ENCODING OF STREAMING PERIPHERAL INFORMATION IN VIDEO GAMES

by

KEVIN B. GRAD

A thesis submitted to the
School of Computing
in conformity with the requirements for
the degree of Master of Science

Queen’s University
Kingston, Ontario, Canada
January 2009

Copyright © Kevin B. Grad, 2009
Abstract

Traditional peripheral displays rely on drawing the user’s attention and gaze through alerts. These displays function best when the central task does not require the user’s constant attention. For tasks that require a user to always maintain focus, alert-based displays are not appropriate. We assert that conveying information to a user without drawing his gaze, allows the user to maintain constant focus on his primary task while still receiving additional information. In this thesis we use video games to examine streaming peripheral displays as a means of presenting information without drawing gaze.

The results of our experiments showed no significant difference between user performance using our display encoded for peripheral viewing versus an unencoded display. Additionally, we found that players were successfully able to perceive information shown on a streaming peripheral display, however, as game difficulty increased the effectiveness of the streaming peripheral display decreased. Finally, we show that as game level increases, users adopt risk-tolerant strategies. Drawing from these results, we have suggested some additional heuristics pertaining to streaming peripheral displays. Moreover, we have suggested further situations where streaming peripheral displays may be useful.
Acknowledgments

First and foremost, I would like to thank my supervisors Dr. T. C. Nicholas Graham and Dr. James Stewart for their direction and guidance throughout my research. Their feedback and suggestions during our weekly meetings were invaluable.

I would like to thank the members of the EQUIS lab for their help with testing my games and providing feedback. I would further like to thank all those who took the time to participate in my experiments.

Next, I would like to extend my gratitude to the Queen’s Biological Communication Centre for allowing me to use their lab and equipment to run my experiments. Specifically, I would like thank Davin Carlson for his help with the Tobii and Dr. Niko Troje for pointing me in the direction of Signal Detection Theory, which was the starting point for our City Flyer experiment.

Finally, I would like to thank my girlfriend Bailey Steinberg for her love and support through this long process. I would also like to thank my family for their endless support, guidance, and willingness to read over my many thesis drafts.
## Contents

Abstract i  
Acknowledgments ii  
Contents iii  
List of Tables v  
List of Figures vi  

### 1 Introduction
1.1 Examples of Peripheral Displays ................................. 2  
1.2 Motivation ....................................................... 6  
1.3 Contributions .................................................... 9  

### 2 Related Work
2.1 The Eye ............................................................ 12  
2.2 Theories of Attention ......................................... 16  
2.3 Visual Interfaces ............................................... 18  
2.3.1 Computer Games and Vision .............................. 19  
2.3.2 Ambient Displays ........................................... 19  
2.3.2.1 Evaluation Techniques for Ambient Displays ....... 20  
2.3.3 Peripheral Displays ......................................... 21  
2.3.3.1 Evaluation Techniques for Peripheral Displays ..... 22  
2.3.4 Attentive User Interfaces .................................. 24  
2.3.5 Gaze Contingent Displays .................................. 26  
2.4 Streaming Displays ............................................. 26  

### 3 CoOp tetris
3.1 Motivation ....................................................... 30  
3.2 Hypotheses ....................................................... 33
List of Tables

3.1 The T-Test results for the display comparison. . . . . . . . . . . . . . 47
4.1 The Pearson R values for peripheral efficiency per player. . . . . . . 71
4.2 The Pearson R values for strategy per player. . . . . . . . . . . . . . 74
4.3 The City Flyer survey results. . . . . . . . . . . . . . . . . . . . . . . 76
List of Figures

1.1 The bus mobile display is a streaming peripheral representation of the local bus schedule. Used with permission from Tara Mathews [16] . . . 3
1.2 The day light display is a streaming display that attempts to show the outside light conditions. Used with permission from Tara Mathews[16]. 4
1.3 A commercially available GPS light bar. The light bar is a streaming display which conveys steering correction data to the driver in his periphery. Used with permission from Danny Mann[17]. . . . . . . . 5
1.4 Mann’s streaming GPS based light bar mounted in a tractor. Used with permission from Danny Mann[17]. . . . . . . . . . . . . . . . . . 6
1.5 Altosaar’s AuraOrb device is an alert-based display that alerts users to incoming emails. Used with permission from Roel Vertegaal[2]. . . 7
1.6 A display from CCP’s Eve Online, the display contains both streaming and alert-based items [5]. The figure on the right shows a simulation of what the player sees when focusing on the center of the display. . 8

2.1 A cross section of the human eye. Used with permission from Rod Nave [27]. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 13
2.2 A diagram of the rod and cone distribution in the eye. Used with permission from Rod Nave [27]. . . . . . . . . . . . . . . . . . . . . . 14
2.3 The visible light colour spectrum. Used with permission from Rod Nave[27]. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 15

3.1 The single player version of Tetris. . . . . . . . . . . . . . . . . . . . 35
3.2 The CoOp Tetris game with the Unencoded display. . . . . . . . . . . . 36
3.3 The rules of CoOp Tetris. . . . . . . . . . . . . . . . . . . . . . . . . . 38
3.4 The CoOp Tetris game with the Encoded display. . . . . . . . . . . . 39
3.5 The Encoded display peripheral icons. . . . . . . . . . . . . . . . . . . . 40
3.6 The CoOp Tetris game set up. . . . . . . . . . . . . . . . . . . . . . . . . 42
3.7 The CoOp Tetris layout. . . . . . . . . . . . . . . . . . . . . . . . . . . 43
3.8 The training game. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 45
3.9 A graph of the distribution of survey responses. . . . . . . . . . . . . 50
4.1 The City Flyer Game. The main screen (left) shows the player’s ship in blue and bombs of different shapes in green. The peripheral screen (right) streams a sequence of geometric shapes.  

4.2 The SDT model. $D'$ is the distance from the signal distribution to the noise distribution. $C$ is the distance from the ideal observer to the subject’s internal threshold [1].  

4.3 Shown is the mean and confidence intervals of the difficulty of the peripheral task ($D'$) for 18 subjects over 7 levels. The line shown is the linear fit, with equation.  

4.4 The Pearson R values for peripheral $D'$ per player.  

4.5 Shown is the mean and confidence intervals of the peripheral efficiency for 18 subjects over 7 levels. The line shown is the linear fit, with equation.  

4.6 Shown is the mean and confidence intervals of the strategy, $C$, for 18 subjects over 7 levels. The line shown is the linear fit, with equation.
Chapter 1

Introduction

A peripheral display is a visual object that functions on the outskirts of a person’s attention. It can be a defined region within a computer screen, or a separate physical device, such as a screen or monitor. Some examples of real world peripheral displays include a fuel gauge in a car or a stock ticker on a computer monitor.

Peripheral displays can be categorized as being either streaming or alert-based. A streaming peripheral display provides a constant flow of information while continually updating its state. This occurs whether or not the display is being focused upon. An example of a streaming display is the odometer in a car. The odometer is situated in the driver’s peripheral vision as his focus is directed at the road. An alert-based peripheral display attempts to draw the user’s attention when there is new information. An example of an alert-based display is the oil change indicator in a car. The oil change indicator remains dark and unobtrusive until an oil change is required. When an oil change is necessary, the indicator both illuminates and emits a beeping sound to draw the driver’s attention.

We define the difficulty of a task in terms of the degree to which it requires a user’s
undivided attention. A **difficult** task requires most or all of the user’s attention; an **easy** task allows the user to concurrently perform other tasks. An **effective** display can be classified as one that a user can both perceive and understand.

We are interested in streaming displays where the user has a difficult central task with a constant stream of information being conveyed in the periphery. This is the type of environment that typically exists in common situations such as driving or playing video games. Many video games have a central task upon which the player must maintain focus while information is provided in the peripheral region. Similarly, a driver must remain focused on the road and immediately surrounding environment while considering peripheral streaming information, such as the odometer and the fuel gauge.

We hypothesize that streaming peripheral displays can be effective in multi-task environments that have a single central task and multiple secondary tasks. However, as the task becomes more difficult, we hypothesize that the peripheral display will become less effective.

### 1.1 Examples of Peripheral Displays

An example of a streaming peripheral display is Mathews’ bus mobile display [16]. This display is used to provide bus travelers with an awareness of when relevant buses are approaching the bus stop. The device is situated in the user’s home and has tags representing the desired buses attached to a tall fixture. As a bus nears its destination, the tag adjusts its height to represent how close the bus is to its stop. The person waiting for the bus does not need to focus on the display to perceive and understand the information provided. This display exists in the user’s periphery, and
CHAPTER 1. INTRODUCTION

Figure 1.1: The bus mobile display is a streaming peripheral representation of the local bus schedule. Used with permission from Tara Mathews [16].

is updated based on the bus schedule.

Another example of a streaming peripheral display is an interior light fixture that dims and brightens depending on the (unseen) light outside [16]. The light on the light fixture is bright when it is sunny outside, and dim if it is dark. A person with this light fixture in their living room can be doing something else, such as watching television, and maintain an awareness of the daylight conditions outside. The display sits in the user’s periphery, dynamically updating itself based on outside conditions without attempting to draw the user’s gaze.

A third example of a streaming peripheral display is the peripheral light bar [17]. The peripheral light bar is used to provide steering information on a tractor that is plowing a field. While driving a tractor, the light bar sits and functions in the driver’s periphery, attempting to assist in steering by use of light-emitting diodes (LEDs). The LEDs alert the tractor driver when he is off course and how to correct
CHAPTER 1. INTRODUCTION

Figure 1.2: The day light display is a streaming display that attempts to show the outside light conditions. Used with permission from Tara Mathews[16].

his steering.

An example of an alert-based display is the AuraOrb [2]. The AuraOrb sits in a user’s periphery doing nothing until the user receives an email, at which time the AuraOrb begins to glow, attempting to draw the user’s attention. When the user’s attention has been attained, as detected by the use of a camera and gaze detection algorithm, the orb displays the title of the email to the user. When the user wishes to read the email, he must touch the AuraOrb and the email will be displayed on the computer screen.

Peripheral display studies commonly consider the topic of gaze. There are many ways to determine when a person is looking at a display. One common technique, eye tracking, is the process of recording eye-movement and fixation patterns [18]. The most commonly used method of tracking eye movements is the “pupil-centre/corneal-reflection” method. This method consists of bouncing infrared light off the eye, so that a camera can detect the positional difference between the pupil reflection and certain known points on the device, to determine where a person is looking.
A commercially available GPS light bar. The light bar is a streaming display which conveys steering correction data to the driver in his periphery. Used with permission from Danny Mann[17].

An Attentive User Interface (AUI) is a combination of an eye tracker and a peripheral display [34]. AUI’s are displays that use embedded eye trackers to adapt to the user’s gaze. An example of such a display is a painting display that adjusts its lighting based on where people look the most [15]. These painting displays use data from many previous users to attempt to provide feedback to the current person standing in front of the painting.
1.2 Motivation

Peripheral displays are most effective when a central task is difficult, requiring most of the user's attention. An effective peripheral display can aid in tasks which require the full use of visual attention by permitting extra information to be perceived in the periphery. As well, a peripheral display can remove clutter from the foveal region in a task and can offload some information into the periphery. Many situations lend themselves to such displays including video games, driving, identification tasks, and
Peripheral display research is of interest to computer scientists in the areas of interface design, game design and human computer interaction. It is also of interest to psychologists in the areas of feature search theory and dual-task paradigms. Feature search theory deals with a person’s ability to differentiate between objects based on a descriptive feature such as colour or shape. Dual task paradigm research focuses on people attempting to concentrate on two discrete tasks at once.
Figure 1.6: A display from CCP’s *Eve Online*, the display contains both streaming and alert-based items [5]. The figure on the right shows a simulation of what the player sees when focusing on the center of the display.

