Gaze vs. Mouse: An evaluation of user experience and planning in problem solving games

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Master's thesis May 2, 2007
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Abstract

The aim of this thesis is to investigate whether gaze-based interaction is a suitable means of input for problem solving games. Where a player has to use his/her eyes not only to select objects, but also to visually perceive the puzzle and plan his/her next move in order to solve the puzzle.

Two common problem solving puzzles were implemented, the Sudoku and the Tile Slide puzzle (or 15 puzzle). Each puzzle can be played with eye gaze or with the mouse. Although test subjects found gaze interesting, the mouse was still the preferred mode of interaction. We found that gaze selection is more erroneous than mouse selection and that these errors can cause a player to lose concentration from the task at hand. We also found that the user interface and the interaction sequence influences both the planning strategy that the player would use and the amount of time it takes him/her to complete the task.

Computing Reviews (1998) Categories and Subject Descriptors:
B.4.2 [Input/Output Devices]: Channels and controllers. C.4 [Performance of Systems]: Design studies. H.5.2. [User Interfaces]: Input devices and strategies.

Contents

Chapter 1

Introduction

1.1 Overview

Human computer interaction (HCI) can be defined as “a discipline that is concerned with the design, evaluation and implementation of interactive computer systems for human use” [Acmsigchi, nd].

Traditionally, computer user interfaces have used *command-based* principles to facilitate the communication between humans and computers. Command-based user interfaces require a user to explicitly issue a command to the system.

Commands come in different forms depending upon the generation of the computer, user interface, selection technique and the purpose or use of the system. Nielsen (1993) singles out two types of command-based user interfaces: function orientated interfaces and object orientated interfaces.

Function orientated interfaces make use of “verb-noun syntaxes”, where the user issues a command by first specifying the function (operation) to be executed and then identifying the item that the operation should be executed on. Nielsen gives an example of deleting a file named “Foo”. The typical syntax for deleting the Foo file in a (line-based) function orientated system would be “del Foo”. In contrast, object orientated interfaces make use of ‘noun-verb syntaxes’, where the user first identifies the object and then specifies the operation to be executed. In a modern graphical object orientated system, the Foo file would be deleted by first selecting the file and then issuing a delete command, for example, dragging the Foo file to trash can.

In recent years, researchers have been moving away from command orientated interfaces, in search for “faster, more natural, and more convenient” [Jacob, 1993] ways of communicating between people and computers. One such approach is *non-command* based interfaces. In non-command based interfaces, the system passively monitors the user as s/he performs a task and provides the appropriate responses during the task, without the user explicitly giving a command.

“These new interfaces are often not even dialogues (commands issued by the user and carried out by the computer) 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” [Nielsen, 1993a].

Nielsen identifies eye tracking, computer music, interface agents, and embedded help as means of achieving non-command based interaction. In this study we focus primarily on eye tracking. Eye tracking (as will be shown later) involves measuring the movement of the eyes.

According to Ware and Mikaelian (1987) object selection is one of the most frequent actions performed by a person sitting in front of a computer. One can therefore infer that, by tracking a user’s eye positions as s/he interacts with an interface, it is possible to obtain information about what a person is selecting. This information is important because it not only give us an indication of where the user’s interests lie, but it also gives us a clue about where the user will go to next for information.

The use of eye gaze data during human computer interaction has some obvious benefits when compared to manual input: a user looks at the object which s/he wants to select even before activating a manual selection device; moving the mouse or pressing a key on the keyboard. Using eye gaze to select targets on the screen is therefore faster than any manual selection device. Gaze input reduces fatigue as the user does not have to engage in physical movement, like moving the mouse around, to acheive selection. Gaze input also provides a natural means of pointing, and is therefore easy to use and learn. Finally, depending on how the interaction is designed, eye gaze interaction also provides a means of non-command based interaction.

1.2 Study objectives

There are currently two main approaches to using eye gaze input in applications [Jonsson, 2005]: *gaze-based* interaction and *gaze-added* interaction. In a gaze-based system, a user solely uses his/her eyes to interact with the system. For example, to select a button on the screen a user would simply look at it. Whereas, in a gaze-added system eye gaze data is used to compliment a manual pointing device such as a keyboard or mouse. For example, to select a button on the screen a user would look at the button and then click on the mouse or press a key on the keyboard.

Many of the applications that use eye gaze input are in the form of typing programs that are targeted at disabled users [Majaranta and Raiha, 2002]. Only a handful of eye-gaze applications exist that provide entertainment – in the form of games. However, many of these gaming applications make use of gaze-added interaction techniques, which are unsuitable for users that are unable to select objects using manual input devices.

The aim of this study was to find out whether gaze-based interaction is a suitable means of input for problem solving games. Where a player has to use his/her eyes not only to select objects, but also to visually perceive the puzzle and plan his/her next move in order to solve the puzzle.

Two common problem solving puzzles were implemented, the Sudoku and the Tile Slide puzzle (or 15 puzzle). The Tobii 1750 eye tracker was used for dwell time selection as well as for recording the eye gaze data while an ordinary (wheeled) desktop mouse was used as a manual selection device.

Research Questions

1. How do users feel about gaze-based interaction?
2. Gaze is the faster than a manual pointing device when we are comparing pointing times, but how does it compare to a manual pointing device when it comes to completing an entire task?
3. Does the interaction technique influence a user's problem solving strategy?

Five voluntary computer science students (from the University of Joensuu) were tested and evaluated for the study. Each participant first played both games using the mouse and then with gaze in order to learn how the interface worked.

1.3 Scope, limitations, and constraints

The scope, limitations, and constraints of this study are as follows:

- I only make use of two puzzle games: the Sudoku puzzle and the Tile Slide puzzle. Other puzzle games are not being considered for this study.
- I have decided to use two selection techniques, a mouse for manual input and dwell-time selection as a gaze-based input technique. Other gaze-based input

techniques (such as blinking and gaze gestures) were not selected as they are regarded as either an unnatural means of input or users in similar studies found them tiring to use [Jacob, 1991, Jacob, 1993, Spakov, 2005].

- It is commonly known that gaze pointing is faster than mouse pointing [Miniotas, 2000, Jacob, 1990, Zhai et al., 1999]. When a person is playing a puzzle, they need to think and plan their next move; thus speed is of little or no concern to the player. This study therefore does not take the interaction response times into consideration. Instead I look at how long it takes to complete a task using both modes of interaction. To this end a dwell time duration of 1 second has been used.

1.4 Thesis organization

This thesis is divided into six parts. Chapter Two, Gaze as a computer input method, discusses various techniques for achieving gaze interaction. Chapter Three, Gaze input in computer games, is a summary of how gaze input is used in other computer games. Chapter Four, FolkiGamez, discusses the design and implementation of the gaze-based FolkiGamez application. Chapter Five, Evaluation, discusses the evaluation of the FolkiGamez application. The conclusions of this thesis are drawn in Chapter Six.

Chapter 2

Gaze as a computer input technique

It is often said ”the eyes are the windows to the soul” as they reveal a glimpse of our inner-most thoughts. People use their eyes to communicate with one another and to collect information about their immediate surroundings by looking at the objects which they find interesting [Bolt, 1982, Miyoshi and Murata, 2001, Ware and Mikaelian, 1987]. Object selection is achieved by imaging the object of interest over the fovea [Miyoshi and Murata, 2001, Ware and Mikaelian, 1987]. The fovea [Stlukeseye, nd] is a small region of the eye that is responsible for sharpening a person’s vision. According to Ware and Mikaelian (1987), object selection is one of the most frequent actions people perform with computers; selection can be achieved using a manual pointing device such as a mouse, keyboard, or finger in the case of a touch sensitive screen. The authors go on further to argue that if a cursor were controlled by the eyes, it would not only be a more natural way of selecting an item, but it would also be considerably faster.

However, we can not just replace the mouse with the eyes as an alternative pointing device because the eyes are perceptual organs [Zhai et al., 1999] and are not suitable for manual tasks such as clicking and dragging. In addition, several problems arise when using gaze as an input device. Gaze interaction research in the context of Human Computer Interaction (HCI) is therefore concerned with finding the most suitable method of using gaze as an alternative input device while at the same time attempting to solve gaze interaction related problems.

In this chapter we will be looking at the known approaches for achieving gaze input, identify the pros and cons of each approach and the problems associated with gaze input in general.

2.1 The Eye

In this section we shall look at the basic anatomy of the eye.

Structure of the eye

When you look at a person's eye, there are certain parts that are distinguishable [Webvision, nd]. The white area is known as the sclera, it provides protection and support for the eye. The iris, the coloured section, has muscles that control the size of the pupil (dilation or constriction) so that more or less light is allowed into the eye. The pupil is positioned at the centre of the eye. A transparent external surface, the cornea, covers both the iris and the pupil.

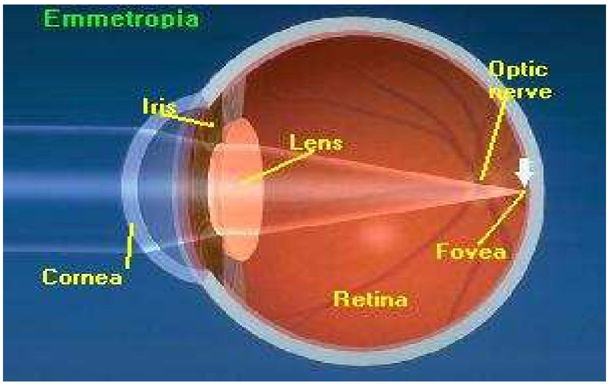


Figure 2.1: Light from an object focused on the fovea [Eyecarass, nd]

Light rays from the external environment will pass through the cornea and the lens and will be focused on the retina (Figure A). The retina is a region in the eye that is covered with perceptrons that convert light into electrical impulses. The fovea is a small region in the retina where the nerve cells are congested. By focusing an image (of an object) over the fovea, a person is able to see the image in greater detail [Eyecarass, nd].

Eye Movements

There are several types of eye movements, however Human Computer Interaction only takes two into consideration, *saccades* and *fixations*. Saccades are brief ballistic eye movements that cover a distance from 1 to 40 degrees of the visual angle. A typical saccade lasts between 30 - 120 ms. The visual system is suppressed during a saccade. There are breaks of up 200ms between saccades. Saccades are usually followed by a period of fixations. Fixations are typically 200-600ms periods where the eye is relatively still. During fixations the eye makes small jittery motions which are less than one degree in size [Jacob, 1993].

2.2 Assumptions of gaze

There is a link between what a person looks at and how it is processed in the mind. Just and Carpenter (1980) used the following assumptions to link eye fixations with their theory of reading [Just and Carpenter, 1980]:

An immediacy assumption

The immediacy assumption states that a person immediately starts interpreting an object as soon as their gaze falls upon it. “The immediacy assumption posits that the interpretations at all levels are not deferred; they occur as soon as possible” [Just and Carpenter, 1980]. Interpretations refer to mental processing at different levels, for example processing a word (during reading) could involve "encoding the word, choosing one meaning for it, assigning it to a referent, and determining its status in the sentence and in the discourse" [Just and Carpenter, 1980].

(An) eye-mind assumption

The eye-mind assumptions states that the eyes fixate on an object for as long as it takes the mind to process it. The gaze duration is used to give an indication of how long it takes to process an object. "The eye-mind assumption posits that there is no appreciable lag between what is being fixated and what is being processed" [Just and Carpenter, 1980].

2.3 Eye Tracking

Eye trackers are devices that measure the movement of the eye. Young and Sheena (1975) identify two types of eye movement measuring techniques: those that measure the position of the eye relative to the head, and those that measure the point where the user is looking in the real world (the point of regard) [Duchowski, 2003] .

Measuring the eye movement in relation to the head

Duchowski identifies three main methods for measuring eye movements in relation to head movements [Duchowski, 2003]: *Electro-oculography* , *Photo-oculography* or *Video-oculography*, and *Scleral contact lens/search coils.*

Electro-oculography is based on the electronic measurement of the potential created by differences between the cornea and the retina when the eye is rotated. Photo-oculography or Video-oculography groups together a variety of eye movement recording techniques which involving the measurement of distinguishable eye features, such as the shape of the eye or the position of the limbus (the iris-sclera boundary). Scleral contact lens/search coils involve attaching a mechanical or optical object to a large contact lens which is worn directly on the eye (covering both the cornea and scleral). This measurement technique is the most precise of all the eye movement measurement techniques but it is also the most intrusive.

Measuring the point of regard

Video-based combined pupil and corneal reflection is an eye movement measurement technique that is able to provide information about where the user is looking in space, while taking the user's eye positions relative to the head into account. It makes use of "inexpensive cameras and image processing hardware to compute the point of regard in real time" [Duchowski, 2003].

This technique uses at least two reference points (the first and forth Purkinje reflections see Figure 2.2) to calculate the gaze point. The reference points are also used to discern head movements from eye movements. The positional difference between the centre of the pupil and the corneal reflection changes when the eye rotates, but remains fairly constant with small head movements.

