Investigating Visual Attention in Hidden Object Games

Daniel Jenkyn

Bachelor of Science in Computer Science with Business with Honours
The University of Bath
May 2018

Investigating Visual Attention in Hidden Object Games

Submitted by: Daniel Jenkyn

Declaration

This dissertation is submitted to the University of Bath in accordance with the requirements of the degree of Bachelor of Science in the Department of Computer Science. No portion of the work in this dissertation has been submitted in support of an application for any other degree or qualification of this or any other university or institution of learning. Except where specifically acknowledged, it is the work of the author.

Signed:

Abstract

The primary focus of this study is saliency, image modulation and their affect on task difficulty. In order to investigate this, a hidden object style game has been developed as a more engaging environment for data collection.

The study has shown that image modulation can reduce task difficulty, and that the hidden object game can serve as a test-bed for future visual studies.

Contents

List of Figures

List of Tables

Acknowledgements

I would like to thank both of my supervisors Eamonn O'Neill and Jacob Hadnett-Hunter for the absolutely invaluable help, support and guidance they have offered. I would also like to thank my family and Hannah for the support throughout my whole degree, I could not of done it without any of you. An additional special thanks must be made to Colonna and Smalls in Bath, who provided an endless supply of caffeine to fuel my degree.

Chapter 1

Introduction

As humans we are continuously searching; whether we are looking for our keys, the light switch, or traffic signs whilst driving. We deploy attention as a mechanism to make sense of a visual world that exceeds the processing capacity of our brain. This so called visual search, is an important part in our repertoire of visual behaviours, it forces us to select one, or multiple items in the scene for more detailed analysis, at the expense of other items (Tsotsos, 2012). This effect is demonstrated in figure 1 from Wolfe and Horowitz (2017). At first it is obvious that the image is filled with different colour variants of the letters M and W, but it takes attentional scrutiny to determine whether or not there is a red and yellow M.

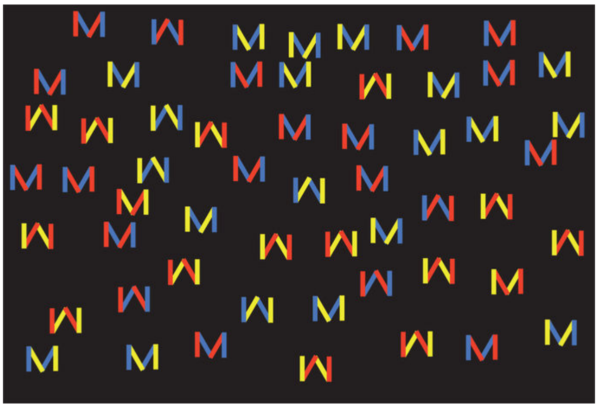

Figure 1.1: Seemingly simple image but a surprisingly difficult search task

The model of visual attention, known as feature integration theory suggests that by breaking down the entire visual scene into smaller regions, they can be analysed and processed in a faster manner (Treisman and Gelade, 1980). In a higher level analogy, this can be thought of as a spotlight, moving and highlighting smaller regions in the visual world (Treisman and Gelade, 1980). Where saliency in this context refers specifically to the bottom-up, visual distinctiveness of an object within the visual field (Treisman, 1988). Visual priority, a combination of bottom-up saliency and top-down task relevance, is the driving force of our allocation of visual attention (Fecteau and Munoz, 2006). Together, visual saliency in combination with visual priority is therefore a way to influence the direction of this spotlight. Simply put, more visually salient locations tend to attract the eye gaze. Is it therefore possible to improve the performance of a search task through saliency or influence the so-called visual attention spotlight?

What shifts the pattern of a viewers gaze may be guided by a variety of influences, these range from the early work of (Yarbus, 1967) on the viewers intent, to more obvious factors such as image modulations proposed by Veas et al. (2011). Most of these techniques can be applied using traditional static images, however they are limited to passive modes of influence patterns. Digital media, more specifically games, offer the opportunity for a more active and dynamic control over the gaze pattern, with a more engaged platform for data collection.,

1.1 Aims and Contributions

The primary focus of this study is saliency, image modulation and their affect on task difficulty. In order to explore saliency and their effect on task difficulty, this project aims to design and develop a hidden object game.

Thus, the main research aims for this project consist of the following:

1. Does image modulation reduce search task difficulty?
2. The creation of an environment for more engaged data collection in the form of a hidden object game.

Hidden object games, perhaps more famously recognised as “Where’s Wally?” books (Handford, 1997), contain large numbers of distractors as well as more and less salient objects; in which the player must find a series of hidden objects. In some sense they represent the other extreme to the standard, simplistic psychophysics visual search tasks. By digitising “Where’s Wally?” (Handford, 1997), a platform, or test-bed is created which gamifies visual search tasks and thus provides an environment for more engaged data collection and experimentation.

Whats more, because of digital media's inherit flexibility, any number of visual properties can be manipulated and changed at will in real-time. As such this opens the possibility of directly influencing where people gaze and how they search in a a more natural form of combined feature search, with targets having more specific context and meaning.

For this reason, a simple 2D game was developed using the Unity game engine. The game itself consists of simple, black and white, hand drawn assets. The simple design of the assets keeps the player focused on the particular search task. The game also features a linear progression system, representing task difficulty. The end result is a collection of various metrics from a complete study, to which an informed evaluation is made on whether manipulating salience, through image modulation has an effect on task difficulty.

1.2 Overview

The general structure of the dissertation is as follows:

Chapter 2 **Literature Review** - This chapter explores the field of visual attention including basic definitions, to a brief overview of the human vision system and the current model of visual attention. Finishing with an overview of techniques used to influence gaze.

Chapter 3 **Software Design and Implementation** - This chapter begins by outlining the high level requirements for the hidden object game, with a review of the design decisions and methodology used in the development of the game.

Chapter 4 **Experimental Design** - This chapter describes the approach taken during the design of the study. This includes a formal outline of both the research questions and hypotheses, finishing with a review of the variables measured and changed throughout our study.

Chapter 5 **Results** - This chapter presents the statistical analyses of the data and metrics collected from the study.

Chapter 6 **Discussion and Conclusion** - This chapter evaluates the results in relation to existing literature. Limitations of the study are reviewed, suggestions are made for areas of future research; finishing with a reflection of the project in it's entirety.

Chapter 2

Literature Review

In this chapter, a deeper look is taken into the field of visual attention. We begin by building an understanding of how the human vision system functions, by exploring basic concepts from neurobiology and psychology. Understanding the human vision system, we can look at how this supports the current models of visual attention and mechanisms used to control eye gaze.

As previously discussed, this project will focus on visual attention and it's relationship with task difficulty. The following sections will provide a logical, section by section review of visual attention from basic definitions and human biology, to gaze influencing techniques.

2.1 What is Visual Attention?

Before even discussing visual saliency, we must first address the concept of visual attention. Though both are related in terms of psychological and neurobiology structures, they are not the same by definition.

The historical study of attention can be dated back to the last century, with William James stating that:

> "Everyone knows what attention is. It is the taking possession by the mind in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought...It implies withdrawal from some things in order to deal effectively with others..."(1890)

James' assertion that everyone intuitively knowing what attention is, simply because they do it all the time, does bear some scrutiny; putting James' words in a more concise manner, we are aware of only a small proportion of information that encompasses us at all times. Attention is, therefore, the allocation of senses and cognitive resources on this information.

When referring to attention, it should be mentioned there are actually several distinct types of attention, as defined in the hierarchical model (Sohlberg and Mateer, 1989). This five layer model states the following:

Focused attention: The ability to respond discretely to specific visual, auditory or tactile stimuli.

Sustained attention: The ability to maintain a consistent behavioural response during continuous and repetitive activity

Selective attention: The ability to selectively maintain the behavioural or cognitive resource on specific stimuli while ignoring the distracting or competing stimuli

Alternating attention: The ability to shift focus between multiple tasks or different task demands

Divided attention: The highest level of attention, where the individual has the ability to respond simultaneously to multiple tasks or task demands.

For the scope of this essay, the type of attention with most relevance and interest is selective attention. Though both focused and sustained attention do play a role in the context of hidden object games, they are more affected by top-down factors (See section 2.3.2) including personal factors such as emotion, motivation and environmental factors (Sohlberg and Mateer, 1989).

Selective attention is needed for visually complex scenes that contain a vast amount of visual information, such as those found in hidden object games. The human vision system alone cannot cope with such quantities of information. Visual attention is a tool employed to help overcome this bottleneck (Desimone and Duncan, 1995; Itti and Koch, 2001) by directing focus to important subsets of information, embedded among a visually complex scene.

Simply put, visual attention is the ability to extract important information from a visually complex scene.

2.2 What is Visual Saliency?

Following the previous definition of visual attention, we are now left to answer what role saliency plays. If visual attention is the process of focus itself, then how are those subsets chosen?

Salience itself is a relative property; it depends on the context of the scene and the relationship of one object with respect to other objects (Wolfe, 1994). An object's physical properties can make an object more salient than other objects in the scene, such as its size, colour, shape, movement or orientation (Wolfe, 1998).

This mechanism most likely developed as the result of survival, ensuring organisms can focus their limited cognitive resources on the most relevant subset of the visual scene such as threats, predators and food (Itti, 2008). Certain organisms may have therefore evolved to become particularly perceptive to some visual properties.

Visual attention is then drawn towards salient visual features. This key piece of information plays a large role in attention and is the basis for this project. However, this is not the full picture, visual saliency so far has been discussed as a task independent process. While this is true, saliency can be influenced, or even over-ridden, by human cognitive influences (Itti and Koch, 2001; Desimone and Duncan, 1995).

Therefore, saliency in this context refers specifically to the bottom-up, visual distinctiveness of an object within the visual field (Itti and Koch, 2001; Treisman, 1988; Wolfe, 1998).

Somewhat unsurprisingly, this concept of a two stage model, where attention can be influenced by tangible features in a scene, and a higher cognitive process can be traced back to William James. His proposed framework suggests that subjects selectively direct attention to objects in a scene using both bottom-up, image-based saliency cues and top-down,task-dependent cues (1890).

Having defined these two vital terms, it should be noted that these definitions provided are of a somewhat high level view; this is done to ensure a logical reading order. Greater clarity of these concepts will become apparent as we discuss the mechanisms behind them in later sections.

Let us now take a brief overview of the human vision system, notably the brain and eyes. We can then move on and consider the several types of frameworks that explain selective visual attention.

2.3 The Human Vision System

This short section is meant to be a basic, non-detailed description of how visual information flows from retina to higher regions in the brain. This process is far more complex than outlined in this literature review and is still a topic of much research. What should become clear, is that the vision system is not a process carried out solely by the eyes, in the same way that visual input processing is not carried out exclusively in the brain.

When discussing the human vision system, we are generally focused on the primary visual cortex and the downstream areas along the pathways for the processing of vision. In between the eyes and the visual cortex, there are also a number of important structures. The general flow of visual information is represented here:

1. The processing of visual information in our vision system begins in the retina.

2. Most of this information is then reaches lateral geniculate nucleus (LNG).

3. Two outputs from LNG will then feed into the primary visual cortex (V1). This is considered to be where the start of information processing begins, in the cortical feed-forward visual pathway. The cortical feed-forward visual pathway has been split by functionality into the dorsal and ventral pathways.

4. The ventral pathway is understood to be responsible for processing location and motion information. Thus it can be described as the “where” pathway. It leads through extrastriate areas to the inferotemporal cortex (IT).

5. The dorsal pathway is understood to be responsible for processing the shape, colour, and identity of visual stimuli. Thus it can be described as the “what” pathway. It leads to from V1 to the medial temporal (MT) and medial superior temporal (MST) (Baluch and Itti, 2011).