While peripheral displays are commonplace in society, one popular pastime and new area of research lends itself strongly to the use of peripheral displays: video games. Many video games integrate some sort of peripheral information, whether it is a mini-map, information about a character’s health and life, or resource information. All of these items are placed in the peripheral regions of the screen and are assumed to be conveying perceptible information to the player. However, players often lose track of this information or pay little attention to it, especially as the pace and difficulty of the game increases.

A major flaw with the presentation of peripheral information in games, is that the information is commonly displayed in a manner that cannot be usefully perceived. This information can often be of vital importance to the game player. If game design integrated the concepts resulting from peripheral display research, it is possible that the peripheral displays within a game would present information effectively to players.

There is almost no existing research relating to the use of peripheral displays in
video games. What little research exists on video games deals with benefits from playing, such as peripheral vision enhancement, increased blink recovery and increased ability to process information over time [13]. Other benefits which have been investigated include computer aided exercise and motivation [36].

1.3 Contributions

In this thesis, we investigated the use of peripheral displays in a video game environment. An experiment was conducted to test whether a person playing an immersive video game can use a streaming peripheral display to improve performance. The effectiveness of a properly encoded display, aimed at the periphery, was tested against a display that was not designed for the periphery. A second experiment was conducted to test a user’s ability to use a streaming peripheral display. We investigated whether a user’s ability to use a peripheral display degrades as the game’s difficulty increases. Finally, insight into the feasibility of translating our data to real world games is offered.

We built two simple games. The first game tested the change in player performance with the addition of peripheral information. The second game tested both the frequency of use and the accuracy of perception of peripheral information as game difficulty increased.

We provide three significant contributions to streaming peripheral display research. Our first contribution is to show that designing a streaming peripheral display to be used in conjunction with a video game is a complex problem that currently has no easy solution. The currently available heuristics for peripheral display design are insufficient to ensure a properly encoded streaming peripheral display. This result is
demonstrated through our “CoOp Tetris” experiment. The CoOp Tetris display is an example of a streaming peripheral display, that was designed following currently available heuristics and guidelines, which was ultimately not effective. During testing our participants could not effectively use our peripheral display in conjunction with the video game provided.

Our second contribution is to suggest additional heuristics, specific to streaming displays, as possible extensions to the currently available heuristics for peripheral display design. Our CoOp Tetris display illustrated shortcomings of the currently available heuristics for peripheral display design. We were unable to use these heuristics to build a streaming peripheral display that added significant benefit to our video game. Through our analysis of the CoOp Tetris experiment we have identified some possible flaws with our design and have suggested some new heuristics that deal specifically with streaming displays.

Our final contribution is to show the effect of increasing task difficulty on the effectiveness of a streaming peripheral display. Our second experiment, “City Flyer,” shows that in at least one case, people can use a streaming peripheral display effectively while playing a video game. The City Flyer experiment also indicates that the effectiveness of our display decreases as the game difficulty increases. These results suggest that a streaming peripheral display might lend itself better to a game that is easy and does not require a user’s full attention.

The structure of this thesis is as follows: Chapter two details the background research relating to streaming peripheral displays upon which we based our research. Chapter three outlines our first experiment “CoOp Tetris.” Chapter four outlines our “City Flyer” experiment. Finally, Chapter five concludes this thesis and offers some
areas that would benefit from further research.
Chapter 2

Related Work

In this chapter, we discuss the basic anatomy of the eye, vision and visual perception. We also discuss research pertaining to visual attention, alert based displays, evaluation techniques and streaming displays.

2.1 The Eye

The retina is a light-sensitive layer of photoreceptors located at the back of the eye. On the retina there is a small indentation which lies directly on the path of light through the eye; this area is known as the fovea. The fovea contains primarily a single type of photoreceptor, known as a cone, and provides a highly detailed image of the world within about two degrees of the line of sight. The fovea is responsible for the clearest area of human vision and is most sensitive when there is ample illumination. Foveal vision takes up approximately four degrees of total vision; the rest of vision is perceived via the peripheral retina [12].

Light enters the eye through the cornea and into a hole called the pupil. Behind
the pupil is the lens, which focuses the light onto a thin network of neurons known as the retina. The retina contains photoreceptor neurons known as rods and cones [12].

Rods and cones differ in shape, function, and placement within the retina. Cones are responsible for high resolution colour vision and are distributed in and around the fovea. Foveal vision is the highest-resolution vision in humans. The fovea is made up primarily of cone photoreceptors.

Rods are more sensitive to low levels of illumination while cones are more sensitive in high levels of illumination. As well, rods are more sensitive to short wavelength light nearer to the blue end of the spectrum while cones are more sensitive to the longer
wavelength light nearer to the red end of the spectrum. The density of cones in the eye decreases substantially with distance from the fovea. The peripheral retina is made up mostly of rod photoreceptors. When the received illumination diminishes, a shift occurs from cone based vision to rod based vision. In areas with ample illumination, vision is the work of mainly the cone receptors. But in low levels of illumination, the cone receptors relax and the rod receptors begin to take over; this is known as the Purkinje shift [12].

Due to the large frequency of cones, foveal vision is most receptive to high frequency wavelengths, such as yellow. Peripheral vision is most sensitive to low wavelengths, such as green or blue, and is sensitive to motion and changing size. Rods are extremely sensitive (more so than cones), but they are not sensitive to colour. Rods
detect motion better than cones and function well at low levels of illumination.

Even though the density of cones outside of the fovea is low, there are still cone receptors present. This is why humans can still detect colour far out into the peripheral region of vision. Since rods are more sensitive to light than cones, dim objects may be invisible to cone-based vision, but visible to rod-based vision.

The electrical signals generated by the rods and cones are transmitted via four other types of neurons and converge in the ganglion cells. From the ganglion cells the impulses then travel through the optic nerve out the back of the eye. Each ganglion cell receives signals from an average of 120 rods but only from six cones, which explains why rod vision is more sensitive and generates a response from less light than cone vision. A majority of the impulses that travel via the optic nerve arrive in the thalamus at the lateral geniculate nucleus. From there, they travel to
the occipital lobe or visual cortex of the brain. Finally the signals travel either via the ventral pathway to the temporal lobe or the dorsal pathway to the parietal lobe of the brain where the brain translates the impulses into vision. A significant portion of the cerebral cortex in the brain is devoted specifically to vision [12].

2.2 Theories of Attention

Throughout psychological history, “attention” has had many definitions. For the purposes of this thesis, we define attention as a neural system used to select visual information to perceive, focus on and perform specific computations and operations [28]. Attention is a conscious effort: a person can exert different levels of attention. People are able to pick and choose what stimuli to focus on and attempt to block any other stimuli [28].

Much of the research in attention has pertained to two opposing theories regarding detection and perception of irrelevant distractors. The problem is: when a person is focusing on a task and some irrelevant information appears, can the person ignore the irrelevant information or is the processing of the new information automatic? The two opposing theories deal with how these irrelevant pieces of information are perceived. The first theory [21] is that focused attention can prevent early perception and processing of irrelevant distractors, thus allowing a person to consciously ignore any irrelevant information. The second theory [21] is that attention only affects the “later” processes (such as memory of the perceived distractor) and that detection of the distractor is automatic. Lavie et al. propose a hybrid model [21] in which distractors can be excluded from perception when the level of perceptual load is sufficiently high to exhaust perceptual capacity. This leaves no perceptual room for
the distractors. However, when there is a low perceptual load, any leftover processing capability will pick up the irrelevant distractors automatically.

Lavie et al. have further proposed a theory of selective attention and cognitive control based on cognitive load. The researchers theorize that there are two mechanisms of selective attention. The first is a passive mechanism which allows a person to ignore irrelevant distractor stimuli in situations when there is a high perceptual load. The second mechanism is an active mechanism which allows a person to reject irrelevant distractors even when they are perceived. The second mechanism is only viable when there is low perceptual load. Lavie et al. showed that having a high perceptual load during the processing of task-relevant stimuli reduces distractor interference. However, a high load during processes of cognitive control such as working memory and task coordination leads to increased distractor interference [21].

Treisman and Gelade have proposed a theory of attention based on feature integration [33]. They claim that features are perceived first when looking at a visual scene. The features of the scene are perceived automatically, and in parallel across the visual field. However, Treisman and Gelade maintain that without focused attention, multiple features cannot be related to one another. The authors define a dimension as a complete range of variations which are separately analyzed by some independent perceptual subsystem. An example of a dimension would be colour, or shape. A feature is defined as a particular value of a dimension such as red or square. Treisman and Gelade have found that single feature identification during a visual search (such as locating the red object or finding the square) is remarkably simple and does not require much attention due to the automatic, parallel nature of perceiving features. However, in order to distinguish objects with two features such as a red
square, focused attention is required.

Karatekin et al. describe a dual task paradigm [20] as performing two tasks simultaneously, resulting in worsened performance on one or both tasks. There are two widely adopted notions as to why performance degrades during a dual task paradigm. The first suggests that there are structural and processing bottlenecks that prevent the distribution of the required amount of resources necessary to carry out two tasks at the same time. The second theory suggests that humans have functional limitations (that is, a finite limit to how many cognitive “resources” a person has). Within the resources approach to functional limitations there are currently two separate ongoing research areas. The first attempts to quantify how many resources a person has, while the second attempts to discover how a person allocates his resources during a given task.

2.3 Visual Interfaces

There are many different types of visual interfaces available that provide information to a user. In this section we examine several different types of computer displays currently being researched. Additionally, we explore some evaluation techniques that exist for determining what makes each separate display effective. Each different interface mentioned provides a unique method of interaction between system and user. The displays discussed within this section are: ambient, peripheral, attentive and gaze contingent.
2.3.1 Computer Games and Vision

Computer games are played by millions of people worldwide and provide an immersive entertainment environment. Video games are an excellent example of an application that uses a visual display. As such, video games provide a natural environment for working with peripheral and non-peripheral displays. Green and Bevelier [13] were able to show that, though video games may seem mindless, they are actually capable of improving a variety of visual skills such as blink recovery and peripheral vision. Specifically, they found that video game players who commonly played in fast-paced environments had an increased ability to process information that is correlated with the number of games that they played. As well, video game players had an enhanced capacity for visual attention both in the trained video games and in other video games in which they had not trained. These results are very encouraging and show that video games are a rich and largely untapped educational environment. In creating peripheral displays for these video games, we may be able to enhance a user’s vision by improving his peripheral vision processing capabilities.

2.3.2 Ambient Displays

An ambient display is an object, device or set of devices that operates around a person and uses any of that person’s senses. According to Wisnesky et al. [35] there are ambient displays around us at all times such as the rain, the wind or a clock ticking in the background. The problem, according to Wisnesky et al., is that computer systems fail to exploit ambient modes of display. Ambient displays try to make use of the background to convey information while the person is engaged in a primary task, usually by drawing that person’s attention when necessary [35].
2.3.2.1 Evaluation Techniques for Ambient Displays

Ishii et al. state that, when designing an interface, the issues of attention, perception, and mental representation all come into play. The Ambient Room [19] attempted to convey a multitude of different things at the same time. Through the placement of clocks, sounds, pinwheels and a variety of other displays, Ishii et al. hoped the person in the room would have an awareness of all of these things. One of the things that Ishii et al. noticed was that all of the objects in the room remained mostly unnoticed until something occurred to make the person notice them. When the person took notice of an object there was a “mental switch” of that object from background perception to foreground perception. Ishii et al. found that there was a threshold at which this switch occurred. As well, there was a threshold for the number of displays that could be running simultaneously before the room became too confusing. When all the contraptions were running at once, people had difficulty focusing on even a single foreground task. The authors postulated that the multitude of devices caused an “information overload” [19].