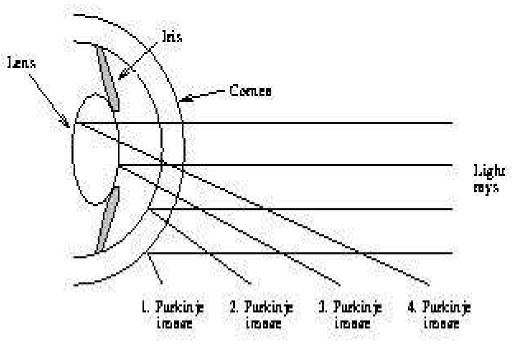


Figure 2.2: The four Purkinje images are shown: the first Purkinje image is a reflection from the outer surface of the cornea and is known as the glint. The second Purkinje image is a reflection form the inner surface of the cornea. The third Purkinje image is a reflection from the outer surface of the lens, while the forth Purkinje image is a reflection from the inner surface of the lens. [Glenstrup and Engell-Nielsen, 1995]

Corneal reflections are typically from infrared or near infrared light sources. Infrared lighting is used because it is undetectable by human eyes and therefore it does not distract a user when it is shone at his/her eyes.

Two techniques are used to identify the pupil during corneal reflection: *dark pupil* and *bright pupil*. The difference between the two is based on the location of the illumination source with respect to the camera and they eye.

The bright pupil effect occurs when the infrared light source is located on the same axis as the camera and the eyes. When the eye is illuminated, the light rays enter the pupil and are reflected from the back of the eye to the camera. Thus causing the pupil to appear "brighter" than the rest of the eye. This approach is similar to the "red eye" effect in flash photography [Smith and Graham, 2006].

A dark pupil effect occurs when the light source is "off-axis"; the infrared light source is located somewhere external to the camera's visual axis. When the eye is illuminated, a darkened pupil stands out against a brighter iris. The pupil can then be thresholded out.

2.4 Gaze interaction methodologies

There are two main approaches to achieving gaze input in user interfaces, *gaze-based* interaction and *gaze-added* interaction [Jonsson, 2005]. Both techniques require an eye tracking device in order to communicate with the user interface. A difference arises in the way in which the eye tracker is used. With gaze-based interaction the user does not need to use his/her hands in order to interact with the interface, the only input device which is used is an eye tracker and the interface is controlled solely by the eyes. Whereas with gaze-added interaction the eye tracker is used to compliment a manual input device such as a mouse or keyboard [Jonsson, 2005].

2.4.1 Gaze-based interaction

Blinking / Winking

This approach requires the user to look at an intended target and blink, with either one or both of the eyes for a predefined amount of time, as a means of object selection. The blink duration is usually long (more than 350 ms), to ensure that an object is not mistakenly selected by unintentional blinking, which is a part of a person's natural eye movements. [Ohno et al., 2003, Spakov, 2005]

Dwell-time selection

Dwell time selection is achieved when a user looks at an object for a specific amount of time [Jacob, 1990]. Hansen et al. (2003) have identified three different techniques for achieving gaze dwell time selection: *continuous dwell activation*, *accumulated dwell activation*, and *adaptive dwell activation*.

With continuous dwell activation, a command is executed if a user continuously looks at a button for a preset period of time. If however the user looks away or the eye tracker has lost the eyes, before the time period has elapsed the time counter will be reset. Whereas with accumulated dwell activation, a command is executed if a user looks at a button for a preset period of time independent of the number of actual activations. The time counter is not reset once the user's gaze is lost, instead the counter will continue to tick ever time the gaze is found on the button. The time counter is reset by some local or global variable. In contrast, with adaptive dwell activation the dwell period (continuous or accumulated) becomes dependent on the users behaviour patterns. Examples of patterns could be the frequency of use, frequency of selection errors, or the number of operations terminated by the user.

Gaze direction gestures

With this approach the user is tracked as s/he glances at off-screen targets, located along the sides of the monitor. Interaction is activated as soon as the user gaze moves into the vicinity of the off screen targets. Object selection is achieved by looking at an object and then glancing at one of the off-screen targets [Spakov, 2005, Juang et al., nd].

2.4.2 Gaze-added interaction

Gaze-Button

A gaze-button allows a user to point at a target on the screen with their eyes and select it using a manual input device such as a mouse or keyboard [Jacob, 1993].

Manual And Gaze Input Cascaded (MAGIC) Pointing

Zhai et al. (1999) argue that it is unnatural to overload the eyes, which are perceptual channels, with “motor control tasks” such as pointing. They propose MAGIC (Manual And Gaze Input Cascaded) pointing as an alternative pointing technique. This approach wraps the cursor to the position where the gaze is fixated and relies on manual pointing for adjustment and target selection. The benefits of this approach include a greater accuracy, an elimination of the Midas touch problem, reduced physical effort and fatigue, and faster than manual pointing. MAGIC pointing makes use of two different approaches, one *liberal* and the other *conservative.*

In the liberal approach the cursor is wrapped to every new object the user looks at; a new object is defined by a specific distance from the current cursor position. The user is able to adjust the position of the cursor by hand if it is not directly above the intended target or s/he can ignore the cursor and search for another target. To avoid distracting the user with small jittery motions as the cursor follows the eyes, an eye-movement parameter is set. If the gaze moves within the defined pixel radius of the cursor, then the cursor will remain stationary, however if the gaze exceeded that boundary the cursor will follow the gaze.

With the conservative approach, the cursor is hidden from the user until s/he activates a manual device, for example, the cursor only appears once the users has moved the mouse. Once the manual device has been activated the cursor is wrapped to the area where the user is looking, which is either on or in the vicinity of the target. To select the target, the user merely has to 'steer' the cursor manually towards the target.

2.5 Problems associated with gaze interaction

Gaze input is both beneficial and problematic. It is beneficial in the sense that it is fast; at fixation periods of between 150-600 ms [Jacob, 1991, Jacob, 1993, Sibert and Jacob, 2000, Ware and Mikaelian, 1987] it is faster than any manual input device. In contrast, its subconscious nature causes it to have some inherent problems [Glenstrup and Engell-Nielsen, 1995].

2.5.1 Accuracy and object size

When a person is looking at an object, s/he is unaware of the tiny jittery movements (less than one degree in size) that the eye makes while visually perceiving the object. This is because the fovea's (Section 2.1) field of view covers an area approximately one degree in diameter; "the width of one word in a book held at normal reading distance or slightly less than the width of your thumb held at the end of your extended arm" [Jacob, 1991].

Thus the size of objects, within a gaze-based interface, have to be at least one degree in diameter in order for the fovea to see it sharply. As a result, objects in gaze-based applications tend to be larger than those in manual pointing systems.

Furthermore, the jitter movements of the eyes, cause accuracy problems for eye trackers. It is possible to improve the accuracy by averaging over fixations, however it is not practical to do so in real time [Jacob, 1991]. An accuracy of less than one degree is obtainable, but this depends on how steady the user keeps his/her head. In addition, the current eye tracking hardware limits the distance between the user and eye tracker to between 50cm - 70cm.

2.5.2 Midas touch

Although we look at many items on a daily basis, we are not familiar to having them react to our gaze, for example, a button being clicked once the gaze has fallen upon it. Unlike a manual pointing device, the eyes can not be turned off neither can the be placed in a state of idleness; where no selection takes place. The constant 'on-ness' of gaze input can therfore lead to Midas touch; every time a user shifts his/her gaze, whether it be intentional or unintentional, an item on the screen is activated – everything s/he looks at turns to gold.

Chapter 3

Gaze input in computer games

Many of the existing eye gaze applications allow users to type or paint images with their eyes. There are however, only a handful of entertainment applications, which allow users to play games using gaze [Spakov, 2005]. There is a great potential for using gaze input in games. Many of the games that have been developed in recent years make use of eye gaze interaction. The level of interaction varies depending on the type of game. Some games allow the player to view the avatar's field of view (viewing the environment from the avatar's perspective) or field of vision (viewing the environment in a specific direction), while others make use of the avatar's eyes in order to communicate with the player [Smith and Graham, 2006]. I have reviewed several gaze applications, which are presented below, that allow players to play games using either gaze-based or gaze-added input techniques. The games can be categorized as *shooting games, first-person shooter games, role-play/storytelling games*, and *mental strategy games.* The game genre information was obtained from [Transgaming, nd, Jonsson, 2005].

3.1 Shooting games

In a shooting game a player has to aim a weapon of some sort (for example, gun, catapult, or bow) at objects that appear at random positions on the screen. The purpose of shooting games is to obtain as many points as possible within a specific time period. Points are earned for each target that is successfully hit.

Lunar Command

Lunar Command [Smith and Graham, 2006] is a modified version of the 1980's Missile Command arcade game. The player is presented with a turret and six cities located at the bottom of the screen (Figure 3.6). Missiles descend upon the cities, from the top of the screen, at increasing speeds. The aim of the game is to stop the missiles, by destroying them with shots fired from the turret, before they reach the cities. However the fired shots take a few seconds before they reach their target. A player earns points for every missile that is successfully destroyed and losses points when a missile reaches one of the cities or when a shot is fired and it misses its target.

The game is played with both mouse and gaze-added input techniques. During mouse interaction a player uses the mouse to aim at the missile that s/he wishes to destroy; this is achieved by moving the mouse to the intended missile and then clicking on the left mouse button to fire the shot. Similarly, during gaze-added interaction a player aims at a missile by "looking" at it and fires a shot by clicking on the left mouse button. The player need not move the mouse during gaze mode, its sole purpose is for firing shots.

Users performed significantly, $F(1, 22) = 18.959$, better with the mouse than with the eyes when Lunar Command was evaluated. Participants found it easier to understand and play the game with the mouse than with the eyes. Although they

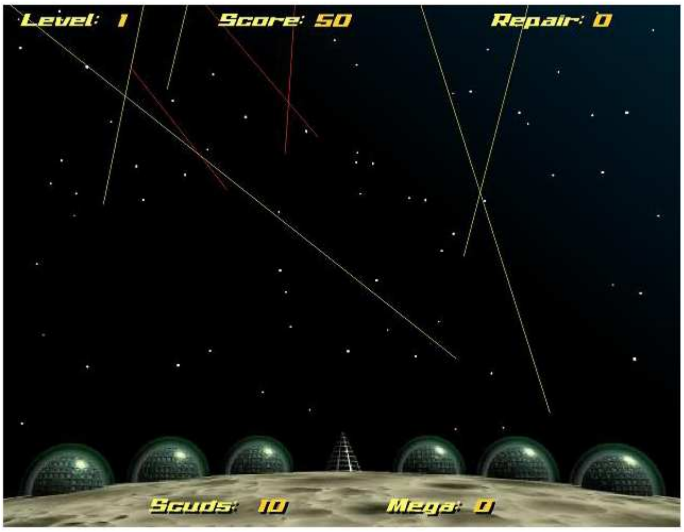


Figure 3.1: Lunar Command: Missiles descending upon the six cities located at the bottom of the display, with the turrent positioned in the middle of them [Smith and Graham, 2006].

found the game more immersing with the eyes.

Sacrifice

Sacrifice [Jonsson, 2005] is another gaze-added shooting game. The aim of the game is to shoot at the monsters that appear at random locations on the screen, before they disappear (Figure 3.2). Points are obtained for every monster that is correctly shot. Sacrifice makes use of the same interaction technique as Lunar Command above. During gaze-added interaction, a player looks at a monster and clicks on the left mouse button to shoot at it.

During testing, participants found the game fun and easy to play. They also experienced a greater level of control with the gaze than with the mouse. Participants played two rounds of the Sacrifice game. Eye gaze out-scored the mouse in each round, the maximum score was 50 points. The average score obtained with the gaze was 42.5 in the first round and 42.1 in the second. While, the average score during mouse interaction was 23.4 and 29.0 in the first and second rounds respectively.

Figure 3.2: Sacrifice: The hand positioned at the bottom of the screen is used to aim (and fling) weapons at the monsters that appear at random locations on the screen [Jonsson, 2005].

3.2 First Person Shooters

First-person shooters are a subset of shooter games where the player views a virtual (three-dimensional) world from the eyes of the gaming character (avatar). This view gives the player a feeling of actually being in the game.

Quake 2

Quake 2 [Smith and Graham, 2006] is a gaze added first-person shooter game where the player's *orientation* in the virtual world is controlled with either the mouse or by gaze. A player is placed at the end of a long winding hallway with a gun that contains an unlimited amount of ammunition. The aim of the game is to reach a door on the other end of the hallway. However, in order to reach the opposite end of the hallway a player has to defeat five monsters along the way.

The player's orientation in the virtual corridor is controlled with both gaze and

Figure 3.3: Quake 2: (a) When the player look at the robot standing on the left-hand side of the screen (b) the virtual world rotates so that the robot is positioned at the centre of the screen [Smith and Graham, 2006].

mouse input. When playing with the eyes, a player simply looks at an object in order to rotate the view so that the object is placed in the middle of the screen (Figure 3.3). Whereas, during mouse interaction, the mouse has to be moved to rotate the view; moving the mouse forward rotates the view up, while moving the mouse backwards rotates the view down. The movement of the player, down the corridor, is facilitated by the following keys on the keyboard: ”A” (left), ”S” (backwards), ”D” (right), and ”W” (forwards). To fire the gun, players has to click on the left mouse button during mouse interaction and during gaze interaction the player has to press the ”Ctrl” key on the keyboard.