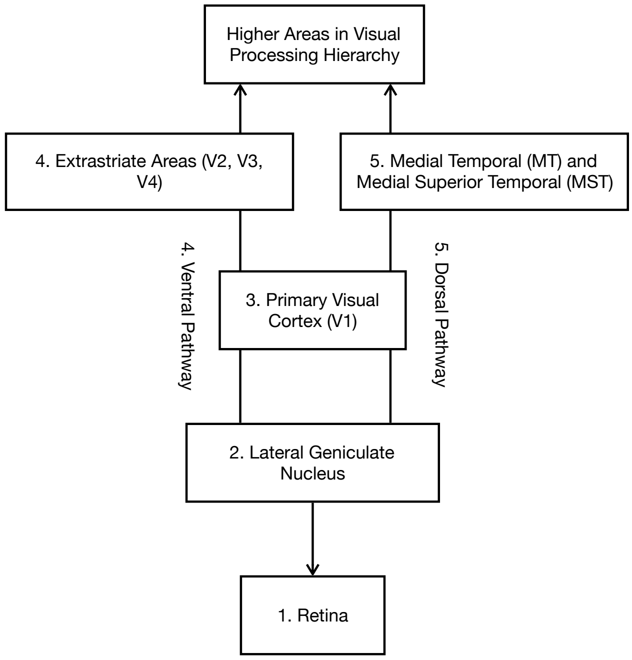

Figure 2.1: A visual representation of the information processing hierarchy

2.3.1 Bottom-Up Processing

Using this figure, along with the information above we can now discuss bottom-up processing.

In the ventral and dorsal pathways, visual information is transmitted from the primary visual cortex to higher regions in the information processing hierarchy. During this communication, visual information is gradually "interpreted" and various visual stimuli will contend with each other. Certain visual stimuli gradually pop-out if they are sufficiently distinct from the other surrounding stimuli. The object that is said to pop-out automatically attracts bottom-up attention (Baluch and Itti, 2011).

Since visual information flows from "bottom" brain regions to "top" regions, the process is described as the bottom-up process and visual saliency generated in this process can be described as the bottom-up saliency. This whole process is extremely fast, in the order of 25-50ms per item, that is excluding eye shift time (Itti and Koch, 2001).

In summary, the bottom-up process is based on low level, early salient features of the visual input such as colour, motion or animation and orientation. This is why a particularly salient region of input stimuli can capture the focus of visual attention.

2.3.2 Top-Down Processing

In contrast to the fast, bottom-up process, there are other sets of considerations at play during visual tasks, in the form of top-down factors. As the name suggests, these influences on attention are generally high level and cognitive, often involving some element of thought, context, mental analysis, and prior experiences or knowledge. The bottom-up process addressed earlier can be modified by these top-down factors of the searcher.

A demonstration of the top-down process can be seen in the proposed experiment by Yarbus (1967). In the experiment, observers were asked several questions about a picture of a piece of artwork, “The Unexpected Visitor”, shown in Fig. 2.2. The visual attention focus of observers was different between the question-less case and a case with a question. The resulting eye movement in the question-less case vs cases with a question were also different. In the case with a question, the selected regions converge around the faces of the people when the observers were specifically asked about persons’ ages (Fig. 2.2).

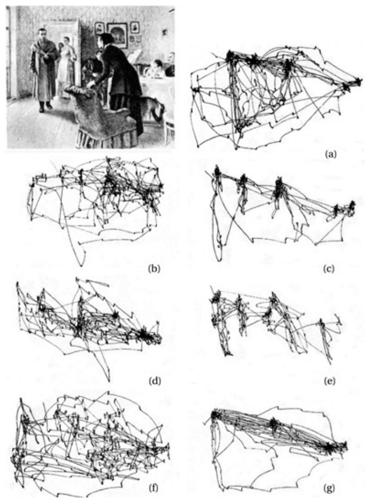

Figure 2.2: The fixations and tracks of saccades noted by Yarbus (a) Free examination. (b) Estimate the material circumstances of the family in the picture. (c) Give the ages of the people. (d) Surmise what the family had been doing before the arrival of the unexpected visitor. (e) Remember the clothes worn by the people. (f) Remember the position of the people and objects in the room. (g) Estimate how long the unexpected visitor had been away from the family(1967)

The top-down process does have an associated price though; commonly, task-driven attention costs around 200ms (not including eye movement time) for a younger, more unpractised individual (Itti and Koch, 2001). Accumulating knowledge and generally learning help to reduce the overall time cost of top-down attention.

We can now state that certain features in the visual world automatically attract attention and are experienced as visually salient, however directing attention to other locations or objects requires voluntary effort, or as Bruner states, "We go beyond the information given"; learning to combine assumptions, with information derived from past experiences, to the evidence of our senses (1957).

2.3.3 Top-Down or Bottom-Up, Which Takes Precedence?

Commonly, both bottom-up and top-down attention mechanisms function concurrently, under test conditions it's also been shown that hardly any search is purely bottom-up or purely top-down driven (Wolfe, 2007). It can be hard to comprehend which attracted region is the effect of bottom-up or which part is influenced by top-down. In the case that an item of considerable bottom-up salience is not the desired target of the current visual search, what would happen, if bottom-up and top-down factors equally oppose each other, will top-down goals supersede those of an otherwise salient item or will that item take precedence and draw attention. Williams suggests that under strong top-down influence, partially salient stimuli are suppressed. However, some stimuli are still very hard to ignore (1985).

Top-down versus bottom-up processing can be demonstrated using the related Stroop effect (Stroop, 1935). The Stroop effect is a phenomenon which occurs when a participant is asked to say the colour of a word, but not the name of the word, an example of this can be seen below:

Blue Yellow Magenta Green Red

As seen, reading each word is far easier than describing the colour of each word. At face value this simple task hides a surprisingly amount of complexity. There is clearly a conflict between task relevant information, the word colour, and the task irrelevant, the word itself; one explanation could be the conflict between bottom-up and top-down processing.

2.4 Feature Integration Theory

Arguably one of the most influential models of human vision attention is feature integration theory (Treisman and Gelade, 1980). Despite the fact the theory has been somewhat altered and revised in recent years (Wolfe, Cave and Franzel, 1989; Wolfe, 1994), the theory is still the foundation of visual attention, having been confirmed by multiple psychological tests reported in the original paper of Treisman and Gelade (Treisman and Gelade, 1980) and various studies on neurological patients (Treisman, 1998).

2.4.1 Concepts of Pre-attention and Attention

As proposed by Neisser (1967), visual attention can be divided into two stages, the pre-attention and attention stages.

The pre-attention stage supplies fundamental information for the subsequent attention processing stage; a feature, for instance size, must be discovered before this stimulus can advance to the next stage for further processing. In pre-attention, both features on the background and the objects themselves are extracted. However, only the objects may draw the observer's attention in the attention stage. Referring back to section 2.3, in the human visual system, more specifically the cells of the primary visual cortex (V1), can excerpt simple features from their receptive fields by applying a variety of filters. This process is involuntary, automatic and happens with extremely high speed. It works in parallel, that is the simultaneous performance of operations, for numerous features in the visual scene.

The attention stage follows the pre-attention stage. The region with important information in the input scene is fixated longer and is observed in detail. In the attention stage, only one target is processed at a time, that is to say it happens in serial. This stage may need the integration of multiple features and can require assistance from an observer's knowledge, experience and their intent.

In summary, pre-attention is a mechanism based on a single feature. In the pre-attentive stage, there is an implied unlimited capacity; that is to say, all information is processed across the entire visual scene. After the scene has been analysed and features are interpreted, attention can then be focused serially, using a more limited capacity system. In the attentive stage, the dominant feature may be selected, or features may be integrated together. A target with multiple features can then be focused.

2.4.2 The Theory

The feature integration theory, suggests that various kinds of visual features are registered unconsciously and automatically in the early stage of the visual process. Feature searches can be performed rapidly, in parallel and pre-attentively for targets defined by only one feature, such as colour, shape, perceived direction of lighting, movement, or orientation. Features are then able to pop out during search.

After this initial stage, the slower conjunction search is performed, only this time with a combination of two or more features in serial. These features are then treated as a whole for object identification. Conjunction search is much slower than feature search because of the required attention and effort, which feature search does not. Consequently, feature search stage is known as the pre-attention stage, while conjunction search stage is known as the focused attention stage.

Various experiments conducted by Triesman and Gelade (1980; 1984), as well as studies on neurological patients, have verified the feature integration hypothesis (Treisman, 1998). There is some uncertainty surrounding feature integration theory, such as which aspects of the visual stimulus can act as the pre-attentive candidates. To address this particular concern, the probable, possible and unlikely pre-attentive features were summarised by Wolfe (2005; 2017) as seen in fig. 2.4.2. These pre-attentive candidates maybe of particular interest to this report's later work.

Probable	**Possible**	**Unlikely**
Colour	Novelty	Intersection
Luminance onset (flicker)	Threat	Faces
Orientation	Shininess	Colour Change
Size (length and spatial frequency)	Threat	Your Name

Table 2.1: A condensed version of Wolfe's probable, possible, and unlikely sources of pre-attentive guidance.

Nonetheless, feature integration theory is still very relevant today and has become the foundation of following studies, such the various versions of Guided Search Theory proposed by Wolfe (Wolfe et al., 1989; Wolfe, 1994).

2.5 How Can Gaze be Influenced?

There are several ways in which to consider how gaze can be influenced. The first being to draw attention by making a visual features appear more salient through the use of basic pre-attentive features such as colour, size, orientation etc. This leads to the question, can we use the same effect to avert eye gaze away from certain areas of a scene. This could be particularly potent mechanism when used in conjunction with search tasks. Lastly, we can influence gaze through the use of top-down processing. This has already been successfully demonstrated by Yarbus (1967) as discussed in 2.3.2, whereby asking a simple question influenced where observers looked. Interestingly, top-down effects may also be used to suppress certain salient bottom-up features (Williams, 1985).

A more detailed account of these affects is given in the following sections.

2.5.1 Drawing and Averting Gaze

It still remains largely unknown the comparative strength of contributions from bottom-up information versus top-down information in determining what people find interesting (Henderson, 2003). Thus it may be the case that bottom-up processing that has predominant role in guiding attention and therefore gaze(Itti, 2005). We will not be focusing on the top-down effect of gaze, purely because it is dependant on the prior experience and the task a person is faced with. While it can be used to influence gaze, implementing this into a piece of software seems counter-intuitive, where a user wants to perform a specific goal.

Most systems that are used to attract eye gaze tend to rely on various pre-attentive mechanisms. The focus here however shall be more on complex and unexplored pre-attentive mechanisms rather than strictly colour or orientation. Some of these pre-attentive mechanisms involve regions of sharp focus and contrasting blurring effects, undetectable warm-cool modulations, depth of field (Kosara, Miksch and Hauser, 2001) or interestingly relative size. As a result, humans may miss objects of the wrong size, given the surroundings as highlighted by (Eckstein, Koehler, Welbourne and Akbas, 2017). Given the large number of pre-attentive features (Wolfe, 2005), we shall first look at methods which are obvious; obvious meaning that the user is aware of a feature influencing their gaze. Perhaps more captivating would be methods in which gaze could be influence, without the user necessarily being aware of it.

A slightly different, unproven and fairly experimental approach would be one based on the idea that visually interesting objects are more salient as raised by Elazary and Itti (2008). They hypothesise given no search task, target or other constraint; an observers bottom-up information might play a predominant role in guiding attention toward potential generically interesting targets. However, it has not been shown whether a visual location that is attracting the gaze is also being judged as interesting. Thus, if interesting features are chosen on a purely bottom-up process, then influence from the the top-down process is not required, and by making region in scene contain interesting features then eye gaze can be attracted. The obvious drawback with this proposed method is that it would alter the visual scene in a rather obvious way. Elazary also concludes that "the presence of low-level features along with some evaluation of their uniqueness in the visual field...are one of the reasons why human subjects would consider a visual location as interesting to look at" and that "such elementary visual properties of scene locations only prime subjects toward attending to salient locations and toward subsequently extracting more information at these locations" (2008).

Texture power maps are an unusual form of pre-attentive mechanisms; the technique is based on the premise that contrast in texture contributes to saliency. This post-processing technique selectively reduces distracting regions using a texture equalization technique to reduce variation in texture (Su, Durand and Agrawala, 2005). The effect is quite subtle, but is still noticeable. Of course this technique is a post-processing effect, meaning, as it stands, there is not real-time a real-time software implementation. Curiously, how this particular technique compares to say Gaussian blur is something to be considered.