Ames and Dey proposed a system [3] of classifying ambient displays. According to Ames and Dey, the goal of an ambient display is to reduce the user’s cognitive load by externalizing memory. The authors maintain that the goal of the display is not to answer questions immediately but, rather, to draw the user’s attention when there is an answer present. Ames and Dey assert that there are eleven important dimensions of design when making an ambient display. The dimensions are intrusiveness, notification, persistence, temporal context, overview to detail, modality, level of abstraction, interactivity, location, content, and aesthetics. Using these dimensions, Ames and Dey have classified [3] many of the available ambient displays, including Ishii
et al.’s ambient room. After classifying the displays in terms of design dimensions, a separate evaluation system must be used to evaluate the design. Ames and Dey suggest many different evaluation techniques such as a heuristic evaluation, design inquiry and user studies. Design inquiries can be interviews and surveys, contextual inquiries or ethnography. Heuristic evaluation is an evaluation performed by a person or team based on a set of rules or principles. Some examples of heuristic evaluations are Mankoff et al.’s adaptation of Nielson’s heuristics, cognitive walkthroughs and GOMS [3].

2.3.3 Peripheral Displays

A peripheral display is a device that functions on the outskirts of a user’s attention. A peripheral display is usually situated at the edge of a user’s range of vision and may attempt to draw attention to itself when something important occurs. A peripheral display is designed to be used as a secondary source of information while the user interacts with a primary display.

Many applications have been developed that attempt to use the periphery to aid in an everyday task. Ebrahimi et al. developed a peripheral vision aid [8] to assist with lip reading. The device was a pair of eyeglasses fitted with two LED’s and improved the accuracy of lip reading dramatically [8]. As well, Mathews et al. explored [25] ways of visualizing non-speech sounds for deaf people using a variety of peripheral devices. The goal was to alert people who are deaf of important occurrences such as a doorbell, fire alarm or ringing telephone [25].
2.3.3.1 Evaluation Techniques for Peripheral Displays

Mankoff et al.’s guidelines [24] state that displays should maintain:

- useful and relevant information;
- “peripherality” of display;
- match between design of ambient display and environments;
- sufficient information design;
- consistent and intuitive mapping;
- easy transition to more in-depth information;
- visibility of state; and
- aesthetic and pleasing design.

According to Mankoff et al. the display should be designed to convey “just enough” information, should add minimal cognitive load, should use real world language and concepts, and should always keep users informed about what is occurring. The display should also be easy for users to navigate and find information, should be unobtrusive until the user needs to see it, should prevent errors, and should cater to both novice and expert users [24].

Mathews et al. [26] identified three design dimensions for peripheral displays: scope, supported activities, and criticality. “Scope” refers to whether the display supports one or many of the user’s activities. “Supported activities” refers to whether the activities are primary, secondary or tertiary for the target user. “Criticality” refers to how important it is that the user is aware of the information in the display. As well,
a set of evaluation metrics were defined for peripheral displays: appeal, learnability, awareness, effects of breakdowns, and distraction.

In a separate article, Hsieh et al. mention the importance of maintaining a good level of distraction [16]. Too much distraction will be irritating or draw attention; too little distraction runs the risk of people forgetting about the display. Finally, Lavie et al. [21] mention that cognitive load must be taken into account in peripheral displays.

Shen et al. [29] have also provided some guidelines for displays:

- Important information in the peripheral display must be in close proximity to the primary screen;
- slow or smooth animation should be used in peripheral displays and
- known visual language and images should be used.

Shen et al. performed an intrusive evaluation [29] of three separate peripheral displays based on distraction, comprehension and efficiency between small and large displays. An intrusive evaluation is one in which the participant is aware of exactly what is being evaluated. Shen et al. examined a primary display and peripheral display in two large screens and two small screens. They used a primary task of typing words from the play Hamlet, with a peripheral task of occasionally shifting focus to a separate display to gain information about three stock quotes. They tested whether a large display performs better than a small display for comprehension of stock quotes and efficiency of data retrieval. They also tested whether more information was retained the more a participant shifted his focus. They found that, surprisingly, larger displays were more distracting and therefore less efficient than small displays, although the results were not statistically significant. Shen et al. concluded that, for
good comprehension, the most important information in the peripheral display must be in close proximity to the primary screen. For minimal distraction from the primary task, slow or smooth animation of moving items should be used on the peripheral display. And for higher efficiency, known visual language and images should be used (such as icons that are commonly used in computing environments).

Finally, Ima and Mann [17] have provided some insight into peripheral displays resulting from their experimentation with GPS-based light bars:

- Low wave length colours such as blue are easier to detect in the periphery; and
- Larger size is easier to detect in the periphery.

### 2.3.4 Attentive User Interfaces

Attentive user interfaces change their behavior depending upon whether or not they have the user’s attention. Using gaze tracking to determine the user’s focus, these interfaces can dynamically change their behavior based on where a user is paying attention. Holman et al. created an attentive art display [15] which had dynamic lighting based on where users looked. The lighting in the portrait changed to reflect the regions that people focused on the most. Regions which were highly focused upon were the brightest and the areas which were focused on the least were the dimmest. Holman et al. argue that the ability to track user’s interest allows easier management of cognitive load [15].

Skaburskis et al. developed an “Auramirror” [30] to track a user’s attention to another human being. The device detected when two people had each other’s attention and displayed this mutual attention on the screen in a graphical way [30].
Altosaar et al. developed an AuraOrb [2], based on attentive principles, for email notification. The globe sits in the user’s periphery and begins to glow when an email arrives. When the user looks directly at the globe, the glow on the device changes into text containing the new email’s title. If the user wishes to actually read the email, he simply touches the globe and the email will show up on the computer. This is an example of a device which sits in the background until it detects the user’s attention via eye contact. It also illustrates that such devices require active feedback from the user, such as a touch, in order to convey their information [2]

Ashdown and Sato explored the use of attentive interfaces across multiple monitors [4]. The researchers’ system allowed a user to control mouse movements with their eyes across multiple monitors. The user could switch the monitor of focus by simply looking at a different monitor and the mouse would move with his gaze. Involuntary eye movements and saccades are a problem when using the eyes to move the mouse. As well, a major problem with eye movement control is the “Midas Touch” problem. The “Midas Touch” problem occurs when a user cannot look casually at anything for fear of inadvertent selection.

Similarly, Fono et al. created an attentive environment which used eye tracking as a means of window selection in a windowed environment [11]. In Fono et al.’s system the window (of multiple open windows) that the user was focused on was the largest and in the center of the display. The window could be swapped at any time for another window by simply looking at that other window. The new window would then “zoom” into the foreground and the old window would minimize. This window switching method showed a significant increase in speed over the use of a mouse.
2.3.5 Gaze Contingent Displays

A Gaze Contingent display (GCD) is an attentive display which modifies itself based on the user’s gaze. Gaze Contingent displays degrade the resolution of peripheral image regions of the display in order to increase the rendering speed. The region near the user’s line of sight is rendered in high detail, while the peripheral regions are coarsely rendered. The high resolution region moves with the user’s line of sight, which is determined with an eye tracker. The difference between Gaze Contingent and Attentive displays is that attentive displays use gaze as a means of interaction between user and display, while gaze contingent displays use gaze as a way of improving a display’s rendering speed [7].

Loschy et al. have summarized six separate studies of Gaze Contingent displays [22]. The studies investigated spatial, resolutional and temporal parameters affecting perception and performance in “eye contingent multi resolutional displays.” This paper gives parameters for judging GCD’s and gives insight into building an effective GCD. Loschy et al. conclude that a delay of as much as 45 ms when updating a display may not actually affect gross measures of performance on visual tasks, but does affect visual processing. [22]

2.4 Streaming Displays

A streaming peripheral display is a display that provides a constant flow of information to a user in his peripheral vision. Streaming peripheral displays do not draw the user’s gaze with alerts; rather, a constant flow of information is “streamed” onto the display. Streaming peripheral displays allow users to focus on a central task while
maintaining a constant awareness of the flow of data on the display.

Hsieh et al. designed two peripheral displays to allow people to monitor incoming emails without having to stop performing their current task [16]. The researchers’ goals were to allow people to be alerted to new email and to monitor the importance of the email in the periphery. It was found that, while neither display was distracting, neither display was successful at supporting awareness; the experiment had ambiguous results. The study showed that there is a fine line between awareness and distraction. The authors found that, surprisingly, their displays were not distracting enough for at least one participant. The participant found that without the distraction element, she often lost track of the display completely. However, with too much distraction, people would be annoyed, or distracted from their primary task. This shows that a proper distraction level in a peripheral display is of vital importance.

Ima and Mann explored the use of a peripheral LED based GPS light bar as a means of improving crop harvesting [17]. The goal of their project was to improve harvesting performance by reducing steering error. Large harvesters are difficult to drive and mis–steering can result in missed crops or twice–harvested strips. A light bar was used to convey whether the driver was steering correctly. The light bar was placed in the driver’s periphery and provided information which could be monitored while focusing attention on the task of driving. Ima and Mann found that there was a significant reduction in steering error while driving with the light bar attached to the tractor. As well, Ima and Mann tested three different sized light bars and found that the largest light bar was the most effective. This is consistent with what we know about peripheral vision and size. Finally, Ima noticed that the colour of the LEDs in the light bar also had an effect on its usefulness. Specifically, the light bar was easier
to perceive with blue LED’s than it was with red ones. This is also consistent with what we know about colour detection in the periphery [17].
Chapter 3

CoOp tetris

Streaming peripheral displays are commonly used in video games. For example, many games include a mini-map, (a small map with the location of relevant people or objects), or a position indicator as part of their head-up display. Games such as Blizzard Entertainment’s Starcraft [9], Ensemble Studios’ Age of Empires [32], and many other strategy games include mini-maps. Most first-person shooter games such as Valve’s Half-Life [6] and Id Software’s Doom [31] include head-up displays. It is a difficult task to design and create effective displays for such games. The study of streaming peripheral displays has many implications toward game design, such as how to design an effective display, and where to locate the display on the game screen. Some key research questions we explore in our research include:

- How effectively can video game players obtain information from streaming displays presented in the periphery?

- At what point do players suffer from cognitive overload when trying to process information presented in both primary and peripheral displays?
• What guidelines might aid the design of effective streaming peripheral displays?

We explore these questions through two experiments. The first, described in this chapter, explores how people utilize streaming peripheral displays in a multiplayer cooperative environment. The experiment compares two peripheral displays: an encoded and an unencoded display. The encoded display is designed using heuristics and guidelines from the literature, and conveys information in the periphery. The unencoded display shows the same screen that the partner player sees with no special visual coding to aid with peripheral viewing.

The second experiment, described in chapter four, tests the hypothesis that a player’s ability to act on information presented in a peripheral display degrades as the player’s primary task increases in difficulty.

Together, these results show that designing peripheral displays is challenging. Poorly designed peripheral displays have little or no benefit over unencoded displays. Furthermore, as the game intensity increases, the player’s ability to process information from the periphery degrades.

We begin this chapter with an overview of the motivation for our first experiment, and then describe our method. We conclude with an analysis of our results.

3.1 Motivation

An effective peripheral display must convey information to its user without requiring that person’s visual focus. The display should enable users to acquire important information while their visual focus is on a separate task. Our interest lies in designing effective streaming peripheral displays for use during video game play. There has been
to date little research on this topic.

