UNIVERSITY OF CALGARY

Exploring Notifications with Pepper's Ghost Illusion

by

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A THESIS

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Abstract

Today people are living a fast-paced environment with many tasks trying to grab our attention leading to multitasking and rapid task switching. Notifications and pop-ups is an effective method of grabbing user's visual attention and helping maintain information awareness. Unfortunately, the current method of notifications has also been considered to be a disruption during tasks. In this work, I explore a different method of gaining user's visual attention with *Pepper's Ghost* optical illusion – called the *Acquario* display. Through a user study the reaction time and user preference was evaluated to understand the benefits and drawbacks of using *Pepper's Ghost* to display pop-up information during a typing task. Results from the pre- and post-study interviews showed that participants liked *Pepper's Ghost Illusion* as a notification application. The illusion provided a less invasive means of notifying by appearing overlaid on the screen and its transparent quality. They also reported that the overlay had legibility issues that need addressing. The study showed that there was no statistical significant difference in the participants words per minute or in reaction time. My contributions include a hardware prototype of a desktop display using the *Pepper's Ghost Illusion*, a study methodology for evaluation notifications with *Pepper's Ghost* and an evaluation of using this technique.

Publications

Some figures and material in this thesis have previously appeared in this prior work:

Pratte, S., Seyed, T. and Maurer, F. 2016. Acquario: A tangible spatially-aware tool for information interaction and visualization. SUI 2016 - Proceedings of the 2016 Symposium on Spatial User Interaction. (2016). DOI:https://doi.org/10.1145/2983310.2989208.

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Dedication

To Grandma Gendron, thank you for always believing in me and inspiring creativity.

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Chapter 1

INTRODUCTION

In this thesis, I explore a different method of gaining user's visual attention with the "*Pepper's ghost*" optical illusion – called the *Acquario* display. This thesis looks at topics that fall under the general categorization of Human-Computer Interactions (HCI), where researchers explore how people operate and perceive computers. Specifically, this thesis looks at visual attention for notifications, a sub-category of HCI. Notifications give users awareness of incoming information such as emails, messages and information about the computer system that may be valuable [23]. However, this incoming information could also be potentially distracting the user from their attention from their primary task [23]. This thesis is concerned with **how the *Acquario* display, a novel display mechanism for viewing notifications using an old technique, *Pepper's Ghost Illusion*, to evaluate reaction time and preference for users.** *Pepper's Ghost Illusion* is an approximation of a holographic display overlaying information on a screen without the addition of a heads-up display.

This chapter provides the introduction for this thesis. Section 1.1 provides the background and motivation for this work to help the reader understand the underlying goals. Section 1.2 then states the research questions followed by the thesis contributions in Section 1.3. Finally, Section 1.4 describes the structure for the rest of the thesis.

1.1 Background and Motivation

1.1.1 Notifications

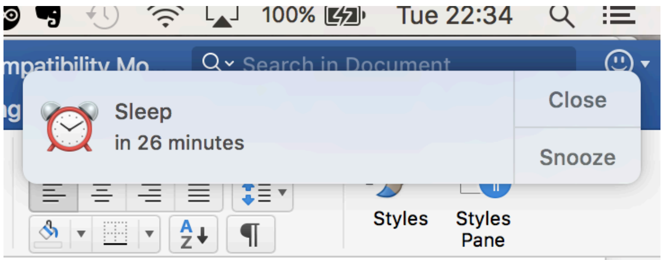

Figure 1.1: Reminder notification on Mac OS.

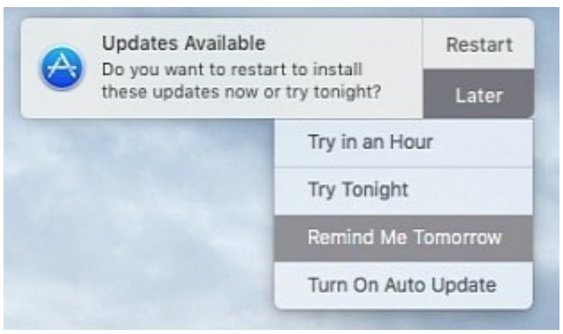

Figure 1.2: System update notification on Mac OS.

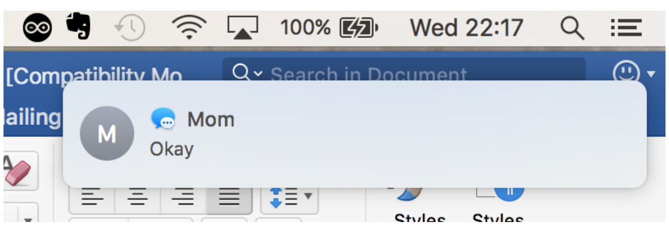

Figure 1.3: Message notification on Mac OS.

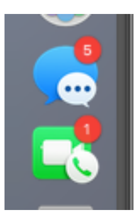

Figure 1.4: Icon badge notification on Mac OS.

Computer work today is very fast paced with many different applications and devices vying for our attention. The amount of information competing for attention has a decisive influence on the direction and design in human computer interactions [23]. Multitasking in computer systems has become a necessity providing users with the ability to quickly switch between and work simultaneously on numerous applications. In this multitasking environment users like to be aware of what is happening in each of the applications that need their attention. A lot of information may be time sensitive or important for the end user, however there is also an equally, or more, amount of information that is not necessary or wanted. There are many different methods of grabbing user's attention that are in use and in research. One method is capturing visual attention through notifications. Notifications systems are designed to draw attention and inform users of digital information away from their primary task to a secondary source (e.g. email, social media, etc.) [17]. There exist today many different types of notifications on both desktop and handheld devices, including notices from the operating systems about updates, system status as well as alerts from different applications running in the foreground and background [7]. Many of the devices today synchronize together and share notifications providing even more awareness to the user. Desktop notifications on Apple Mac OS typically appear in the top right-hand corner of the display as seen in Figure 1.1. This figure shows a reminder notification sent from an Apple iOS device. Figure 1.2 is an example of a system update notifications; this notification will remain on the screen in the foreground until the user acknowledges it and chooses one of the options displayed. Messages from the users iPhone and iPad also can sync with their Mac OS desktop giving users awareness without having to check on multiple devices using banner notifications (Figure 1.3) and badges on icons (Figure 1.4). Mobile phones today have their own OS as well, displaying similar notifications (system updates, messages, emails and calendar notices). iPhones utilize several different methods of notifying the user, for example, notifications on the lock screen (Figure 1.5.A), banner during phone use on the home screen (Figure 1.5.B) and badges on icons (Figure 1.6.A). Both iPhones and Macs also have a notification centre where the users can view all notices in one place (Figure 1.6.B). Google Android devices provide similar forms of notice to the users. Comparably, Microsoft Windows OS provides the same kind of notifications in a similar way for similar events. The various operating systems all provide methods of controlling these

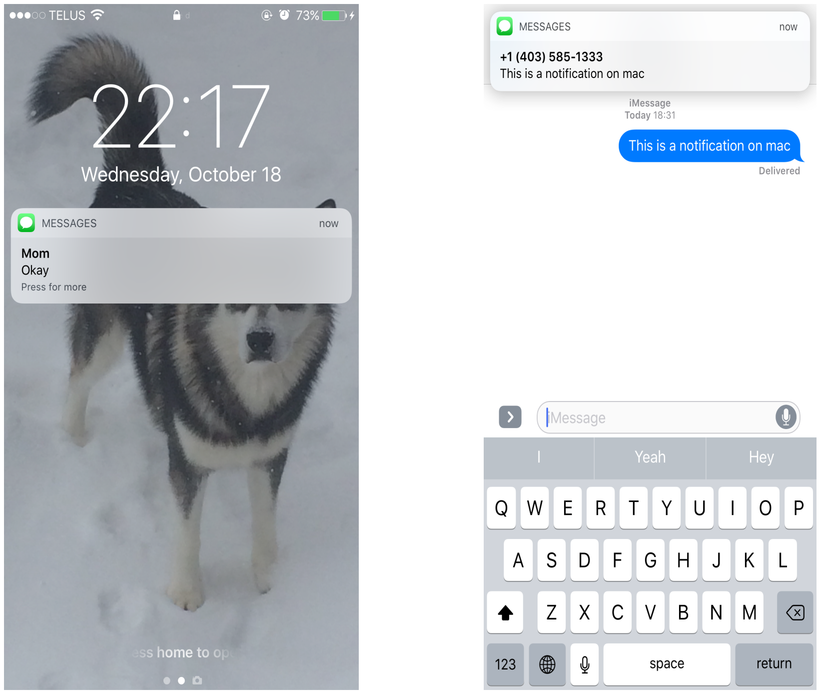

Figure 1.5: (A) Notification on the Home Screen on an iPhone. (B) Notification during phone use on an iPhone.

