because they were used to utilize the mouse for interaction. Five persons thought that it felt more straining to control the game with the mouse than with the eyes. One test subject wrote in the questionnaire, "I felt a bit glassy-eyed and dry in the eyes after a while". Another participant remarked that he did not feel totally relaxed since he had to remain in the same seating position when using eye tracking.

Seven of the eight participants graded that they experienced the game to be more difficult when played with the mouse compared to the eyes. One person commented in the questionnaire, "When the calibration works and you get used to the game, it is ridiculously easy with eye tracking". Five persons rated the game to be more challenging when using the mouse than the eyes. One subject commented that the game was pretty simple but that it was cooler to play with the eyes. Another wrote, "The difficulty is to manage to aim in time. The harder, the more challenging".

All participants graded that it was faster to interact with the eyes than with the mouse, see Figure 11. The average rate for speed of interaction with eyes and mouse was 6.75 and 3.25 respectively.

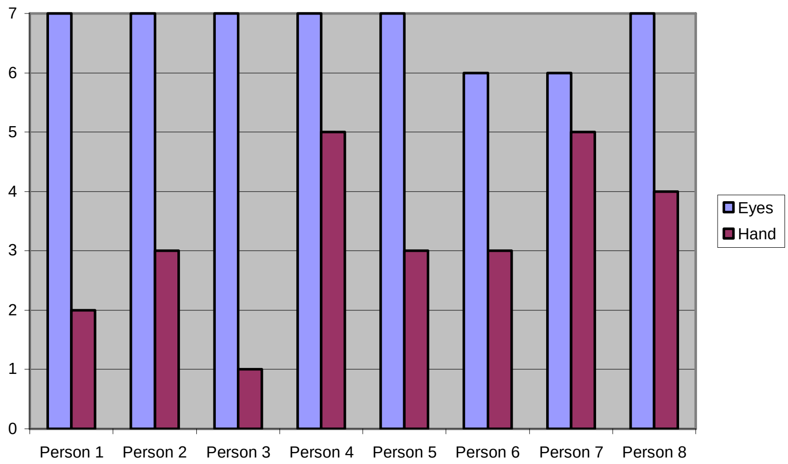

Figure 11. Sacrifice – ratings on how fast the interaction was perceived.

Thinking aloud

When thinking aloud, one participant commented that it felt like controlling the game with the eyes was faster than with the mouse. One person said that it was very fun to play with the eyes and that he felt that it was easy to get used to. Another pointed out that he sometimes fired the weapon before the weapon sight reached the target.

Score

The test subjects played Sacrifice four times each, two times with mouse and two times with eye tracking. One half started to interact with mouse and the other half with eyes. The player received one point per killed monster and the total score was noted; see Table 4 for average score. Maximum score was 50 points per playing session. The performance was not significantly different between those that started with different input devices. When interacting with eyes, the participants directly yielded a high score, despite that they had no prior experience of eye tracking. The average score was about the same between first and second game round played with eye tracking. After the first round with mouse steering of the game, the average score was 23.4, near half the result for eye tracking. For the second round with mouse steering, the average score had increased to 29. This could be a sign that eye tracking lacks a similar learning curve to that of the mouse. It is however difficult to draw any conclusions since the data in this study is limited.

Average score

	Eyes	**Mouse**
Round 1	42,5	23,4
Round 2	42,1	29,0

Table 4. Average score in Sacrifice.

Half Life

The first Half Life demo, HL Mouse, was played in traditional way with mouse and keyboard. The keys were used to move around in the environment and the mouse to change the field of view/aim. Then HL Eyes was played, the demo where the player controls the field of view/aims with the eyes. The keys were still used for movements in the environment but mouse steering was replaced with eye tracking. The interaction with the game environments of these demos function in the same way, but are controlled with different input devices. Afterwards the participants were asked to fill in a questionnaire where they, with respect to different characteristics, graded their experience of playing Half Life with eye tracking and mouse steering respectively.

The third and last demo to be played was HL Combined, where control of view and aiming is made separate. In this version the weapon sight is not locked in the middle of the screen, hence the interaction method used in this game environment is not comparable to that of HL Mouse and HL Eyes. The keys were used for movements, the mouse to change field of view and the eyes to aim the weapon. Since the interaction is made with a combination of mouse- and eye steering it is not possible to make a comparison in the same way as between HL Mouse and HL Eyes, were interaction is made either with mouse or eyes. The participants answered a questionnaire about HL Combined and the combined interaction technique.

HL Mouse and HL Eyes

A comparison between the rates for mouse and eye control of the field of view was made. Six of the participants experienced better control when steering with the mouse than with the eyes. Five persons graded that they had better accuracy when interacting with the mouse. One person commented that he was very used to utilize the mouse. Another test subject wrote: “To control the view vertically was more difficult with the eyes. However, good shooting accuracy with the eyes, faster reaction time.”