Although participants found it more immersing to play Quake 2 with the gaze, they felt it was easier learn and more natural to play the game with the mouse. It took less time for players to reach the end of the virtual corridor with the mouse than with gaze.

Half Life

Half Life [Jonsson, 2005] is another first-person shooter game that has been modified to allow gaze interaction. The aim of the game is to navigate through the virtual world and shot at objects. As Quake 2 above, both mouse and gaze interactions are used in the game, however the manner in which they are used differs. As before, the player is able to control his/her orientation in the virtual environment, with both the mouse and the eyes, by rotating the environment to the point where the user is looking or in the direction mouse is moving.

The second method of interaction allows the player to control the gun's field of view using gaze while using the mouse to control the field of view. When controlling the gun's field of view, the player is able to aim anywhere on the screen while the environment remains static. Unlike the original Half Life, the modified version also allows the user to change the angle of the weapon (Figure 3.4). During gaze interaction, both the weapon's angle and the direction at which it is aimed depends on where the player is looking.

Figure 3.4: (a)Half Life player's view where orientation is controlled by the eyes. (b)Half Life player's view where the gun's field of view is controlled by the eyes [Jonsson, 2005].

When controlling the field of view of the Half Life game, most of the test subjects preferred the mouse. They felt that the mouse gave them better control and accuracy than the gaze. However participants felt that the game was more enjoyable when played with the mouse. Participants felt that controlling the orientation with the gaze was less natural than with the mouse and therefore found the game harder to play.

Players found the combination of gaze and mouse (using the mouse to control the orientation and the gaze to aim the weapon) more natural, accurate, and fun to use than the interaction sequence where gaze was used to solely control the orientation.

3.3 Role-play / storytelling games

In role-playing / storytelling games, the player is placed in an unknown environment which has to be explored in order to have an adventure, solve a mystery or complete a mystery. The game is played in a *first-person* or *third-person* view. In a third-person view, the player is able to watch a character as it navigates through the virtual world. Many third-person views make use of an avatar, which is a character that represents the user in the virtual environment [Defthat, nd].

EyeVenture

EyeVenture [Gips et al., 1996] is a gaze-based (first-person) multimedia adventure game, which was implemented for the Disney channel. A player is placed in a virtual environment with several objects located inside it. The player moves through the simulated environment through exploration; searching for specific places, listening and watching various media, and solving puzzles. The environment is controlled solely by gaze. If the player looks to the left or the right side of the screen, the world is rotated to the left or right respectively. Looking at a specific object within

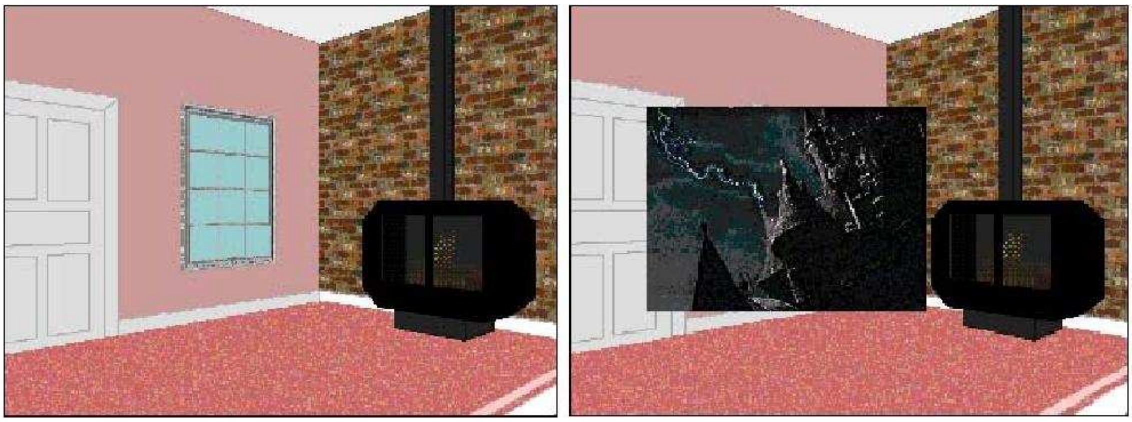


Figure 3.5: EyeVenture: looking at the window causes a video clip of a storm to play [Gips et al., 1996].

the virtual world can cause an event to occur. For example looking at a window could open a video clip (Figure 3.5).

Neverwinter Nights

Neverwinter Nights [Smith and Graham, 2006] is an interactive role-playing game, which involves moving an avatar around as it explores a virtual environment (Figure 3.6). The environment contains of a large room with several objects, such as chests and crates.

A player communicates with the avatar by pointing to the item(s) that s/he would like the avatar to interact with. To move the avatar, during mouse interaction, the player clicks on a point in the environment and the avatar will move there. Similarly, during gaze interaction, the player controls the avatar's movement by "looking" at a location where s/he wants the avatar to move to and then left-clicking the mouse. The player does not need to move the mouse to the desired location. The mouse click is only used to indicate that the avatar is meant to move. The same technique is used to communicate with the objects within the environment; by gazing at a door or the lid of a chest, and left-clicking the mouse, the avatar opens the door or chest respectively.

Player has joined as a player.
[Server] You are now in a No PVP area.
PAUSED

Figure 3.6: Neverwinter Nights: the avatar as it moves through the virtual world towards a stock of crates [Smith and Graham, 2006].

Test subjects found it immersing to play Neverwinter Nights with eye gaze input. They felt that using gaze was more natural then the mouse. Additionally, subjects felt that the game was more enjoyable and easier to play using gaze. However, players managed to complete the task faster with the mouse than with the gaze.

The Little Prince storyteller

The Little Prince storyteller [Starker and Bolt, 1990] is a gaze-based story telling game which is based on Antoine de Saint Exupery's book "The Little prince". The environment is shown as a small revolving planet. A number of objects appear on the surface of the planet, such as staircases, volcanoes, and flowers. The "Little Prince", shown in the top left corner of the screen (Figure 3.7), gives a narration about the planet using synthesized speech.

The narration's generality and specificity is a function of the scope of focus of the user's attention. If the user glances around the environment in a random manner, the Little Prince's narration is general, for example, "This is where I live. It is not very large, maybe about two hundred feet across, but I call it home ...". If the user

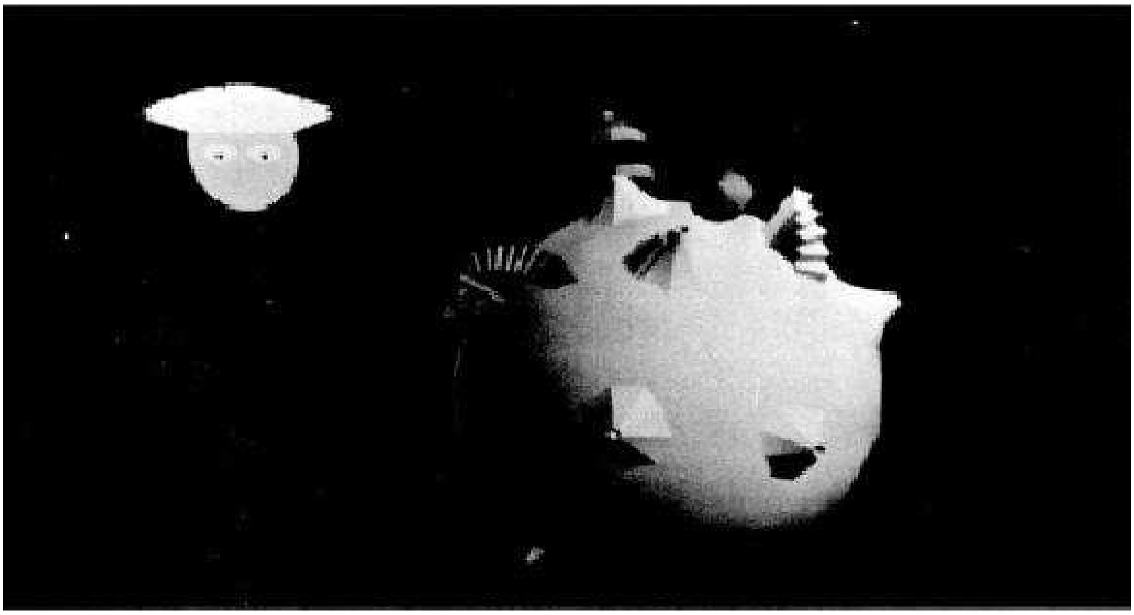


Figure 3.7: The Little Prince Storyteller: The “Little Prince” is shown in the top left corner. While his little planet, with all its objects, is positioned at the centre of the screen [Starker and Bolt, 1990].

glances back and forth between two objects (e.g. two staircases), the narration will change to include the objects that the user is looking at. For example, “My latest hobby is collecting staircases ...”. If the user’s gaze is fixated on one particular object (e.g. a green stair case), the narration will once again change to include that object, “I found this green staircase on a trip by Pluto ...”.

3.4 Problem solving games

Problem solving games, are games where the outcome is determined by the mental skills of the player rather than by pure chance. These types of games are usually intellectually challenging and they require the player to think, plan, and strategize in order to play or solve the game.

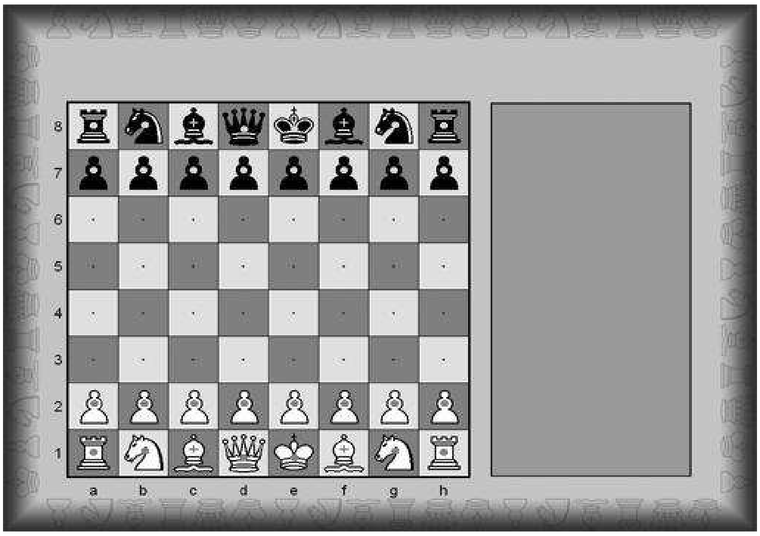


Figure 3.8: EyeChess: The start configuration of the EyeChess game. The user's pieces, in white, are positioned along the bottom of the screen. While the computer's pieces, in black, are positioned along the top of the screen [Spakov, 2005].

EyeChess

EyeChess [Spakov, 2005] is a gaze-based chess game that was developed to teach beginners how to play chess (Figure 3.8). A player plays against the computer and has to try and checkmate the Black King in three moves. The game is played by selecting a chess piece and then moving it to a destination square. The game uses colour highlighting to indicate where a specific piece can be moved to. A valid move is indicated by a square highlighted in green, while a red-highlighted square indicates and invalid move.

EyeChess allows a player to choose between three gazed-based interaction techniques: dwell time, intentional blinking, and gaze gestures. During dwell time selection a player has to look at the square that s/he wishes to select (for 1.8 seconds), once the square has been highlighted, the player will then look at the square that s/he would like to move the piece to. The chess piece will move to the destination square if the move is valid. During blink interaction, the player has to look at the square that s/he wishes to select and then intentionally blinks to select it. A long blink duration of between 350 - 1000 milliseconds is used to avoid selecting the incorrect button due to unintentional blinking. Finally, the application also makes use of gaze gesture selection. Gaze gesture selection is achieved using off-screen targets. A player selects a square by looking at it and then quickly (1 second at most) looks at one of the off-screen targets and back at the same square of near to it.

[Spakov, 2005] has however reported that users that have played EyeChess with the latter two methods have characterized them as rather fatiguing and thus chose dwell time as the primary selection technique during evaluation. The average time it took users to make the three moves was 71.4 seconds; 78 percent (56 seconds) of the this time was spent making the first correct move. The second and third moves were significantly shorter. Overall users found the game easy to play.

3.5 Summary

In this chapter we have looked at how gaze interaction has been achieved in several gaming applications. Each application is different and gaze data has been used differently. It can be agreed that participants (from the games that have been evaluated) found gaze both interesting and enjoyable.

Users found gaze-added input in role-playing / story-telling games more natural and immersing than the mouse. Gaze-added input also performed considerably well in pointing games such as Sacrifice. Gaze-added interaction sequences where also preferred to the mouse in game where the orientation of the virtual world could be controlled, for example, Half Life and Quake 2. However the mouse was the overall preferred interaction method for all the games which allowed users to use a mouse.