Video games often require players to perceive, process, and act on extensive time-sensitive information. For example, in a real-time strategy game, players must simultaneously monitor the state of different locations on a large map, while managing combat, resource gathering, and production. In a multiplayer first-person shooter game, players must monitor the locations and activities of their teammates and opponents while rapidly moving, aiming and firing. Often, what distinguishes a poor game player from a proficient one is the ability to deal with such a profusion of time-sensitive data. This is easily seen in a massively multiplayer game such as Blizzard Entertainment’s World of Warcraft [10]. In a player versus player battle ground, or while running a cooperative dungeon, players must be aware of their own health, positioning and targeting as well as the status of their allies.

Multiplayer environments provide ideal conditions for the added utility of a peripheral display. However, an improperly designed display could detract from game play by introducing a high cognitive cost of use. The cost of using a poorly designed display is a loss of game immersion or distraction from the goal of the game. These costs are especially severe in games with time sensitive content, where a distraction from the game could translate to a death in the game. The design of informational displays is therefore an important part of creating a challenging and entertaining experience for players. A properly encoded display should allow the user to perceive all the intended information at a minimal cognitive cost. The display should not require the player’s full attention; all information should be provided completely in the periphery.
Our first experiment explores whether a peripheral display can be used to effectively convey state awareness in a video game. Providing awareness of other players’ activities is an ideal application of peripheral displays; the player’s foveal view can be reserved for his central game task, while the periphery can be used to represent the state of his teammates. To address this problem, in our first experiment we chose to design a display to be used with an adaptation of the Tetris game.

We modified Tetris, a well known video game, to be a multi-player cooperative game. In our new CoOp Tetris, a streaming peripheral display provides information about the player’s partner. The peripheral display provides constant awareness of the status of the partner’s game well. We used this display to test whether players could improve their game performance by having a constant awareness of their partner’s game state.

When designing our display for this experiment, we used a number of guidelines and heuristics found in the literature, most notably the heuristics provided by Mankoff et al. [24]. These guidelines have been applied to evaluate Altosaar’s AuraORB [2] (as discussed in section 2.3.3.1). The research of Ima and Mann [17], and Shen et al. [29] along with the Mankoff group’s heuristics served as a foundation for our own display design.

The results of the CoOp Tetris experiment show that contrary to our hypotheses, performance did not improve when the peripheral display was available. In some cases, player performance actually degraded. Furthermore, with our display, players did not maintain a constant awareness of their partner’s game state as we had hoped they would. This experiment illustrates that adhering to the heuristics and guidelines discussed in chapter two is not sufficient to guarantee a display that improves
performance. These results show that further guidelines and heuristics are necessary for streaming displays. Our experiment provides feedback on the effectiveness of currently available guidelines. Additionally, we outline some of the available heuristics which do not apply to the area of streaming peripheral displays. Finally, we suggest some possible new guidelines that are catered to the unique challenges that are presented by streaming peripheral displays.

3.2 Hypotheses

When designing the display for our initial experiment, our ultimate goal was to explore how effectively players obtain information from streaming peripheral displays. In order to design our display, we first devised a number of hypotheses about how a properly designed peripheral display would be used in game play:

- We hypothesize that using the guidelines and heuristics described by Mankoff et al. [24], Ima and Mann [17], Shen et al. [29] and knowledge of the eye will lead to a peripheral display from which users can successfully extract information while attending to other tasks.

- We hypothesize that adding an encoded streaming peripheral display will result in higher scores and a better awareness of the partner player’s game state.

3.3 Experiment

In order to test these hypotheses, we extended the game Tetris for use with a peripheral display that we created. The game is both multiplayer and cooperative. The
peripheral display we created attempts to provide constant awareness of the partner player’s game state by encoding his game screen. We compared the encoded display to one which simply shows the partner’s game screen. Section 3.3.1 discusses traditional Tetris game play. Section 3.3.2 describes CoOp Tetris. Section 3.3.3 outlines the unencoded display we created for use with the game. Section 3.3.4 outlines the encoded display we created for use with the game.

3.3.1 Tetris

The popular game Tetris, created by Alexey Pajitnov, is a game of making lines. Tetris consists of a game well and a single falling piece. The object of the game is to manipulate the falling piece and place it at the bottom of the game well so that in combination with other pieces it makes a horizontal, space-free line of blocks. Once a piece has been placed, a new piece begins to fall. Players’ performance in Tetris is measured by score. When a horizontal line has been completed with no spaces, that line is then removed from the well and points are added to the score. A greater number of points are awarded for multiple lines created simultaneously. A “Tetris” occurs when four lines are created at once. There are seven separate game pieces to manipulate, each with a different shape. The game’s difficulty is increased by the rate at which the pieces fall. Tetris was released in 1984 and has been a commercial success with multiple releases since its initial release. Figure 3.1 shows a version of the classic Tetris game.
3.3.2 CoOp Tetris

CoOp Tetris is a game we created that adapts the original game of Tetris. CoOp Tetris is a two-player version of Tetris in which both players collaborate to maximize their scores. While there are numerous Multiplayer Tetris games, in CoOp Tetris the players cooperate rather than compete. The core rules of multiplayer Tetris are similar to those of single player Tetris: each player attempts to make lines with falling pieces and to achieve the highest possible score. The cooperative version of the game differs from traditional Tetris by allowing two players to play simultaneously. The game score is the sum of both players’ scores. Each player has his own game well in which he plays the game. As well, players can swap pieces with one another. Play terminates when one player has lost, so it is in each player’s interest for the other player to play successfully.
Figure 3.2 shows CoOp Tetris. Both players’ game wells are shown side-by-side on the same screen. The player controls the left game well, and the right game well is controlled by the player’s partner. The right game well is an awareness display, allowing the player to see the state of his partner’s game. If the player focuses on his own game well, the awareness display will be seen in his periphery. The display in Figure 3.2 is the same as the partner’s primary display, and is therefore not specially encoded for peripheral viewing. During experimentation, players played the game shown above with an unencoded display as well as a game with a display specifically encoded for peripheral vision.

The game as described thus far allows two people to play together, but does not allow them to cooperate. We further extend the game to allow players to swap pieces as they are falling. Either player can invoke a swap by pressing the space bar. The
other player is not given any choice as to whether the swap takes place, but can of course use his own swap key to change the pieces back. Invoking a swap causes the two players’ falling pieces to be exchanged. The swapped piece is positioned at the same position as the piece that it replaces. The only communication between the two game wells is through swapping. The rules of CoOp Tetris can be found in Figure 3.3.

Swapping introduces interesting dynamics to the game. In Tetris, players frequently wait for a particular piece in order to complete a row or set of rows. If the player’s partner receives that piece, swapping can allow the player to make the desired move, increasing his score. To take advantage of this potential for swapping, players must be aware of the other player’s current piece. Since the game is cooperative, it is not sufficient just to know what the other player’s piece is. Sometimes, initiating a swap can harm the partner more than it helps the player. Perhaps the partner was waiting for the same piece, or perhaps the swap will confuse the partner, leading him to make a poor move. It is particularly bad to swap when the partner’s piece is nearing its destination or when the partner’s pile of dropped pieces is high, limiting his reaction time to realign the new piece. Therefore, players require more detailed knowledge of the partner’s game state, indicating how much a swap will inconvenience the partner, allowing the player to balance the benefit to him against the harm to his partner.

3.3.3 The Unencoded Display

The unencoded game display shown in Figure 3.2 provides sufficient information for a player to decide whether it is helpful to swap pieces with his partner. The unencoded
A player gains points by placing pieces into his game well and making horizontal lines.

- Lines increase in points depending on the number of lines consumed at a time. The maximum possible number of lines consumed at one time is four.
- If either the player or his partner’s game well fills up, the game ends for both players.
- A swap can be initiated to trade the player’s piece for his partner’s piece.

Figure 3.3: The rules of CoOp Tetris.

display shows the entire state of the partner’s game well. All the necessary information to judge the impact of a piece swap is present. The player can see whether his current piece is of particular use to the partner. He can also determine how close the piece is to the bottom of the game well, and how much space the partner has left in his well. Although all the necessary information is present, it is challenging for the player to use this information to his advantage. The partner’s well sits in the player’s peripheral vision. The player must move his attention from his own well to the partner’s well to decide whether to swap. His lack of attention to his own well in the meantime may negatively impact his performance. The unencoded version of the game simply shows, in full detail, the partner’s game well. The pieces are small, and hard to perceive in the periphery. As well, there are many less important pieces of information being displayed, such as the rotation of the game piece, the column the piece is currently in and the arrangement of the pieces in the game well. None of this information is relevant to deciding whether or not to swap.

3.3.4 The Encoded Display

We created a new version of the partner’s well intended for view in the periphery. It is intended that with this addition, players should be able to fixate on their own
well at all times, while gaining information through their peripheral vision. The peripheral encoding is a simplified presentation of the normal game well, as seen in Figure 3.4. The encoding does not add any new information to the game; it simply redispays already existing information. It also does not combine information from multiple different sources; it highlights only existing information. We encode three concepts that are critical to deciding when to swap pieces: the shape of the partner’s falling piece, the height of the partner’s pile of dropped pieces, and the distance of the partner’s falling piece to its destination directly below. We identified the three required pieces of information in order to make a swap and hid the rest. We hypothesized that including only the three pieces of information would make the display easier to understand than showing the entire game state. As well, we hypothesized that using fewer pieces of information would make the display easier to
perceive in the periphery.

Three “peripheral icons” are used, following the guidelines listed in section 2.3 as well as our knowledge of the physiology of the eye. Figure 3.5 shows a close up version of the display with the icons. The partner’s falling piece is enlarged due to larger items being easier to detect in the periphery. A spinning rod is used to show the distance of the partner’s piece to its destination below; as the distance decreases, the rod spins faster. This takes advantage of the fact that motion is easily detected in the periphery. Finally, a vertical thermometer-like gauge is used to show the height of the partner’s pile of dropped pieces. The height of the bar is equal to the highest point of the highest piece in the pile of placed pieces.
3.4 Experimental Setup

The CoOp Tetris experiment tested 18 participants drawn from the university community. The single requirement for participation was rudimentary knowledge of how to use a computer. We did not require any previous game play experience, nor did we have requirements for age or gender. Of the 18 participants, ten were female and eight were male. The median age was 25 years old; the youngest participant was 18, and the oldest was 30.

All participants were tested using a PC equipped with a Tobii eye tracker. The eye tracker recorded where the subjects were looking while playing the game, allowing us to determine whether they were accessing information using their peripheral vision, or instead gazing directly at the peripheral display. Additionally, the eye tracker was used to blank the partner’s game well if at any time the player looked away from his primary game well.

The Tobii eye tracker runs at 50 Hz with an accuracy of 0.5 degrees. The eye tracker works by beaming infrared light at the subject, and triangulating the reflection of this light from the subject’s pupils via cameras with infrared filters. The Tobii eye tracker tracks both eyes simultaneously using “binocular tracking” and can accurately continue to track gaze for a time even if one of the pupils becomes hidden. Players were seated 46 cm from a 34 cm computer display. The CoOp Tetris game was built using Java™ technology. The game wells had a width of approximately 9 cm. When staring at the center of the primary display, the angle of vision for the center of the peripheral display was approximately 28 degrees. Foveal vision is approximately a 2 degree cone [12]. This ensured that our peripheral display was always in the player’s peripheral vision when he focused on the primary display. A chin rest was used to
ensure that players’ positions remained constant with respect to the display. This ensured that the eye tracker never lost track of the participant’s vision as well as allowing us to ensure that our display was in fact in the player’s peripheral view. The game logged the player’s interactions. Positions were recorded as coordinates relative to the upper-left corner of the display. All of our statistical analysis was performed using Microsoft Excel. Figures 3.6 and 3.7 show our experimental setup.