Five of the eight participants rated that the game was more fun when played with the eyes than with the mouse, see Figure 12. Two test subjects, both rated eye tracking to be more fun, wrote comments: “A more present feeling, fun!”, “The game gets much more fun!” Four test subjects rated that they were more engaged in the game when interacting with the eyes, two persons rated the opposite and the remaining two gave the same rating. One person, that felt more engaged when playing with the eyes, wrote: “It feels more like it is yourself that moves around.”

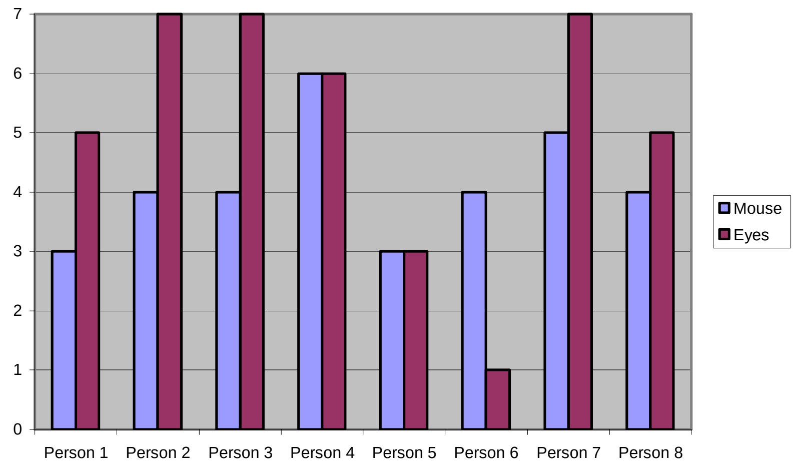

Figure 12. HL Mouse and HL Eyes – rankings on how fun the game was perceived.

Mouse steering was, according to five of the participants, perceived to be more natural than eye control. One person wrote that the naturalness of using the hand is due to experience. Another wrote: “The eye steering is not natural – the reflex is to turn your head.” Eye control was by six of the participants perceived to be more straining than mouse control. One test subject commented that he was used to mouse steering. Another person wrote: “It was a bit frustrating when the eye tracker lost focus.”

Half of the participants graded the game to be more difficult when played with the eyes, three persons graded the opposite and one person gave the same grade. One commented that using the mouse was easy since he was an experienced Half Life player and that it felt a bit weird to turn the body with the eyes. One person that rated the game to be more difficult with the eyes wrote that he had bad control. Another person wrote: “Unfamiliar. You choose to look at one thing, but sways there. Oversteering.” Half of the test subjects rated the game to be more challenging when played with the eyes, one person rated the opposite and three persons gave the same grade. One person wrote: “It is the same game, but it is unfamiliar to play with the eyes.”

HL Combined

The rated values from the HL Combined questionnaire was compared to those collected for HL Eyes and HL Mouse questionnaires. Six of the test subjects rated that they had greater control when playing HL Combined than HL Eyes. Three test subjects rated that that they had more control when playing HL Combined than HL Mouse, one rated the opposite and three persons gave the same rating for both interaction methods. One participant commented: “Besides that the calibration was not so good, it was rocking!” The perception of control differed between participants, one person wrote: “Good control with the mouse but bad with the sight.” Another wrote: “It was difficult to steer with the hand but the sight was good, excellent!” Five persons perceived the accuracy to be better with the combined interaction method than with the interaction used in HL Eyes. Compared to mouse accuracy, four persons rated that they had the better accuracy in HL Combined while two persons rated the opposite and the remaining two gave the same rating. Two subjects commented that the calibration was a bit off, one of them experienced that the accuracy differed depending on where on the screen he looked.

The combined interaction method was by six participants perceived to be more natural than the interaction used in HL Eyes. The same number of participants rated that the combined interaction was more natural than HL Mouse as well, see Figure 13. One test subject commented that it felt totally natural. Another wrote that there was no big difference in the experience between using the combined interaction and only the mouse.