Users were accustomed to the mouse and therefore found it more natural and easier to play the games with it, however they still found gaze more immersing.

From the evaluated games, there where three games (Sacrifice, Quake 2, and Neverwinter Nights) that evaluated the performace difference of the mouse and gaze-added interation. In two of the three games, there was no significant differences in the user's perfomace using the mouse and gaze-added input. However, there is a lack of performance data for comparisons between the mouse and gaze-based interaction. Additionally, there is insufficient data about how users perceive gaze-based interaction, this is because mostly gaze-added interaction games were evaluated.

Chapter 4

FolkiGamez

In this chapter I will discuss the design and implementation of the gaze-based application, *FolkiGamez*, which I have developed. The application consists of two commonly known puzzles, *Sudoku* and the *Tile-Slide puzzle*. The games were developed in Avalon (Windows Presentation Foundation) using the Windows SDK September 2006 CPT for the WinFX framework.

A lack of gaze-based puzzle games was the main motivating factor for developing this application. The application makes use of a mouse as well as gaze-based interaction techniques, thus making it accessible to all players (including physically disabled players).

4.1 Interaction Techniques

In this section I shall explain the interaction techniques used in the two puzzle games. The interaction techniques are: mouse click and continuous dwell time activation (see Section 2.4).

Mouse

We make use of a common desktop (wheeled) mouse for selecting buttons on the screen. Target selection is a two part process. The first part involves using a mouse to position the cursor over the target, while the second, involves using a finger to click on the left-hand button of the mouse.

Continuous dwell time activation

Continuous dwell time activation [Jacob, 1990, Hansen et al., 2003] is a selection method which allows a command to be executed once a user's gaze is on a button for a predefined amount of time. The executed command is equivalent to a single (left button) mouse click.

A dwell time counter is starting as soon as a user's gaze falls upon a button. Once the counter has reached the predefined time limit, a command is executed. However, if the user's gaze leaves the button before the counter reaches the time limit or if the eye tracker fails to see the eyes, the counter is reset (Figure 4.1). This selection technique is commonly used in many gaze-based applications [Hansen et al., 2003].

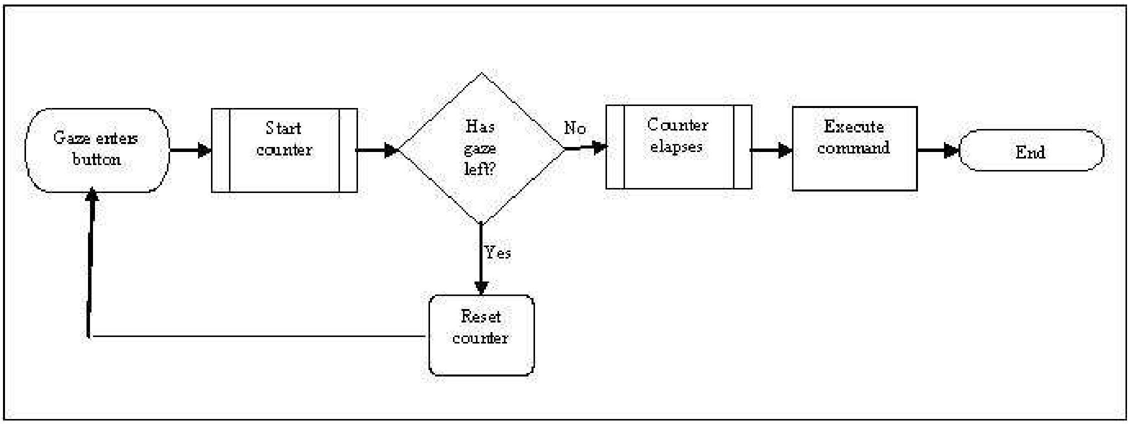


Figure 4.1: Continuous dwell time selection

For the purpose of this study, a dwell time of 1 second was selected [Hansen et al., 2003, Spakov, 2005]. A longer gaze dwell time was selected because a player needs to think, plan and strategize his/her next move in order to solve the puzzle. A shorter dwell time may lead to a situation where the wrong button is constantly being selected [Jacob, 1990, Jacob, 1991, Jacob, 1993]. A Tobii 1750 eye tracker was used to track the location of the eye gaze on the screen.

4.2 Sudoku Puzzle

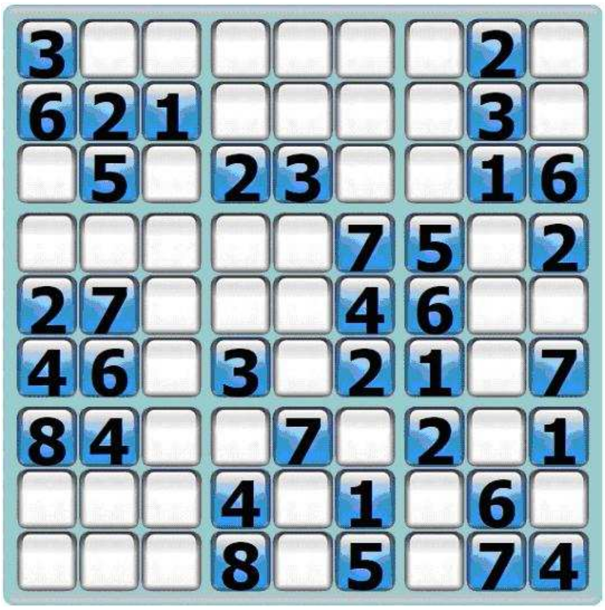
In this section we will look at the Sudoku puzzle in more detail. Sudoku is an abbreviation for a longer Japanese phrase *"Suji wa dokushin ni kagiru"* meaning *"the digits must occur only once"* [Nikoli, nd, Galanti, nd]. The Sudoku puzzle is a logic based number placement game, which was originally invented by an American named Howard Garns in 1979 under the name "Number place" [Nikoli, nd]. The game is played by filling blank cells with digits between 1 to 9, so that each row, column, and 3x3 block contain a single occurrence of the digits.

Puzzle Design

The Sudoku puzzle is made up of a 1280 x 1024 pixel screen, which consists of a 9x9 (810 x 810 pixels) grid that is further divided up into nine 3x3 blocks (Figure 4.2). The puzzle has two types of buttons: grid buttons and number dial buttons.

Grid buttons are presented as the white and blue buttons on the grid surface. There are in total 81 grid buttons each with a width and height of 77 pixels (2.3 cm) in size. There is a 6 pixel (0.1 cm) space between buttons within the same block and a 16 pixel (0.4 cm) space between blocks. The blue grid buttons represent the buttons which already have values, these values are fixed (they can not be selected by the user) and they serve as clues to the puzzle player. The white buttons on the other hand allow the player to enter values into them. Each button can be filled with ether a blank value or a digit from 1-9. Initially all white buttons are blank.

Once a player selects a grid button a number dial (Figure 4.3(a)) appears around the selected button. The number dial has 10 buttons, each button represents one of



3							2	
6	2	1					3	
	5		2	3			1	6
					7	5		2
2	7				4	6		
4	6		3		2	1		7
8	4			7		2		1
			4		1		6	
			8		5		7	4

Figure 4.2: Sudoku Board: Configuration of a typical Soduku board. The prefilled blue buttons serve as visual clues to solve the puzzle, while the (clear) white buttons are used to enter values.

the ten values that a white grid button can contain, that is one blank button (which represents a null value) and nine buttons with the numbers 1-9 in them. Once a dial button is selected its value will replace the contents of the white grid button (Figure 4.3(b)). The value inside a white button can be changed as the player sees fit. The player is unable to select any of the other grid buttons while the number dial is open.

Solving the puzzle

To solve a Sudoku puzzle a player needs continuously repeat the following three processes: *scanning, mark-up,* and *analysis* [Onlearnhav, nd, Sudokugrok, nd]:

Scanning is the first action that the player will perform and it is performed throughout the entire game between the various analysis stages. Scanning consists of two techniques: *cross-hatching* and *counting*. Cross-hatching is concerned with checking the rows and columns one at a time to determine in which row or column a certain

Figure 4.3: (a) The opened number selector dial contains 10 buttons; the buttons 1 - 9 represent the nine possible values the highlighted button contain, while the blank dial button (null value)is used if the player wishes to keep the button blank. (b) White grid button after the number '4' is selected.

number can occur. In contrast, counting requires the player to count, usually backwards from the number nine, to determine which number is missing from a row, column, or 3x3 block.

The mark-up phase is concerned with identifying prospective values for a specific cell. The player can either find the values that a specific cell can contain or alternatively s/he can identify values that can not be in that cell. The user is free to either memorize the values or write them down on a piece of paper.

Finally, the analysis process comprises of two techniques: *candidate elimination* and *what-if*. Candidate elimination requires a player to match cells within a row, column or 3x3 block with one another if they contain the same set of numbers. For instance, if two cells within the same scope (for example, a row and a 3x3 block) contain the same candidate numbers , then it is said that the cells are matched. Placing the candidate numbers elsewhere within the same scope will make the game unsolvable.

Using the what-if technique, the user has to guess which of the alternatives values is the most suitable for a specific cell. If the player has selected the wrong number s/he has to backtrack and select another alternative.

4.3 Tile Slide Puzzle

In this section we shall look at the Tile Slide puzzle in more detail. The Tile Slide puzzle (also known as the n-puzzle or the 15-puzzle) is a tile rearrangement game that was invented by an American puzzle expert, Sam Loyd in 1878 [Broeders, nd]. The rules of the Tile Slide game are simple. You have to arrange the tiles of the puzzle in ascending order so that each tile lies in its original location, and the individual tile backgrounds form a complete picture.

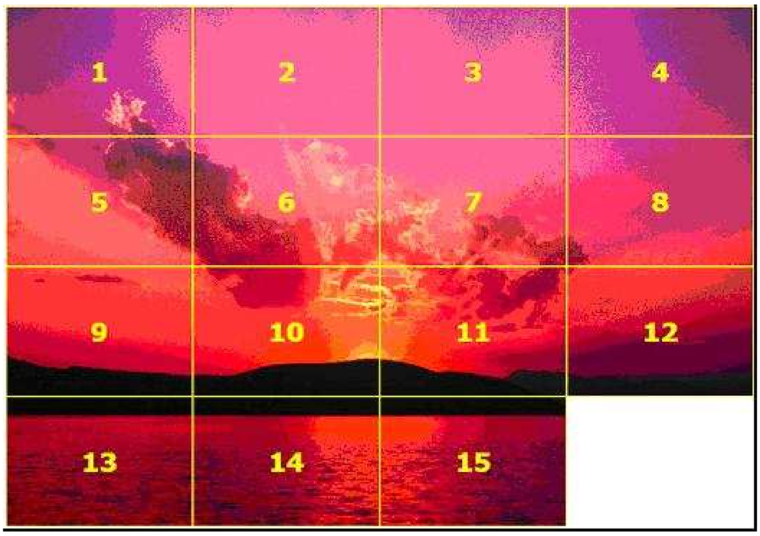


Figure 4.4: Tile Slide Puzzle at the onset of the game. The tiles are arranged in numeric order (from left to right), with the blank tile appearing at the bottom right-hand corner of the display.

Puzzle Design

The Tile Slide puzzle is a 1280 x 1024 pixel screen, which consists of an image, with a width of 800 pixels (24.5 cm) and a height of 600 pixels (18 cm), that is divided into $n^2 - 1$ tiles where n is the number of rows/columns (rows and columns are equal); if $n = 4$ then we have a 15 puzzle, similarly if $n = 5$ then we have a 24 puzzle.

Tiles are numbered in ascending order from left to right with an empty space appearing at the bottom right corner of the board (Figure 4.4). In the case of the 15-puzzle, each of the tiles, including the empty space, have a width of 200 pixels (6 cm) and a height of 150 pixels (4.5 cm). A space of 6 pixels (0.1 cm) separates the individual tiles.

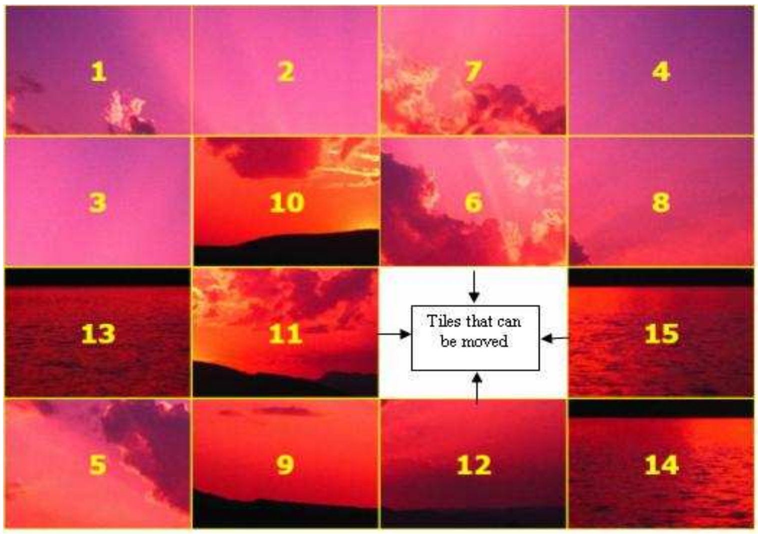


Figure 4.5: Tile Slide Puzzle after shuffle

At the onset of the game, each of the tiles is shown in their original position. While the full (un-shuffled) image is being viewed, the grid is disabled, the user is unable to select (move) any of the tiles. After 5 seconds the image is shuffled (Figure 4.5) and the interface is enabled - the user is able to select or move the tiles.