Most of what has been discussed so far has been applied and tested on static images, however with access to digital mediums such as videos, games and daily interactions with UI interfaces, are there more subtle, inconspicuous techniques of influencing gaze. Subtle Gaze Direction (SGD) is technique designed to do just that. The SGD technique relies on the fact that human peripheral vision processes stimuli faster than foveal vision (Ogden and Miller, 1966). When initially viewing a scene, the peripheral vision of the human visual system locates areas of interest. The slower, but more perceptive foveal vision, is then involuntarily directed to focus on these areas. SGD works by modulating areas that only appear in the peripheral vision. Once again, the foveal vision then focuses on this area. Subtle luminance or warm-cool modulations can be used to attract foveal vision (Bailey, McNamara, Sudarsanam and Grimm, 2009). This mechanism has been used relatively successfully directing gaze in narrative art (McNamara, Booth, Sridharan, Caffey, Grimm and Bailey, 2012) and Guiding Attention in Controlled Real-World Environments (Booth, Sridharan, McNamara, Grimm and Bailey, 2013), however the technique does require use of an eye tracker.

An alternative method to SGD, is that of visual Saliency Modulation Technique (SMT) (Veas, Mendez, Feiner and Schmalstieg, 2011). The main idea behind this alternative method is to modify features of the real-world image, rather than adding new objects. This can be done in real-time, but so far has shown some promise for pre-recorded videos under lab conditions, with SMT shown to "significantly shift attention and influence memory to selected areas of a video without the viewer becoming aware of any manipulation." (Veas et al., 2011). Much like SGD, the method is very subtle, with differences only becoming apparent when frames of the unmodulated and modulated video are compared side by side. Arguably though, this method is more invasive. However, because of this, there is not a reliance on eye tracking hardware, thus making it easier to implement into AR and video based systems.

Averting gaze is not as frequently studied, neither is it as common as itâĂŹs previously mentioned counterpart, most likely due to the fact that drawing attention to a region rather averting it from every other region is more logical. Naturally, the methods mentioned for drawing gaze can be used to avert eye gaze, by simply drawing gaze away from an intended region. As previously mentioned, it would be interesting to see the affect of drawing gaze to help in search tasks, while also using the same effect to hinder search tasks; averting the gaze from specific regions

This section has focused on a small number of potential mechanics and techniques that could be used to influence eye gaze, all have various advantages and drawbacks, but most have had limited software implementation. While some, such as SGD, have certainly been used with static images (McNamara et al., 2012), they still have not made the transition to dynamic software environments.

2.6 Chapter Summary

This literature survey has discussed the concepts that underpin visual attention, from its earliest exploration by James (1890), the high-level discussion on the Human Vision System, to the highly influential feature integration theory (Treisman and Gelade, 1980), culminating in a review of proposed approaches to manipulate gaze.

While there has been an abundance of previous work that utilise simple arrays of geometric objects, there seems to be a lack of a more applied, practical and natural form of visual search. Hidden object games are an order of magnitude more complex than the arrays of geometric objects that are typically used in visual search studies, the scenes are deliberately cluttered and contain large numbers of distractors as well as more and less salient objects. In some sense they represent the other extreme to the simplistic scenes used in previous work. Results on such images certainly leave open a range of intermediate visual complexity in which salience effects might be weaker and harder to detect.

Whats more, because of digital media's inherit flexibility, any number of visual properties can be manipulated and changed at will in real-time. As such, this opens the possibility of directly influencing where people gaze and how they search in a natural environment.

In closing, while the field of vision attention has attracted a huge amount of interest and research, manipulating gaze has been somewhat neglected with a lack of software based implementations. While trivial in nature, a hidden object style game provides the perfect testing environment for the various studies surrounding visual attention. This has demonstrated that it would be worthwhile developing such a game with the aims of exploring visual saliency and it's effect on search task difficulty; with additional benefit of creating a test-bed for future work.

Chapter 3

Software Design and Implementation

This chapter focuses on the design of a test-bed that gamifies visual search tasks providing a an environment for more engaged data collection and experimentation. This chapter includes the key design considerations made during the development of the game, culminating in the creation of an initial prototype for use within a pilot study. A list of code can be found within section D, as well on the provided USB stick.

3.1 Requirements

All requirements are derived from issues and considerations raised in the literature review. If these requirements are delivered, then all goals of this research project should be achieved.

As this project intends to include multiple iterations of implementation, adjusting aspects of the system based upon pilot studies, the requirements are noted at a high-level so that they can be altered if necessary. In addition, since the main purpose of the game is to address the proposed research questions, the requirements emphasise the core system functionality.

Each specific requirement will be assigned a priority indicated by use of the words *MUST*, *SHOULD* and *MAY* in accordance with RFC 2119 (Bradner, 1997) outlined below, followed by the defined requirements.

MUST - An absolute requirement of the specification.

SHOULD - There may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood and carefully weighed before choosing a different course.

MAY - An item is truly optional.

3.1.1 The game must collect valid metrics and data for each level, reflecting participants performance

In order to assess the effectiveness of the game and provide insight for the study, the game needs to record data to help quantify participants performance.

3.1.2 The collected data must remain anonymous

To keep the study ethical, participants identities and collected data will remain anonymous for the benefit of their own individual beliefs. In addition, a participant or subject is more likely to provide honest responses when their identity is not going to be exposed.

3.1.3 Two versions of the game must be created

Two versions of the game must be created. One that includes image modulation, one that does not. The final experiment will include both.

3.1.4 One version of game must include luminance modulation

The game must include luminance modulation as it doesn't require any additional equipment, and because of it's relative ease of implementation.

3.1.5 The image modulation should be subtle

The modulations should not be obvious and as subtle as possible.

3.1.6 The game must include include linear progression from easy to hard

To asses whether image modulation has an effect on task difficulty, some form of linear progression must be included in the game.

3.1.7 Each level must be unique, to limit top-down effects

The top-down effects and learning effect must be eliminated through the use of uniqueness. If each level is unique, with no prior participant knowledge then top-down effects are limited and the learning effect is eliminated.

3.1.8 The game should have three levels

Having three levels in the game reduces the amount of assets and design required for the game. In addition, three levels makes it easy to define difficulties and difficulty progression i.e. easy, medium, hard.

3.1.9 Each level may have a time limit

To prevent participants having difficulty and taking limitless time on one level, a timer may be included. This also keep the experiment running in a timely manner.

3.1.10 The game should be a test-bed

While this is certainly a more high level and vague requirement, effort will be made to keep the game simple and malleable for use within other visual studies, hence the idea of it being a test-bed.

3.2 Game Overview and Goals

To gain a clearer conceptualisation of the game, a brief overview of the format and goals of the game are listed below:

- Participants are presented with three objects to find, which are hidden in the scene.
- Once a participant has found an object they left click on the object.
- After the three objects have been found they are taken to the next level.
- There are a total of three levels, and an additional training level for the final experiment.
- There will be two versions of the game. One with luminance modulation, one without. Participants will only be exposed to one version of the game.

It is also important that by design the game is simple, it is nothing more than a digitised version of "Where's Wally?" (Handford, 1997). The main reason behind this choice is to limit the number of confounding variables. Animation, sound, even colour all have their place within a game, but for this study on salience and task difficulty these are not required and could even have adverse affects on the results. It is also worth reiterating that this is meant to be a test-bed for future studies; the idea being that if a study was proposed, centred around animation, then the game assets could simply be swapped out.

3.3 Software Choices

In this section, an outline is given on the choice of game engine, programming language and the reasons behind each choice.

3.3.1 Game Engine

The first real decision to make was that of the game engine. It is common knowledge, that any experienced game developer would be able to create a small scale project like this in any one of the popular game engines such as Unreal Engine 4, Unity or Godot.

For a hidden object style game, all of the engines and their respective feature sets would be equally suited. The biggest factor in deciding which engine to use came down to the amount of online documentation. Unity was a clear winner in this regard. From a personal perspective, Unity was a tool that I had little experience with and had never had the opportunity to fully explore. Factoring this in, Unity became the choice of game engine.

3.3.2 Programming Language

After deciding that Unity would serve as the game engine; the choice, or lack of, left the C#programming language; with UnityScript(JavaScript) being deprecated in late 2017 (Fine, 2017). While not possessing a great deal of experience with C#, the vast amount of online documentation for Unity, combined with prior experience in both Java and C would most likely result in the choice of C# not having an negative impact on development.

3.3.3 Other Tools

Having used Unity in the past; MonoDevelop, the IDE supplied with Unity has proven to be fairly unstable, frequently crashing on other projects causing data loss and other problems. For this reason the Sublime text editor was used to write code.

For editing images, Adobe Photoshop CC 2018 was used. With IBM SPSS Statistics used to analyse the results and Microsoft Excel to create a variety of graphs.

3.4 Version Control

Originally GitHub was used as version control for the game, with the added benefit of issue tracking. When development of the game actually began, it became clear that more time was spent managing the project than actually building it. This is not a criticism of GitHub itself, rather it was due to the small nature of the project. Eventually GitHib was abandoned all together.

3.5 Level Design

Level design was a fairly major component of the overall game design. The levels had to be designed in way that they felt familiar to participants and something they could relate to. If the levels were set in some form of fantasy setting, participants may not know what objects they are searching for, or worse, unable to make sense of the overall scene.

Each level had to be designed with difficulty in mind. The problem here is differentiating between what is considered an easy search task and what is considered a hard search task, with an array of individual variables at play (Wolfe and Horowitz, 2017). Many variables had to be considered, including the location of the hidden objects, their relative size (Wolfe, 2017), the overall amount of visual clutter (Henderson, Chanceaux and Smith, 2009; Asher, Tolhurst, Troscianko and Gilchrist, 2013) in the scene and the task of scaling difficulty across three levels.

Originally it was intended that to make this design task simpler, the level size could increase for each difficulty, thus increasing overall task difficulty (Chan and Hayward, 2009). The problem was now a case of screen real estate, fitting everything on a display and keeping overall clarity of the scene. Scrolling, or panning could not be used because of the potential side effects on completion time and image modulation.

In order to stimulate participants to search efficiently, in all levels, they would be given a limited time to complete the level. This time limit would not appear on screen but they would be informed verbally before the study and in the study brief. This has the additional benefit of ensuring participants do not have difficulty on a particular level, and would keep the experiment running in a timely manner.

Figure 3.1: An early version of level 2

With all this taken into consideration levels were first sketched out by hand on paper, to get a general sense of proportion. Once the focal point hand been determined, these sketches could then be digitally scanned, where they could then be layered with objects, and any blemishes fixed.

3.6 Asset Creation

Once the level design was complete, assets were created in the same way, by hand drawing them in pen and then digitally scanning them.

The assets were hand drawn for two reasons, a lack of skill in terms of creating digital art, even when it comes to simplistic styles such as “Pixel art”. Secondly, despite an abundance of free game art available under Creative Commons licence, the art styles would not match, thus having their own individual undesired effects on saliency and visual attention.

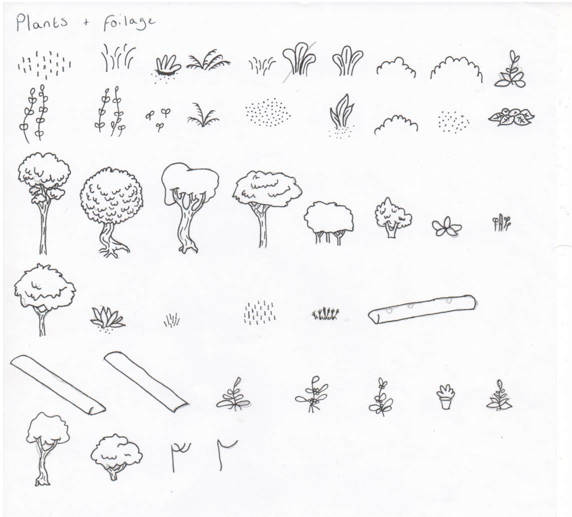

Figure 3.2: Variety of hand drawn objects, not all were necessarily used in the final version of the game

Creating the assets took longer than expected. To speed up the process some objects were reused, but flipped to create different variations. Rather than drawing each object individually (figure 3.2) and then placing them in the scene, sections of scenes were created and then pieced together (figure 3.3). The hidden object locations had been determined during level design, and after the full scene was complete, these individual objects were placed in the scene. Other minor elements such as the UI were created digitally using Photoshop.