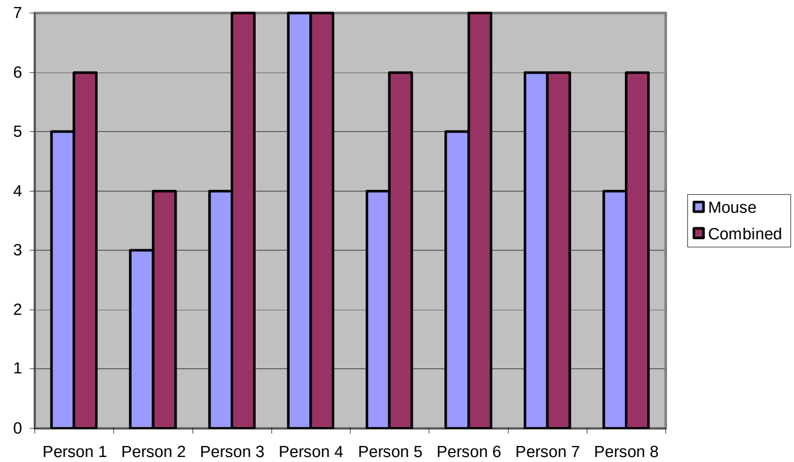

Figure 13. HL Mouse and HL Combined – estimations on how natural interaction was perceived.

Five participants felt that the combined interaction was less straining than using the eyes to control the view. Half of the participants felt that the combined interaction was less straining than controlling the view with the mouse as well – one rated the opposite and three subjects gave the same rating for both interaction methods. One subject wrote that the combined interaction method felt very natural. Another commented: “More relaxing for the eyes when they can wander about without the view following. The risk of motion sickness is less than in the previous case.”

HL Combined was by six participants perceived to be more fun than HL Mouse and half of the participants rated HL Combined to be more fun than HL Eyes. One test subject wrote: “Total power!” One person that had rated HL Combined to be more fun than the other demos commented: “It became easy!” Another participant wrote that there was no difference to playing with only mouse and keyboard. Five of the test subjects felt that they were more engaged in HL Combined than in HL Eyes. Seven of the test subjects rated that they were more engaged in HL Combined than in HL Mouse. One person wrote: “I love this game, the eye control gives a new meaning to the word action!” Another commented that it was a lot more fun this way. One participant who rated in favor of HL Eyes wrote: “The feeling of presence is not as strong as when the view was controlled with the eyes”.

Five persons graded HL Eyes to be more difficult than HL Combined. Four participants rated HL Mouse to be more difficult than HL Combined, two persons rated the opposite and two gave the same ratings. One person wrote that it was easy since he had played Half Life before and one commented that it was hard to hit the target. The HL Combined demo was by half of the participants perceived to be equally challenging as HL Eyes. Five participants rated HL Combined to be more challenging than HL Mouse.

Thinking aloud

When playing HL Eyes, one test subject pointed out that it was uncomfortable that the view changed immediately when the gaze focus changed. He felt that the view was swaying too much; especially when gaze focus was moved quickly from one place to another. Another person commented that it was strenuous that the environment was moving every time he changed gaze focus. Three persons mentioned that this interaction form could cause travel motion sickness. One person commented that it felt pretty cool to only use the keys to play while another said that it felt weird to only play with eyes and keyboard. Two test subjects commented the naturalness of the interaction – one said “Pretty cool but not totally natural” and another commented that “it feels unnatural”. One test subject pointed out that his calibration did not feel good when he moved.

When playing HL Combined, the comments differed a bit. Two participants commented that HL Combined was a lot easier and more fun than HL Eyes. A third participant commented: “What a feeling, this is the way you want it, very cool!” He thought that it would be very powerful if the accuracy was better. Two other participants thought the opposite – that HL Eyes was more fun. One of them pointed out: “This is more like you are used to, more intuitive. But, the previous was more fun.” The other commented: “Only reason to run this is that you can relax more and not get motion sick. Previous was more fun – do not know if it was the charm of novelty.” He added: “Feels a bit like cheating to steer with the eyes, almost too easy – you will need to adapt the computer games.”

Interview

The interview started with a question about the test subject’s spontaneous impression of eye tracking. Everybody was very positive and gave comments like “very fun”, “cool” and “amusing”. Several test subjects mentioned that it felt natural and was easy to learn to interact with the eyes. One of the participants remarked that steering with the eyes did not require as much concentration as steering with the mouse.

Benefits and disadvantages

The participants were asked about what benefits and disadvantages they had experienced with eye tracking compared to mouse steering. The opinions about benefits and disadvantages differ between the game environments and interaction methods. The majority, six out of eight participants, thought that eye tracking was most suitable for aiming a weapon rather than controlling the field of view.

Four test subjects mentioned that interaction with the eyes was much faster than with the mouse. Other characteristics, pointed out by the participants, was that eye tracking felt natural, more intuitive than mouse steering and that it was easy to learn even if it was the first time they tried it. One person remarked that the natural feeling achieved when interacting with the eyes, resulted in a feeling of reality; he felt more immersed in the game and got a “VR feeling”. This was above all experienced in HL Eyes, where the field of view was controlled with the eyes. An important benefit mentioned by near all subjects was that eye tracking was experienced to be fun and amusing.