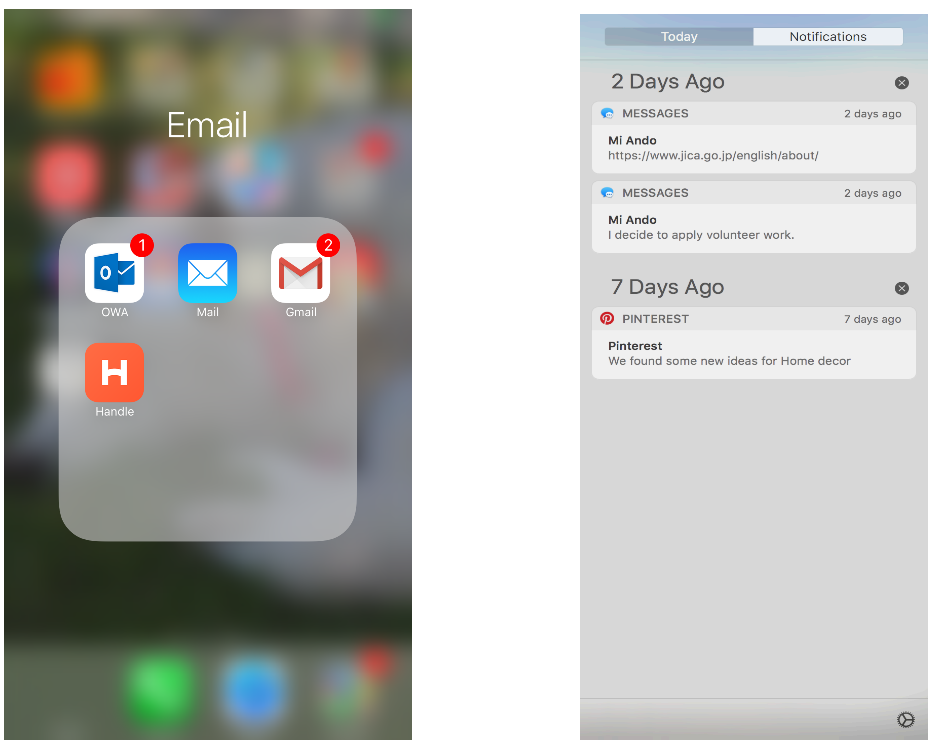

Figure 1.6: (A) Icon badge notification on an iPhone. (B) Notification center on Mac OS.

notifications, for example, in Mac OS you can set a "Do Not Disturb" time where no notices will be presented and choosing the style of notification (e.g. no banners just icon badges) (Figure 1.7). Combine these devices and the rise of devices such as smart watches, smart TVs and smart glasses provide a vast amount of information vying for user's attention at once.

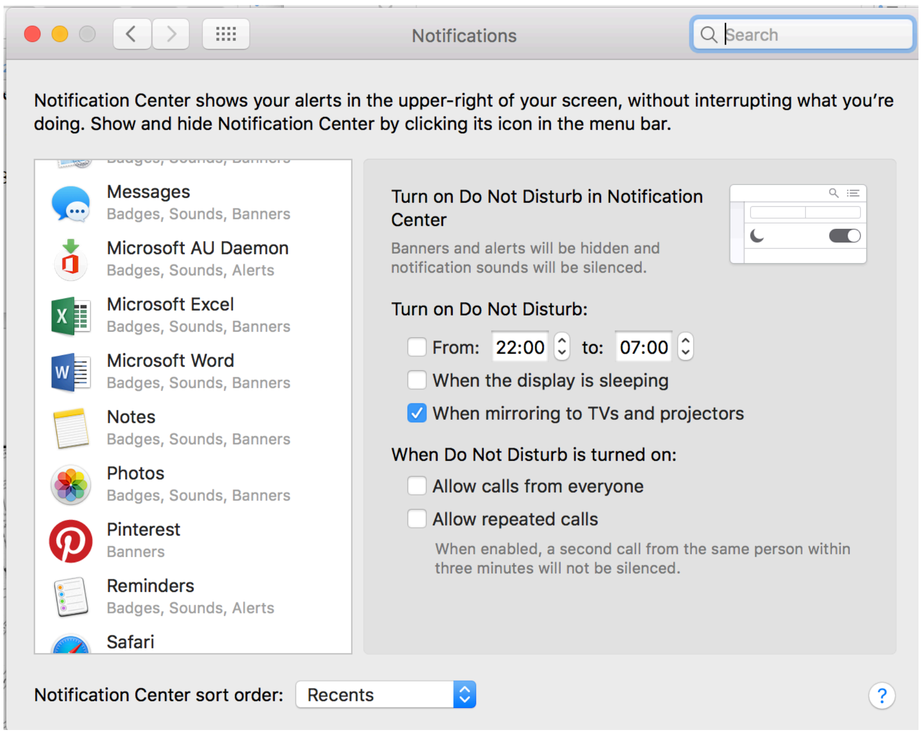

Figure 1.7: Notification control center on Mac OS.

One thing that all of these visual notifications have in common is that they are a solid display that appears for a designated time before disappearing or requiring the user to respond in some way before the notification is removed. While these notifications may be useful in keeping the user informed they are also potentially disruptive. Not all notifications are equally as important to the user, especially considering the context and the situation when the notification comes in. However, an effective approach for filter important notifications has not yet been accomplished. Companies like Apple, Google and Microsoft have all created methods of controlling notifications across devices. However, if users choose to turn off the notifications they could miss valuable information while on the other side they are bombarded with notifications across devices, a catch-22. Literature has explored many different aspects of the trade-offs between disruptions and awareness that are caused by notifications [4, 8, 10, 12, 16]. These works have looked at both awareness in the workplace on a desktop and on mobile devices which happen at any time. With the synchronization of devices becoming more and more prevalent and the possibility of multiple devices reaching users at once amplifies the effects of notifications and the disruptive qualities [22]. Increasing task time and frustration are some of the negative effects of disruptions on users while working on desktops [1, 2].

One method of countering the negative effects of notifications is to provide more subtle forms of notifications and this work is exploring such an alternative using *Pepper's Ghost Illusion*.

1.1.2 Pepper's Ghost Illusion

"Hear what I offer! Forget the sorrow, wrong, and trouble you have known!"

- *The Haunted Man by Charles Dickens*

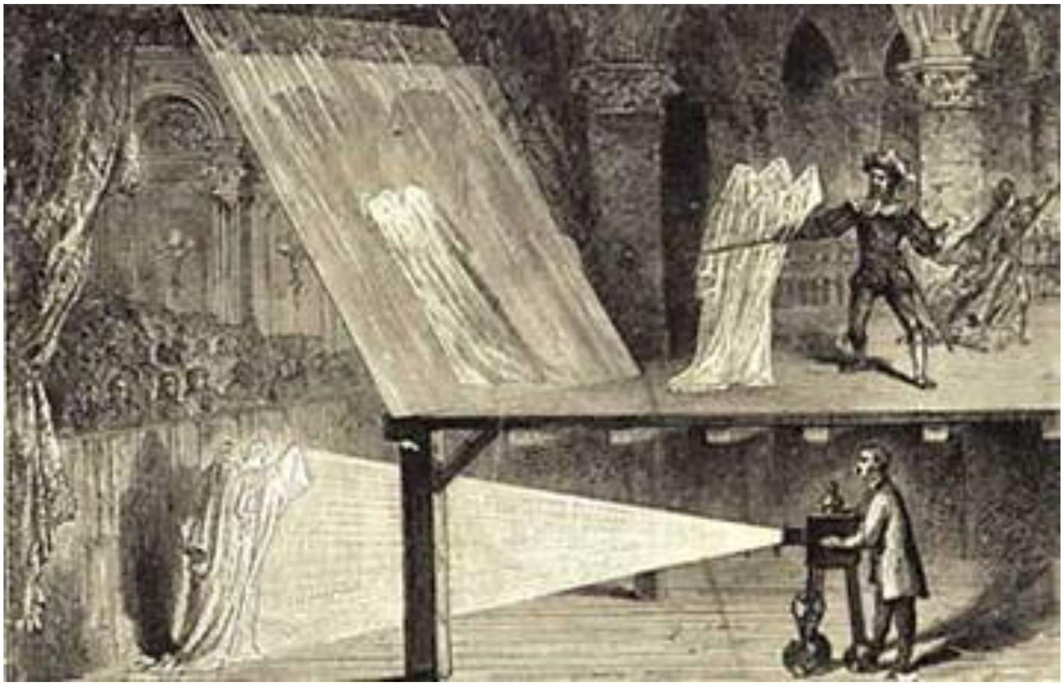

Figure 1.8. Example of the original setup of Pepper's Ghost Illusion.