When participants arrived to participate in the experiment, they were first given a demonstration of the game, including the rules and instructions on gameplay. They were informed that there were two versions of the game, identified as encoded and unencoded, as well as a control identified as single player. The encoded version of the game consisted of the player’s game well and our simplified display representing his
partner's game well. The unencoded version of the game showed the player's game well and the unencoded partner's game well (figure 3.2). The single player version was a version of the standard Tetris game (figure 3.1). Players were then given five minutes of training time to play through the unencoded version of the game, followed by five minutes on the encoded version. They were required to play the entire five minute period to ensure all participants had the same training time.

Participants then played a training program to familiarize themselves with identifying shapes in their periphery. Participants were asked to focus on their own game well while a single piece was portrayed in their teammate’s game well. The participants were then asked to identify which piece was being displayed. This was used to familiarize participants with identifying pieces in the periphery, as well as reinforcing the fact that they could use their periphery to play the game. Figure 3.8 shows the CoOp Tetris training game.
After the training program was completed, the actual experiment began. Participants played the three versions of the Tetris game: single, unencoded, encoded, in a randomized order. Each of the six possible game play orderings was played by three participants. The randomized order was used to ensure that the results were not influenced by a training effect. Participants were told to play the game normally; no mention of using the periphery to identify pieces was made. This was done because we wanted to see if people could adapt to the game environment without being directed specifically to use their periphery. Before each run of the game, the rules of the version to be played were read out. As well, participants were informed that during the experiment they were allowed to ask questions; however, they would not be answered until after the experiment was completed. This ensured that the experimenter did not bias the experiment by interacting with the participants.

After they completed the games, participants were asked to fill in a questionnaire relating to their experience. The questionnaire consisted of 12 questions using a five point Likert scale. The goal of the questionnaire was to ascertain how players felt they performed using each version of the game. It was also used to see if players’ opinions of performance differed from their actual performance at the game. Questions were also asked about whether players were able to utilize the display in their periphery and how effective they found the encoded display. The questionnaire is provided in Appendix A.

In summary, the CoOp Tetris experiment tested three versions of the CoOp Tetris game: unencoded, encoded and single player. The unencoded version consisted of the player’s game well as well as the unmodified partner’s game well. The encoded version consisted of the player’s game well as well as the partner’s game well modified
for viewing in the periphery. The single player version consisted of only the player’s
game well. All of the versions were evaluated based on score accumulated over a
five minute period of play. The scores from the encoded version were compared to
the scores of both the unencoded version and single player version using a paired
T-Test. The player’s ability to use the display was evaluated via a written survey
using a Likert scale as well as from free form comments collected during and after the
experiment.

3.5 Hypotheses Restated

Now that we have presented the conditions and measures of evaluation, we can restate
the hypotheses formally:
• **H1**: The score in the encoded display condition will be greater than the score in the unencoded display condition.

• **H2**: The score in the encoded display condition will be greater than the score in the single player condition.

• **H3**: Players will prefer the encoded display condition over the unencoded display condition.

### 3.6 Results

Our first hypothesis (H1) compares the encoded display condition and the unencoded display condition. A Kolmogorov-Smirnov test was used to determine whether the underlying distribution between the populations was normally distributed. The results of the Kolmogorov-Smirnov test showed that the underlying distribution is indeed normal ($P = 0.897$). A paired T-Test was conducted to evaluate the difference in score between the encoded display condition and the unencoded display condition. The independent variable, the encoded display factor, includes two levels: encoded display present and unencoded display present. The null hypothesis is that the encoded display scores and the unencoded display scores are equal. The results of the T-Test with $\alpha = 0.05$ showed a T-Score of -1.53 and a $P(T \leq t) = 0.067$. In this case, our P value exceeds our $\alpha$ marginally preventing us from rejecting the null hypothesis. We are unable to conclude with a 95% confidence that the encoded display condition scores and the unencoded display condition scores are different. These results have been summarized in Figure 3.1. From these results we are unable to conclude that H1 is correct.
Table 3.1: The T-Test results for the display comparison.

Our second hypothesis (H2) compares the scores in the encoded display condition to those of the single player condition. A Kolmogorov-Smirnov test was used to determine whether the underlying distribution between the populations is normally distributed. The results of the Kolmogorov-Smirnov test showed that the underlying distribution is indeed normal ($P = 0.218$). A paired T-Test was conducted to evaluate the presence of the encoded display and score. The independent variable, the encoded display factor, includes two levels: encoded display present and encoded display absent. There is a single dependent variable: score. In this case the null hypothesis is that the single player condition scores and the encoded display condition scores are equal. The results of the T-Test with $\alpha = 0.05$ showed a T-Score of -0.96 and a $P(T \leq t) = 0.17$. In this case, our $P$ value exceeds our $\alpha$ preventing us from rejecting the null hypothesis. We are unable to conclude with a 95\% confidence that the encoded display condition scores and the single player condition scores are different. From these results we are unable to conclude that H2 is correct.

3.6.1 Survey Results

To test our third hypothesis (H3), we surveyed each of the 18 subjects after the subject’s trial was complete. The results are summarized in Figure 3.9. Additionally we collected free–form comments from participants during and after testing.
• Seven of the participants indicated that they play video games in general. All participants indicated that they had played Tetris previously and 13 participants indicated that they considered themselves experienced at Tetris. This indicates that our subjects’ possible inexperience at playing Tetris was not a factor in their inability to monitor both displays.

• Ten participants felt that the unencoded display improved their performance while only eight participants felt that the encoded display improved performance. This suggests that perhaps our simplified display design was responsible for players being unable to improve performance during the encoded experiment. It is possible that with a different display, players might achieve better scores at the CoOp Tetris game.

• Five participants found the unencoded display confusing or mentally fatiguing while only three found the encoded display confusing. This indicates that most participants were not distracted by either display. Additionally, our encoded display was slightly less confusing than just displaying the partner player’s screen as is.

• Fourteen participants indicated they made use of the unencoded display most of the time when deciding whether to swap pieces, whereas only 11 participants indicated the same for the encoded display. This suggests that even though our encoded display was reported as being less confusing, more participants used the unencoded display as a swap indicator than the encoded display. This could also imply that the reason people reported more confusion for the unencoded display, is that more people were using it.
Eleven participants preferred the encoded display over the unencoded display. Additional comments showed that participants specified that they did not use the vertical bar (to determine the height of the partner’s pile of dropped pieces.) Most reported that, while they could sense the spinning bar to determine the distance from the partner’s piece to its destination, they did not pay attention to it. Subjects principally used the large version of the partner’s piece to decide when to swap, taking no account of whether this would harm the partner’s game play.

Finally, most players indicated through informal comments that they lost track of, or did not make use of the peripheral display for periods of time during game play. This can also be seen in the game play logs: most players have large gaps where they do not swap for an extended period of time. These gaps could also be explained by there simply being no piece the player wanted to swap for during those times.

3.7 Discussion

During our CoOp Tetris experiment we found no significant difference in players’ scores between the encoded and unencoded versions. When surveyed, players indicated no clear preference between the two game versions. We found that players using the encoded display attained lower scores than in our control case of a single-player version of the game. That is, players’ use of the peripheral display actually lowered players’ scores. Players performed the best at the single player game with an average score of 3,205 followed by the unencoded version of the game with an average score
Figure 3.9: A graph of the distribution of survey responses.

of 3,083. Performance was the poorest at the encoded version of the game with an average score of 2,555.

CoOp Tetris’ display was successful in that players could correctly perceive the information it showed. Participants indicated verbally that they were able to see what was on the display. However, in the heat of game play, they did not use this information beyond the simplest use of the large symbol showing the partner’s current piece. We believe that this problem hinged on the limit of players’ attention. Participants reported that they found it difficult to play the game and monitor their
partner simultaneously. Some players indicated verbally that as their game well grew and the difficulty of the game increased, their ability to see the peripheral display decreased. Just to manage their own well, players need to keep track of the current falling piece, determine where best to put it, and maneuver it appropriately. As the game speeds up, this consumes all of players’ attention. Even though they can in theory keep track of the state of their partner’s well, in practice they simply do not have sufficient cognitive capacity to do so without sacrificing the quality of play in their own game well.

This indicates a significant limitation in presenting streaming information in a peripheral display. Players attending to a primary task must have sufficient cognitive resources to be able to attend to the information presented in this peripheral display in addition to their primary task.

It is also possible that the play time at each version of the game was insufficient. Players only received five minutes of training time with each of the versions of the game. It may be that with more time to master the CoOp version of the Tetris game, scores would have surpassed those of the single player version. The game with a second display required more thinking and thus had a higher difficulty level than the original single player Tetris. Further testing would be required with a lengthened play time and evaluating more participants to see the differences between the encoded and unencoded versions.

In CoOp Tetris, the approach we took when developing our display was to simplify the game elements on the partner’s screen to allow for easy monitoring in the periphery. We believed that if the player could easily monitor his partner’s screen using his peripheral vision, it would improve his game performance. We found that there were
two fundamental challenges when designing our display. The first challenge was to find an appropriate way of encoding the requisite information in the periphery. While experiments done by earlier researchers and knowledge of the physiology of the eye provide hints as to what kinds of encodings may be successful, the encoding turned out to be a challenging undertaking. The second challenge was to determine whether requiring players to attend to peripheral displays in addition to their primary foveal display produces a form of information overload, where the additional information fails to improve performance or even worsens it.

The results from our testing with CoOp Tetris revealed that our theory of simplifying game elements and placing them in the periphery was promising; however, our implementation failed to convey the necessary information to the player. In our experiment, most participants adopted a selfish strategy and swapped too often, usually without any regard for the partner’s game state. We anticipated that players would show more concern for their partner’s well being; however, this turned out not to be the case. Players indicated through verbal feedback that the reason they did this was that they had no concept of another player. They were not concerned over negatively affecting a simulated player as there was no feedback from that player. As well, players indicated that they only used the large piece portion of the display. They did not know how close the player was to losing his game, despite having access to our three peripheral icons. Players were always surprised when their game ended, and expressed confusion as to why their game spontaneously restarted. Without knowledge of how their partner was actually doing, players did not think about how their swap would adversely affect their partner. This led to the partner’s game ending quickly due to the inability to recover from poor swaps. This adversely affected the player’s
game since both games end when either game ends. This was due to the player’s inability to process the data shown on the display.

We expected that the encoded version of the game would outperform the unencoded version. We also expected that both the unencoded and encoded versions of the game would outperform the single player Tetris game. The fact that the single player game was found to have the best performance may be explained by the increased level of complexity from the addition of swaps. It might also be explained by the fact that while all participants had previous experience with regular Tetris, none had experience with swapping, and the time required to learn how to use swapping effectively may be greater than the five minutes they were given. Players indicated in the survey as well as verbally following the experiment that the three peripheral icons representing game state were confusing. This was further supported by the fact that players performed better in some cases with the unencoded version of the game. As well, players indicated that they rarely made use of two of the icons. The icon that received most use was the enlarged piece. Additionally, players were not concerned with their partner’s performance when playing the game. We had hypothesized that our display would simplify the game and provide a conducive environment for swapping, but in fact, it complicated the game with perhaps too much information and a confusing overall display.

The written survey further pointed out the problems with our display design. There was no clear preference of the simplified display over the detailed display. Seven of 18 participants actually preferred the detailed display. There was also a mismatch in participant perception of performance. Players thought they performed better with encoded version of the game, but in fact performance was best with the
single player version. This mismatch in perceived performance is interesting and could benefit from further study.