A disadvantage, mentioned by three test subjects, was that they had to remain still while playing; the accuracy was deteriorated when they moved. All of the participants thought that it was essential that they could move freely and turn their heads. To control a game solely with the eyes, as in HL Eyes, was by some participants experienced to be unfamiliar and a few participants pointed out the risk for travel motion sickness with this interaction method.

Ideas

Two of the participants were interested in the use of head tracking to control the field of view; they thought that it would be natural to turn the head when looking sideways. The participants had following proposals of game environments were eye tracking could be appropriate:

- Flight simulators
- Racing games
- Football games
- First Person Shooter
- Strategy games

One participant commented that eye tracking was, “Easy and excellent, should be possible to use for almost any interaction instead of mouse”. Another test subject thought that all computer games where the mouse is much used should be suitable for eye tracking, to reduce the movements of arm and hand. One test subject said that eye tracking would be useful in “Reaction games, all games where the player needs to react fast”.

4.2 Discussion and Analysis

The findings of the usability study are based on the use of three different methods – questionnaires, thinking aloud sessions and an interview. This procedure proved very useful, since the results from different methods complemented each other and made it easier to get a comprehensive picture of the users' attitudes. A limited number of persons participated in the usability tests. This made it difficult to draw any wide conclusions and impossible to create statistical significantly data. In this chapter a summary of the characteristics evaluated in the usability study is presented together with some possible sources of error and suggestions of improvements of the study.

4.2.1 Characteristics of eye interaction

Focus of the usability study was to evaluate some different aspects of the users' subjective satisfaction with the various interaction methods and game environments. In this chapter a discussion about the result from the usability study is made with respect to different characteristics of eye tracking.

Control and accuracy

In Sacrifice, several test subjects rated both control and precision to be considerably better with eye tracking than with mouse steering. The accuracy performance of the mouse is in theory higher than that achievable with the eyes. Hence the result is somewhat surprising. One reason could be that the objects in Sacrifice are fairly big. It is of great interest to evaluate the use of eye tracking for aiming in an environment with smaller objects. One conceivable game environment is a FPS game where the player is approached by several far distant enemies (small objects).

The HL Mouse and HL Combined demos got similar rankings for control and accuracy. The control was rated 42 for HL Mouse and 44 for HL Combined, accuracy 38 and 39 respectively. When only using the eyes to interact, control and accuracy was rated lower. This result suggests that the perception of eye control differs depending on the context.

The test subjects commented the quality of the calibration in several cases – for instance that the accuracy was deteriorating during gaming and that the accuracy differed in different parts of the screen. The accuracy of the eye tracking will differ from person to person depending on the quality of the personal calibration – which of course will have impact on the experience. Other aspects of the interaction, like speed, may also relate to the ratings of control and accuracy.

Fun and committing

Eye tracking can according to the usability study provide a fun and committing gaming experience. All players rated that they experienced Sacrifice to be more fun when playing with the eyes than with the mouse. A majority rated the Half Life demos to be more fun when played with eye tracking than with mouse steering. A comparison of the rankings of fun between the two eye controlled Half Life demos do not show any clear tendency; four test subjects ranked HL Combined higher, one person gave similar ranking and three test subjects rated HL Eyes higher. It is interesting to point out that all three persons that rated in favor of HL Eyes gave the maximum rate seven. The result could be influenced by the charm of novelty; none of the test subjects had any prior experience of eye tracking. To interact in a totally new way, as with eye tracking, could be exciting and very amusing. Eye tracking can also be perceived to be a bit “magical”; it is possible to control the computer without any contact. These experiences could naturally have influenced the ratings of fun. It is thus essential with usability studies that evaluate long-term use of eye tracking.

Natural and relaxed

The result suggests that eye tracking is perceived to be a natural and relaxed way to interact with computer games. In the Sacrifice questionnaire the average ranking for naturalness of eye tracking and mouse steering was 6.5 and 4.5 respectively. It is important to notice that all participants were very familiar with the mouse and no one had any prior experience of eye tracking. Several test subjects commented that they experienced eye tracking to be a natural and intuitive way to interact. None of the participants needed any training to learn the eye controlled interaction methods. Some test subjects remarked that the fact that they had to sit in the same position affected the natural and relaxed feeling negatively.

The combination interaction method used in HL Combined was regarded as more natural and relaxed than the one used in HL Eyes. In HL Combined, the interaction method resembles the traditional way to interact with a FPS game. In HL Eyes, the interaction is made without mouse and the environment behaves in a way that the player is totally unfamiliar with; hence it could be an interaction form that takes longer time to get used to. Several users pointed out that changing the view with the eyes could cause travel motion sickness. Some test users felt that it was uncomfortable with a game view that changed immediately when their gaze focus changed. One attempt to solve this problem is to develop algorithms that calculate a smooth and desirable control of the field of view. This could for example be done to make the environment “sway” less. One option is to try a gaze added interface where the control of weapon sight and field of view is made separate, but both with eyes; the view starts to scroll when the player looks in the outer edge of the game display, otherwise it is static and the eyes control the weapon sight. An eye controlled field of view may be more suitable in other game environments than FPS games. Adventure games, where interaction usually is slow and methodical, could be an appropriate environment.