Pepper's Ghost Illusion is an optical illusion patented and popularized by John Henry Pepper and Henry Dircks' in 1863 (patent year). John H. Pepper (1821 – 1900) was a Victorian era showman and scientist known for his experiments in physics where he combined the worlds of science and theatre [19]. Pepper and Dircks "ghost" appeared on stage in the Royal Polytechnic Institution in a short playlet based on the short story "The Haunted Man and the Ghost's Bargain" by Charles Dickens (1848) on December 24, 1862 [19]. *Pepper's Ghost Illusion* is more complicated then it seems however it is simple a control of lighting with mystic effect. The illusion is achieved by placing a plane of glass at a 45° angle originating from the audiences' line of sight (Figure 1.8). The actor of the ghost is below stage hidden from the audience and in a compartment below stage completely lined with black cloth to reduce any

Figure 1.9. The Ballroom scene in the Haunted Mansion ride at Disney Theme Parks.

other reflections but the actors and strongly illuminated by initially a oxy-hydrogen limelight lamp [3, 6] (Figure 1.8). The illuminated actor is reflected on the glass in front of the stage, to the audience it looks like a transparent figure is on the stage interacting with the actors such as, stabbing it with a sword (Figure 1.8) or walking through furniture. Actors had to skillful interact with the ghost because the illusion is not visible to the people behind the glass, only to those in the audience. There are many examples of *Pepper's Ghost Illusion* in modern days. The two biggest examples of *Pepper's Ghost Illusion* today are the Haunted Mansion in Disney theme parks and in music festivals. Disney theme parks have the largest setup of the illusion today in the Ballroom scene (Figure 1.9). The audience moves along in a buggy on a track facing a large piece of glass and they audience looks down on the scene from above. The "ghosts" are placed in a second blackened room in a mirrored position where they are illuminated and reflected into the

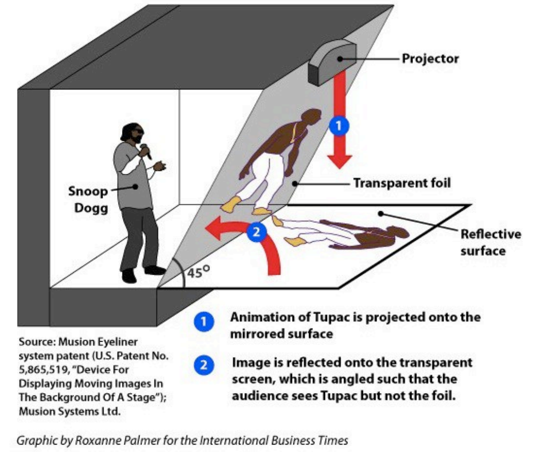

Figure 1.10. (A) "Hologram" of deceased rapper Tupac Shakur performing with live artists Snoop Dogg and Dr. Dre. (B) The setup of the illusion for the concert.

room with the scenery and props. Music festivals use a slightly different setup for *Pepper's Ghost Illusion*. A recent example of the illusion in music festivals is the performance of rappers Dr. Dre, Snoop Dogg and the deceased artist Tupac Shakur at the Coachella concert in 2012. In this concert the artists Dr, Dre and Snoop Dogg gave a live performance including a piece collaborating with a "hologram" of Tupac (Figure 1.10.A). For this part of the concert they used a high-performance projector aimed downward at black backdrop which was reflected at a thin transparent film at a 45° angle on the stage (Figure 1.10.B). This is a high impact example of the *Pepper's Ghost Illusion* because it gave the illusion of a beloved rap icon coming back from the dead to perform with living artists for the first time in many years. This same technique was used to "bring back" other deceased artists such as Michael Jackson. It has also been used to give "live" performances from animated artists like The Gorillaz and the Japanese artist Hatsune Miku. Most of the examples of *Pepper's Ghost Illusion* today, involve living people interacting with digital objects reflected in a physical space.

1.1.3 Motivation

As pervious stated, the main issue with notifications today is the fact that they can be distracting and pulling too much of user's attention from their primary task. An example of how to alleviate this issue is to make notifications subtler, giving the user the awareness they need while not pulling too much attention. As such, my research is interested in looking at the following challenges and how *Pepper's Ghost Illusion* can be used to answer these problems:

Problem 1: Notifications are distracting.

Notifications while distracting are also very important to users to help provide awareness. In previous studies, researchers have found that the trade-offs for distraction and awareness pay-off for having notifications. This has led to researchers trying to find ways of providing more subtle notifications.

Problem 2: *Pepper's Ghost Illusion* has not been utilized with a digital background.

Pepper's Ghost Illusion has been explored since the 1800s in various situations. However, not much has been done to how it can be utilized as an overlay to a digital background. The examples described above in section 1.1.2 are all overlays of images superimposed on to physical backgrounds; Dr. Dre projected the co-artist Tupac on stage with him and Disney Parks impose "ghost" on to a physical setup in the Haunted Mansion. But there has been little work with *Pepper's Ghost* being imposed on to a digital display.

1.2 Research Questions

In order to solve the problems stated above, my approach is to explore how *Pepper's Ghost Illusion* can be utilized as an overlay to a desktop computer to provide more subtle notifications. The transparency and overlaying effect produced by *Pepper's Ghost Illusion* can provide a more discrete form of awareness without the distraction of a solid notification by allowing the user to see through their work.

Research Question 1 (RQ1). Does *Pepper's Ghost Illusion* allow for more subtle notifications?

Pepper's Ghost Illusion has not been explored in research as a means for more subtle notifications. A subtle notification consists of a less invasive notification. Studies have shown that notifications interrupt tasks and negatively impact task performance. A notification that still provides an awareness of information to the user while not pulling their focus away from their primary task. This work explores how the transparent effect of the illusion can be explored to allow for a subtler notification. The answer for research question 1 (RQ1) is based on the subjective views of the participants.

Research Question 2 (RQ2). Can *Pepper's Ghost Illusion* be effectively used with a digital background?

Pepper's Ghost Illusion has been very successful at providing a means to produce "holographic" images in physical environments. However, it had not been explored as an overlay to a digital background. The overlay is a *Pepper's Ghost Illusion* created with a piece of Plexiglas and a second display. The primary display is the display on which the user is preforming their primary task; this becomes the digital background. To answer this question, this work searches for a setup for the illusion using two digital displays, one to be reflected as an overlay and the other as the primary screen and the background for the illusion. The answer is discovered through exploratory research.

Research Question 3 (RQ3). Do users have the same reaction time with an overlay notification as with a standard notification?

Does *Pepper's Ghost Illusion* provide the same awareness and reaction time as standard notifications? If the overlay is not noticed as quickly as a standard notification then it would not be an effective method as a notification system. The goal of this question is to test the reaction time of users with both methods to see if there is a difference.

1.3 Thesis Contributions

This thesis provides the following contributions:

Thesis Contribution 1. *Acquario*, a method of using *Pepper's Ghost Illusion* as an overlay on a standard digital display.

Thesis Contribution 2. A qualitative study methodology used to explore the effects of *Pepper's Ghost Illusion* on a digital surface.

Thesis Contribution 3. The results of the study exploring *Acquario*, and its possible use as a notification system.

1.4 Research Acknowledgements

The work of this thesis had the aid and support of multiple collaborators and fellow researchers Teddy Seyed and Maria and Shannon Hoover; Teddy is a PhD student who helped in the early iterations of the *Acquario* Display and provided guidance as a senior research student, and Maria and Shannon Hoover of ArcheLoft Makerspace helped in the construction and provided a space to present the early version at Calgary's Maker Fair in 2016. I also received much needed guidance from my supervisor Dr. Frank Maurer and from Dr. Tony Tang. I wrote this thesis in my personal perspective from the research I have led during my Master's Thesis and will be using personal pronouns – *I, my* – for the remainder of this document.

1.5 Thesis Structure

In this chapter, **Chapter 1: Introduction**, I introduce the context and motivation that inspires this thesis. I also describe the guiding research questions and scope of this thesis. The remainder of this work is divided into the following five sections:

Chapter 2: Literature Review

In this Chapter, I present prior work in research exploring notification systems and using *Pepper's Ghost Illusion* put in perspective of my research work.

Chapter 3: Design and Implementation

Chapter 3 describes an exploratory study for the design guidelines of the Acquario Display and how to implement *Pepper's Ghost Illusion* as an overlay to a digital display, and then the final design of the Acquario Display for this thesis.

Chapter 4: Study

This chapter describes the qualitative and quantitative study employed to look at how the Acquario Display can support notifications using *Pepper's Ghost Illusion.*

Chapter 5: Study Results and Discussion

Chapter 5 presents the results of the study described in Chapter 4 and discusses the implications of these results.

Chapter 6: Conclusion

I conclude this thesis in Chapter 6 by summarizing the contributions of this work and present possible future work.

Chapter 2

LITERATURE REVIEW

As stated in the previous chapter, notifications are used to inform users about new messages, events and system status. With the number of devices and information vying for user's attention the benefits of notifications as a means of awareness quickly becomes a distraction and added stress for the user. A lot of research has been devoted to the study of notifications and how they can be made less distracting from the users' primary task while maintaining awareness.

The work of this thesis is to explore notifications with *Pepper's Ghost Illusion* to create a more subtle, less distracting form of notifying. While *Pepper's Ghost Illusion* has not been explored for notification systems directly, some forms of it have appeared in research. *Pepper's Ghost* itself has been explored as a 3D holographic display.

This chapter describes the previous work in notification systems and in applications with *Pepper's Ghost Illusion*. The past literature helps place this thesis in perspective. First, I describe literature on notifications themselves followed by notification systems using similar designs as presented in this thesis. Finally, I write about work in computer science using *Pepper's Ghost Illusion*.

2.1. Notification Systems

Notifications, visual pop-ups with or without auditory cues, have been an effective way of helping users maintain information awareness. Unfortunately, notifications have been seen as a disruption to primary tasks [4, 9, 10]. Iqbal and Horvitz worked to understand the influence of external interruptions on task switching [9]. The researchers conducted a week-long study of task switching and interruptions. The study found that participants switched tasks frequently and encounter many interruptions throughout their day. Participants recommended an ability to monitor the user's productivity to maintain a work-state controlling interruptions. This work focuses more on task switching between applications. However, these switches are triggered by notifications drawing the user's attention to another task. In later work, Iqbal and Horvitz found some contradictory views. They created a monitoring tool analyzing disruptions and resumptions of software tasks. In this later work, they found that users view alerts as an awareness tool rather than a trigger to switch tasks. However, alerts often cause the opposite. User's often switch tasks when a notification comes in to address it immediately. They also found that if the suspended task is visible while the user attends to a notification they recover from the disruption faster. Adamczyk and Bailey found that if the notification is displayed at the correct moments in task execution it produces less annoyance, frustration and time pressure [1]. However, this is not always the best solution for creating less obtrusive notifications because the correct moment for a notification varies greatly between users.