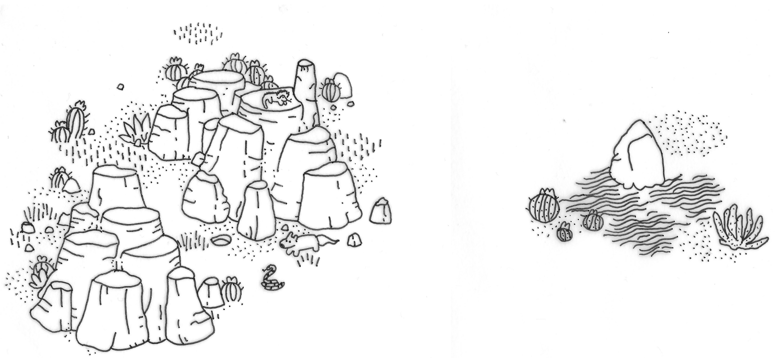

Figure 3.3: Two hand-drawn sections of a level

3.7 Image Modulation

Luminance modulation was chosen for it's subtlety, and its non-reliance on colour, fitting with the overall game aesthetic. As highlighted by Wolfe, there is also evidence to show that luminance modulation is one of stronger forms of guiding attributes (2017; 2005). Below shows an asset from the game, with a slightly exaggerated version of both, warm-cool modulation and luminance modulation. Note, that this is an exaggeration and not an exact representation of the modulation used within the final version of the game.

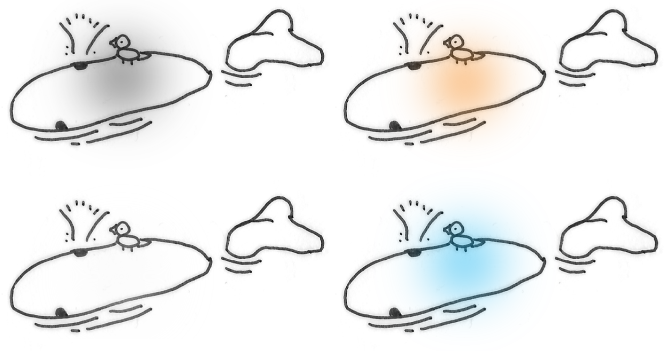

Figure 3.4: On the left is an example of luminance modulation, on the right warm-cool modulation

In order to control the on-off, or flicker effect, in accordance with time, a simple sine wave is used. Where 1 represents on and -1 represents off; more specifically 0 acts as a switch point, where any value over 0 is considered on and any value less than 0 is off. The frequency of the on-off modulations per second, or Hz will determine the number of times the on-off effect occurs. This can be seen diagrammatically here:

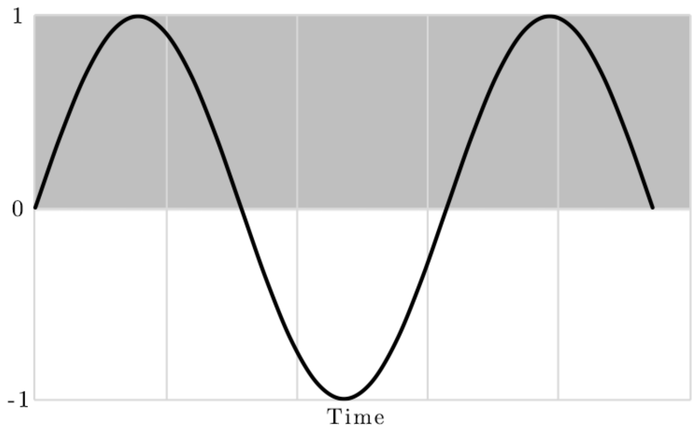

Figure 3.5: Sine wave used to express the on and off oscillation according to time

The result was fairly easy to implement in working code. What became obvious though is that determining values such as the on-off rate (Hz), how long it should remain on screen and alpha values was far more difficult and using arbitrary values was not an option.

To overcome this problem a separate pilot study was carried out to determine the frequency of the modulations and their respective alpha value (transparency). Further details on this pilot study and the prototyping process in general can be found in section 3.8.2.

```
void startFlicker() {
    // Update frequency time-step
    dtime += Time.deltaTime;
    // Sample the wave at a specific time.
    double wave = Mathf.Sin((dtime * 2.0f * Mathf.PI) *
        cycleHz);
    // Cycle between enabling based on the wave
    if(wave > 0.0f) {
      GetComponent<SpriteRenderer>().enabled = true;
    } else {
      GetComponent<SpriteRenderer>().enabled = false;
    }
    // Prevents dtime from climbing to infinity
    if (wave == 0.0f) {
      dtime = 0.0f;
    }
}
```

Listing 3.1: Below shows how the luminance modulation was implemented. The method itself is called within an update method, causing it to be called every frame.

An unforeseen issue that became obvious during development was the relationship between refresh rate of the monitor, frame rate and the Hz of the image modulation.

Generally speaking if an image is being rendered at a slower rate, than the monitors refresh rate, the same frame is displayed for a brief time. The image modulation could then remain on screen for multiple frames; too fast, and screen tearing occurs. In either case, the subtlety of the image modulation would be impacted. This wasn't so much of an issue for the main study because it would use the same monitor, with the same refresh rate for every participant.

3.8 Data Logging

As part of the requirements in sections 3.1.1 and 3.1.2 it was noted that the game must keep track of the participants performance and keep this data anonymous.

Metrics are logged whenever a participant finds an object, or in the case where a participant fails to find an object, data is saved when the level timer expires. When the user has completed all levels, these metrics are written into a simple `.csv` file. Each participants data is stored in a different `.csv` file, mainly as a safety precaution against data loss. This `.csv` contains, the name of the object found,the time taken to find each object and the number of clicks taken to find an object. From this, other data can inferred such as total time to complete a level.

The data collected is not associated with participants name, or any means of identification as per requirement 3.1.2.

3.8.1 Prototyping and Testing

Despite the perceived simplicity of the game, testing and prototyping played a larger role than anticipated.

Having created a set of high level requirements in section 3.1, the initial thought was that two cycles of development would take place, including user testing and adjusting requirements as needed. As previously mentioned, in section 3.7, it became clear during development that the image modulation would require its own pilot study, to establish a number of variables.

Furthermore, there were other subtle issues, associated with the execution order of mouse events within Unity. `OnMouse()` methods actually execute before the `Update()` methods (Technologies, 2018*b*). This resulted in the number of mouse clicks being incorrectly recorded, when a user found a hidden object. The documentation surrounding the issue were fairly scarce. For a more experienced developer, this may have been obvious during development, but in this case it wasn't until user testing was carried out that the error became clear.

This issue highlighted the importance of user testing and prototyping, even more so in this case where they software would be used within a controlled scientific study.

3.8.2 Exploratory Pilot Study for Determining Software Values

To determine the values such as the frequency of the image modulations and there transparency, a small pilot study was conducted. Three participants were involved in this pilot study. Each participant was shown a small demo with a version of the luminance modulation to be used in the final version of the game.

The modulations were very noticeable to begin with, with a very low frequency and high opacity. Participants were instructed to use the controls provided to adjust the modulations to the point where they were just barely noticeable.

Adjustment increments for each value were +/- 2 for Hz and +/- 0.1 for the alpha value. The final values for Hz and alpha were obtained by taking an average of the three participants end values. With Hz a value of 29.3 was obtained and alpha at a value of 0.26.

These values were slightly altered for the final study with a Hz value of 30 and alpha value of 0.3.

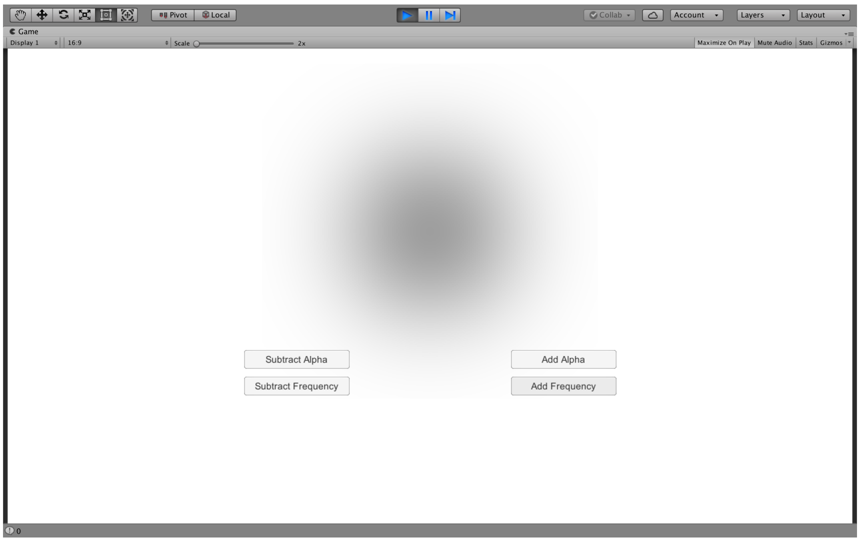

Figure 3.6: A screenshot taken from the pilot study demo

3.9 Chapter Summary

This chapter presented the approaches taken in design and implementation phase. The prototypes build on the initial requirements, with the final prototype being refined in a pilot study. With a final tested prototype, attention can now be turned to the experimental design and how the prototype can be used as tool to achieve test the research questions.

Chapter 4

Experimental Design

This chapter will detail the design approaches undertaken before conducting the study. This includes a formal outline of both the research questions and hypotheses, and then a review of the variables measured and changed throughout the study. The experimental procedure is refined through a preliminary pilot study. Concluding this chapter is a summary of the ethical and study materials, along with a description of the participant demographic.

4.1 Aims

The overall, and main aim of this study is to understand the effect of image modulation on task difficulty within a hidden object style game.

Furthermore, the study aims to demonstrate, that hidden object games; which are essentially a digital manifestation of "Where's Wally?" books (Handford, 1997), can be a way to experience a more natural form of combined feature search, with targets having more specific context and meaning. Additionally, games in general offer a dynamic experience allowing a greater opportunity in visual studies to easily manipulate variables in real-time that would otherwise be unavailable using more traditional mediums.

In section 2.5.1 it also became clear there are not only a limited number of approaches for directing a viewers gaze, but also a lack of subtlety. Those such as subtle gaze direction (Bailey et al., 2009) also require additional equipment in the form of an eye tracker and rely on less natural forms of combined feature search.

4.2 Experiment Setup

4.2.1 Format

The study has a between-group design for this experiment, with participants being randomly assigned to a group. Repeated measures would not have been suitable for this study due to ordering effects. Most noticeably this would have been fatigue, and the learning effect of participants becoming familiar with the search tasks.

In the scope of this project, we were not expecting to entirely remove gender as a potential extraneous variable due to the realistic number of participants we would be able to recruit. Nevertheless it did allow us to reduce data variance in a minor, peripheral way.

4.2.2 Pilot Study

A short pilot study was conducted with two participants. These participants would be experiencing the game, and search tasks for the first time. One participant was assigned to the version of the game with image modulation, the other to the regular, non-modulated version. The purpose of completing a pilot study was to validate the final version of the game, furthermore, to refine the study design and evaluation process.

After the execution of the pilot study, and subsequent data analysis, there were only minor revisions made to the study structure and visualisations. These are summarised below:

1. The macOS build of the game resulted in a crash, caused by a lack of write permissions to the save data location. This was fixed by changing the save location to `Application.persistentDataPath` a safer save location written into the user Library folder (Technologies, 2018*a*).