Easy

The game Sacrifice was by seven of the participants perceived to be easier when interaction was made with eye tracking instead of mouse steering; an indication that is not necessarily a benefit. The average score performed in Sacrifice was near twice as good with eye tracking than with mouse steering. The results from the two game sessions with mouse steering show a legible learning curve; the players performed better the second time they played with mouse. This tendency is missing in the score result achieved with eye tracking; the result is near identical between first and second game session. It is probably essential with a learning curve to make a game interesting. The player needs a challenge and the possibility to improve his skills over time. For that reason, it may not be appropriate to use eye tracking in game environments similar to Sacrifice. There is obviously the possibility to develop new games that are adapted to the responsiveness of eye tracking, thus giving the player a challenge.

Fast

The aspect of speed is only regarded in the questionnaire that considers Sacrifice. The result showed a very high ranking of the speed of eye tracking compared to that of the mouse, 6.75 and 3.25 respectively. This confirms the information from the literature study – fast interaction is one of the benefits with eye tracking. High speed is probably one of the reasons that made the participants perceive Sacrifice to be easier when played with eye control than with mouse control. One test participant commented that he looked at objects and fired, but missed since the weapon sight was not positioned. This indicates that the performance of the eye tracking despite high speed was a bit too slow.

4.2.2 Sources of error

The result of this study may be affected by several things, some described here. First of all, a limited number of persons participated in the usability study. This made it difficult to draw any clear conclusions from the collected data.
The participants’ experience of eye controlled interaction is obviously affected by the quality of their personal calibration. The quality of the calibrations differed between the eight participants, but was all regarded as acceptable. In the questionnaires, participants were asked to rate how good accuracy and large control the different interaction methods offered. These factors are directly affected by the quality of the personal calibration. But also other factors, for instance how fun the game was perceived, are indirect influenced by the performance of the personal calibration. Some participants reported during

the thinking aloud session that their personal calibration functioned properly. Others thought that the calibration worked worse; accuracy differed in various places of the screen and precision was deteriorated when they moved.

Experienced game players often utilize special game configurations for mouse and keyboard. They are presumably used to the performance and features of their own computer environment, e.g. headphones, high resolution and powerful hardware. The test subjects were allowed to configure mouse and keyboard, but other features could have had an affect on the experience. The fact that none of the participants had any experience of eye tracking could have influenced the findings; there is the possibility that eye tracking was high valued due to being novel and exciting.

4.2.3 Improvements

In the eye controlled Half Life demos, there was no visible weapon sight. Since the speed and accuracy of the eye tracker are not perfect, the users needed more feedback of where their gaze focus was according to the computer. One way to achieve a better feedback is obviously to implement a crosshair that follows the gaze. It is not certain that this is a good solution, due to the same disadvantages that an eye controlled pointer involves.

Some participants perceived the eye controlled environment in HL Eyes to be too agile and swaying. A future interesting subject is to develop and evaluate algorithms for smooth and natural control of the field of view.

Sacrifice was used without any modification. Preferably a similar application had been developed from scratch, to make it possible to design the software in the desired way. For example more quantitative data could be gained from the gaming session by adding a record of the players' number of shootings and hit rate. It would of course be beneficial to perform the study with a larger basis of participants.

4.2.4 Future

When developing new user interfaces, there is a great focus on multimodality. With access to new, non-intrusive eye tracking technology, eye tracking may be incorporated in the development of multimodal user interfaces and interaction methods. The result of this study suggests that the participants were positive to eye tracking. At the same time, they had very different opinions about for what kind of interaction eye control was most appropriate. No clear conclusion can be drawn from the limited number of participants in this usability study.

A lot of the current studies of eye tracking, like this, are made with existing user interfaces and applications. When developing eye tracking as a new interaction method, it is clearly important to investigate new user interfaces and contexts where it is suitable. The use of eye tracking creates totally new possibilities for interaction – some ideas are covered in this report. Eye tracking can offer "a third hand", as in the Half Life demo where controlling the field of view and the weapon sight is made separate. Other ideas mentioned are to use eye tracking to create eye contact, unexpected events or to change storyline in a computer game depending on what the player has seen.

Eye controlled computer games is a very new area that needs to be further investigated. Proper interaction methods and gaming environments need to be developed and evaluated. At the time of this study, the eye tracker used was under development. Today the eye tracking technology has developed; hence it is of great interest to perform further studies.