However, distracting notifications are, they are still seen as necessary. Iqbal and Horvitz conducted a field study on the use and perceived value of email notifications in the workplace

[18]. The field study was conducted for two weeks: the first week evaluated the users experience with email notifications enabled, the second week the notifications were disabled. The results showed that participants said they would rather have the notifications enabled even though they said that they were distracting, because the consequence of missing urgent information outweighed the distraction.

In another light, Mark et al. conducted an empirical study to find out if the context of an interruption effects how the notification is perceived and the effect on the task performance [23]. They found that notifications do not make a difference based on the context. They found that people compensate for interruptions by working faster but experience higher levels of stress and frustration. This suggests that the notifications have a negative impact on the user not because they are there but because they pressure the user to switch tasks.

The notifications mentioned above have been deployed on a desktop display. However, notifications also commonly appear on smartphone devices. While this thesis does not focus on mobile notifications, the results and perspectives of this form of notification is still of value to my work. The essence of the notifications both pros and cons can still be applied to desktops. Mashhadi et al. looked at

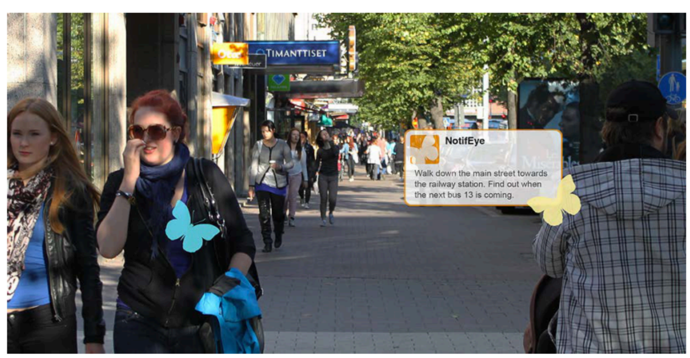

Figure 2.1. Lucero and Vetek (2014) Participants' view using the NotifEye system.

how notifications are perceived on mobile devices [16]. Similar to desktop display notifications, they found that visual cues users remembered their unread notifications better over sound or vibration. This work did not address the impact on the current task, mental work on a mobile device is different from the work on a desktop. Norrie and Murray-Smith looked at notifications on both desktop displays and mobile devices [18]. They looked at notifications that appeared on either a desktop display of on a mobile device placed beside the user during a typing task. They believed that a smartphone notification would be less obtrusive and provide the same awareness as the desktop notifications. However, notifications on the desktop display were significantly preferred over mobile notifications during the task.

The final work I discuss on notifications related to this thesis is the work presented by Lucero and Vetek [13]. Lucero and Vetek present NotifEye, an application that allows users to receive social network notifications on interactive glasses while maintaining awareness of their environment. The researchers found that participants could receive information while still keeping track of their surroundings. Participants indicated that they could receive minimal notifications through the glasses with discreet interactions that did not distract them from what they were seeing or doing (e.g. walking). Figure 2.1 shows an example of what the notifications

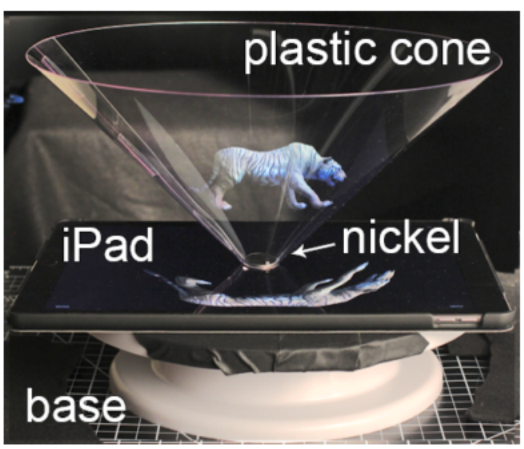

Figure 2.2. Luo et al. (2017) Pepper's Cone setup.

displayed on the interactive glasses from the user's perspective. The notifications have a similar appearance as the notifications presented in this thesis, both are information overlaid on to a background. The transparent quality of the notifications allows the users to see through the notice and be able to see what they are doing.

2.2. *Pepper's Ghost* in Computer Science

In the previous chapter, I discussed the past and present examples of how *Pepper's Ghost Illusion* was used. This section now describes the influence that Pepper has had on the computer science community. The literature on *Pepper's Ghost* does not always mention the illusion but the influence is clear in the construction.

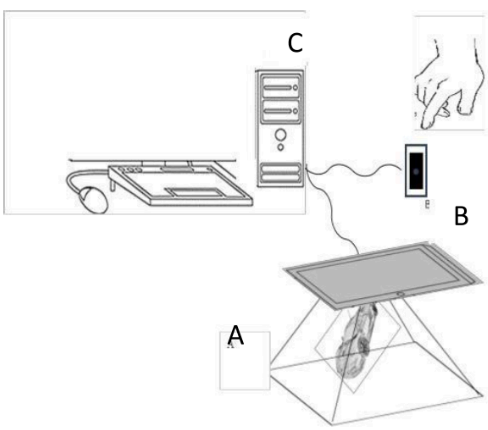

Figure 2.3 Luo et al. (2017) example of a pyramid setup.

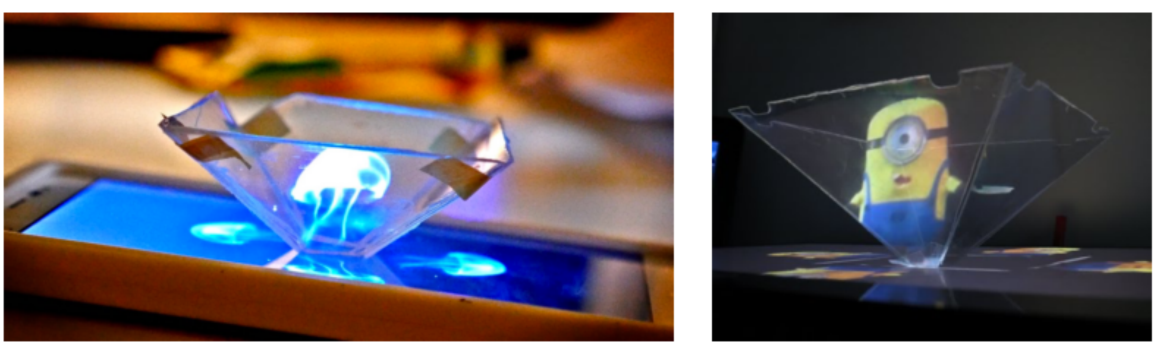

Figure 2.4. Luo et al. (2017) examples of 'do it yourself' setups of a "hologram" created with a pyramid structure using *Pepper's Ghost Illusion*.

The clearest example of Pepper's Ghost in computer science is the work presented by Luo et al. [14]. Luo et al. present Pepper's Cone, a 'do it yourself' display that provides a convincing way to view 3D scenes as "holographic" images. This work is a take on *Pepper's Ghost Illusion*, consisting of a thin hollow cone placed on top of a tablet display. The cone reflects the pre-warped images on the tablet display rendering a 3D scene that appears to be suspended inside the cone (Figure 2.2). This work is inspired by the work by Dalvi, which is an early example of a pyramid setup of *Pepper's Ghost Illusion* (Figure 2.3) that is popular on YouTube as 'do it yourself' videos (Figure 2.4) [5]. The pyramid setup is very similar to the setup presented in Pepper's Cone, except the cone is replaced with a pyramid and images are not pre-warped. These two examples from literature show the simplicity of *Pepper's Ghost Illusion* and how easily a setup can be made to explore different research avenues.

Figure 2.5. Bolton et al. (2011) Spherical display of a 3D object.

The work presented by Bolton et al. presents a spherical display with Fish Tank VR display for interacting with 3D objects [21]. This setup consists of an acrylic hallow sphere with a hole cut in the bottom. A projector is aimed upward at a mirror inside the sphere reflecting the image on the inside surface of the sphere. The sphere allowed user to interact with the object through gesture interactions to rotate and zoom the object. Figure 2.5 shows an example of an object displayed in the spherical display.

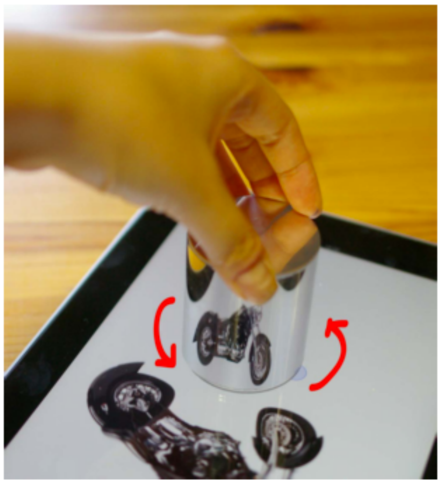

Figure 2.6. Suga and Siio (2011) Interactive anamorphicon

Suga and Siio's work created an interactive system using Anamorphicons, a 2D display reflected on a cylindrical mirror [22]. A distorted image is shown on a flat display or tabletop is reflected on to the cylindrical mirror displaying the original image. When the cylinder is rotated the image displayed rotates to show that side of the image. Figure 2.6 shows an example of how an anamorphicon setup can be used as an interactive system.