The heuristics and guidelines we used were a useful starting point for building our display. Even though we employed these guidelines, our display did not perform as we had hoped. We believe this is because the guidelines and heuristics available to us fail to address problems specific to streaming displays. Mankoff et al.’s heuristics [24] were designed for ambient displays which are predominantly alarm-based. Alert-based displays draw the user’s attention when they have something important to convey. Most peripheral displays reported in the literature fall into this category. Mankoff et al. do not distinguish between alarm-based and streaming displays. Our display, however, was intended to provide a continuous stream of updates and information.

Mankoff et al.’s heuristics are expressed in the form of high-level guidelines. It is therefore challenging to objectively validate the degree to which we satisfied them. The guidelines proposed by Shen et al. [29] and Ima and Mann [17] were more concrete, although still geared towards alarm-based displays.

There exist no heuristics to our knowledge that are intended specifically for streaming displays. We believe that extensions or modifications of current available heuristics are needed to address streaming displays. Certain heuristics that are specific to drawing attention can be omitted for streaming displays. An example of a heuristic which can be omitted for a streaming display is Mankoff et al.’s heuristic advising the display to remain unobtrusive until attention is required. In addition, heuristics that include information about attention and anatomy of the eye should be added. These might contain information such as which colours to use, size of the display and use of motion when designing for information retrieval in the periphery.
Some possible heuristics for displays meant to function in the periphery could include:

- Items on the display should use low frequency wavelength colours such as blue.
- Limit the number of items on the display to one or two items which are easy to comprehend.
- Items on the display that require attention should be large and moving.

### 3.8 Moving Forward

Our reliance on the aforementioned heuristics was not solely to blame for the flaws present in CoOp Tetris; there were a number of flaws which ultimately led to the failure of our peripheral interface to improve game performance. First, participants could not attend to all portions of our display at the same time. Even though we tried to make our display as minimalist as possible, there was too much important information to convey successfully. Perhaps if we had limited ourselves to one or two important items, participants may have been able to comprehend both.

The CoOp Tetris display did not improve player score; however, we learned some key lessons about peripheral display design from designing and running our experiment. These include:

- Players were able to perceive the display in their periphery; however, they did not maintain a constant awareness of what was on it.
- Players indicated that during game play, they lost track of what was happening on the peripheral display for extended periods of time.
Players were able to detect all three icons on the display; however, players mostly used only the large piece icon.

Incorporating information about peripheral vision into the design of our display was a step in the right direction. However it was not enough to ensure that our display was successful.

Our Co Op Tetris experiment left us with a few unanswered questions, as well as a few new questions which require exploration. These include:

• Does there exist a peripheral display design which would have improved player scores?

• If considerations are made for attention and task, will players be able to maintain an awareness of what is on the display throughout the entire game?

• As a game gets more difficult, does the player’s ability to perceive the peripheral display decrease?

• Since players lost track of the display when the game got too difficult, does there exist a game difficulty level that is optimal for using a peripheral display?

To address some of these questions we developed our second experiment, City Flyer, which will be discussed in chapter 4.
Chapter 4

City Flyer

The peripheral display in our CoOp Tetris game of the previous chapter did not improve player performance. In this chapter, we consider another peripheral display, in a different game, to test a player’s ability to use a streaming peripheral display during video game play.

We also explore how the use of the peripheral display changes as the game level increases. This is motivated by our anecdotal observation in the CoOp Tetris game that players tended to use the peripheral display less, and lost track of the peripheral display, when the game pace became frantic. We will consider the following questions:

- Can the presence of a peripheral display improve game performance?
- How does the player’s ability to use the peripheral display change with the level of difficulty?
- How does the player’s strategy of using the peripheral display change with the level of difficulty?
4.1 Hypotheses

In our new game, the streaming peripheral display will, from time to time, present an opportunity for the player to improve his performance. We define the player’s “peripheral efficiency” as the fraction of these opportunities that the player uses.

We will test the following hypotheses, as applied to the new game that is introduced in this chapter.

- A player’s peripheral efficiency decreases as the game level increases.
- A player’s strategy to use the peripheral display becomes more risk-tolerant as the game level increases (where “risk-tolerant” refers to the user increasing the number of risks taken).

4.2 Experiment

We developed a new game, called “City Flyer”, in which the player flies over a city while dodging bombs. The game display consists of a main screen and an adjacent peripheral screen. The action of the game takes place on the main screen, while the streaming peripheral screen presents information that permits the player to improve his performance.

4.2.1 Description of the Game

The City Flyer game is shown in Figure 4.1. The city landscape scrolls downward below the player’s blue ship, giving the appearance of flying upward above the city. The player uses the left and right arrow keys to dodge green bombs of various shapes
Figure 4.1: The City Flyer Game. The main screen (left) shows the player’s ship in blue and bombs of different shapes in green. The peripheral screen (right) streams a sequence of geometric shapes.

that move downward at different speeds. The player’s score is proportional to the distance traveled before being hit with a bomb. The number of bombs and the downward speed of the bombs both increase with the level of difficulty, which itself increases as the game progresses.

The peripheral screen shows a sequence of three shapes, consisting of a circle, a triangle, and a square. Transitions between shapes are smooth, with the old shape slowly fading out as the new shape fades in. The order of the shapes is randomized so that players cannot predict when a particular shape will appear. The speed at which the shapes fade out and in is constant. The right side of Figure 4.1 shows a triangle fading out and a square fading in. The difficulty in city flyer is based on bomb speed.
As the game progresses, the bombs fall at faster speeds. The shapes on the peripheral display always fade in and out at the same rate, independent of game difficulty.

The peripheral screen allows the player to improve his score, as follows. If the player presses the space bar while a square is shown on the peripheral screen he receives a brief speed boost to his ship. This speed boost allows the player to increase his score by traveling farther in the same time, as long as he does not get hit by a bomb. However, if the player incorrectly presses the space bar while a circle or a triangle is shown, his speed is briefly slowed and his score is correspondingly reduced. If the player is gazing at the peripheral screen when the space bar is pressed, that press is ignored by the game, whether it would have had a positive or a negative effect. This was done to avoid biasing our data in favor of false positives.

When two shapes are visible in the peripheral display (i.e. one fading in while the other is fading out), we consider the shape shown to be the shape that is more opaque. The opacity of each shape varies linearly with time between 1 (completely opaque) and 0 (completely transparent).

Strategically, it is to the player’s advantage to pay attention to the information in the shape display. The highest score possible can only be obtained by perfect square identification. However, if too much attention is devoted to the peripheral screen, the chance of hitting a bomb is increased. A perfect number of correct identifications is meaningless if the player is hit by a bomb early in the game.

The player has to balance his attention between the main screen and the peripheral screen. We believe that this balancing act will be easy to accomplish when the game level is low, but will be hard to accomplish when the level is high. As the game level increases, we expect that more of the player’s attention will be devoted to dodging
bombs on the main screen, with less to the peripheral screen and a corresponding decrease in peripheral efficiency.

4.2.2 Design Decisions and Related Theory

Two areas of research helped to guide the design of our City Flyer game: feature search and dual-task paradigms.

A feature search is a task in which a person attempts to distinguish an object by a defining factor, such as color or shape. Feature searches can require the identification of more than one feature. A single-feature search involves objects which differ by a single factor such as colour, whereas a double-feature search involves two distinguishing features such as colour and shape. It is well known in psychology that a single-feature search is easy for humans, but that any search involving more than a single feature is difficult [33].

A peripheral display should therefore be limited to single-feature searches. In the previous game, CoOp Tetris, we had three icons on the peripheral display. Each of these icons was used in an independent, single-feature search. But this proved to be too much for our subjects to successfully handle. In the next game, City Flyer, we decided to use only a single icon, a shape, in a single-feature search. We also decided to vary the icon’s shape, instead of its colour, because we know that colours are difficult to distinguish in the periphery [17].

A dual-task paradigm is a psychological construct in which a person is required to focus on a primary task while simultaneously engaged in an alternate task. Keretekin et al. [20] and others show that a dual-task paradigm is a challenging undertaking. There are significant performance losses on both the primary and secondary
tasks, and the task becomes even more difficult if one of the tasks requires more attention than the other. Depending on the tasks, people can perform adequately at both tasks in a dual-task paradigm.

The new game, City Flyer, uses a dual-task paradigm. The player is expected to simultaneously play the game and attend to the peripheral display. Since this is challenging, we decided to keep the peripheral display simple by limiting it to contain only three large shapes.

Our experiment differs from typical dual-task experiments in two ways. First, the peripheral display is a streaming display, rather than a static display. Second, the secondary task (of recognizing a shape in the peripheral display) is completely voluntary. The player is not explicitly penalized for not using the peripheral display to boost his score (although the highest possible game scores are only attainable by using the peripheral display).

We also incorporated the same heuristics and guidelines as with the previous CoOp Tetris game. We used the applicable heuristics from the Mankoff group [24] as well as the guidelines suggested by Shen [29], and Ima and Mann [17] as well as knowledge of the physiology of the eye.

4.3 Statistical Theory

To evaluate performance in the City Flyer game, we employed a statistical model, commonly used in psychology, known as Signal Detection Theory (SDT). The aim of SDT is to determine a subject’s performance independent of the subject’s strategy. SDT provides a number of measures; for our study, we use the discriminability and strategy measures.
In the Signal Detection Theory model, a subject is asked whether a stimulus is present or absent. Each time the subject is asked, the stimulus may be present or absent, and the subject may respond “present” or “absent”. The four possible situations are denoted *True Positive*, *False Positive*, *True Negative*, and *False Negative*:

- **True Positive** The subject correctly states that the stimulus is present.
- **False Positive** The subject incorrectly states that the stimulus is present.
- **True Negative** The subject correctly states that the stimulus is absent.
• **False Negative** The subject incorrectly states that the stimulus is absent.

Figure 4.2 shows a graphical representation of the SDT model. The horizontal axis represents the strength of the subject’s perception of the stimulus. The vertical axis represents the probability density of the occurrence of a certain strength of perception.

There are two distributions shown on the graph: the noise distribution and the signal–plus–noise distribution. The noise distribution describes the strength of the subject’s perception of the stimulus in the absence of a stimulus. The signal–plus–noise distribution represents the strength of the subject’s perception of the stimulus in the presence of a stimulus.

The noise can consist of other stimuli that generate a perception (positive or negative) of the stimulus in question. In particular, the noise can consist of “distractors”, which may lead the subject to believe that the stimulus is present when, in fact, it is absent.

The noise distribution is assumed to be a standard normal distribution (with a mean of zero and a standard deviation of one), as shown in Figure 4.2. The presence of the stimulus is assumed to add a positive, constant amount to the strength of the subject’s perception of the stimulus. Thus, the signal–plus–noise distribution has the same shape as the noise distribution, but is shifted to the right.

The integral of either distribution between two values, $a$ and $b$, on the horizontal axis is the probability that the strength of the subject’s perception will be in the range $[a, b]$ for the situation (i.e. presence or absence of stimulus) that the distribution models.

The discriminability of the signal from the underlying noise is denoted $D'$ and is the separation between the two distributions, measured in $z$–values (i.e. units of
standard deviation):
\[
D' = \frac{\text{separation}}{\sigma},
\]
where \( \sigma \) is the standard deviation of the noise distribution. According to Heeger [14], \( D' \) is “a complete characterization of the detectability of the signal assuming that the noise follows a normal (Gaussian) distribution with a fixed variance, independent of the signal strength.”

The SDT Model assumes that the “present” or “absent” response of the subject depends upon whether the strength of the subject’s perception is above or, respectively, below, some threshold, \( B \). Each subject can have a different threshold.

An ideal observer is one who maximizes the true positive rate while minimizing the false positive rate. For the distributions shown in Figure 4.2, the ideal observer has a threshold midway between the peaks of the two distributions.