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Appendix 1 – Test material

Summary

This Appendix contains the material used in the usability study:

Schedule – Instructions to the test leader; a schedule of how to perform the test, step by step.
Introduction – Information pamphlet with an outline of the test.
Questionnaire, background – Questionnaire about the participant's age, computer habits etc.
Game instructions – Instructions read by the test leader before each game session.
Questionnaires, game – Three different questionnaires with rankings of the different demos.
Interview – Questions to be asked in the interview.

SCHEMA

Innan fp kommer
Kolla att demorum är städat
Sätt på dator, högtalare
Sätt upp ”Stör ej”-skylt
Ställ in mineralvatten/läsk

När fp kommit
Välkommen!
Gå in i demorum
Dela ut information om upplägg av testet
Dela ut enkät om försökspersonens bakgrund

Sacrifice
Ge kort info om spelet

Med mus
Starta Sacrifice
Skriv ner resultat
Kör 2 gånger

Med ögon
Gör kalibrering
Green point – peka med penna
Starta Sacrifice
Skriv ner resultat
Kör 2 gånger

Dela ut enkät.

Half Life
Ge kort info om spelet.

Test 1a – ändra synfält/sikte med musen
Välj ikon “test1a”, byter DLL och startar Half Life
N (New Game)
E (Easy Game)
SHIFT + §   map c1a0   Enter
SHIFT + §   impulse 101   Enter   SHIFT + §   2   Enter
Spela

Test 1b – ändra synfält/sikte med ögonen
Gör kalibrering
Green point – peka med penna
Välj ikon “test1b”, byter DLL och startar Half Life
N (New Game)
E (Easy Game)
SHIFT + §   map c1a0   Enter
SHIFT + §   impulse 101   Enter   SHIFT + §   2   Enter

Spela

Kalibreringtest
Kolla med Green point att kalibrering fortfarande är bra.

Test 2 – ändra synfält med musen och sikta med ögonen
Välj ikon "test2", byter DLL och startar Half Life
N (New Game)
E (Easy Game)
SHIFT + §   map c1a0   Enter
SHIFT + §   impulse 101   Enter   SHIFT + §   2   Enter
Spela

Dela ut enkäter om Half Life.

Intervju
Gå in i avskilt rum, alternativt stanna i demorum. Gör intervju.

Tack
Tacka försökspersonen, dela ut biobiljett!

Välkommen!

Du kommer att vara anonym och kan avbryta när som helst, oavsett anledning. Under den avslutande intervjun finns möjlighet att ta upp frågor som rör studien.

Upplägg

Till varje delmoment kommer en kort beskrivning att ges. Är något oklart, fråga försöksledaren.

1. *Enkät*

2. *Demonstration av Eye-tracker, kalibrering*

3. *Test, Sacrifice:*

Du kommer att få spela Sacrifice. Du kommer att testa att spela både med mus och med ögonstyrning. Försöksledaren berättar vilket du börjar med.

4. *Enkät*

5. *Test, Half Life:*

Du kommer att få spela Half Life. Först kommer du att spela med mus. Därefter kommer du att få testa att styra med ögonen på två olika sätt.

- Test 1a, Ändra synfält/sikte med musen.
- Test 1b, Ändra synfält/sikte med ögonen.
- Test 2, Ändra synfält med musen och sikta med ögonen.

6. *Enkät*

7. *Intervju, diskussion*

Tack för din medverkan!

Erika Jönsson

Fyll i enkäten och lämna den till försöksledaren när du är klar.
…………………………………………………………………………………………..

Kön

☐ Kvinna ☐ Man

Ålder

☐ 15 – 25 ☐ 26 – 35 ☐ 36 – 45 ☐ 46 – 55 ☐ 56 – 65 ☐ 66 –

Hur van är du att använda datorer?

☐ Inte van ☐ Van ☐ Mycket van

Hur ofta spelar du dataspel?

☐ Aldrig ☐ Några gånger per år ☐ Någon gång per vecka ☐ Varje dag

Vilka plattformar använder du för spel?

☐ PC/Mac ☐ Arkadspel ☐ Konsoll t ex Nintendo ☐ Spelar inte ☐ Annan:

Skriv ner namnen på de spel du oftast spelar:

Har du spelat Sacrifice?

☐ Ja ☐ Nej

Har du spelat Half Life?

☐ Ja ☐ Nej

Var spelar du dataspel?

☐ Hemma ☐ Jobbet ☐ Game studio ☐ Arkadhall ☐ Spelar inte ☐ Annat:

Vad använder du för speltillbehör?