As soon as a user selects a tile, whether it is with by gaze or by mouse, that particular tile is depressed. The depressed tile will then slide into the empty space. Only one tile is permitted in the empty space at a time. In addition, only tiles that lie north, south, west, and east of the empty tile can be moved. Tiles that lie diagonal to the empty space can not be moved. Each move is an important part of the puzzle solving strategy as it opens up a path within the puzzle gird.

Solving the puzzle

To solve the puzzle a player needs to sort the puzzle one row at a time, starting with the top-most row and working downwards towards the bottom-most row. Each row is sorted from left to right. The player selects the tile that s/he wishes to position and then navigates it to its intended position. To move the tile in a certain direction, a player needs to move the other tiles around until the empty space is next to the tile that the player intends to move, in the direction the player wants to move it. Once a tile has been placed in its correct position, the player should try not to move it again. This process should be repeated until the entire puzzle is sorted [Japp, nd, Hayes, 2001].

Chapter 5

Evaluations

"Usability testing measures the suitability of the software for its users, and is directed at measuring the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments or contexts of use. Effectiveness is the capability of the software product to enable users to achieve specified goals with accuracy and completeness in a specified context of use. Efficiency is the capability of the product to enable users to expend appropriate amounts of resources in relation to the effectiveness achieved in a specified context of use. Satisfaction is the capability of the software product to satisfy users in a specified context of use."
[Teswp, nd]

In this chapter I will evaluate the FolkiGamez. I will discuss how the usability testing was conducted and summarize and discuss the results.

5.1 Method

I used three methods for collecting data from the users: a short questionnaire, think aloud and an interview.

Questionnaire

At the beginning of the testing session, each of the participants were asked to fill out a short questionnaire. The aim of the questionnaire was to collect information about the participants' backgrounds and experiences. I wanted to find out whether the participants had experience with gaze input and if they had played either of the games before.

Think Aloud

Think Aloud is a method for collecting data during usability testing. During think aloud, test participants are encouraged to talk as they perform a task. Participants are encouraged to talk about what they are thinking, what they are attempting to do, and how they feel as they perform their task [Lewis and Rieman, 1993]. The think aloud data is important to the evaluators because they are able to get an overall understanding of how or the way in which a test participant has performed the given task. One of the limitations of the think aloud method is that some participants may find it difficult and unnatural to talk about what is on their minds.

Interview

At the end of the testing session, a small interview (Appendix A) was conducted to find out what the participants views were about the gaze input after having played both games with both modes of interaction. The participants were asked to rate the games and interaction sequences on a scale of 1 ("I hate it") to 5 ("I love it"). In addition to the above, participants had to give a reason for their preference ratings and their opinions on gaze-based interaction.

5.2 Material and apparatus

5.2.1 Tobii 1750 eye tracker

For the purpose of this study, a Tobii ET 1750 [Tobii, nd] eye tracker (Figure 5.1) was used for tracking the eye gaze movements of the users and for gaze dwell time selection. The Tobii 1750 eye tracker is a non-intrusive dark-pupil eye movement tracker that is integrated within a 17” monitor with a maximum resolution of 1280 x 1024.

Tobii 1750 consists of a high resolution camera which is able to capture images of the user and the user’s eye gaze at angles of up to +/- 40. It also makes use of Near Infra-Red Light-Emitting Diodes (NIR-LEDs) that are used to generate light and reflect patterns in the user’s eyes. Both the camera and the NIR-LEDs are built into the monitor and are hidden behind optical filters.

The non-intrusive nature of the eye tracker also gives the user the freedom to move their head. At a distance of 60cm from the screen the user has a head movement freedom of 30 x 16 x 12 (width x height x depth), thus the eye tracker is able to accommodate the normal head motions a person makes when sitting in front of a monitor. The camera also provides an accuracy of 0.5 and a drift rate of ¡1 at the same viewing distance.

At a response time of between 8 - 16 ms it is not only provides fast responses but also a low delay in image presentations and movie stimuli. Tobii 1750 allows binocular tracking; tracking both the right and left eye simultaneously and is able to distinguish between the eyes regardless of head movements or blinking.

The Tobii 1750 eye tracker is suitable for monitor based studies. For example, websites, slide shows, video, text, imagery and computer programs / applications. It is also suitable for users from many different cultural backgrounds. It is also able to track users that wear spectacles, however it is unable to track users that wear bi-focal glasses.

Figure 5.1: Tobii 1750 eye tracker [Tobii, nd]

5.2.2 Procedure

The testing process was conducted in the following manner: A participant entered the Usability and Cognition Laboratory and took a seat. I told him/her what the testing involved and what was expected from him/her. Then I administered the pre-test questionnaire; I asked the questions and then filled in the answers myself. The next step was to calibrate the participant's eyes using Clear View and start the recording. At the beginning of each task, I explained what the participant had to do. Each participant first played the TS puzzle, followed by the Sudoku puzzle using the mouse and then using gaze. Once a participant had played all four games, I led him/her out of the usability laboratory for a cup of coffee/tea and a slice of cake; where we had a short interview in a more 'relaxed' setting. Once the interview ended I thanked the participant and the testing process was over.

5.2.3 Tasks

To learn how to use the interface, players were asked to play each game first using The mouse and then gaze. The participants' eye gaze patterns were recorded as they completed each of the tasks, using both interaction sequences. The results are shown in Section 5.3.

Tile Slide Puzzle

At the beginning to the puzzle, the player is able to see how the entire puzzle looks like. After 5 seconds the puzzle is shuffled. The task is to reorder the puzzle. The player is either asked to reorder the one of the rows in the puzzle. In Figure 5.2(a), the player's task is to reorder the first row of the puzzle so that tile *B* is in the position of tile *X*. The same also true for each of the remaining three rows; the player has to reposition the tiles so that the tile marked *X* is replaced with the tile that is highlighted either *B* or *C*. The optimum number of moves in each case is nine.

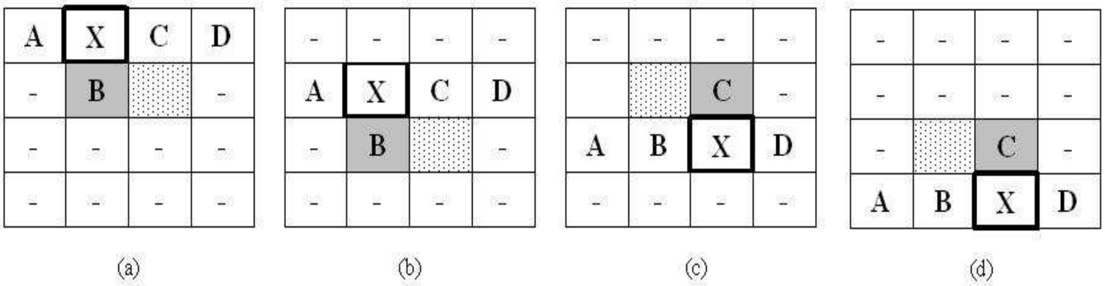


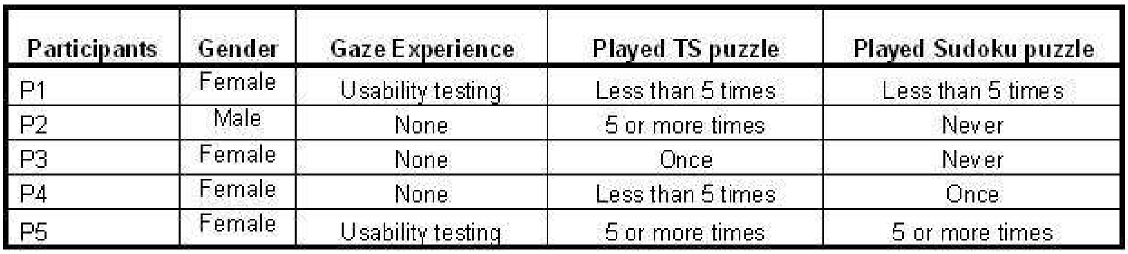
Figure 5.2: Configuration of the TS puzzle after the shuffling. The task is to reorder: (a) the top row, so that tile *B* is in the position of *X*. (b) the second row from the top, so that tile *B* is in the position of *X*. (c) the third row from the top, o that tile *C*is in the position of *X* (d) the bottom row, so that tile *C* is in the position of *X*

Suduko Puzzle

Players were presented with a standard (9x9) Sudoku puzzle. Their task was to enter the digits 1-9 so that a row, column, or a 3x3 block in the puzzle was filled.

Players had to adhere to the rules of the Sudoku puzzle, such that each digit could only appear once in every row, column, and 3x3 block.

5.2.4 Participant profiles



Participants	Gender	Gaze Experience	Played TS puzzle	Played Sudoku puzzle
P1	Female	Usability testing	Less than 5 times	Less than 5 times
P2	Male	None	5 or more times	Never
P3	Female	None	Once	Never
P4	Female	None	Less than 5 times	Once
P5	Female	Usability testing	5 or more times	5 or more times

Table 5.1: Summary of the participants' profiles; showing each participant's gender, and their individual experience with gaze input and the two puzzles

Nine computer science students from the University of Joensuu volunteered to be test participants in this study. Five of which were female and the remaining four participants were male. One of the male participants could not be calibrated, as the eye tracker failed to detect his eyes. The data from three of the tested participants became corrupted after testing and was not included in this evaluation. To this end only five participants were evaluated; four female and one male participant (Table 5.1). The participants' ages ranged from 21 to 45 years. Two of the participants wore spectacles, while the remaining three report no known visual impairments.

All of the participants were experienced computer users and they all understood the logic of how the puzzles were solved. Two of the participants (P1 and P5) reported prior experience with eye gaze. Both participants (P1 and P5) had used gaze in usability studies related to the web page usability, while P5 had also used gaze in several visual attention studies. The remaining three participants (P2, P3, and P4) had never used gaze before.

Participant P5 had the most prior experience playing both the puzzles, followed by

P1. While participant P3 had never played Sudoku before and only reported playing the TS puzzle once before this study. The playing experience of the remaining two participants varied according to game. Both participants P2 and P4 had never played the Sudoku puzzle prior to this study, but had played the TS puzzle.

5.3 Results

In this section I shall discuss the results of the usability test. Part of the information from the post-test interview, think aloud, and gaze data is summarized and presented below.

5.3.1 User Satisfaction

One of the main purposes of this study is to find out how the users feel about gaze interaction as they solve the puzzles; their first impressions of gaze interaction and their subjective satisfaction. Subjective satisfaction refers “to how pleasant it is to use a system” [Nielsen, 1993b]. According to Nielsen, subjective satisfaction is one of the key attributes which determines the level of personal enjoyment that a user will have when making use of ‘non-work related environments’, such as games, interactive fiction, or creative planning [Nielsen, 1993b].

The preferences of the participants are summarized in Table 5.2. After playing both games (Sudoku and TS) using both interaction sequences (mouse and gaze), participants where asked to rate them on a scale from 1 (“I hate it”) to 5 (“I love it”).

The mouse was the preferred interaction method in both games, with an average rating of 5. When asked why they preferred using the mouse, most of the participants mentioned that it was because they were accustomed to using it, others said it

	SODUKU		TILE SLIDE PUZZLE	
Participants	Mouse	Gaze	Mouse	Gaze
P1	5	2	5	4
P2	5	2	5	3
P3	5	2	5	4
P4	5	3	5	3
P5	5	2	5	4

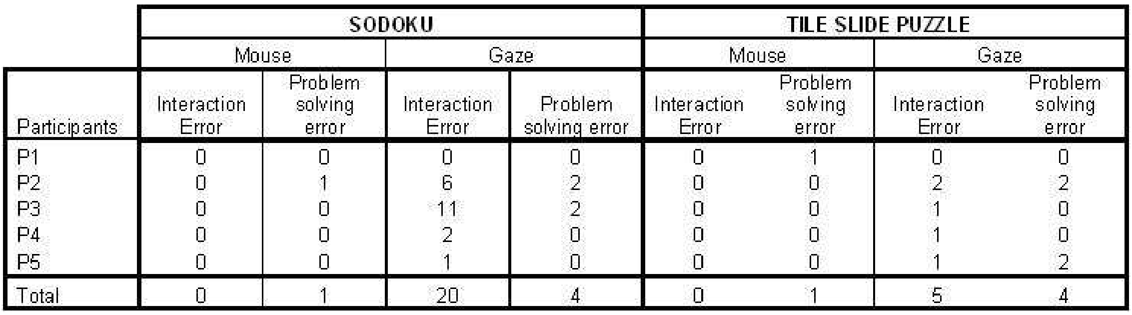
Table 5.2: User preferences by game and interaction. Where: 1 = "I hate it" , 2 = "I dislike it" , 3 = "its okay" , 4 = "I like it" , and 5 = "I love it"

gave them the freedom to think without selecting items, while participant P5 stated "I always know where the mouse is because I can see where the cursor is located, but with the gaze I am never sure of where the eye tracker thinks my eyes are".