2.3. Conclusions

This chapter summarizes related literature on notifications and *Pepper's Ghost* used in computer science. Previous work on notifications revealed that notifications though distracting is perceived by users as necessary. Notifications can be made more subtle by being unobtrusive and allowing the user to continue their work without having their attention pulled too much away. The closest form of the notifications being presented in this work is the NotifEye system which provides transparent notifications that keep the user informed while allowing them to continue their tasks. *Pepper's Ghost* has not been explored much in computer science but researchers have focused their interests in using it as a means of creating a "holographic" displays. This thesis takes the results of previous work and applies them to a design for *Pepper's Ghost* that has not been explored in this area before.

Chapter 3

DESIGN AND IMPLEMENTATION

In this chapter, I describe the process I undertook to explore *Pepper's Ghost Illusion* and how it can be used as a notification system. The first part of this chapter describes *Acquario 1.0* in detail, explaining the foundation created for this thesis work and how the feedback was incorporated to create the final design. Next, I describe an exploratory study looking at the different variables of *Pepper's Ghost Illusion* to create a solution for using *Pepper's Ghost Illusion* in a setup for two displays. The variables explored are position and angles for the overlay, brightness and visibility of each device and the thickness of the glass for the illusion. Finally, I describe *Acquario*, the implementation design choices used for the study.

3.1. Technical Information

Acquario is a display configuration and software application created to explore notifications with *Pepper's Ghost Illusion*. *Acquario* is an online application that can be accessed on any device with an internet connection allowing the researcher to assign any device to be the role of the primary screen that the user interacts with or the overlay, the source of the illusion, e.g. allowing a Mac OS desktop display with a Microsoft Tablet as the overlay device. This allows for quick communication between devices to explore the differences between notifications on a standard display versus notifications on an overlay display. The system was developed using JavaScript, HTML5 and CSS3 with the communication through a Node server and connects through custom Socket.io[1] events.

3.2. First iterations

The first iteration of *Acquario* (1.0) was a spatially aware visualization tool that enables users to interact with web-based visualizations in several different ways. This early work was essential in understanding how *Pepper's Ghost Illusion* is created to address the research goals of this thesis. The main goal of *Acquario 1.0* was (1) to provide designers of visualizations a means

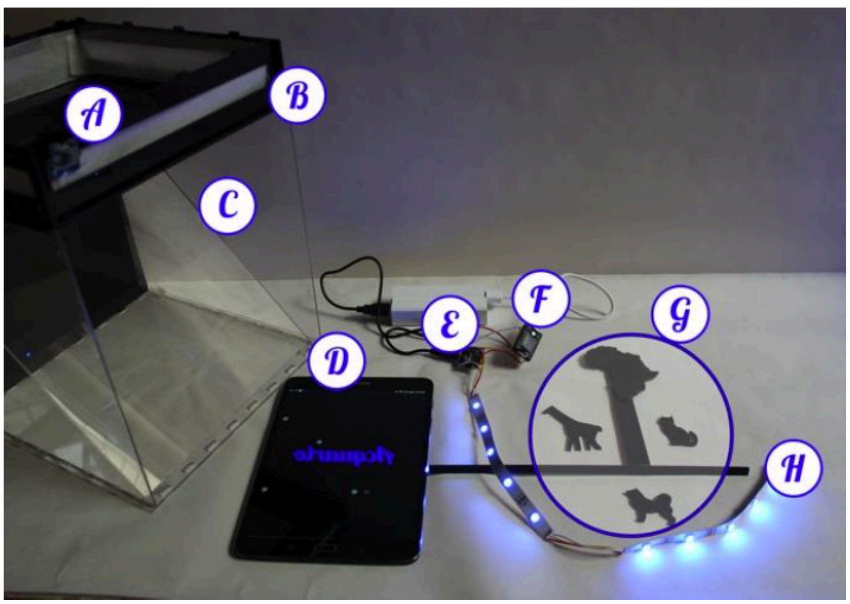

Figure 3.1. Inner components of the Acquario Tool; (A) Grove Gesture Sensor, (B) plexiglass cube encasing, (C) sheet of plexiglass placed at a 45° angle, (D) Samsung GALAXY Tab S2 tablet running demo software application, (E) Xadow Duino, (F) Spark Core microcontroller, (G) plexiglass laser cut tokens with NFC tags, and (H) strip of RGB LED lights. Pratte et al. (2016)

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[1] http://socket.io

to enable proximity, tangible and gestural interactions, and (2) to allow users to explore visualizations in a manner that allows them to “get their hands on the data” [1].

Acquario 1.0 was composed of several different components that connect to a server that integrated events and sensor information, using custom Socket.io events. The primary components of the system include a Samsung Galaxy Tab S2 8” tablet (Figure 3.1.D), a Spark Core development board (Figure 3.1.F), and custom laser-cut physical tokens with NFC tags (Figure 3.1.G). Each Spark Core development board is connected to either a Grove Gesture Sensor or a GestureR gesture sensor (Figure 3.1.A) and a Xadow Duino (Figure 3.1.E) that controls a strip of 10 addressable RGB LED lights (Figure 3.1.H).

Each Samsung tablet ran a custom Android application that utilized the native ANT+ sensor, providing proximity information to the server through Socket.io. Using this sensor, *Acquario 1.0* supported three ranges of proximity, close, near and far (Figure 3.2).

All components of *Acquario 1.0* are contained in a custom-laser cut Plexiglas cube (Figure 3.1.B). The display of the tablet is reflected on a thin sheet of Plexiglas inside the cube, at ~45° degree angle from the tablet’s screen (Figure 3.1.C). The reflection on the Plexiglas sheet creates a faux “hologram” that is projected onto the back surface of the cube. This uses *Pepper’s Ghost Illusion* and makes digital information appear inside the cube, as seen in Figure 3.3.

Figure 3.2. The Acquario 1.0 interactive, spatially aware cubic display running a web-based demo application highlighting the proximity ranges of 'close' (B), 'near' (A) and 'far' (C). Pratte et al. (2016)

Tangible objects are also recognized by the Samsung tablet using NFC and the custom android application. When a user places a tangible object inside the cube from the left side, the NFC tag is recognized, causing an event to be triggered (e.g. query data). Additionally, depending on the design of a token, virtual information can be displayed on or around the token inside the cube (Figure 3.3).

The main design goals behind *Acquario 1.0* were to focus on creating a tangible, spatial visualization tool that was self-contained and portable – allowing for proxemic ranges, as well as the easily manipulation of tangible tokens within the cube. As stated above, is quite different from the research goals of this thesis. This work focused on an application that could be used to explore querying visualizations and not on *Pepper's*

Figure 3.3. *Acquario 1.0* application using *Pepper's Ghost Illusion* to display information inside the cube on and around physical tokens. Pratte et al. (2016)

Ghost Illusion itself. While exploring this application, we took a step back and choose to explore the illusion itself more. In *Acquario 1.0,* portable battery chargers power all components of the tool so users are not tied down to a specific location by wires. *Acquario 1.0* was built upon much existing work for interactions, for interactions involving querying information, results from past research [7] were used for the design. For example, Valdes et al. show that users created queries and compounded queries by neighboring tangible objects. Two web-applications were created to highlight the concepts of *Acquario 1.0*. The demo application and the visualization application which demonstrated how each feature of *Acquario 1.0* can be used to query a data set for visualizations. This work explored the bigger design space by creating a an application utilizing *Pepper's Ghost Illusion*. By exploring the design space I could learn more about the illusion itself and focus on how it can be used for notifications.

The first iteration was shown at two different venues: The Maker Fair Calgary[2] in 2016 and then in the *Spatial User Interfaces SUI* ACM conference later that year. This work and feedback received at both events has led to further exploration of *Pepper's Ghost Illusion* and how it can be used. People at both events were most interested in the illusion itself, specifically how the illusion was accomplished and how it can be used with technology. In *Acquario 1.0,* there is a black piece of plexiglass used for the back panel of the cube to make the illusion standout more, this also gave the appearance that the back panel was actually the display. Several

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[2] https://calgary.makerfaire.com

of the viewers commented on this effect, leading to the question of how *Pepper's Ghost Illusion* can be utilized with two displays creating an overlay on a digital screen.

3.3. Exploring *Pepper's Ghost Illusion*

As previously stated in Chapter 1, the illusion can be accomplished in different forms. The Calgary Maker Fair displaying *Acquario 1.0* was an exploration design to get feedback quickly and explore a broader design space, final design to evaluate the benefits or a specific aspect that was deemed to be most interesting. I chose to explore the different methods of creating the effect to find the an interesting setup for an overlay on a digital background. This exploration phase was very beneficial to this thesis work. That said, exploratory research is not intended to provide a conclusive solution to a research question but to help gain a deeper understanding of the research question. The main goal of this exploratory research was to look at different setups, including angles of the glass and position of the overlay display, and to look at brightness and visibility of the primary display and the overlay.