☐ Ratt ☐ Joystick ☐ Ljuspistol ☐ Gamepad ☐ Mus ☐ Spelar inte

☐ Annat:

Är du åksjuk?

☐ Ja ☐ Nej

Har du hört talas om begreppet ögonstyrning?

☐ Ja ☐ Nej

Om ja, hur? Har du testat själv?

SPELINSTRUKTIONER

Sacrifice

Din uppgift är att skjuta så många monster som möjligt. Varje träff ger en poäng. Du kommer att testa att spela både med mus och med ögonstyrning – tre gånger på varje sätt.

Uppmuntra försökspersonen att ”tänka högt” – säga vad han/hon tycker under spelets gång.

Uppmuntra försökspersonen att slappna av och sitta still.

Mus – sikta med musen, skjut med musknappen.
Ögon – sikta med ögonen, skjut med musknappen (muskulan tas ut för att hindra att man rör musen av misstag).

Half Life

Uppmuntra försökspersonen att ”tänka högt” – säga vad han/hon tycker under spelets gång.

Uppmuntra fp att slappna av och sitta still.

Uppgift:

Be fp att skjuta på tv-skärmarna, därefter på människorna (första vakten går inte att döda) och sen springa runt i miljön. I test2 är det viktigt att uppmuntra fp att stå stilla och känna på interaktionen för det är lätt att annars använda musen för att centrera synfältet – idén med att sikte separat utnyttjas inte.

Test 1a, Ändra synfält/sikte med musen

- w, framåt s, bakåt a, vänster straife d, höger straife

Musen, ändra synfält och sikte. Musknappen, skjuta.

Test 1b, Ändra synfält/sikte med ögonen:

- w, framåt s, bakåt a, vänster straife d, höger straife

Enter, skjuta (för att hindra att musen används som komplement till ögonen).

Test 2, Ändra synfält med musen och sikte med ögonen:

- w, framåt s, bakåt a, vänster straife d, höger straife

Musen, ändra synfält. Musknappen, skjuta.

Sacrifice

Frågorna i denna enkät behandlar hur du upplevt mus- respektive ögonstyrning i spelet Sacrifice. Skalan är 1 till 7 där 1 = lite och 7 = mycket. Fyll i enkäten och lämna den till försöksledaren när du är klar.

………………………………………………………………………………………

1. Ranka hur stor kontroll du upplevde när du styrde med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

2. Ranka hur naturligt det kändes att sikta med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

3. Ranka hur svårt du upplevde spelet när du styrde med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

4. Indikera hur snabbt det gick att flytta siktet med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

5. Ranka hur bra precision du hade när du siktade med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

6. Ranka hur utmanande du upplevde spelet när du styrde med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

7. Indikera hur roligt du upplevde spelet när du styrde med

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

8. Ranka hur ansträngande det var att styra med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

9. Indikera hur engagerad i spelet du kände dig när du styrde med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

Half Life:

Test 1a & 1b, Ändra synfält/sikte med mus eller ögon.

Frågorna i denna enkät behandlar hur du upplevt mus- respektive ögonstyrning i spelet Half Life – när du ändrar synfält/sikte med mus eller ögon. Skalan är 1 till 7 där 1 = lite och 7 = mycket. Fyll i enkäten och lämna den till försöksledaren när du är klar.
……………………………………………………………………………………

1. Ranka hur svårt du upplevde spelet när du styrde med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

2. Ranka hur naturligt det kändes att ändra synfält och sikte med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

3. Indikera hur engagerad i spelet du kände dig när du styrde med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

4. Ranka hur bra precision du hade när du styrde spelet med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

5. Ranka hur utmanande du upplevde spelet när du styrde med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

6. Indikera hur roligt du upplevde spelet när du styrde med

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

7. Ranka hur stor kontroll du upplevde när du styrde synfält och sikte med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

8. Ranka hur ansträngande det var att styra med,

ögonen:	handen:
1 2 3 4 5 6 7	1 2 3 4 5 6 7

Eventuell kommentar:

Half Life:

Test 2, Ändra synfält med musen och sikta med ögonen.