The preferred puzzle amongst the participants was the TS puzzle. The average preference rating for gaze input in the TS and Sudoku puzzles were 3.6 and 1.8 respectively. When asked why they preferred the TS puzzle all the participants said it was easier to play because the tiles (buttons) were larger. Participant P2 stated "it is easier to move and understand the game", while participant P3 mentioned that the interface's restricted selection making it easier to plan. When asked about the Sudoku puzzle, four of the participants said they found if difficult, whereas participant P1 found the game "more interesting and challenging than the TS puzzle". Participant P4 also mentioned that it was hard to remember which number to fill into the grid button.

5.3.2 Errors

I discern between two types of errors, interaction errors and problem solving errors (Table 5.3). Interaction errors occur due to the nature of the input device, whereas



	SODOKU				TILE SLIDE PUZZLE			
	Mouse		Gaze		Mouse		Gaze	
Participants	Interaction Error	Problem solving error	Interaction Error	Problem solving error	Interaction Error	Problem solving error	Interaction Error	Problem solving error
P1	0	0	0	0	0	1	0	0
P2	0	1	6	2	0	0	2	2
P3	0	0	11	2	0	0	1	0
P4	0	0	2	0	0	0	1	0
P5	0	0	1	0	0	0	1	2
Total	0	1	20	4	0	1	5	4

Table 5.3: Errors experienced during tasks.

problem solving errors occur because of the problem solving strategy used by the user. With the aid of the think aloud data, it is possible to understand what the player's intentions were while solving a task. For example, in the Sudoku puzzle if a player intends to fill a grid button with number 7, but 6 is selected accidentally. This is an example of an interaction error as it was not the user's intention to select 6. Whereas a problem solving error occurs when a player intentionally selects 6, while a 6 already exists in the row, column or 3x3 block.

In the TS puzzle, a problem solving error would result in backtracking behavior during the solution. According to O'Hara and Payne (1998) "backtracking behavior is a characteristic of search via display manipulation whereby a particular move or move sequence is carried out and evaluated with the display. If proves to be a poor choice the problem solver can reverse the move sequence to get back to where they were and try a different sequence". Backtracking therefore increases both the total number of moves and reflected number of moves in a puzzle. Reflected moves occur when "the second hand of moves is a mirror image of the first half e.g. 1,2,3,3,2,1" [O'Hara and S.J., 1998].

There were no interaction errors, in either of the puzzle, while using the mouse. This is mainly due to the fact that user are accustomed to using the mouse. the nature of the mouse also allows a user to control when s/he would like to select an object.

However, here where two problem solving errors during mouse interaction. Both participants P1 and P2 had played the Sudoku puzzle and TS puzzle respectively, prior to this study however each of them still experienced problem solving errors.

Four participants experienced interaction errors while solving their task using gaze input. Most of the interaction errors where a result of Midas touch caused by the small jittery eye movements made by the eye. Participants P2 and P3 experienced the most interaction errors while playing Sudoku. the interaction errors reduced during the TS puzzle, this was a direct result of the limited selection of the user interface and the size of the tiles (buttons).

Four problem solving errors where experienced in each game. Participants P2 and P3 both experienced two problem solving errors during the Sudoku puzzle. This was mainly because the players spent some of their time on their interaction problems which in the end distracted them from the task at hand. Participants P2 and P3 both experienced two problem solving errors each while solving the TS puzzle.

5.3.3 Task completion time

Gaze is the faster than a manual pointing device when we are comparing pointing times. One of the main purposes of this study was to find out how efficient gaze-based input is when a user has to complete an entire task. The time it took to complete a task was measured and the results are presented below.

Sudoku Puzzle

The completion times varied depending on the mode of interaction (Figure 5.3. The task completion times during mouse interaction where significantly less than the completions times recorded during gaze interaction for four of the five participants.

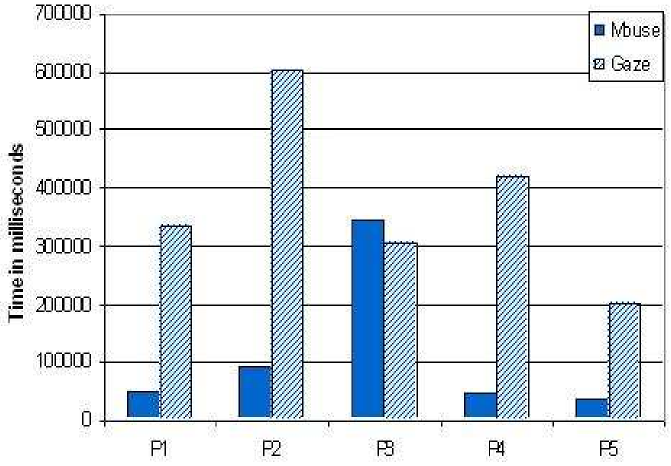


Figure 5.3: Sudoku: task completion time by mouse and gaze input for each participant

Participants P1, P2, P4 and P5 all managed to complete the task in less than 10 seconds using the mouse.

All players understood the rules of the game, but the players (P1, P4, and P5) were slightly more experienced in playing Sudoku and were therefore able to complete the task faster using the mouse.

The level of playing experience is reflected by the time it took individual participants to complete their tasks using the mouse. Participant P5, being the most experienced Sudoku player, amongst the participants, remained to have the shortest completion time for the Sudoku puzzle with gaze. However, participants P1 and P3, both of whom had played Sudoku before, had long completion times. Participant P1 experienced no errors while completing the task with the gaze Yet participants P4 and P5 experienced two and one errors respectively.

There is a small difference in the task completion times for Participant P3 when solving the task with the mouse and by gaze. Participant P3 had no prior experience with the Sudoku puzzle, this is reflected in the long completion time with the mouse. However there is a slight improvement (decrease) in P3's completion time when using the gaze.

The small size of the data is however, not sufficient enough for me to draw a conclusion on the relationship between prior experience of the participants and the amount of time it took to solve the puzzles using gaze.

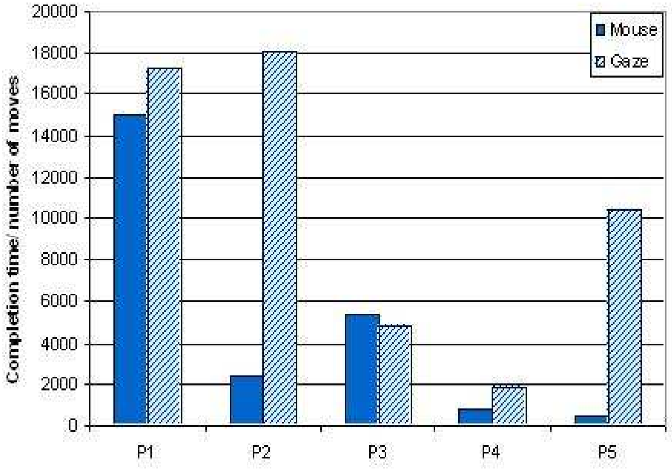


Figure 5.4: Tile Silde puzzle: Completion time/ number of moves ratio by mouse and gaze input for each participant

Tile Slide Puzzle

In order to compare the amount of time it took for participants to complete the TS puzzle, I made a ratio of the total time spent on a task to the number of moves for each participant. The results are summarized in Figure 5.4.

In all but one case the (participant P3), the time spent solving the puzzle using the mouse was less than the completion times recorded with the gaze. Participants P1, P3, and P4 recorded slight differences between completion times with the mouse and gaze. While the completion times for participants P2 and P5 showed great differences in completion time.

All participants had played the TS puzzle at least once before this study. Participants P1 and P4 have both played the TS puzzle less than five times prior to this study however there is a great difference in their completion times. Whereas participants P2 and P5 have both played TS more than five times however there is a large difference between the completion times of the gaze interaction and that of the mouse.

It seems though that the participants that were less experience with the game, showed less of a difference in completion times was compared to participants that had more. However the sample size of the data insufficient to draw conclusions about this observation.

5.3.4 Planning and problem solving

In order to determine if gaze interaction changes the problem solving strategies of the users, I decided to analyze the participant's think aloud data. The think aloud data for each participant was divided into durations lines of one second each. The lines where then categorized using the scheme presented below. A ratio of the categorized data was calculated for each participant using each interaction sequence. The mean percentages for each puzzle can be seen in Figures 5.5 and 5.6 .

Categorization scheme

The categorization scheme was adopted from the O'Hara and Payne (1998). The scheme was originally intended for the Tile Slide puzzle, but minor modifications allowed me to generalize it to the Sudoku puzzle:

Planning and plans:

Planning is the activity of plan development and the evaluation of plans' consequences via mental execution of plans under consideration. Words such as "if", "when", and "then" are useful indications of verbal statements corresponding to planning activity. For example, in the Tile Slide puzzle "If I move 2 down and the 4 down there be a space in the top right to move the 1 over and then the 3 up". While in the Sudoku puzzle "If I put the 2 here, both this row and column will have a two".

Verbal statements considered to be plans are utterances which contain general or specific information about how the subject is going to attain the desired state or property. Such utterances generally contain the designated goal followed by a sequence of actions of visa versa. For example in the Tile Slide puzzle statements such as "I'm going to get 3 in its correct position so I'll move 8 down, 2 across, and 3 up" or "I'll just rotate them to get 1 into its position" are examples of plans. While in the Sudoku puzzle, "I need to remove number 5 and replace it with number 2" would be categorized as plans.

Intentions:

Utterances which suggest that the subject is trying to attain a particular state or property but without any specific indication of how these states or property are to be achieved. For example, in the Tile Side puzzle statements such as "I want to get 2 to its correct position" or "I need to get 3 out of the way" would be coded as intentions. While in the Sudoku puzzle, "I need to put a 3 in this row" would be coded as intentions.

Cognitions:

Verbal statements coded as cognitions are those which explain what information the subject is considering or has discovered. They refer to subjective characterizations of the current situation using the perceptually available information. The knowledge emerging from such situations can be a useful source for determining the subject's subsequent actions. For example, in the Tile Slide puzzle statements such as "I must first look where the digits 1,2,3, and 4 are located, 2 is in the corner" or "They are in the right sequence but in the wrong position", would be categorized as cognitions. While in the Sudoku puzzle statements such as "I have 1,2,3, and 4, that means 5 is missing" or "This row has a 3" would be categorized as cognitions.

Evaluations:
Evaluations are conceptually similar to cognitions, but not specific about the object being evaluated. For example, statements such as "That was good" or "I've messed it up" are placed under this category.

Concurrent move/selection descriptions:
This refers to utterances which describe the moves or selection that are currently being made or that are immediately about to be made.

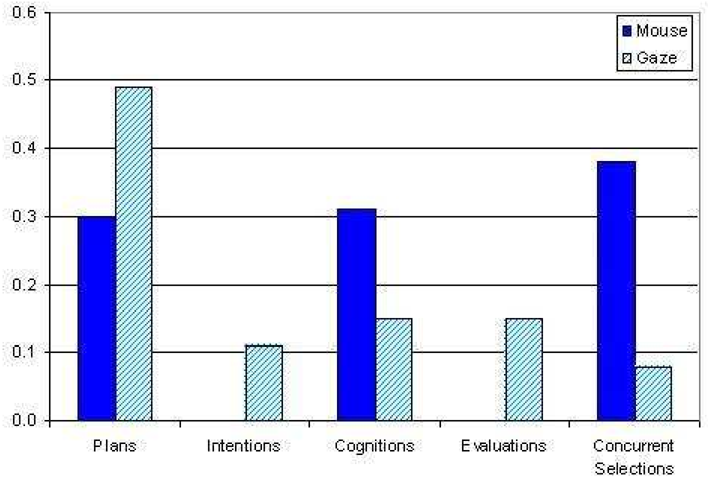


Figure 5.5: Tile Silde puzzle: proportion of think aloud data according to category and interaction sequence

Sudoku Puzzle

Participants stated that they preferred using the mouse to the gaze when, solving the Sudoku puzzle, because it gives them time to think. However, Figure 5.5 shows that participants actually spent more time planning while using gaze interaction.

From the diagram we can see that participants changed their problem solving strategies when using the mouse and gaze-based interaction. When using gaze input, participants would spend a greater proportion of their time analyzing the puzzle and planning their move. Participants also stated their intentions clearly when using gaze and evaluated their selection afterwards.

The nature of the mouse is a probable explanation of why there is a lack of evaluations during mouse interaction. Users are aware of their selections and they therefore do not need to evaluate their decisions.

“I want to fill this third row with number 2” was an example of an intention during gaze interaction while “There is no 9 here and no 9 here in the x,y so I can put 9 here” was an example of Participant P2’s plan during mouse interaction. Statements such as “It does not have 2 and 3” and “I need to rotate 7 should go down” and “2, 7, and 8. What else is missing?” were examples of cognitions made during gaze and mouse interaction respectively. While “Now it is not so good” was an example of an evaluation by Participant P3 during mouse interaction.