2. Some instances of the luminance modulation were not centred on the hidden object. This was caused by bounding boxes for some of the sprites being slightly larger than required.

4.2.3 Study Procedure

The following bullet point list was designed for use by the researcher conducting the experiment. The study consists of three main stages, with a training stage for those unfamiliar with the concept of hidden object games. These stages are detailed below as to ensure consistency of the experiment, and that both participants as well as the researcher is aware of the role.

Participant Brief

1. Show the participants the consent form. Explain the contents of the brief and answer any potential questions. A full version of the participant brief can be found in appendix A.1
2. Reiterate verbally each stage of the experiment.

Training

1. Introduce the game, the concept behind a hidden object game; referring to Where's Wally? to familiarise participants with the concept.
2. Explain the game controls to the participant.
3. Explain that each level has time-limit of three minutes.
4. Make sure that the participant is comfortable and ready.

Main

1. After completion of training, ensure participant is comfy and ready for the main study.
2. The participant can start at any time they wish.
3. The study ends when all levels are completed and participant reaches the end screen.

Debrief

1. Explain the main objectives of the study and answer any further questions which the participants may have
2. Finally, thank them for their time.

4.2.4 Ethics and Study Materials

In addition to the study brief A.1, which was read to the participants at the start of the study, participants were able to request the University of Bath, computer science departmental 13-point ethics checklist. This 13-point checklist was discussed with both supervisor Jacob Hadnet-Hunter, and can be found attached in appendix A.2.

The study procedure discussed in section 4.2.3 was also printed as a guide for the researcher running the experiment.

4.3 Participants

The experiment utilised a between-group design consisting in a total of 18 participants. We strove to consider a diverse and balanced mix of participants for our study. The sample age was relatively young with an average of 33.83 (SD of 15.15) and as a result of convenience sampling, comprised largely of university students.

The participants recruited had not seen the game during development, nor had they been part of either pilot study. Therefore, during the main study, participants would experience the game for the first time.

4.4 Variables

This section outlines the main variables which we focused on during the study. The following are key variables that are defined, manipulated and measured within the study.

4.4.1 Independent

These are the variables which were changed over the course of the experiment. There are two independent variables, forming a 2x3 design.

- Luminance modulation vs No luminance modulation
- Task difficulty (easy, medium and hard)

	Luminance modulation	No Luminance modulation
Easy Medium Hard		

Table 4.1: Graphical representation of the 2x3 design

4.4.2 Dependant

These are the variables which were measured after changing the independent variables defined above.

- Completion time for each level
- Time taken to complete an individual search task
- Number of mouse clicks taken to complete an individual search task

These variables are operationalised in terms of specific, measurable statements below:

Completion time

This is deemed to be the time in seconds from when the level begins, to when the participant completes all search tasks; the level end.

Time taken for individual search task

The time in seconds from when the level begins, to when the particular search task is completed.

4.4.3 Control

In order to ensure the veracity of the study, potential confounding variables have been identified. With the aim to reduce the effect of these confounding variables such that bias and variance on the dependent variables was either reduced or eliminated.

Training

Participants did not require any technical background to be involved in this study. A training session before the study allowed participants to gain experience with the hidden object game and the process of completing search tasks. This training level consisted of unique scenes, with none of the search tasks featuring any of the same objects used in the main study.

Environment and Equipment

Participants were seated in front of the computer screen in a well illuminated room, with environmental noise levels kept to a minimum. An office chair was used with adjustable height to ensure each participant was comfy and that their eye position was level with the centre of the display.

The study took place on the same device for all participants. An early 2016 MacBook, was used to run the hidden object game, with a larger 22-inch external display (with a screen resolution of 1920x1080) used as the main means of interaction.

Ordering

To prevent order bias threatening validity of the study, different participants are used in each condition of the independent variable. Random allocation of participants ensured that each participant has an equal chance of being assigned to one group or the other.

4.5 Hypothesis

The following hypotheses were derived and used in the study. These hypotheses are a result of initial research questions and a review of the literature.

4.5.1 Experimental Hypothesis

- An increasing time to complete levels with no image modulation
- A reduced time to complete levels for levels using image modulation.

- Therefore image modulation normalizes task performance regardless of task difficulty.

4.5.2 Null Hypothesis

The experimental hypotheses would then imply the following null hypotheses:

- No significant increase in time without image modulation
- Little, or no effect on completion time for levels using image modulation.
- Image modulation therefore does not normalizes task performance across any difficulty.

4.6 Chapter Summary

This chapter outlined the initial research questions and outlined the full experiment setup, including the study procedure and how this was informed through a pilot study, as well as the consideration of ethics. Concluding this chapter was a full breakdown of the variables involved in the study, culminating in the hypothesis.

The subsequent chapter contains the results from the study, together with the analysis to fully evaluate the hypotheses described in this chapter.

Chapter 5

Results

The following chapter presents statistical analyses of the data collected from the experiment. The data output from the hidden object game has been statistically analysed with IBM SPSS Statistics version 24.

Recalling the independent within participant factors, these are:

- Image modulation (Two conditions)
  - Image modulation
  - No Image modulation
- Task difficulty, represented by in-game levels (Three conditions)
  - Easy
  - Medium
  - Hard

In order to test the effects of image modulation and task difficulty (represented in the game by levels) on time taken to find an object, a split-plot ANOVA was used. A separate split-plot ANOVA was also used to find any effect of image modulation and task difficulty on the number of mouse clicks.

Data screening did not revealed any univariate or multivariate outliers. In addition, there was no missing data. Hence, all data collected from the participants were included into the main analysis.

Raw results for both version of the game can be found in appendix B, as well as supporting statistics in appendix C.

5.1 Search Time

Descriptive statistics are presented in the below table 5.1.

Levels	Image Modulation	Mean	Std. Deviation	N
Level 1	No	65.1975	27.80915	9
	Yes	28.2622	25.99828	9
Level 2	No	94.2779	33.75319	9
	Yes	48.3518	52.36264	9
Level 3	No	104.9424	38.26412	9
	Yes	65.5482	33.38153	9

Box's test of equality of covariance matrices was not statistically significant $F(6, 1854.79) = 1.799$, $p > .05$, which indicates that covariance matrices between image-modulated and non image modulated group are equal.

The results of the ANOVA analysis have shown that the effects of image modulation $F(1, 16) = 86.123$, $p < .001$ and task difficulty (game levels) $F(2,32) = 12.733$, $p < .001$ are statistically significant while the interaction between the factors is not statistically significant $F(2,32) = .181$, $p > .05$.

5.1.1 Effect of Image Modulation on Search Time

The results presented in figure 5.1 show that participants, on average, took significantly less time to find an object in situations when images were modulated ($M = 47.387$, $SE = 7.783$) in contrast to situations when images were not modulated ($M = 88.139$, $SE = 7.024$). Hence we may conclude that the image modulation significantly decreases the time needed to find an object and to complete one level of the game.

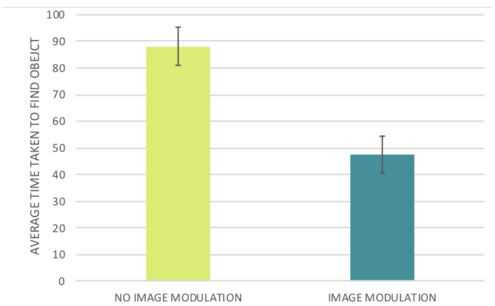

Figure 5.1: Average time taken to find an object across the two groups of participants. Error bars represent standard error

5.1.2 Effect of Task Difficulty on Search Time

The results presented in figure 5.2 show that participants, on average, took significantly less time to find an object on Level 1 difficulty (M = 46.730, SE = 7.612) in contrast to Level 2 (M = 71.315, SE = 11.510) and Level 3 (M = 85.245, SE = 9.449), $p < .01$. However, the results showed that the difference between Level 2 and Level 3 is not statistically significant $p > .05$.

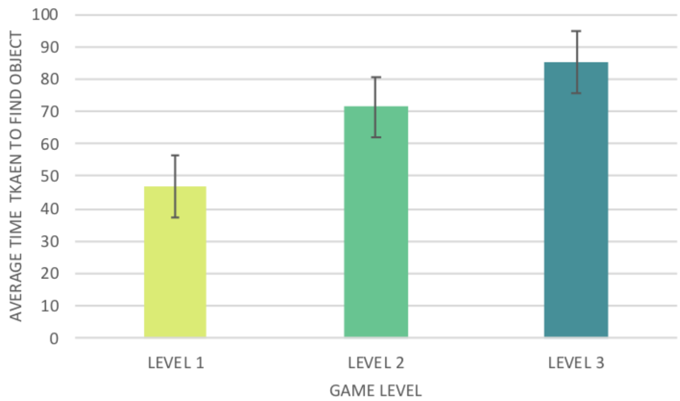

Figure 5.2: Average time taken to find an object across the three levels. Error bars represent standard error

Table 5.1.2 shows the pairwise comparisons for each level. The the results showed that the difference between Level 2 and Level 3 is not statistically significant $p > .05$.

Levels (I)	**Levels (J)**	**Mean Difference (I-J)**	**Std. Error**	**Sig**
1	2	-24.585	6.019	.001
	3	-38.515	8.184	.000
2	1	24.585	6.019	.001
	3	-13.930	8.718	.130
3	1	38.515	8.184	.000
	2	13.930	8.718	.130

5.2 Mouse Clicks

Descriptive statistics are presented in the below table 5.2.

	Image Modulation	**Mean**	**Std. Deviation**	**N**
Level 1	No	8.037	6.9571	9
	Yes	2.4444	0.66667	9
Level 2	No	3.3519	1.27051	9
	Yes	2.4074	1.03786	9
Level 3	No	4.9074	3.01744	9
	Yes	3.2593	0.89408	9

Box's test of equality of covariance matrices was not statistically significant $F(6, 1854.79) = 6.5499$, $p > .05$, which indicates that covariance matrices between image-modulated and non image modulated group are equal.

The results of the ANOVA analysis have shown that while the the effects of image modulation $F(1, 16) = 88.036$, $p < .001$ are statistically significantly, while the effect of task difficulty (game levels) $F(2,32) = 2.439$, $p > .05$ are not statistically significant and the interaction between the factors is not statistically significant $F(2,32) = .181$, $p > .05$.

5.2.1 Effect of Image Modulation on Mouse Clicks

The results presented in figure 5.3 show that participants, on average, clicked significantly less when images were not modulated ($M = 5.432$, $SE = 0.905$) in comparison to situations when images were modulated ($M = 2.704$, $SE = 0.180$).

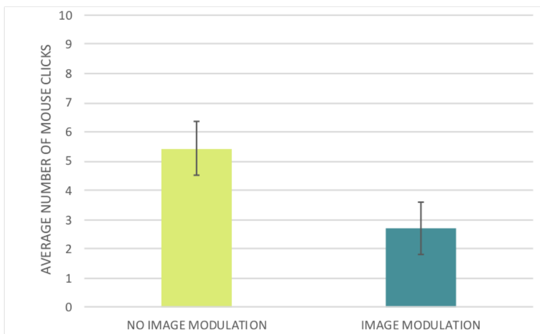

Figure 5.3: Average clicks taken across the two groups of participants. Error bars represent standard error

5.2.2 Effect of Task Difficulty on Mouse Clicks

The results presented in figure 5.4 show that participants across both groups, took a greater average number of clicks in level 1 (M = 5.241, SE = 1.254) and level 3 (M = 4.084, SE = 0.525) in comparison to level 2 (M = 2.88, SE = 0.277). There is no statistical significance between any of the levels p > .05.