3.1.1 Position of the overlay device

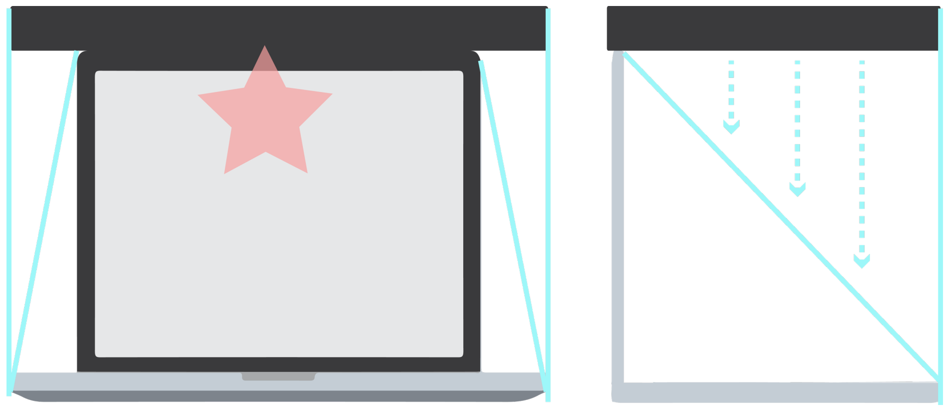

Figure 3.4. Diagram of the top setup for *Pepper's Ghost Illusion*.

The different angles I explored were from the overlay device angled from the top, bottom, and both left and right sides of the primary screen. The overlay in the top position was the first angle attempted because it naturally flowed from the *Acquario 1.0* setup. Figure 3.4 shows a diagram of how each device was placed and how the overlay appeared. The overlay device is a wireless tablet placed in the lid of the Plexiglas cube used in *Acquario 1.0*. The back panel was removed and replaced with the primary screen, a Mac OS laptop. To create the illusion the piece of glass is placed at various angles starting at the top of both screens. To test the quality of the display the primary screen displayed an image of a field and the overlay displayed a GIF of a dog running. The dog image was overlaid on the field to see the visual quality of the overlay image with the digital background of the primary screen. The drawbacks from this setup was the optimal viewing position is at the top of the primary screen where it was not as easily seen for the viewer and the illusion only reached downward to the middle of the screen losing the bottom half because of the size of the device used for the illusion. A larger device screen can be used to reach to the bottom but it then becomes difficult to see the top of the screen because it is being obstructed from the overlay device. When the overlay device is moved upward the quality of the illusion is lost.

The next setup explored is a similar setup to the original design of *Pepper's Ghost Illusion* with the illusion coming from the bottom scene, in this case the primary screen. A tablet was used for the overlay screen with a desktop display used for the primary screen (Figure 3.5).

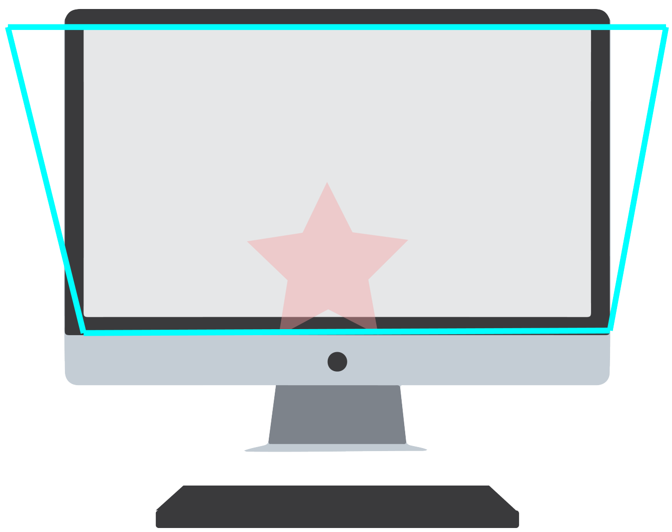

Figure 3.5. Diagram of the bottom setup for *Pepper's Ghost Illusion*.

A desktop display was used to explore the different height positions of the overlay device from the primary without a laptop keyboard limiting the exploration of this setup. In the original setup, the actor (the overlay) was several feet below stage, this did not work for a two-device structure because the overlay did not appear bright enough from a distance. An effective placement for this structure was immediately below the primary screen. However, the bottom setup for the overlay device faced similar problems to the top setup. Only the bottom half of the screen had an easily viewable region for the overlay on the primary screen. Both the top and bottom structure for the overlay address the most common regions of Mac OS and Microsoft notifications respectively but do not provide a good setup for both systems. In order to explore notifications with *Pepper's Ghost Illusion* on computer systems, however, it may skew the results if one common region from a popular OS is limited or ignored all together. This is way I decided against these setups and continued to explore others.

The final setups explored are the left and right positioning. In this setup, a tablet was used for the overlay device with a Mac OS laptop used as the primary screen, a desktop could also be used in place of the laptop however the resolution was better on the laptop then the desktop I had available. Figure 3.6 shows the structure for both left and right setups respectively, for the right setup the left-hand side of the tablet is placed perpendicular to the right side of the primary screen with the glass placed where the screens meet at various angles. This ended up being an effective setup for the digital background because the illusion could reach over the entire screen.

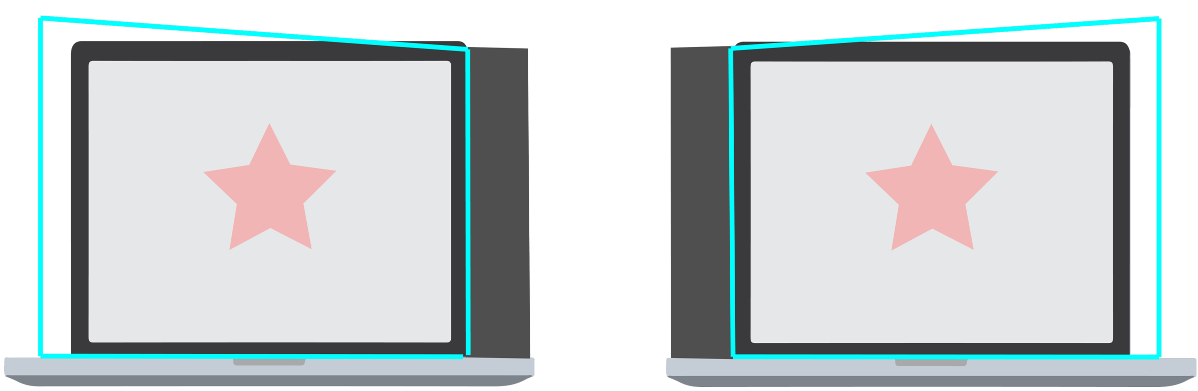

Figure 3.6. Diagram of the right and left setup for *Pepper's Ghost Illusion*.

This is partially because the illusion display can be placed tight to the primary screen without obscuring it. The illusion can then reach the full length of the primary screen to display information giving the effect of more viewing space. The side setups still lose quality on the far side of the primary display but the space utilized for the high-quality portion is in the regions most commonly used for notifications (e.g. the top and bottom right of the primary screen). The right-hand side setup is the final set up that was used because this structure had an effective viewing region on the right side where most major OS's display notifications.

Several different angles for the illusion glass were looked at in this exploration phase. In all the different setups (top, bottom, left and right) the best angle for the glass to create the illusion was about a 45° angle as in the original setup. When the glass is at a 45° angle the boundaries of the illusion "fits" and appears flat on top of the background, in this case the primary screen. Different angles produced interesting effects as well, especially when the glass was moving. For example, when the glass is moving towards the primary screen the illusion gives the effect of travelling inside the primary screen and vice versa for the opposite direction. However, this effect was not in the scope of this research and could be explored in future work. This work is interested in the overlay effect only.

3.1.2 Brightness and visibility

One of the main issues with the two-device setup is the backlight from the primary screen. The light counteracts the light of the reflection which is already reduced to about 10% of the original device [6]. The further the reflection is from the overlay device the lower the quality of the reflection creating an optimal view point in each setup, ultimately why the top and bottom position did not work for two displays but work well with dark backgrounds. The optimal view point is the first half of the reflection closest to the origin of the illusion where the glass meets the overlay device. This region allows good visibility regardless of the background colour of the primary device. The level of brightness for each of the devices also plays an important factor in the quality of the illusion. If the brightness is lower on the overlay device versus the primary screen then the illusion is difficult to read. The best setup for me is to have the brightness level on the primary screen set to less than 50% with the overlay device set to maximum brightness. The environment lighting also has an effect on the illusion, the higher the lighting level is in the environment the lower the quality of the illusion becomes.

3.1.3 Glass thickness

Another factor in the quality of the *Pepper Ghost Effect* is the sheet of glass used to create the illusion. The illusion can be accomplished using many different materials (e.g., glass, plastic). However, the performance of that illusion depends on the properties of the materials used. The surface of the materials used should be uniformly smooth and shiny to create a sharp refection [15]. The thickness of the glass can have an adverse effect on the quality of the illusion. The thickness of the glass creates a doubling effect on the illusion which causes fine details to be lost, for example, when the glass is thicker then 3mm smaller text is very difficult to read and comprehend. I chose to use 3mm thick framing glass.

3.4. Study Implementation – Acquario

The final physical setup for the study is the right-side setup with a tablet placed perpendicular to the right side of the primary screen and a piece of glass beginning at the place where the two displays meet, extends outward at a 45° angle. The tablet display was set to maximum brightness and the primary screen was set to about 30% brightness in order to make the illusion appear at a good quality.