The subject’s strategy, denoted \( C \), can be expressed as the distance from the subject’s threshold to the ideal observer’s threshold. A positive \( C \) corresponds to a conservative strategy; a negative \( C \) corresponds to a liberal strategy [1].

### 4.3.1 SDT in the CityFlyer Experiment

The CityFlyer experiment had three states. In each state, a circle, a triangle, or a square was shown at greater than 50% opacity in the peripheral display. Each state persisted for a certain interval of time, during which the corresponding shape first increased from 50% opacity to 100% opacity, then decreased again to 50% opacity. After this, the next state was entered with a different shape.

The subject was instructed to press the spacebar when he perceived a square in the peripheral display. We considered each state and its associated interval to be a
single opportunity for the subject to respond. If the subject pressed the space bar, the subject’s response was considered to be “present” for that interval; in the absence of a press during the entire interval, the response was considered to be “absent”. If the subject looked directly at the peripheral display during a particular interval, that interval was discarded from our analysis, whether the subject pressed the spacebar or not.

For our experiment, the horizontal axis in the SDT model corresponds to the strength of the subject’s perception of a square in the periphery. We calculated discriminability as the difference in the z-scores of the true positive rate and the false positive rate. A z-score is the distance of the data from the population mean in standard deviations. The z-score is positive when the score is above the mean and negative when it is below. The formula used:

\[
D' = z\left(\frac{\text{truepositives}}{\text{maxtruepositives}}\right) - z\left(\frac{\text{falsepositives}}{\text{maxfalsepositives}}\right)
\]

If there were no true positives, we set

\[
\text{truepositiverate} = \frac{1}{2n}
\]

where \(n\) is the number of samples. This is in accordance with MacMillan and Creelman [23], as \(D'\) cannot be calculated if there are no true positives. We calculated the subject’s strategy as

\[
C = -\frac{1}{2}(Z_{TP} + Z_{FP})
\]

The formulas for \(D'\) and \(C\) were taken from Abdi [1].
4.4 Experimental Setup

Similar to the CoOp Tetris experiment, the City Flyer experiment tested 18 subjects drawn from the university community. We did not require any previous game play experience, nor did we have requirements for age or sex. Twelve subjects were female and six were male. The average subject age was 25 years; the youngest was 20 and the oldest was 40.

All subjects were tested using a PC equipped with a Tobii eye tracker. The eye tracker recorded where the subjects were looking while playing the game, allowing us to determine whether they were using their peripheral vision or gazing directly at the peripheral display.

The Tobii eye tracker reports eye direction at 50 Hz with an accuracy of 0.5 degrees. Please refer to Section 3.4 for a complete description of the Tobii eye tracker.

Players were seated 46 cm from a 34 cm (horizontal) computer monitor. A chin rest ensured that a player’s position remained constant relative to the display. This ensured that the eye tracker never lost track of the subject’s vision and that our peripheral display was, in fact, in the player’s peripheral view. All of the player’s actions were logged, including eye fixations, which were recorded in window coordinates. Figures 3.6 and 3.7 (in the previous chapter) show our experimental setup.

Two versions of the game were played, an enhanced version that included the peripheral display and a regular version without it.

The experiment started by allowing subjects as much training time as they required with the City Flyer game. Subjects played only the enhanced version during the training period.

After the training period, subjects played the enhanced game twice and the regular
Each version of the game was played until completion. A full game consisted of seven levels of difficulty with 30 possible square identifications per level. Game durations ranged from five to seven minutes. During the testing period, the experimenter did not answer any questions; any questions were answered after the experiment was over. This ensured that the experimenter did not direct the player to play in any particular fashion.

After completing the games, each subject was asked to complete a questionnaire which consisted of 11 questions using a five-point Likert scale. The goal of the questionnaire was to determine whether a player’s opinion of their own performance differed from their actual performance. Players were also asked whether they were able to use the display with their peripheral vision, and whether they thought that the peripheral display helped them. The City Flyer questionnaire is included in Appendix B.

4.5 Results

Each of the two hypotheses from Section 4.1 is discussed below.

*Hypothesis 1 (H1):* A player’s peripheral efficiency decreases as the game level increases.

*Hypothesis 2 (H2):* A player’s strategy to use the peripheral display becomes more risk-tolerant as the game level increases.
Recall that “peripheral efficiency” is the fraction of squares in the periphery that the player correctly identifies. In the language of SDT, it is

\[ PE = \frac{N_{TP}}{N_{TP} + N_{FN}} \]

where \( N_{TP} \) and \( N_{FN} \) are the numbers of true positives and false negatives, respectively and \( N_{TP} + N_{FN} \) = Total number of square opportunities. The “strategy” is defined by SDT as the value \( C \), and the “difficulty” of the peripheral task is defined by SDT as the discriminability value, \( D' \). A small value for \( D' \) indicates a large peripheral task difficulty.

### 4.5.1 Peripheral Task Difficulty versus Game Level

In this section, we verify that the peripheral task difficulty (i.e. the player’s \( D' \) values) is correlated to the game level.

We calculated each subject’s difficulty, \( D' \), for each game level. Linear regression calculated an \( R^2 = 0.619 \). The regression line had the equation:

\[ y = -0.046x + 0.874 \]

Figure 4.3 shows the mean and confidence intervals of peripheral task difficulty, \( D' \), for our subjects per level.

We calculated correlation between game level and peripheral task difficulty using Pearson’s R correlation coefficients. The R values are shown in Figure 4.4. The correlation coefficients over all of the players had a mean of -0.287 and a standard error of 0.081. A negative correlation with Pearson R values implies that as one set increases, the other set decreases.

Our results show that some players had a very high correlation between peripheral
Figure 4.3: Shown is the mean and confidence intervals of the difficulty of the peripheral task ($D'$) for 18 subjects over 7 levels. The line shown is the linear fit, with equation $y = -0.0469x + 0.6749$ and $R^2 = 0.6195$.

Task difficulty and level, while some did not. The 95% confidence interval of the mean of the correlation coefficients was $[-0.129, -0.444]$. Since this interval does not contain zero, we claim with 95% confidence that there is a correlation between peripheral task difficulty and game level. This suggests that overall, as the game level increases, the peripheral task difficulty increases. Additionally, this justifies our use of game level as a difficulty measure.
4.5.2 Peripheral Efficiency versus Game Level

We calculated each subject’s efficiency for each game level. Linear regression calculated an $R^2 = 0.726$. The regression line had the equation:

$$y = -0.0148x + 0.2428.$$ 

Figure 4.1 shows the mean and confidence intervals of peripheral efficiency for our subjects per level.

We calculated correlation between peripheral efficiency and game level using Pearson’s R correlation coefficients. The R values are shown in Figure 4.1. The correlation coefficients over all of the players had a mean of -0.469 and a standard error of 0.078. A negative correlation with Pearson R values implies that as one set increases, the other set decreases.

The 95% confidence interval of the mean of the correlation coefficients was $[-0.316, -0.621]$. Since this mean does not contain zero, we claim with 95% confidence...
Figure 4.5: Shown is the mean and confidence intervals of the peripheral efficiency for 18 subjects over 7 levels. The line shown is the linear fit, with equation.

that there is a correlation between peripheral efficiency and game level. Using this, we conclude that Hypothesis 1 is true. That is, a player’s peripheral efficiency decreases as the game level increases.

### 4.5.3 Strategy versus Game Level

We calculated each subject’s strategy for each game level. Linear regression calculated an $R^2 = 0.835$. The regression line had the equation:

$$ y = 0.051x + 1.147. $$

Figure 4.6 shows the mean and confidence intervals of the strategy, $C$, for our subjects per level.

We calculated correlation between strategy and game level using Pearson’s R
Figure 4.6: Shown is the mean and confidence intervals of the strategy, C, for 18 subjects over 7 levels. The line shown is the linear fit, with equation.

correlation coefficients. The R values are shown in Figure 4.2. The correlation coefficients over all of the players had a mean of 0.559 and a standard error of 0.069. A positive correlation with Pearson R values implies that as one set increases, the other set increases.

The 95% confidence interval of the mean of the correlation coefficients was [0.424, 0.693]. Since this mean does not contain zero, we claim with 95% confidence that there is a correlation between strategy and game level. Using this, we conclude that Hypothesis 2 is true. That is, a player’s strategy to use the peripheral display becomes more risk-tolerant as the game level increases.
4.5.4 Survey Results

We surveyed each of the 18 subjects after the subject’s trial was complete. The results are summarized in Figure 4.3.

- Only four subjects found that they were not able to monitor the peripheral display without looking. This shows that, overall, people felt that they could attend to both the game and the display at the same time. This is consistent with what we observed from the tests.

- Eleven subjects indicated that they often lost track of what was happening on the peripheral display. This shows that, while they could monitor the display, there were difficulties with attention. Observing the peripheral display was a conscious effort. During periods of furious game activity, players indicated verbally that they would lose track of what was happening on the display. Furthermore, when the action calmed down, they could once again perceive the display properly.

- Only six subjects found the display distracting or confusing. This shows that the simpler display is far less confusing than the display used in the CoOp Tetris experiment. This confirms our belief that the reduction of the number of types of peripheral icon from three to one did, indeed, simplify the display.
• Nine subjects indicated they had to make a conscious effort to attend to the peripheral display, with six subjects being neutral in the matter. This supports our belief that attending to the display requires a conscious effort and therefore requires attentional resources.

• Seventeen subjects indicated that as the game speed increased they found it more difficult to attend to the peripheral display, supporting the first and second hypotheses.

• Twelve subjects indicated that, while attending to the peripheral display, they were more likely to make a mistake in the game. This supports our notion of a maximum capacity for attentional resources. When attending to both displays simultaneously, the player has to split his pool of resources resulting in a degradation of performance on both displays.

4.6 Discussion of Coop Tetris and City Flyer

The goal of the City Flyer experiment was to test the usability of our streaming peripheral display. This differed from our CoOp Tetris experiment, which attempted to improve player performance.

We concluded that the CoOp Tetris environment was too complicated for a streaming peripheral display. In City Flyer, we designed both the primary and peripheral tasks to be as simple as possible. These simplifications allowed us to test display usability at different difficulty levels, and to test whether peripheral task performance degraded as the game level increased.
Our experimental results and survey feedback indicated that every subject used the peripheral display to try to improve their score, even though the task was voluntary. This shows that, in at least one game, subjects can use a streaming peripheral display successfully.

We found a significant decrease in square identification performance as the game level increased. When surveyed, players indicated that they were able to monitor the second display without looking at it directly. However, they often lost track of exactly what was happening on the primary display. Players indicated that they had to make a conscious effort to attend to the second display. This was more apparent

| % Agree | 39 | 61 | 33 | 56 | 94 | 67 | 22 |
| % Neutral | 39 | 17 | 0 | 33 | 6 | 22 | 11 |
| % Disagree | 22 | 22 | 67 | 11 | 0 | 11 | 67 |

Table 4.3: The City Flyer survey results.
as the game level increased. We believe this is due to a re-orienting effect. We have two theories as to why this would occur.

Our first theory is that while the game is slow, players have time to occasionally glance at the peripheral display to re-orient themselves with the display. However, as the game gets increasingly fast, the re-orientation becomes harder to achieve.

Our second theory is that as the game is in its early stages, the player’s entire mental capacity is not used up. Players have enough attention to split between the primary display and the peripheral display. However, as the game intensifies, the primary display requires more attention and therefore players lose track of what is on the peripheral display.

The results have shown that attention plays a key role in the design of a streaming peripheral display. The heuristics and guidelines for peripheral display design have no mention of attention; we believe that they should.