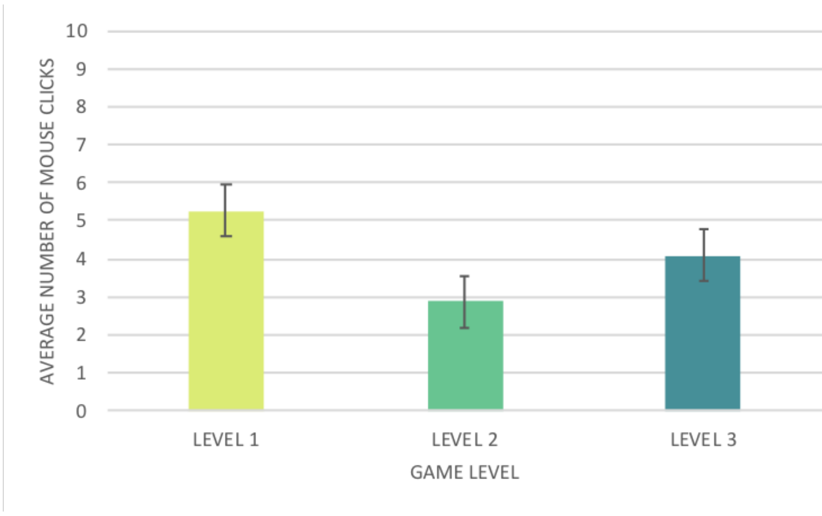

Figure 5.4: Average clicks taken across the three levels. Error bars represent standard error

Table 5.2.2 shows the pairwise comparisons for each level. The table showed no statistical difference between any of the levels.

Levels (I)	Levels (J)	Mean Difference (I-J)	Std. Error	Sig
1	2	2.361	1.100	0.048
	3	1.157	1.384	0.415
2	1	-2.361	1.100	0.048
	3	-1.204	0.551	0.044
3	1	-1.157	1.384	0.415
	2	1.204	0.551	0.044

5.3 Chapter Summary

This chapter reported findings on the effect of image modulation and task difficulty on time taken to complete search tasks. There was evidence to suggest, that image modulation did indeed have an effect on reducing the time taken to complete search tasks. In the next chapter, a more detailed discussion of the results will take place.

Chapter 6

Discussion and Conclusion

In this chapter a discussion takes place, with the implications of our results discussed in the context of research question outcomes. Limitations of the study are reviewed, suggestions are made for areas of future research; finishing with a reflection of the project in its entirety.

6.1 Discussion of Results

Through statistical analysis there is evidence to suggest that the statements made in the hypotheses were true. The interaction between the game level and the image modulation was not significant it can be concluded that the effect of image modulation is significant across all three levels of game difficulty. In other words, image modulation does in fact decrease the time to complete a search task over varying difficulties. A visual representation of this can be seen in figure 6.1.

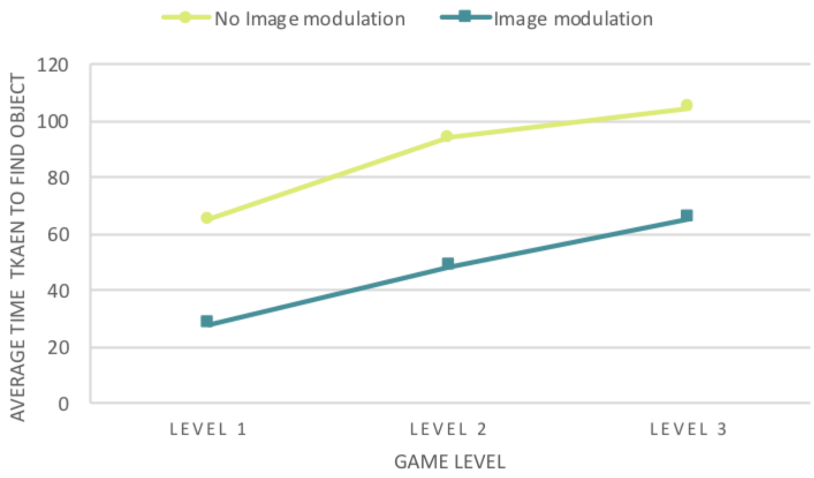

Figure 6.1: Average time taken to find an object for both image modulation and no image modulation

This would also imply that the luminance modulation used within the study does indeed capture attention, as has been demonstrated in traditional visual search tasks (Christ and Abrams, 2006; Schreij, Owens and Theeuwes, 2008) and is reinforces the fact that luminance modulation is one of stronger forms of guiding attributes (Wolfe and Horowitz, 2017).

What has become clear is that there is no correlation between the average number of mouse clicks and task difficulty, nor is there a correlation between mouse clicks and image modulation. This is likely the result of how the mouse is used as a form of interaction, and how participants were instructed to use the mouse. The first form of interaction would be clicking on an object once a participant has found it, the second form of interaction would simply be a miss-click and lastly, clicks were used by some participants as part of a wider strategy to "brute-force" the search task in the hope that they would randomly click the object needed to be found. This strategy may be due to the time pressure participants were under, and it could be speculated that if the same study were repeated with significantly reduced time limits, that we would see overall increase in the number of mouse clicks.

Figure 6.1 indicates the scaling of difficulty across levels was design and implemented correctly, with a steady increase in time taken to complete a level, regardless of whether image modulation was present or not. This may caused by the gradual increase of both visual clutter across levels (Henderson et al., 2009; Asher et al., 2013) and the increasing scale of each level (Chan and Hayward, 2009).

Overall this study suggests that image modulation, significantly decreases search time regardless of task difficulty. The research has also determined that their is no correlation between the average number mouse clicks and task difficulty, nor is there a correlation between mouse clicks and image modulation.

6.2 Discussion of the Game

Recalling each of the requirements outlined in section3.1. The game achieved all aspects of requirements. Although, there a few points of contention which should be highlighted.

The requirement *The game should be a test-bed* on hind sight is very vague, and high level. What constitutes as a test-bed, what would the game need to in order to be considered a test-bed? In it's current state the game is fairly modular, and it would be relatively simple for anyone with practical knowledge of Unity to add more hidden objects and levels at will. The issue here, is a lack of additional assets, documentation and collaborative efforts to begin the process of turning the game into a true test bed for future studies. Future additions to the game are discussed in section 6.4.2.

As noted in section 3.4, GitHub was initially used as a means of version control and issue tracking for the project. On reflection, prevailed use of GitHub would have resulted in a full history of the project available being available for anyone to view, along with documentation on how to use the game; making it easier to convert the game to a more fully fledged test-bed with open source development.

The image modulation should be subtle, again the same problem is demonstrated, the requirement is simply too vague. The term subtle should have been formally defined, and a threshold set. While an initial pilot was used to determine if the image modulation was subtle, there was no real hard benchmark value to compare against. This is further discussed in the following section.

6.3 Limitations

There are however some caveats to this which should be highlighted. Firstly, the study was carried out on a relatively small sample size, with only nine participants in each group. This makes it difficult to be sure that any statistical analysis carried out holds true weight. While there was varying representations of age and gender, this still did not account for the small sample size. One reason for the small sample size was simply due to the time constraints under which this dissertation took place.

The second caveat, and perhaps more importantly, is luminance modulation itself. While great care was taken during development to ensure its subtly, through the use of the pilot study referred to in section 3.8.2, it is not clear how subtle the effect was for each participant. This presents the obvious problem of having an effect so salient, that the search time is artificially reduced.

6.4 Future Work

This final section, presents ideas for future work that may build upon the study and it's findings.

6.4.1 Improvements for Future Studies

The simplest improvement would be to increase the number of participants, providing greater representation of the wider population and reducing the chance of a false premise. In future it would be best to carry out a sample size calculation as part of the experimental design.

For future iterations of the study, qualitative data should be included. This may be in the form of verbal communication, where participants rate each level of the game on a Likert scale for naturalness; with lower values indicating a natural looking image and higher values representing an unnatural, manipulated image. Thus a better idea of how subtle the image modulation can be obtained.

There would also be the possibility of adding additional levels to the game, encompassing a wider spectrum of task difficulty. As mentioned in chapter 3.5 this becomes increasingly difficult when designing levels, due to the sheer number of individual variables that can effect task difficulty. Furthermore difficulty then has to be scaled across an increasing number of levels, requiring a finer level of granularity. If, however, this could be achieved, then a continuation of the correlation shown in figure 5.1 should be seen.

6.4.2 Avenues for Future Research

There a number of avenues to explore in terms of future research. A fairly obvious choice would be to focus on a more feature complete version of the game and extending it's capability as a test-bed. This could involve making the project open source so people could add their own assets, animations, configurations and contributions. During this project alone, there were a number of unused assets, that when combined could be used to create additional levels and scenes. The end goal would be a more flexible, modular tool for future visual studies.

Once a more elaborate test-bed is in place, there would be a possibility to explore the other forms of image modulation and saliency modulation proposed in section 2.5.1 . A comparison between techniques could then be made on criteria such as their ability to decrease task difficulty or their subtlety.

From a more personal standpoint, investigating the relationship between audio, more specifically auditory cues in combination with visual search would interesting. The fields of vision, audio and language are well studied in their own right, but there is little literature on how they interact with each other. It has already been shown that language acts as a distinct gaze prompt (Tanenhaus, Spivey-Knowlton, Eberhard and Sedivy, 1995). Again, with a digital medium such as the hidden object game created, incorporating elements such as audio into the game should not pose a problem at all.

6.5 Reflection

Overall I feel as if the project was a success but there were still areas open to improvement.

Time management was an essential part of this project, and is something that is almost impossible to plan for in the long term. In retrospect there is nothing I necessarily regret, however I vastly underestimated the amount of time needed to hand draw each asset and design every level. Any mistake, or something particularly out of place would require, digitally editing the image or redrawing sections by hand, then scanning them back into digital form. I was really happy with the final outcome of the game, and towards the end of the design phase the whole process took a reduced amount of time.

There are also other aspects of this project which were not even considered before I encountered them, such as the research that went into actually designing an experiment, as well as research into how to analyse the data from the study; with it being my first doing both. In the future, if I were ever to carry out similar studies, I would feel more comfortable with the experience gained.

This project was certainly a steep learning experience from start to end. Most aspects of this project were subjects that I had no prior knowledge of; I have never conduced a piece of formal research, I have never finished a working game using Unity, nor have I been particular well skilled in drawing, even the statistics was some what challenging as someone who has never attended a single statistics class. This project at the very least has provided valuable insight and experience into practical piece of research. The end result is a piece of software that could, in future, be used as the basis for further research, with room for a great deal of expansion. I hope to continue it's development, and maybe even conduct further research in my own time. Overall, the project was a huge undertaking, but was very enjoyable and something I personally feel very proud of.

Bibliography

Asher, M. F., Tolhurst, D. J., Troscianko, T. and Gilchrist, I. D. (2013), 'Regional effects of clutter on human target detection performance', *Journal of Vision* **13**(5), 25.
URL: *+ http://dx.doi.org/10.1167/13.5.25*

Bailey, R., McNamara, A., Sudarsanam, N. and Grimm, C. (2009), 'Subtle gaze direction', *ACM Trans. Graph.* **28**(4), 100:1–100:14.

Baluch, F. and Itti, L. (2011), 'Mechanisms of top-down attention', *Trends in Neurosciences* **34**(4), 210 – 224.

Booth, T., Sridharan, S., McNamara, A., Grimm, C. and Bailey, R. (2013), Guiding attention in controlled real-world environments, *in* 'Proceedings of the ACM Symposium on Applied Perception', ACM, New York, NY, USA, pp. 75–82.

Bradner, S. (1997), Key words for use in RFCs to Indicate Requirement Levels, RFC 2119, RFC Editor.
URL: *https://tools.ietf.org/html/rfc2119*

Bruner, J. S. (1957), Going beyond the information given, *in* H. E. Gruber et al., eds, 'Contemporary Approaches to Cognition', Harvard University Press, Cambridge, Massachusetts, pp. 119–160.

Chan, L. K. and Hayward, W. G. (2009), 'Feature integration theory revisited: Dissociating feature detection and attentional guidance in visual search.', *Journal of Experimental Psychology: Human Perception and Performance* **35**(1), 119.

Christ, S. E. and Abrams, R. A. (2006), 'Abrupt onsets cannot be ignored', *Psychonomic Bulletin & Review* **13**(5), 875–880.
URL: *https://doi.org/10.3758/BF03194012*

Desimone, R. and Duncan, J. (1995), 'Neural mechanisms of selective visual attention', *Annual Review of Neuroscience* **18**(1), 193–222.