Acquario, the current version referenced as *Acquario* from this point forward, was implemented with HTML5 and CSS3 as a web application. A Node.js[3] server was created to

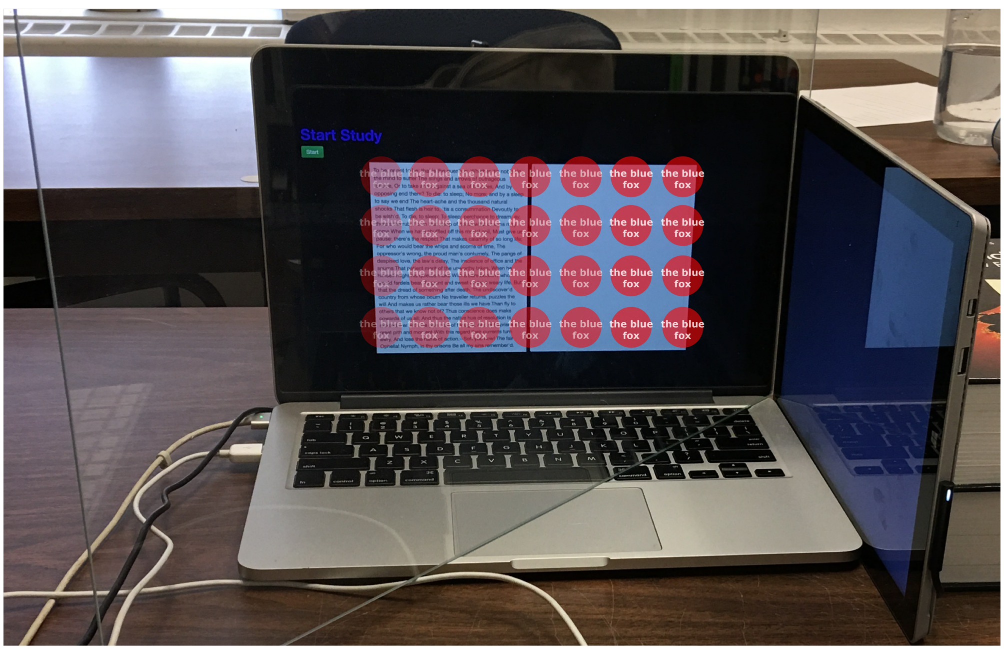

Figure 3.7. Grid pop-up examples for study application.

[3] https://nodejs.org/en/

connect two applications for the study, an application for the primary screen and one for the overlay. Both applications are created in the simplest form. The primary screen application consists of a paragraph and a text block were the participants are to copy the paragraph into. The pop-ups appear as circles with text in the center. The pop-ups appeared in a grid across the screen so that I could evaluate the different perspectives of the pop-ups from the participants. For example, I wanted to see if the pop-ups had a different effect if they were in a more distracting location such as over the text the participants are trying to copy. Figure 3.7 shows an example of the grid used for the study (note that the participants could not see this grid, only a single notification as it appeared). Text input remains functional during pop-ups to prepare for the case that a pop-up would not be seen and the participant can precede with their task. Missed pop-ups are important for analysis, if the participant misses a pop-up then *Pepper's Ghost Illusion* may not be an effective method for notifications. The overlay was designed with the same setup for the pop-ups; a grid across the same region of the primary screen and the same size circles with text in the center. The only differences are that the pop-ups are the only thing displayed on the overlay screen and the text in the pop-ups had to be reversed backwards so that the reflection is legible to the participants.

3.4.1. Design Choices

Several design choices were made during the creation of the system in addition to the ones described previously in this chapter. The main design choices were in the colours and with the text.

3.4.2. Text design choices

The main design choices for the text were for the pop-up text size and the font used. The text size used for the pop-ups was 20-point font from the Verdana font family. At one point, the minimal font used in web applications was set to 16 points, however now screen size, resolution and the distance from the screen all have an effect on the legibility of the text. Legge et al. explored how text size can affect reading speed and comprehension [11]. They found that text has the fastest reading speed when the text's x-height has an arc of 0.3°. The x-height of text is the minimum size for readers; readers with 20/20 vision require a visual arc of 0.2°, older readers require 0.3°. The visual arc is determined by the size of the object (the text) viewed and the distance the viewer is from that object (Figure 3.8). Different typefaces have different x-heights for lower case letters; the larger the x-height for lower case letters the easier the typeface is to read. However, resolution is another factor that affects the visual arc because font point size is not the same as pixels. There are always 72 points per inch but the pixels per inch varies depending on the device. For the 13" Macbook Pro device used in this study the pixels per inch are 113 ppi.

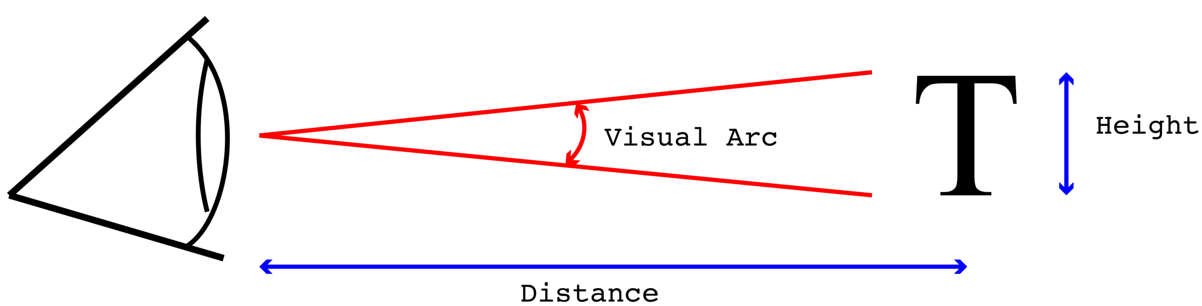

Figure 3.8. Diagram of visual arc, a factor for the distance a person is from the object and the height of the object.

The typeface Verdana is not only one of the most legible fonts to read on a computer but it also has an x-height ratio of 0.545. This x-height calculated with the distance of ~61 cm from the screen and a 113 ppi results in a font size of 20 pts with an arc of 0.31° - a nice and readable text size and font for most participants.

3.4.3. Colours

The main design choices for the colours used in this study were for legibility and to help bring out *Pepper's Ghost Illusion*. To bring out *Pepper's Ghost Illusion* on the overlay the background was set to all black. If any other colour is used for the background for the overlay then this would also be reflected. This is also why the address bar for the webpage had to be hidden, the reflection of anything but the pop-ups take away from the study. The pop-ups were designed with red circles and white text. Red is the first colour noticed by people and white text provides an easy contrast for participants to read.

3.5. Conclusion

This chapter outlines the design process used to explore and create a system for notifications using two devices with *Pepper's Ghost Illusion.* The final setup used for the study places the primary screen in the direct line of sight of the user with the overlay device placed perpendicular to the primary screen on the right side. The glass for the illusion is placed at a 45° angle from the overlay device originating at the point where the two devices meet. The next chapter describes the study setup and the participants.

Chapter 4

STUDY

This chapter describes the qualitative and quantitative methodology employed for this study on the *Acquario* Display for supporting notifications using *Pepper's Ghost Illusion*. I discuss the methods I used to observe participants interacting with the system and the interview process conducted before and after the study. I also discuss the data collected during the study.

The focus of the study was to analyze the participant's reaction time of notifications while their focus is on a primary task. This helped in understanding the important aspects of how users perceive notifications and compare the difference between standard pop-up disruptions with a pop-up using the *Pepper's Ghost Illusion*. This was also an opportunity to understand how the system can be improved and expanded on for further research.

4.1 Methodology

The aim of this study, is to answer the research questions described in Chapter 1 Section 1.2 and fulfill the goal of this Thesis: to explore an **effective setup for *Pepper's Ghost Illusion* with two displays** in order to **evaluate the subtlety of notifications using the illusion** and the **reaction time** in comparison to standard notifications. In this thesis I define the "subtlety" of notifications as a less invasive method of displaying information to the users without losing awareness. Considering the nature of the illusion, it is expected that the reaction time will be the same for both standard notifications and notifications using the illusion and that users will find the transparency of *Pepper's Ghost Illusion* will be preferred over current notification methods.

4.1.1 Participants and Pre-Study Interview

For this study, participants were not excluded on any grounds, assuming that most people have been exposed to notifications in some way. After running two pilot participants, I iterated slightly on the study by changing the colours of the pop-ups and the text font from a serif typeface to a sans-serif typeface. I recruited 10 participants for the final study, 5 females and 5 males: all were graduate-level students from the University of Calgary – all with backgrounds in Computer Science and a mean average of 18 years of experience with computer systems. Only two of the participants had any previous knowledge or experience with *Pepper's Ghost Illusion*. *Pepper's Ghost Illusion* was not explained till after the pre-study interview so that the participants results were not influenced by anticipation of the study.

The above information was gathered in a pre-study interview. This interview also investigated information about users experience and views of notifications. Participants were asked **if they like to receive notifications on their computers**? and **if they could change something about the why notifications are currently displayed what would it be**? A copy of the pre-study interview can be seen in Appendix I.