Our test results gave insight into a few psychological areas, but more exploration would be necessary to see if these insights were in fact true. We found that players did not have enough attentional resources to adequately monitor both the peripheral display and the primary display in the CoOp Tetris experiment. However, players seemed to be able to monitor both the primary and peripheral displays in City Flyer. We also saw, that as the task in City Flyer became more difficult, the attentional resources seemed to become inadequate to maintain perfect awareness of both primary and peripheral display. It would be of interest to know how large a person’s pool of attention is.

Some interesting questions on attention as a result of our experimentation include:

- Does the amount of attentional resource grow with increased proficiency at a
task?

• Is there a maximum level of attentional capacity?

• Do people differ in their attentional capacity abilities naturally?

• How are attentional resources distributed during game play?

It is interesting to note that player strategy became more risk-tolerant as the game level increased. This seemed to correspond to a drop in the usage of the peripheral display. This leads us to believe that as the game level increased, the players guessed more. This implies that there simply was not enough time or attentional capacity to attend to the second display while the difficulty level was tough.

In summary, the key lessons we learned from testing City flyer were:

• People can play a game and use a streaming peripheral display simultaneously while the game speed is slow.

• As the game level increases, the ability people have to make use of the streaming display decreases.

• As the game level increases, player strategy becomes more risk-tolerant.
Chapter 5

Conclusion

In this study, through two experiments, we have explored the use of streaming peripheral displays in video game environments. We initially attempted to show, with our CoOp Tetris game, that a streaming peripheral display could be used to improve game performance. We found that with the display we used, performance did not increase as anticipated. However, it remained unclear whether this was a result of the design of our peripheral display, or the use of a peripheral display in general. Drawing from the results of CoOp Tetris, we considered another peripheral display in our City Flyer game to test a player’s ability to use a peripheral display during game play. We explored how the effectiveness of the peripheral display changed as the difficulty of the game increased. We found that players were able to use our display in City Flyer, but as the difficulty of the game increased, the effectiveness of the display decreased.
5.1 Summary

Chapter two introduced four different types of peripheral based displays: ambient, peripheral, attentive and gaze-contingent. We illustrated the differences between streaming and alert-based displays. We introduced the concept of attention, feature search and dual-tasks. In addition, we presented heuristics for creating displays, and evaluation techniques for determining whether a display is effective.

Chapter three discussed CoOp Tetris, the first of our two experiments with streaming peripheral displays. CoOp Tetris tested a player’s ability to use a specially encoded streaming peripheral display to improve in-game performance. The results of the experiment were ambiguous, which led us to conclude that our particular display did not boost in-game performance. In our analysis of the experiment we presented and evaluated the data collected using our encoded peripheral display. We discussed our application of heuristics and guidelines from previously published literature that we adapted for use in our own display. We investigated how the physiology of the eye ties into display design. We outlined the experiment and discussed our results including the flaws and shortcomings of our display design. Finally, we presented some possible alternative heuristics specific to streaming peripheral displays. Our proposed heuristics were:

- Items on the display should use low frequency wavelength colours such as blue.
- Limit the number of items on the display to one or two items which are easy to comprehend.
- Items on the display that require attention should be large and moving.
Chapter four outlined City Flyer, the second of our two experiments with streaming peripheral displays. The City Flyer experiment tested a person’s ability to use a streaming peripheral display during game play. City Flyer also explored the hypothesis that a player’s ability to act on information presented in a peripheral display degrades as the player’s primary task increases in difficulty. The results of our experimentation showed that players were able to use our streaming peripheral display while playing the City Flyer game. Furthermore, performance seemed to decrease as the game difficulty increased, as hypothesized.

During our presentation of our second experiment we expanded upon the areas from our CoOp Tetris experiment that we wished to improve upon. We introduced the ideas of attention and attentional resources. We drew upon the study of feature integration theory as well as dual task paradigms to interpret our results. We applied signal detection theory as a means of statistical assessment. We presented and evaluated our second encoded peripheral display. Finally, we outlined the experiment and discussed our results.

5.2 Conclusion

Through our two experiments we showed that designing a streaming peripheral display is a difficult task. It requires extensive planning of the display’s layout as well as knowledge of physiology and the study of attention. The current research in the field of peripheral displays does not sufficiently take these factors into account. The heuristics and guidelines we encountered in our research led us to believe that designing effective peripheral displays was an easy task. The ambiguous results of our CoOp Tetris experiment showed that this was more challenging than anticipated.
We identified a number of reasons for why designing and creating streaming peripheral displays is a complex undertaking: A player has limited attentional resources, making it difficult to divide attention between the primary task and the streaming display. It is especially difficult to allocate attentional resources to a peripheral task when the primary task is challenging. Additionally, humans have physical limitations in relation to focusing on an object using their peripheral vision due to the physiology of the eye and the rod-cone distribution in the peripheral retina.

The City Flyer experiment was an example of a game where players were successfully able to use a peripheral display during game play. Players successfully engaged in a peripheral task while maintaining focus on a centralized task. However, in this same experiment we also found that as the game’s difficulty increased, the display’s effectiveness decreased. This implies that streaming peripheral displays may be less beneficial to users in a game with a difficult central task. In contrast, the users in our CoOp Tetris game did not successfully utilize the peripheral display. We were unable to show that the streaming peripheral display had a positive effect on performance.

Our experiments highlighted some of the limitations present when designing and using streaming peripheral displays. One major obstacle to consider during peripheral display design is the physiology of the eye. The peripheral retina is more adept at viewing larger objects with low wavelength colours. As well, movement is easily detectable in a person’s peripheral vision, although it is hard to distinguish fine detail in the periphery. These physical limitations have an effect on what can be included in a streaming peripheral display. Objects within the display are easier to perceive if they are larger, coloured properly and moving.

A second limitation for designing streaming peripheral displays is attention span.
CHAPTER 5. CONCLUSION

A person has a finite set of attentional resources that are available for distribution among the multitude of concurrent tasks presented at any given moment. A person using a streaming peripheral display will have to split his attentional resources between two tasks. This dual-task limits the effectiveness of streaming peripheral displays since the player only distributes a portion of his attention to the peripheral display at any given time. We showed that a streaming peripheral display’s effectiveness degrades substantially if the primary task is very engaging. This implies that streaming peripheral displays may function best in environments with automatic primary tasks or when the primary task is easy.

We have shown that the traditional heuristics and guidelines for peripheral displays are not sufficient when designing a streaming display. We have explored the limitations of our physiology and attentional capacity through the aforementioned experiments. We have suggested additional heuristics and guidelines to aid with the design of streaming displays. Furthermore, we have shown that designing a streaming peripheral display is a challenging task requiring knowledge of psychology, interface design and physiology. Additional experimentation and testing in the area of streaming displays is needed to identify all the key components of design for a streaming display.

5.3 Directions for Further Research

Throughout our exploration of streaming peripheral displays we identified some questions which we were unable to answer. We also outlined some limitations we found when designing streaming peripheral displays.

Some remaining questions from the results of the CoOp Tetris experiment include:
CHAPTER 5. CONCLUSION

• If we reduced the number of peripheral icons from three to two or even one, would the display have been successful?

• Does an encoding exist for a streaming peripheral display that will measurably improve performance?

Some questions remaining from the City Flyer experiment include:

• If we changed the feature type, e.g. from shape to colour, would we achieve the same results?

• Can we extend the experiment to a two feature search and achieve positive results?

• If we added more objects to the shape display, would people still be able to identify the square? Is there a maximum?

• How would making the identification task mandatory affect performance on the main screen?

Many additional questions relating to streaming peripheral displays and games are worth additional study. One interesting topic for exploration would be to discern the methods and reasons that cause a person to allocate his attentional resources. Study of the allocation of attentional resources could allow for displays designed to streamline attentional resource division. A display designed with attentional resource allocation in mind could simplify the process of concurrently focusing on both tasks in a dual-task activity.

Additional areas of interest with respect to how players perceive the data on a streaming peripheral display include:
• does playing video games have an effect on a person’s ability to multi-task?

• is it possible to predict whether a streaming peripheral display would lead to cognitive overload?

The results of our experiments as well as the possible results of further research within the field of streaming peripheral displays can have wide ranging implications that are not limited only to video game play. Additional areas that this research could be extended to include: extending our findings to a real world application such as driving. Investigating the use of streaming peripheral displays within military operations, air flight applications or similar tasks where straying from a single focus point could prove dangerous.

Our initial goal was to show that a streaming peripheral display can be an effective tool to convey real time information in a task intensive environment. Although we were initially unable to show that a streaming peripheral display could be used to improve a player’s score in a video game, we successfully showed that players were able to perceive and make use of a streaming peripheral display while playing our City Flyer game. In addition, we showed that streaming peripheral displays are better suited for environments where the central task is easy. Finally, we proposed some design heuristics and guidelines for building streaming peripheral displays. These results provide a solid foundation for any further research into streaming peripheral displays. Now that we have successfully shown one situation where people can use a streaming peripheral display effectively, researchers can use these results to explore scenarios that successfully use streaming peripheral displays to improve video game performance.
Bibliography


Appendix A

CoOp Tetris Questionnaire
Questionnaire:

Circle the answer to each question on a scale of 1 to 5 where applicable,

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

1. Age: ______

2. Sex: M / F

3. Do you play video games? Y / N

4. Have you played Tetris before? Y / N

5. How would you rate your experience with Tetris?

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never Played</td>
<td>Beginner</td>
<td>Moderate</td>
<td>Good</td>
<td>Expert</td>
</tr>
</tbody>
</table>

The following questions relate to trials using the detailed display (see front page):

6. I believe that the presence of the detailed display improved my performance.

   1 2 3 4 5

Comment: ____________________________________________

7. I found the detailed version of the game mentally fatiguing or confusing.

   1 2 3 4 5

Comment: ____________________________________________

8. I made use of the detailed game screen when deciding whether or not to swap pieces.

   1 2 3 4 5

Comment: ____________________________________________
Circle the answer to each question on a scale of 1 to 5 where applicable,

1   2  3  4  5
Strongly Disagree    Disagree         Neutral          Agree          Strongly Agree

The following questions relate to trials using the simplified display (see front page):

9. The presence of the simplified display improved my overall performance during the Tetris game.
1   2  3  4  5
Comment:___________________________________________

10. I found the simplified version of the game mentally fatiguing or confusing.
1   2  3  4  5
Comment:___________________________________________

11. I made use of the simplified game screen when deciding whether or not to swap pieces.
1   2  3  4  5
Comment:___________________________________________

12. Which version of the game provided more useful information?
1   2  3  4  5
Detailed a lot   Detailed a little   Neither   Simplified a little   Simplified a lot
Comment:___________________________________________
Appendix B

City Flyer Questionnaire
Experiment Survey

Circle the answer to each question on a scale of 1 to 5 where applicable:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

1. Age: ______
2. Sex: M / F
3. Do you play video games? Y / N

The following questions relate to trials using the second display:

4. I was able to monitor the second display without looking.
   1  2  3  4  5
   Comment:___________________________________________

5. I often lost track of what was happening on the second display.
   1  2  3  4  5
   Comment:___________________________________________

6. I found the second display distracting or confusing.
   1  2  3  4  5
   Comment:___________________________________________

7. I had to make a conscious effort to attend to the second display.
   1  2  3  4  5
   Comment:___________________________________________
8. As the game speed increased I found it more difficult to attend to the second display.

1  2  3  4  5

Comment:___________________________________________

9. I made use of the second display to improve my score ______.

Rarely  Sometimes  Most of the time  Every time

Comment:___________________________________________

10. When I was attending to the second display I was more likely to make a mistake in my game.

1  2  3  4  5

Comment:___________________________________________

11. I could attend to the second display without any conscious effort.

1  2  3  4  5

Comment:___________________________________________