Eckstein, M. P., Koehler, K., Welbourne, L. E. and Akbas, E. (2017), 'Humans, but not deep neural networks, often miss giant targets in scenes', *Current Biology* **27**(18), 2827 – 2832.e3.

Elazary, L. and Itti, L. (2008), 'Interesting objects are visually salient', *Journal of Vision* **8**(3), 3.

Fecteau, J. H. and Munoz, D. P. (2006), 'Salience, relevance, and firing: a priority map for target selection', *Trends in Cognitive Sciences* **10**(8), 382 – 390.
URL: *http://www.sciencedirect.com/science/article/pii/S1364661306001616*

Fine, R. (2017), 'UnityscriptâĂŹs long ride off into the sunset', `https://blogs.unity3d.com/2017/08/11/unityscripts-long-ride-off-into-the-sunset/`. Accessed: 2018-03-22.

Handford, M. (1997), *WhereâĂŹs Wally? The Wonder Book*, Walker Books.

Henderson, J. M. (2003), 'Human gaze control during real-world scene perception', *Trends in Cognitive Sciences* **7**(11), 498 – 504.

Henderson, J. M., Chanceaux, M. and Smith, T. J. (2009), 'The influence of clutter on real-world scene search: Evidence from search efficiency and eye movements', *Journal of Vision* **9**(1), 32.
URL: *+ http://dx.doi.org/10.1167/9.1.32*

Itti, L. (2005), 'Quantifying the contribution of low-level saliency to human eye movements in dynamic scenes', *Visual Cognition* **12**(6), 1093–1123.

Itti, L. (2008), Computational cognitive neuroscience and its applications, *in* 'Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2007 Symposium', The National Academies Press, Washington, DC, USA, pp. 87–98.

Itti, L. and Koch, C. (2001), 'Computational modelling of visual attention', *Nature Reviews Neuroscience* **2**(5), 194–203.

James, W. (1890), *The Principles of Psychology*, Vol. 2, Henry Holt and Company.

Kosara, R., Miksch, S. and Hauser, H. (2001), Semantic depth of field, *in* 'Information Visualization, 2001. INFOVIS 2001. IEEE Symposium on', IEEE, San Diego, Ca, USA, pp. 97–104.

McNamara, A., Booth, T., Sridharan, S., Caffey, S., Grimm, C. and Bailey, R. (2012), Directing gaze in narrative art, *in* 'Proceedings of the ACM Symposium on Applied Perception', ACM, New York, NY, USA, pp. 63–70.

Neisser, U. (1967), *Cognitive psychology*, New York: Prentice-Hall.

Ogden, T. E. and Miller, R. F. (1966), 'Studies of the optic nerve of the rhesus monkey: Nerve fiber spectrum and physiological properties', *Vision Research* **6**(9), 485 – IN2.

Schreij, D., Owens, C. and Theeuwes, J. (2008), 'Abrupt onsets capture attention independent of top-down control settings', *Perception & Psychophysics* **70**(2), 208–218.
URL: *https://doi.org/10.3758/PP.70.2.208*

Sohlberg, M. M. and Mateer, C. A. (1989), *Introduction to Cognitive Rehabilitation. Theory and Practice*, The Guilford Press.

Stroop, J. R. (1935), 'Studies of interference in serial verbal reactions', *Journal of Experimental Psychology* **18**, 643–66.

Su, S. L., Durand, F. and Agrawala, M. (2005), De-emphasis of distracting image regions using texture power maps, *in* 'Texture 2005: Proceedings of the 4th IEEE International Workshop on Texture Analysis and Synthesis in conjunction with ICCV'05', pp. 119–124.

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M. and Sedivy, J. C. (1995), 'Integration of visual and linguistic information in spoken language comprehension', *Science* **268**(5217), 1632–1634.
URL: *http://www.jstor.org/stable/2888637*

Technologies, U. (2018*a*), 'Application.persistentdatapath', `https://docs.unity3d.com/ScriptReference/Application-persistentDataPath.html`. Accessed: 2018-04-10.

Technologies, U. (2018*b*), 'Execution order of event functions', `https://docs.unity3d.com/Manual/ExecutionOrder.html`. Accessed: 2018-03-26.

Treisman, A. (1988), 'Features and objects: The fourteenth bartlett memorial lecture', *The Quarterly Journal of Experimental Psychology Section A* **40**(2), 201–237.

Treisman, A. M. (1998), 'Feature binding, attention and object perception', *Philosophical Transactions of the Royal Society of London B: Biological Sciences* **353**, 1295–1306.

Treisman, A. M. and Gelade, G. (1980), 'A feature-integration theory of attention', *Cognitive Psychology* **12**, 97–136.

Treisman, A. M. and Paterson, R. (1984), 'Emergent features, attention, and object perception', *Journal of Experimental Psychology: Human Perception and Performance* **10**, 12–31.

Tsotsos, J. K. (2012), *A computational perspective on visual attention*, Cambridge, Mass. : MIT Press.

Veas, E. E., Mendez, E., Feiner, S. K. and Schmalstieg, D. (2011), Directing attention and influencing memory with visual saliency modulation, *in* 'Proceedings of the SIGCHI Conference on Human Factors in Computing Systems', CHI '11, ACM, New York, NY, USA, pp. 1471–1480.

Williams, L. J. (1985), 'Tunnel vision induced by a foveal load manipulation', *Human Factors* **27**(2), 221–227.

Wolfe, J. M. (1994), 'Guided search 2.0 a revised model of visual search', *Psychonomic Bulletin & Review* **1**(2), 202–238.

Wolfe, J. M. (1998), Visual search, *in* H. Pashler, ed., 'Attention', Psychology Press, Oxford, chapter 1, pp. 13–74.

Wolfe, J. M. (2005), Guidance of visual search by preattentive information, *in* G. R. Laurent Itti and J. K. Tsotsos, eds, 'Neurobiology of Attention', Elsevier Academic Press, Amsterdam, chapter 17, pp. 101–104.

Wolfe, J. M. (2007), Guided search 4.0: Current progress with a model of visual search, *in* W. D. Gray, ed., 'Integrated Models of Cognitive', Oxford University Press, Oxford, chapter 3, pp. 99–119.

Wolfe, J. M. (2017), 'Visual attention: Size matters', *Current Biology* **27**(18), R1002 – R1003.
URL: *http://www.sciencedirect.com/science/article/pii/S0960982217309612*

Wolfe, J. M., Cave, K. R. and Franzel, S. L. (1989), 'Guided search: An alternative to the feature integration model for visual search', *Journal of Experimental Psychology: Human Perception and Performance* **15**, 419–433.

Wolfe, J. M. and Horowitz, T. S. (2017), 'Five factors that guide attention in visual search', *Nature Human Behaviour* **1**(3).

Yarbus, A. L. (1967), *Eye Movements and Vision*, New York: Plenum Press. High resolution image taken from `https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3563050/`.

Appendix A

Study Documentation

A.1 Study Brief

I am a final year Computer Science with Business student at the University of Bath; under the supervision of both, Jacob Hadnet-Hunter a PhD student and Eamonn O'Neill, head of the university computer science department.

For my project I am investigating whether image modulation has an affect on task difficulty. The investigation is carried out using a hidden object style game, similar to digitalised version of the Where's Wally books.

This study will consist of three parts:

1. To obtain your consent for partaking in the study.
2. A training phase: This is simply a training level is to familiarise yourself with the game. All you need to do is find the object and once you have found it, left click on the object. Each level has time limit of three minutes.
3. The main study: After completing the training level, the main study can begin. This is exactly the same process as before, except you will be required to complete three levels rather than one. This should take roughly ten minutes of your time.
4. A debrief of the study: An overview of the aims of the study will be provided and how your involvement supports these aims.

All data collected during the study will be stored securely, anonymously and only accessible by the main researcher and supervisor. Your participation in this study is completely voluntary and you are free to withdraw at any time, without giving a reason and without any consequences.

If you have any questions or queries after the study, please do not hesitate to get in touch with me at dj357@bath.ac.uk

Your signature indicates that you have read the above, and that you have received enough information about this study and consent to participating. Your participation is voluntary and you can withdrawn at any time.

Signature: .... Date: ....
Researcher: Daniel Jenkyn
Project Supervisors: Jacob Hadnet-Hunter and Eamonn O'Neill

A.2 Ethics Checklist

1. **Have you prepared a briefing script for volunteers?**
   Potential user study participants will be provided with a briefing script. They will be able to read this before agreeing to participate in the study. On the day of the study, this briefing script will again be provided.

2. **Will the participants be using any non-standard hardware?**
   No.

3. **Is there any intentional deception of the participants?**
   There is no intentional deception of participants. The image modulation explained to participants at the end of the study.

4. **How will participants voluntarily give consent?**
   Potential user study participants will be provided with a briefing script. At the end of this script participants are asked if they wish to partake in the study. Participants will only engage in the study once their consent has been obtained.

5. **Will the participants be exposed to any risks greater than those encountered in their normal work life?**
   No.

6. **Are you offering any incentive to the participants?**
   Yes. Participants will be offered tea or coffee on completion of the study.

7. **Are any of your participants under the age of 16?**
   Yes, parental consent was given.

8. **Do any of your participants have an impairment that will limit their understanding or communication?**
   No.

9. **Are you in a position of authority or influence over any of your participants?**
   No.

10. **Will the participants be informed that they could withdraw at any time?**
    Potential user study participants are given the briefing script, which includes a statement specifying that they may withdraw at any time. This briefing script is also repeated before the commencement of the study. The right to withdraw is further highlighted through verbal communication at the start of each part of the study.

11. **Will the participants be informed of your contact details?**
    Yes.

12. **Will participants be de-briefed?**
    Yes. An overview of the aims of the experiment will be provided and how their involvement supports these aims.

13. **Will the data collected from the participants be stored in an anonymous form?**
    Yes.

Appendix B

Raw Results Output

The raw texttt.csv data is stored on the provided USB stick.

No Image modulation				
Level	**Object Name**	**Time taken to find**	**No. Left Mouse Clicks**	**Age**
Level 1	Wig	64.68716	17	25
Level 1	FilmReel	87.90333	18	
Level 1	Microphone	108.9694	20	
Level 2	Lizard	34.61898	2	
Level 2	Glasses	142.4691	3	
Level 2		180.0356	3	
Level 3	Glove	43.31967	1	
Level 3	Hat	82.38493	2	
Level 3	Arm	143.6847	4	
Level 1	Wig	16.4531	1	27
Level 1	Microphone	28.90221	5	
Level 1	FilmReel	34.21878	6	
Level 2	Lizard	15.23697	1	
Level 2	Glasses	62.30228	4	
Level 2	Bottle	76.35271	5	
Level 3	Hat	56.78703	1	
Level 3	Glove	151.8356	9	
Level 3	Arm	172.4686	10	
Level 1	FilmReel	8.536361	1	29
Level 1	Microphone	39.1189	3	
Level 1	Wig	121.6677	4	
Level 2	Lizard	47.15219	1	
Level 2	Glasses	81.03575	2	
Level 2	Bottle	178.0167	3	
Level 3	Arm	59.85091	2	
Level 3	Hat	69.13509	3	
Level 3	Glove	110.901	4	
Level 1	FilmReel	29.81977	6	55
Level 1	Microphone	80.38795	8	
Level 1	Wig	146.4743	10	
Level 2	Lizard	31.58845	1	
Level 2	Bottle	137.0909	3	
Level 2		180.0424	3	
Level 3	Arm	89.29044	3	
Level 3	Hat	150.6753	7	
Level 3		180.0427	8	
Level 1	FilmReel	9.951632	1	22
Level 1	Wig	15.90202	4	
Level 1	Microphone	167.3161	11	
Level 2	Lizard	23.50172	1	
Level 2	Glasses	47.46888	3	
Level 2	Bottle	54.21782	4	
Level 3	Arm	18.55201	2	
Level 3	Glove	60.26808	3	
Level 3	Hat	73.00212	4	
Level 1	FilmReel	25.07047	1	23
Level 1	Wig	47.43591	2	
Level 1	Microphone	59.0848	3	
Level 2	Lizard	7.103714	1	
Level 2	Glasses	96.66795	3	
Level 2	Bottle	104.9357	4	
Level 3	Arm	31.08462	2	
Level 3	Glove	56.78399	4	
Level 3	Hat	74.96603	5	
Level 1	FilmReel	36.65419	1	52
Level 1	Wig	140.1065	28	
Level 1		180.0415	35	
Level 2	Lizard	100.569	4	
Level 2		180.0371	7	
Level 3	Hat	104.8566	3	
Level 3		180.0424	4	
Level 1	FilmReel	13.70086	4	58
Level 1	Wig	25.1997	6	
Level 1	Microphone	88.84908	8	
Level 2	Lizard	14.81898	1	
Level 2	Glasses	103.2522	4	
Level 2	Bottle	150.5015	6	
Level 3	Hat	35.13686	1	
Level 3	Arm	109.9512	11	
Level 3		180.0502	24	
Level 1	FilmReel	32.63715	2	59
Level 1	Wig	50.21955	3	
Level 1	Microphone	93.888	9	
Level 2	Lizard	36.92162	2	
Level 2	Glasses	139.2249	7	
Level 2		180.0421	7	
Level 3	Hat	22.05524	1	
Level 3	Glove	179.0377	5	
Level 3		180.4053	6	