Frågorna i denna enkät behandlar hur du upplevt en kombination av mus- och ögonstyrning i spelet Half Life – när du ändrar synfält med musen och siktar med ögonen. Skalan är 1 till 7 där 1 = lite och 7 = mycket. Fyll i enkäten och lämna den till försöksledaren när du är klar.
………………………………………………………………………………………

1. Indikera hur roligt du upplevde spelet,

1 2 3 4 5 6 7

Eventuell kommentar:

2. Ranka hur svårt du upplevde spelet,

1 2 3 4 5 6 7

Eventuell kommentar:

3. Ranka hur stor kontroll du upplevde när du styrde synfältet med musen och siktet med ögonen:

1 2 3 4 5 6 7

Eventuell kommentar:

4. Ranka hur bra precision du hade när du siktade med ögonen,

1 2 3 4 5 6 7

Eventuell kommentar:

5. Ranka hur utmanande du upplevde spelet,

1 2 3 4 5 6 7

Eventuell kommentar:

6. Indikera hur engagerad i spelet du kände dig,

1 2 3 4 5 6 7

Eventuell kommentar:

7. Ranka hur ansträngande det var att sikta med ögonen,

1 2 3 4 5 6 7

Eventuell kommentar:

8. Ranka hur naturligt det kändes att sikta med ögonen,

1 2 3 4 5 6 7

Eventuell kommentar:

INTERVJU

Ditt spontana intryck av ögonstyrning?

I vilken spelmiljö passade ögonstyrningen bäst:

□ Sacrifice, sikta med ögonen
□ Half Life, styra synfält/sikte med ögonen
□ Half Life, sikta med ögonen (ändra synfält med musen)

Fördelar/nackdelar

Har du några egna idéer kring hur man skulle kunna använda ögonstyrning i dataspel?

Appendix 2 – Statistics

Sacrifice Statistics

Person	1.Control Eyes	1.Control Hand	2. Natural Eyes	2. Natural Hand	3. Difficult Eyes	3. Difficult Hand
1	6	3	6	1	2	6
2	6	2	7	4	2	3
3	6	2	7	3	1	6
4	4	5	5	7	3	2
5	5	5	6	4	2	4
6	4	6	7	7	4	6
7	6	5	7	5	1	5
8	6	5	7	5	2	5
Sum	**43**	**33**	**52**	**36**	**17**	**37**

Person	4. Fast Eyes	4. Fast Hand	5. Accuracy Eyes	5. Accuracy Hand	6. Challenging Eyes	6. Challenging Hand
1	7	2	4	6	4	4
2	7	3	7	3	5	5
3	7	1	5	1	2	7
4	7	5	5	3	2	1
5	7	3	5	4	2	4
6	6	3	4	6	3	7
7	6	5	6	5	2	4
8	7	4	6	4	2	5
Sum	**54**	**26**	**42**	**32**	**22**	**37**

Person	7. Fun Eyes	7. Fun Hand	8. Straining Eyes	8. Straining Hand	9. Engaging Eyes	9. Engaging Hand
1	5	2	2	5	4	4
2	7	3	4	4	7	3
3	7	1	1	6	5	2
4	3	2	2	1	1	1
5	7	3	1	5	6	3
6	5	1	2	5	5	3
7	7	3	1	2	4	4
8	6	5	3	2	7	5
Sum	**47**	**20**	**16**	**30**	**39**	**25**

HL Mouse and HL Eyes Statistics

Person	1. Difficult		2. Natural		3. Engaging	
	Eyes	Mouse	Eyes	Mouse	Eyes	Mouse
1	4	5	3	5	5	4
2	5	6	7	3	6	5
3	5	4	5	4	4	4
4	3	3	1	7	3	4
5	5	3	3	4	4	4
6	7	3	2	5	3	5
7	3	1	5	6	6	2
8	4	5	6	4	6	5
Sum	**36**	**30**	**32**	**38**	**37**	**33**

Person	4. Accuracy		5. Challenging		6. Fun	
	Eyes	Mouse	Eyes	Mouse	Eyes	Mouse
1	2	5	4	4	5	3
2	4	5	5	5	7	4
3	6	4	5	5	7	4
4	3	6	5	3	6	6
5	4	3	4	5	3	3
6	2	6	7	4	1	4
7	2	5	7	2	7	5
8	5	4	6	4	5	4
Sum	**28**	**38**	**43**	**32**	**41**	**33**

Person	7. Control		8. Straining	
	Eyes	Mouse	Eyes	Mouse
1	3	5	3	4
2	7	5	6	4
3	4	4	4	3
4	4	6	6	2
5	4	5	3	4
6	1	4	7	4
7	3	7	4	1
8	5	6	4	3
Sum	**31**	**42**	**37**	**25**

HL Combined Statistics

Person	1. Fun	2. Difficult	3. Control	4. Accuracy
1	5	3	5	5
2	4	6	5	6
3	6	4	7	6
4	7	2	7	7
5	4	4	5	3
6	6	2	6	5
7	3	6	3	1
8	6	4	6	6
Sum	**41**	**31**	**44**	**39**

Person	5. Challenging	6. Engaging	7. Straining	8. Natural
1	5	5	3	6
2	5	5	2	4
3	6	6	1	7
4	5	7	2	7
5	4	5	4	6
6	2	6	2	7
7	6	3	4	6
8	6	7	3	6
Sum	**39**	**44**	**21**	**49**