Tile Slide Puzzle

There were no significant differences in the level of utterances for the TS puzzle. It seems that participants used similar problem solving strategies to complete the TS puzzle when using the mouse and gaze input. The greatest proportion of time for both gaze and mouse interaction was spent on concurrent move descriptions. While the time spent on intentions, cognitions and evaluations remained fairly low for both interaction sequences.

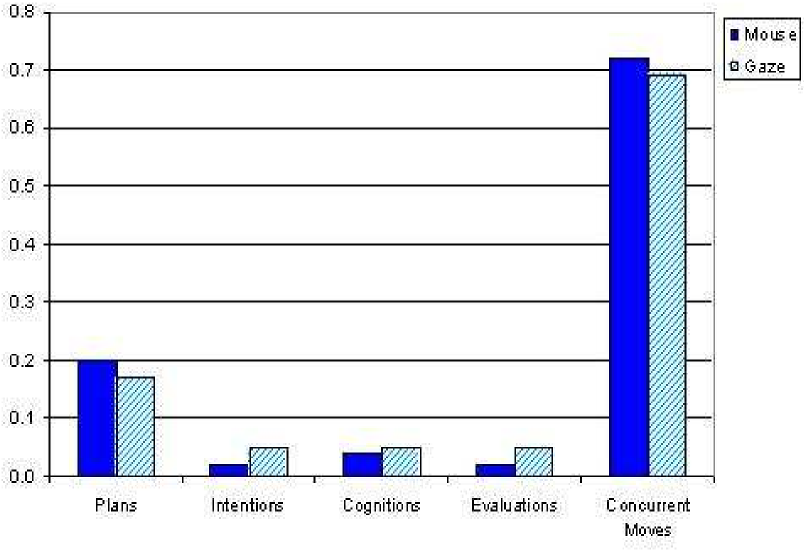


Figure 5.6: Tile Silde puzzle: proportion of think aloud data according to category and interaction sequence

The proportion of time spent planning during mouse was slightly higher than that of the gaze. During the interview, some participants had mentioned that using the mouse gave them more time to think. From Figure 5.6, one can see that the proportion of time spent on planning was fairly equal using gaze and mouse. However one would need a larger sample in order to confirm or reject this assumption.

"5, 6, 7 so I am going to have to move the 6 here" was an example of a plan, while "I want to move number 6" was an example of an intention. An example of an evaluation made by participant P3, during gaze-based interaction, when she realized that she had made a mistake was, "Ohh I made a mistake, here I should put a 7".

5.3.5 Think Aloud

The participants perceived the gaze input, while playing the puzzles, in different ways. Participant P2 thought the gaze selection was amusing, “this is a funny thing”, while another found it difficult to use because s/he felt like s/he had no control of the selection. Two of the participants found gaze interaction tiring, “now we have to rest”, “I wonder if my eyes are too tired”.

Participants were not sure when the gaze interaction would take place. One of the users had identified a grid button to select and started looking at it, however the gaze left the button due to jittery eye movements and the participant’s response was:“oh, it does not want to come up”. In a separate case, participant P1 exclaimed, “Hey, that was more than 1 second” when the button she was looking at failed to be activated. While another participant questioned the gaze duration. Participant P5 said, “I think if I concentrate too much then I squint my eyes” when s/he noticed that a tile s/he was trying to select in the TS puzzle would not move.

5.4 Discussions

Control and accuracy

Participants where generally able to control their gaze and look at a specific button on a puzzle, however the small jittery eye movements made by the eyes made it difficult to keep their eyes steady while fixating on a button.

During gaze interacton, two participants (P2 and P3) experienced a lot of Midas touch problems. The biggest problem that most participants had was the small jittery eye motions which made it difficult to select buttons during the Sudoku game.

Game selection durations

Compared to the Sudoku puzzle, the TS selection durations for the TS are considerably less than those of the Sudoku puzzle, for both the mouse and gaze. This is mainly because the selection in the TS is a one step process; the player clicks on the puzzle tile and then it moves. Whereas in the Sudoku puzzle a player has to first select a grid button to open the number dial and then s/he has to select a number from the dial, thus making it a two step process.

User interface

When dealing with gaze-based input, the gaze selection technique is not sufficient for efficient and effective interaction. Designers need to carefully consider the user interface and the task that needs to be performed, both of which support the gaze-based selection.

During this study I presented two puzzles with two different user interfaces. One interface was restrictive; participants were only allowed to select specific tiles (buttons). While the second interface gave the user the freedom to select which button they chose to select. Coincidentally, participants preferred the former user interface.

The restrictive nature of the TS puzzle allowed a player to think and plan while playing the game. Whereas the Sudoku puzzle allowed a player to select any 'selectable' button on the puzzle grid's 9x9 button surface and then one of the ten circular buttons on the number dial. For two of the participants this led to some Midas touch problems.

Participants also preferred the TS puzzle because the button or tiles were larger than those in the Sudoku puzzle. Additionally, the numbers painted on the centre of the tiles severed as anchor points for the gaze selection. This feature was missing in the Sudoku puzzle buttons, however participants still chose a point at the centre of the buttons to look at. Interestingly though, the same was not true for the circular conjoined number dial buttons. Although the dial buttons had numbers printed at the centre, participants' gaze fell mostly in the region where two buttons joined.

Interaction errors and distraction

There is a relationship between interaction errors and problem solving errors. During gaze interaction, when ever there is an interaction error there likely to be a problem solving error. It seems that interaction errors break a user's concentration as they steer them away from the task at hand. Therefore, interfaces that use of gaze input techniques should ensure that the interaction is as free of errors as possible.

Chapter 6

Conclusion

6.1 Conclusion

The aim of this thesis was to find out whether gaze-based input was suitable for problem solving games; where the player had to use their eyes not only to understand and visually perceive the puzzle but also to solve it.

Firstly I wanted to find out how users felt about gaze input. Participants had mixed feelings about the gaze; some of the participants found it interesting and fun, while others found if difficult to use and tiresome. The mouse was the preferred input method, this was mainly because participants were accustomed to using the mouse and they felt that the mouse gave them a greater control over the selection of objects.

Secondly, I wanted to find out whether it would be efficient to solve a task using gaze. Generally, participants performed better with the mouse than with the gaze. However, the performance varied according to game. In the Tile Slide puzzle, there was a slight difference between the completion times for the mouse and gaze for three of the participants. While in the Sudoku puzzle, the mouse out performed the gaze for four of the five participants.

Finally, I wanted to find out if the interaction method had any affect on the problem solving behavior of the users. I found that the interaction sequence (in conjunction with the user interface) influence the problem solving behavior of the users. There was no significant differences in the problem solving strategies of the Tile Slide puzzle. Whereas, there where great difference is the level of planning, cognitions and concurrent selection during the Sudoku puzzle. Additionally, participants would state their intentions and evaluate their moves during gaze interaction. Intentions and evaluations only occurred during gaze interaction, as a direct effect of the interaction.

In conclusion, there is a potential for using gaze-based interaction techniques in problem solving games, however in order for gaze-based interaction to replace the mouse (in problem solving games), a lot of research still needs to be conducted and gaze related problems such as accuracy and Midas touch have to be solved and more attention should be given to the layout of gaze-based user interfaces.

6.2 Future developments

A few future development goals would be to re-test the application with a larger number of participants so as to obtain more information about: The relationship between the interaction sequence and user experience in solving the games. To see if there are any significant changes in the problem solving strategies of users while solving the puzzles. Finally, to explore the effect of interaction errors on a user's problem solving strategy.

A change in both the interface and interaction techniques in the puzzle games may yield better results in the future. Off-screen gaze directional gestures can be used to move the tiles in the Tile Slide puzzle. While a traffic light type interaction system can be used in Sudoku puzzle. Once a player has looked at a button on the Sudoku board, the button will be highlighted red. The button's color will then change to amber and finally to green depending on the gaze duration. In this way the player is always aware of when a selection is going to take place.

Bibliography

[Acmsigchi, nd] Acmsigchi (n.d.). Acm sigchi curricula for Human-Computer Interaction. Retrieved on February 27, 2007. `http://acm.org/sigchi/cdg/cdg2.html`.

[Bolt, 1982] Bolt, R. A. (1982). Eyes at the interface. In *Proceedings of the 1982 conference on Human factors in computing systems*, pages 360–362, New York, NY, USA. ACM Press.

[Broeders, nd] Broeders, H. (n.d.). History of the 15 puzzle. Retrieved on December 20, 2006. `http://bd.thrijswijk.nl/15puzzle/15puzzen.htm`.

[Defthat, nd] Defthat (n.d.). Definethat: Avatar definition. Retrieved on December 12,2006. `http://www.definethat.com/define/368.htm`.

[Duchowski, 2003] Duchowski, A. T. (2003). *Eye Tracking Methodology: Theory and Practice*. Springer-Verlag New York, Inc., Secaucus, NJ, USA.

[Eyecarass, nd] Eyecarass (n.d.). Eyecare associates. How the eye works: Basic eye anatomy. Retrieved on December 12, 2006. `http://www.eyecaretyler.com/anatomy.htm`.

[Galanti, nd] Galanti, G. (n.d.). Concept is puzzles: History of Sudoku. Retrieved on February 23, 2007. `http://www.conceptispuzzles.com/articles/sudoku/`.

[Gips et al., 1996] Gips, J., DiMattia, P., Curran, F. X., and Olivieri, P. (1996). Using eagleeyesan electrodes based device for controlling the computer with your eyesto help people with special needs. In *ICCHP '96: Proceedings of the 5th International conference on Computers helping people with special needs. Part I*, pages 77–83, Munich, Germany, Germany. R. Oldenbourg Verlag GmbH.

[Glenstrup and Engell-Nielsen, 1995] Glenstrup, A. and Engell-Nielsen, T. (1995). Eye controlled media: Present and future state. Retrieved on November 11, 2006. `http://www.diku.dk/\~panic/eyegaze/article.html`.

[Hansen et al., 2003] Hansen, J. P., Johansen, A. S., and Hansen, D. W. (2003). Command without a click: Dwell time typing bu mouse and gaze selections. In *Human-Computer Interaction – INTERACT'03*, pages 121–128. IOS Press.

[Hayes, 2001] Hayes, R. (2001). The sam loyd 15-puzzle. Retrieved on March 2, 2007. `https://www.cs.tcd.ie/publications/tech-reports/reports.01/TCD-CS-2001-24.pdf`.

[Jacob, 1990] Jacob, R. J. K. (1990). What you look at is what you get: eye movement-based interaction techniques. In *CHI '90: Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 11–18, New York, NY, USA. ACM Press.

[Jacob, 1991] Jacob, R. J. K. (1991). The use of eye movements in human-computer interaction techniques: what you look at is what you get. *ACM Trans. Inf. Syst.*, 9(2):152–169.

[Jacob, 1993] Jacob, R. J. K. (1993). Eye-movement-based human-computer interaction techniques: Toward non-command interfaces. *Hartson, H. R., Hix, D.*

[Japp, nd] Japp (n.d.). Jaap's puzzle page: 14-15 puzzle / Boss puzzle. Retrieved on March 2, 2007. `http://www.geocities.com/jaapsch/puzzles/fifteen.htm`.

[Jonsson, 2005] Jonsson, E. (2005). If looks could kill - an evaluation of eye tracking in computer games. Master's thesis, Department of numerical analysis and computer science, Royal Institue of Technology: Stockholm.

[Juang et al., nd] Juang, K., Jasen, F., Katrekar, A., and Ahn, J. (n.d.). Use of eye movement gestures for web browsing. Retrieved on November 9, 2007. `http://andrewd.ces.clemson.edu/courses/cpsc412/fall05/teams/reports/group2.pdf`.

[Just and Carpenter, 1980] Just, M. A. and Carpenter, P. A. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review*, 87:329–354.

[Lewis and Rieman, 1993] Lewis, C. and Rieman, J. (1993). *Task-Centered User Interface Design: A Practical Introduction.*

[Majaranta and Raiha, 2002] Majaranta, P. and Raiha, K.-J. (2002). Twenty years of eye typing: systems and design issues. In *ETRA '02: Proceedings of the 2002 symposium on Eye tracking research & applications*, pages 15–22, New York, NY, USA. ACM Press.

[Miniotas, 2000] Miniotas, D. (2000). Application of fitts' law to eye gaze interaction. In *CHI '00: CHI '00 extended abstracts on Human factors in computing systems*, pages 339–340, New York, NY, USA. ACM Press.

[Miyoshi and Murata, 2001] Miyoshi, T. and Murata, A. (2001). Input device using eye tracker in human-computer interaction. In *0th IEEE International Workshop on Robot and Human Interactive Communication*, pages 580–585.

[Nielsen, 1993a] Nielsen, J. (1993a). Noncommand user interfaces. *Commun. ACM*, 36(4):83–99.

[Nielsen, 1993b] Nielsen, J. (1993b). *Usability Engineering*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.