Image modulation				
Level	Object Name	Time taken to find	No. Left Mouse Clicks	Age
Level 1	FilmReel	11.50356	1	15
Level 1	Wig	24.73676	3	
Level 1	Microphone	31.78788	4	
Level 2	Glasses	12.23664	2	
Level 2	Lizard	23.95314	3	
Level 2	Bottle	29.7696	4	
Level 3	Glove	26.63859	2	
Level 3	Hat	48.58888	4	
Level 3	Arm	77.17318	5	
Level 1	FilmReel	6.398638	2	23
Level 1	Wig	18.17904	3	
Level 1	Microphone	21.568535	4	
Level 2	Lizard	12.337706	1	
Level 2	Glasses	24.59772	3	
Level 2	Bottle	28.776851	4	
Level 3	Hat	36.84209	1	
Level 3	Arm	53.511586	3	
Level 3	Glove	94.735233	5	
Level 1	FilmReel	7.786929	2	23
Level 1	Wig	11.1698	3	
Level 1	Microphone	16.51954	4	
Level 2	Lizard	11.54344	1	
Level 2	Glasses	21.74307	2	
Level 2	Bottle	24.84251	4	
Level 3	Hat	29.98656	1	
Level 3	Arm	53.08704	2	
Level 3	Glove	91.70317	5	
Level 1	FilmReel	12.00419	1	28
Level 1	Wig	23.35305	2	
Level 1	Microphone	57.53664	5	
Level 2	Lizard	21.88626	1	
Level 2	Bottle	73.51867	2	
Level 2	Glasses	83.5694	3	
Level 3	Hat	25.23322	1	
Level 3	Glove	34.56743	2	
Level 3	Arm	47.13391	4	
Level 1	FilmReel	11.06884	1	51
Level 1		180.0402	1	
Level 2		180.0412	0	
Level 3	Arm	89.70551	2	
Level 3	Hat	109.5551	3	
Level 3		180.0407	4	
Level 1	FilmReel	11.1369	1	53
Level 1	Wig	24.52027	2	
Level 1	Microphone	38.03628	3	
Level 2	Lizard	51.91945	1	
Level 2	Glasses	60.70143	3	
Level 2	Bottle	75.26897	5	
Level 3	Glove	73.26795	3	
Level 3	Hat	116.068	5	
Level 3	Arm	161.8664	6	
Level 1	Microphone	14.975073	1	22
Level 1	Wig	22.451688	3	
Level 1	FilmReel	30.893624	4	
Level 2	Lizard	9.08386	1	
Level 2	Glasses	21.152683	4	
Level 2	Bottle	30.060985	5	
Level 3	Glove	27.453181	2	
Level 3	Hat	51.265378	5	
Level 3	Arm	82.531598	6	
Level 1	FilmReel	7.006157	2	22
Level 1	Microphone	12.053151	3	
Level 1	Wig	16.23886	4	
Level 2	Lizard	9.908214	1	
Level 2	Glasses	18.134415	4	
Level 2	Bottle	23.604608	5	
Level 3	Hat	22.670845	2	
Level 3	Glove	53.561444	3	
Level 3	Arm	85.382989	6	
Level 1	Microphone	11.60289	1	21
Level 1	Wig	15.21977	2	
Level 1	FilmReel	29.7363	3	
Level 2	Glasses	24.55436	1	
Level 2	Bottle	31.83757	2	
Level 2	Lizard	40.37221	3	
Level 3	Hat	25.88748	1	
Level 3	Arm	29.68878	2	
Level 3	Glove	41.65529	3	

Appendix C

Supporting Data and Statistics

The output of SPPS, .spv files are stored on the provided USB stick.

C.1 Time Taken

Levene's Test of Equality of Error Variances				
Levels	**F**	**df1**	**df2**	**Sig.**
Level 1	0.456	1	16	0.509
Level 2	0.283	1	16	0.602
Level 3	0.673	1	16	0.424

Mauchly's Test of Sphericity							
					Epsilon		
Within Subjects	**Mauchly's W**	**Approx. Chi-Square**	**df**	**Sig.**	**Greenhouse-Geisser**	**Huynh-Feldt**	**Lower-bound**
Levels	0.838	2.659	2	0.265	0.86	1	0.5

C.2 Mouse Clicks

Levene's Test of Equality of Error Variances				
Levels	**F**	**df1**	**df2**	**Sig.**
Level 1	11.4	1	16	0.004
Level 2	0.592	1	16	0.453
Level 3	5.16	1	16	0.037

Mauchly's Test of Sphericity							
					Epsilon		
Within Subjects	**Mauchly's W**	**Approx. Chi-Square**	**df**	**Sig.**	**Greenhouse-Geisser**	**Huynh-Feldt**	**Lower-bound**
Levels	0.334	16.449	2	0	0.6	0.662	0.5

Appendix D

Code

The full Unity project is stored on the provided USB stick.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class scrTimer : MonoBehaviour {

  private float currentTime = 0, endTime = 180;//Three
     minutes

  private scrLevelManager levelManager;
  private scrClickControl clickControl;

  // Use this for initialization
  void Start () {
    levelManager =
        GameObject.FindObjectOfType<scrLevelManager>();
    clickControl =
        GameObject.FindObjectOfType<scrClickControl>();
    StartCoroutine(timer(endTime));
  }

  // Update is called once per frame
  void Update () {
    currentTime += Time.deltaTime;
  }

  IEnumerator timer(float delay) {
    yield return new WaitForSeconds(delay);
```

```
      scrDataManager.saveData(SceneManager.GetActiveScene().name,
          "", CurrentTime, clickControl.MouseClicksLevel);
        levelManager.loadNextLevel();
    }

    public float CurrentTime {
      get {
        return currentTime;
      }
    }
}
```

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using System.Text;
using System.IO;
using System;

public static class scrDataManager {
  private static List<string[]> rowData = new
      List<string[]>();

  public static void saveData(string level, string objName,
      float foundTime, int clicks) {
    string[] rowDataTemp = new string[4];
    rowDataTemp[0] = level;
    rowDataTemp[1] = objName;
    rowDataTemp[2] = foundTime.ToString();
    rowDataTemp[3] = clicks.ToString();
    rowData.Add(rowDataTemp);
  }

  public static void writeCSV() {
    string filePath = getPath();
    StreamWriter outStream =
        System.IO.File.CreateText(filePath);

    outStream.WriteLine("{0},{1},{2},{3}", "Level", "Object
        Name", "Time taken to find", "No. Left Mouse Clicks");
    string[][] output = new string[rowData.Count][];

    for(int i = 0; i < output.Length; i++) {
      output[i] = rowData[i];
    }

    string delimiter = ",";
    StringBuilder sb = new StringBuilder();

    for(int index = 0; index < output.GetLength(0); index++)
        {
      sb.AppendLine(string.Join(delimiter, output[index]));
    }

    outStream.WriteLine(sb);
    outStream.Close();
  }

  private static string getPath() {
    DateTime dt = DateTime.Now;

```

```
    string path =
        Path.Combine(Application.persistentDataPath, "data");
    path = Path.Combine(path,
        DateTime.Now.ToString("hh:mm:ss")+ ".csv");

    if (!Directory.Exists(Path.GetDirectoryName(path))) {
         Directory.CreateDirectory(Path.GetDirectoryName(path));
    }

    return path;
  }
}
```

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class scrFlicker : MonoBehaviour {
  private SpriteRenderer sRen;
  private int flickerLength, flickerDelay;

  // Hz, the number of cycles
  private float cycleHz = 30, dtime = 0, toggletime;

  void Start () {
    sRen = gameObject.GetComponent<SpriteRenderer>();

    Color alpha = sRen.color;
    alpha.a = 0.35f;
    sRen.color = alpha;

    flickerLength = Random.Range(1, 3);
    flickerDelay = Random.Range(5, 10);
  }

  // Update is called once per frame
  void FixedUpdate() {
    toggletime += Time.deltaTime;

    // Flicker will occur from 1-3 seconds
    if(toggletime < flickerLength) {
      startFlicker();
    } else if (toggletime > flickerDelay) {
      // Reset timer after 5-10 seconds have passed
      // Nothing will occur between 2-4 seconds
      toggletime = 0;
    }
  }

  void startFlicker() {
    // Update frequency time-step
    dtime += Time.deltaTime;

    // Sample the wave at a specific time.
    double wave = Mathf.Sin((dtime * 2.0f * Mathf.PI) *
        cycleHz);

    // Cycle between enabling based on the wave
    if(wave > 0.0f) {
      GetComponent<SpriteRenderer>().enabled = true;
    } else {
      GetComponent<SpriteRenderer>().enabled = false;
```

```
    }

    // Prevents dtime from climbing to infinity
    if (wave == 0.0f) {
      dtime = 0.0f;
    }
  }
}
```

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class scrLevelManager : MonoBehaviour {

  public void loadLevel(string name) {
    if(!SceneManager.GetSceneByName(name).IsValid()) {
      StartCoroutine(WaitAndLoadScene("Main Screen/Main"));
    }
    StartCoroutine(WaitAndLoadScene(name));
  }

  public void loadNextLevel() {
    StartCoroutine(WaitAndLoadScene());
  }

  public void quitGame() {
    scrDataManager.writeCSV();
    Debug.Log("Quit requested");
    Application.Quit();
  }

  IEnumerator WaitAndLoadScene() {
    yield return new WaitForSeconds(0.5f);

    if((SceneManager.GetActiveScene().buildIndex + 1) <
        SceneManager.sceneCountInBuildSettings) {
      SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex
          + 1);
    } else {
      StartCoroutine(WaitAndLoadScene("Main Screen/Main"));
    }
  }

  IEnumerator WaitAndLoadScene(string name) {
    yield return new WaitForSeconds(0.5f);
    SceneManager.LoadScene(name);
  }
}
```

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class scrTimer : MonoBehaviour {

  private float currentTime = 0, endTime = 180;//Three
      minutes

  private scrLevelManager levelManager;
  private scrClickControl clickControl;

  // Use this for initialization
  void Start() {
    levelManager =
        GameObject.FindObjectOfType<scrLevelManager>();
    clickControl =
        GameObject.FindObjectOfType<scrClickControl>();
    StartCoroutine(timer(endTime));
  }

  // Update is called once per frame
  void Update() {
    currentTime += Time.deltaTime;
  }

  IEnumerator timer(float delay) {
    yield return new WaitForSeconds(delay);
    scrDataManager.saveData(SceneManager.GetActiveScene().name,
        "", CurrentTime, clickControl.MouseClicksLevel);
      levelManager.loadNextLevel();
  }

  public float CurrentTime {
    get {
      return currentTime;
    }
  }
}
```