[Nikoli, nd] Nikoli (n.d.). Nikoli: Sudoku. Retrieved on February 23, 2007. `http://www.nikoli.co.jp/en/puzzles/sudoku/index_text.htm`.

[O'Hara and S.J., 1998] O'Hara, K. and S.J., P. (1998). The effects of operator cost of planfulness of problem solving and learning. *Cognitive Psychology*, 35:34–70.

[Ohno et al., 2003] Ohno, T., Mukawa, N., and Kawato, S. (2003). Just blink your eyes: a head-free gaze tracking system. In *CHI '03: CHI '03 extended abstracts on Human factors in computing systems*, pages 950–957, New York, NY, USA. ACM Press.

[Onlearnhav, nd] Onlearnhav (n.d.). Online Learning Haven: Playing Sudoku. Retrieved on March 2, 2007. `http://www.learninghaven.com/articles/play-sudoku.html`.

[Sibert and Jacob, 2000] Sibert, L. E. and Jacob, R. J. K. (2000). Evaluation of eye gaze interaction. In *CHI '00: Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 281–288, New York, NY, USA. ACM Press.

[Smith and Graham, 2006] Smith, J. D. and Graham, T. C. N. (2006). Use of eye movements for video game control. In *ACE '06: Proceedings of the 2006 ACM SIGCHI international conference on Advances in computer entertainment technology*, page 20, New York, NY, USA. ACM Press.

[Spakov, 2005] Spakov, O. (2005). Eyechess: The tutoring game with visual attentive interface. In *G. Evreinov (ed.) Proceedings of "Alternative Access: Feelings*

Games 2005", number B-2005-2, pages 81–86. Department of Computer Sciences, University of Tampere.

[Starker and Bolt, 1990] Starker, I. and Bolt, R. A. (1990). A gaze-responsive self-disclosing display. In *CHI '90: Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 3–10, New York, NY, USA. ACM Press.

[Stlukeseye, nd] Stlukeseye (n.d.). St. Lukes Eye: Eye anatomy. Retrieved on December 19, 2006. `http://www.stlukeseye.com/anatomy/Fovea.asp`.

[Sudokugrok, nd] Sudokugrok (n.d.). Sudoku Grok. Retrieved on February 23, 2007. `http://www.sudoku-grok.com/help.jsp`.

[Teswp, nd] Teswp (n.d.). Testing Standards Working Party: Usability Guidelines. Retrieved on March 2, 2007. Website.

[Tobii, nd] Tobii (n.d.). Tobii technology. Retrieved on August 7, 2006. `www.tobii.com`.

[Transgaming, nd] Transgaming (n.d.). Transgaming Technologies: Game categories. Retrieved on February 23, 2007. `http://transgaming.org/gamesdb/categories/view.mhtml?gametype=`.

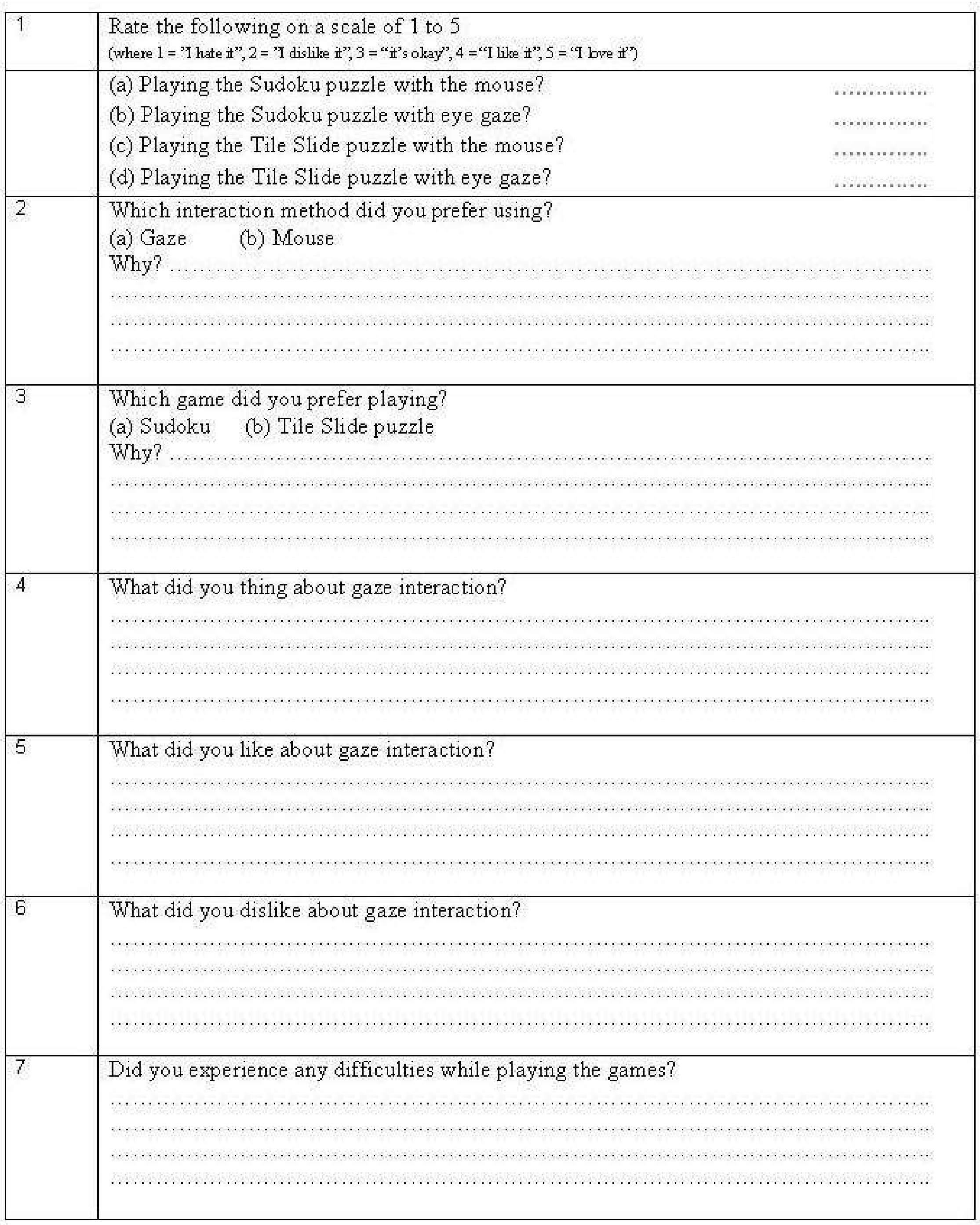
[Ware and Mikaelian, 1987] Ware, C. and Mikaelian, H. H. (1987). An evaluation of an eye tracker as a device for computer input2. In *CHI '87: Proceedings of the SIGCHI/GI conference on Human factors in computing systems and graphics interface*, pages 183–188, New York, NY, USA. ACM Press.

[Webvision, nd] Webvision (n.d.). Webvision: Gross anatomy of the eye. Retrieved on December 19, 2006. `http://webvision.med.utah.edu/anatomy.html`.

[Zhai et al., 1999] Zhai, S., Morimoto, C., and Ihde, S. (1999). Manual and gaze input cascaded (magic) pointing. In *CHI '99: Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 246–253, New York, NY, USA. ACM Press.

Appendix A

Post-test interview questionnaire



1	Rate the following on a scale of 1 to 5 (where 1 = ’I hate it”, 2 = ’I dislike it”, 3 = “it’s okay”, 4 =“I like it”, 5 = “I love it”)
	(a) Playing the Sudoku puzzle with the mouse? ………….. (b) Playing the Sudoku puzzle with eye gaze? ………….. (c) Playing the Tile Slide puzzle with the mouse? ………….. (d) Playing the Tile Slide puzzle with eye gaze? …………..
2	Which interaction method did you prefer using? (a) Gaze (b) Mouse Why? ……………………………………………………………………………… ………………………………………………………………………………….. ………………………………………………………………………………….. …………………………………………………………………………………..
3	Which game did you prefer playing? (a) Sudoku (b) Tile Slide puzzle Why? ……………………………………………………………………………… ………………………………………………………………………………….. ………………………………………………………………………………….. …………………………………………………………………………………..
4	What did you thing about gaze interaction? ………………………………………………………………………………….. ………………………………………………………………………………….. ………………………………………………………………………………….. …………………………………………………………………………………..
5	What did you like about gaze interaction? ………………………………………………………………………………….. ………………………………………………………………………………….. ………………………………………………………………………………….. …………………………………………………………………………………..
6	What did you dislike about gaze interaction? ………………………………………………………………………………….. ………………………………………………………………………………….. ………………………………………………………………………………….. …………………………………………………………………………………..
7	Did you experience any difficulties while playing the games? ………………………………………………………………………………….. ………………………………………………………………………………….. ………………………………………………………………………………….. …………………………………………………………………………………..

Appendix B

Test Data

B.1 Task Completion times

Sudoku puzzle Task Completion times:

	Mouse	Gaze
P1	50377	335086
P2	91261	601345
P3	342712	307132
P4	45778	420880
P5	35359	202487
Average	113097.4	373386

TS puzzle Task Completion times:

Participants	Mouse	MMoves	Gaze	Gmoves		MouseTime	GazeTime
P1	165624	11	223854	13		15056.7	17219.5
P2	21686	9	270904	15		2409.6	18060.3
P3	59705	11	38598	9		5427.7	4288.7
P4	11425	14	48413	26		816.1	1862.0
P5	30089	66	167393	16		455.9	10462.1
Average						4833.2	10378.5

B.2 Planning and problem solving

Sudoku Mouse:

Participants	Plans	Intentions	Cognitions	Evaluations	ConMoves	RowTotals
P1	3	0	4	0	3	10
P2	5	0	5	0	2	12
P3	7	0	5	0	2	14
P4	0	0	0	0	4	4
P5	3	0	4	0	3	10

Sudoku Gaze:

Participants	Plans	Intentions	Cognitions	Evaluations	ConMoves	RowTotals
P1	2	1	1	0	0	4
P2	5	1	2	3	0	11
P3	7	2	1	2	1	13
P4	6	0	1	1	1	9
P5	4	1	2	3	3	13

Sudoku Mouse Proportions:

Participants	Plans	Intentions	Cognitions	Evaluations	ConMoves
P1	0.30	0.00	0.40	0.00	0.30
P2	0.42	0.00	0.42	0.00	0.17
P3	0.50	0.00	0.36	0.00	0.14
P4	0.00	0.00	0.00	0.00	1.00
P5	0.30	0.00	0.40	0.00	0.30
Average	0.30	0.00	0.31	0.00	0.38

Sudoku Gaze Proportions:

Participants	Plans	Intentions	Cognitions	Evaluations	ConMoves
P1	0.50	0.25	0.25	0.00	0.00
P2	0.45	0.09	0.18	0.27	0.00
P3	0.54	0.15	0.08	0.15	0.08
P4	0.67	0.00	0.11	0.11	0.11
P5	0.31	0.08	0.15	0.23	0.23
Average	0.49	0.11	0.15	0.15	0.08

Total Soduko Proportions:

	Mouse	Gaze
Plans	0.3	0.5
Intentions	0.0	0.1
Cognitions	0.3	0.2
Evaluations	0.0	0.2
Concurrent Selections	0.4	0.1

Tile Slide puzzle Mouse:

Participants	Plans	Intentions	Cognitions	Evaluations	ConMoves	RowTotals
P1	3	1	2	1	15	22
P2	4	0	0	0	10	14
P3	1	1	0	1	11	14
P4	0	0	0	0	9	9
P5	5	0	1	0	4	10

Tile Slide puzzle Gaze:

Participants	Plans	Intentions	Cognitions	Evaluations	ConMoves	RowTotals
P1	2	1	0	0	7	10
P2	2	0	2	0	8	12
P3	4	1	1	1	6	13
P4	0	0	0	0	15	15
P5	3	1	0	3	12	19

Tile Slide puzzle Mouse proportion:

Participants	Plans	Intentions	Cognitions	Evaluations	ConMoves
P1	0.14	0.05	0.09	0.05	0.68
P2	0.29	0.00	0.00	0.00	0.71
P3	0.07	0.07	0.00	0.07	0.79
P4	0.00	0.00	0.00	0.00	1.00
P5	0.05	0.00	0.10	0.00	0.40
Average	0.11	0.02	0.04	0.02	0.72

Tile Slide puzzle Mouse proportion:

Participants	Plans	Intentions	Cognitions	Evaluations	ConMoves
P1	0.20	0.10	0.00	0.00	0.70
P2	0.17	0.00	0.17	0.00	0.67
P3	0.31	0.08	0.08	0.08	0.46
P4	0.00	0.00	0.00	0.00	1.00
P5	0.16	0.05	0.00	0.16	0.63
Average	0.17	0.05	0.05	0.05	0.69

Total TS puzzle propotions:

	Mouse	Gaze
Plans	0.2	0.2
Intentions	0.0	0.1
Cognitions	0.0	0.1
Evaluations	0.0	0.1
Concurrent Moves	0.7	0.7