4.1.2 Study Setup

During the study, a Macbook Pro 2015, 13" laptop (Figure 4.1(2)), with a resolution of 2,560x1,600, was used for the primary screen in which the participants directly interacted. For the *Pepper Ghost Effect*, a Microsoft Surface 3 (Figure 4.1(3)) with a resolution of 1920x1280 was reflected on a 40.6cm x 50.8cm x 3mm piece of clear glass (Figure 4.1(1)) placed at a 45° angle from the Surface 3. Participants sat about 2.5 feet from the displays with direct viewing of

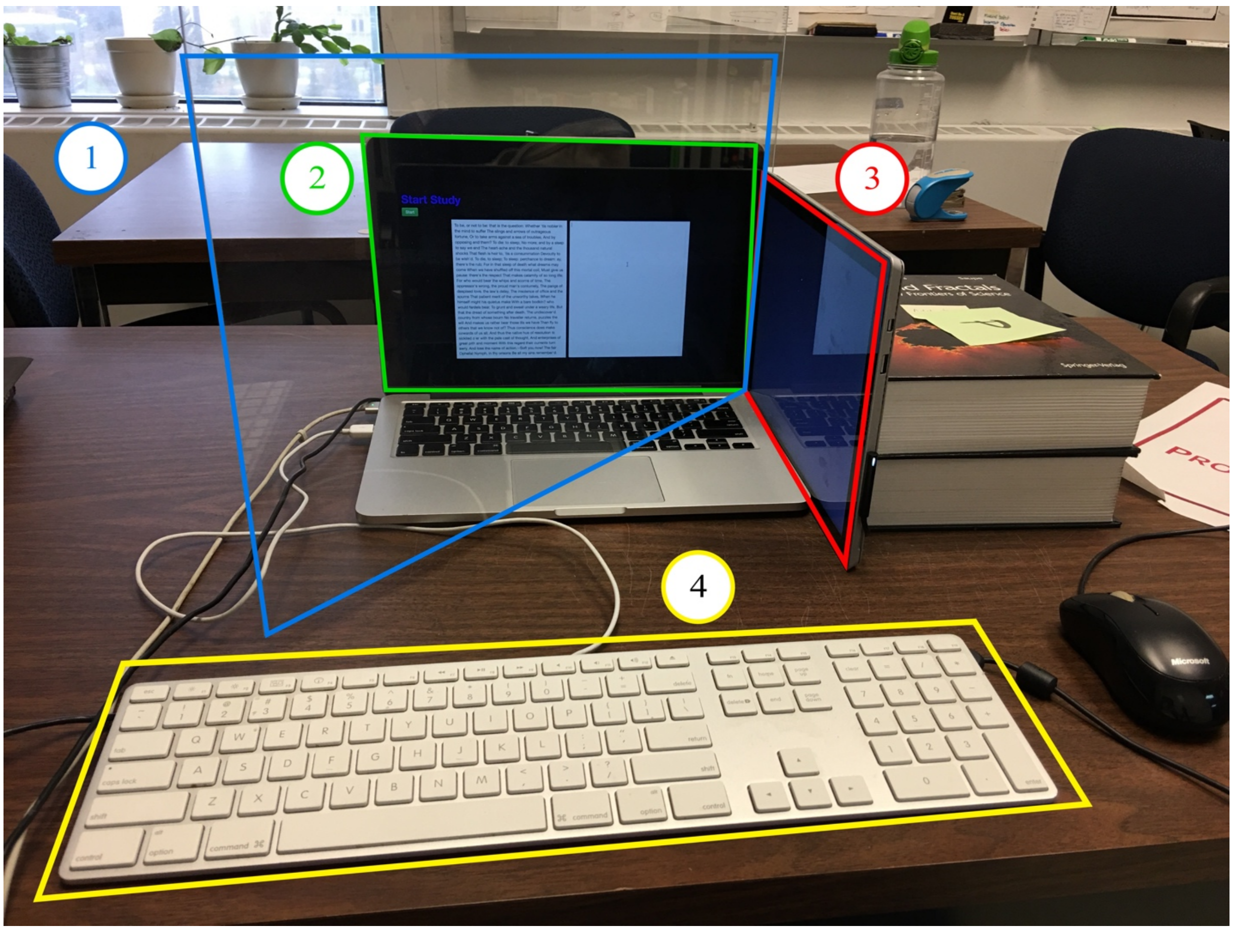

Figure 4.1. The study setup. (1) A 3mm sheet of glass placed at a 45° angle from the Microsoft Surface 3 (3) creating *Pepper's Ghost Illusion*. (2) the primary screen participants interacted with. (4) the keyboard the participants interacted with – the only interaction with the system.

the primary screen and the reflected display. A 1080p HD Microsoft LifeCam Studio webcam with 30 fps was placed behind the participant to capture the pop-ups and audio recording to capture participant's responses.

4.1.3 Tasks

The participants were interviewed and run through the study on an individual basis in 30 – 45 minute sessions. The participant's task was to transcribe the text displayed to the left-hand side of the primary screen into a text area on the right. The text they were to transcribe was an excerpt from Shakespeare's Hamlet, this text was chosen because of the generally unfamiliar style requiring more user focus. At this point in the study *Pepper's Ghost Illusion* was explained to the participants along with their task in the study. Participants were told that all they were to do was to copy the text, no other button pressing or action was required, and if they saw a pop-up they were to verbally acknowledge it by reading the text displayed. Pop-ups appeared for 5 seconds before disappearing. If they could not read the text they were to just verbalize acknowledgement by saying they could not read the text. Participants went through 10 rounds of pop-ups which the participants were told would appeared randomly on the primary screen or on the overlay display using the illusion. 5 rounds of pop-ups appeared on the primary screen and 5 on the overlay screen. Pop-ups also would appear at random locations on either display. The method used was a distraction test [18], the participants were told that their main task was to copy the text accurately and keep typing with the pop-ups. The goal was to explore how distracting each type of pop-up was in order to see if there was a preference.

During the study, participants' average words per minute and reaction time to notifications were recorded. The purpose for recording words per minute was to determine if there was a decrease in the participants' performance after the notification in one method or another. A decrease in participant's typed words per minute in a particular method could indicate whether one method is more distracting than the other; the participant's focus is being pulled away from the transcription task too much. The first minute of the study was used to record the participants' expected typed words per minute. Throughout the remainder of the study the participants' words per minute were recorded before a notification appeared and then again after it disappeared. The words per minute were calculated by taking the number of words typed in the text area between notifications and dividing it by the time between notificaions, in minutes. To record reaction time, a camera was placed behind and to the right of the participant to capture when a notification first appeared. Participants were told that they were to verbally acknowledge that they saw a notification and then try to read the text on it; if they could not read the text, they were to say that they could not. The reaction time was recorded to see if there was a difference between methods on when participants first perceived the notification. I chose a less complex method in order to simulate a real workplace environment.

4.1.4 Post-Study Interview

The post-study interview was conducted after the participant interacted with the system to gain qualitative feedback on their experience. Six questions were asked in a semi-structured interview and notes taken on further comments. The six main questions asked were (a copy of the post-study interview can be seen in Appendix II):

1) **Which method (on primary screen or overlay) did you prefer to display notifications?**

The main goal of this question was to gain an understanding of user's preference and to find out why they preferred the one they did. The response here is important to understand because even if the qualitative data collected shows differences in performance, participants may still prefer one method over the other.

2) **Which method was easier to read (primary screen or overlay)?**

Since there is text on the pop-ups it is important to gauge with one the participants thought had better legibility.

3) **Was one method (primary screen or overlay) more distracting to your task than the other?**

Distraction can be subjective to the user, this question gains insight into which method and why it was more distracting to them during the study.

4) **What did you like AND dislike about the overlay screen method? Explain**
5) **What did you like AND dislike about the primary screen method? Explain**

The two questions above give an insight into not only the participants' preference with each method but also things that can be improved in future work.

4.2 Conclusions

In this chapter, I discuss the methodology used to conduct the study in this thesis. The study consists of three parts: the pre-study questionnaire, the study task itself, and the post-study interview. This chapter describes the study setup in detail, how it was run, and how task performance and participants' preference were measured.

Chapter 5

RESULTS AND DISCUSSION

This chapter presents the quantitative results from the data collected from the study and the qualitative results from the pre- and post-study interviews. Chapter 4 gave an overview of the methodologies used to conduct the study and an overview of the questions asked during the post-study interview. Section 5.1 describes and discusses the study results including analysis of words per minute and reaction time. Section 5.2 describes and discusses the results from the pre- and post-study interviews on participants perspectives and preferences. The observations of the study are described in Section 5.3. Lastly, the chapter is concluded in Section 5.4.

5.1. Study Results

5.1.1 Words Per Minute

At the beginning of the study the participants were told that their task was to transcribe the text given and notifications would appear at random on either the primary screen display or on the overlay display. However, they were not told when the notifications would begin to appear. For both methods, the participants showed no sign of decrease in their performance. The majority of the results, 85 out of 100 tasks completed (10 participants with 10 tasks each), showed that the words per minute before and after a notification remained the same or on a very few occasions decrease by one, however, this occurred in both the primary and overlay methods. Results of participants' words per minute during the study can be seen in Appendix V.

5.1.2 Reaction Time

Reaction time was recorded throughout the study by filming the participants. One hypothesis of this study was that because of the more subtle nature of the overlay method, the reaction time might be lower. However, participants consistently acknowledged each of the notifications in less than one second, regardless of the notification method. This could mean that the overlay method is just as noticeable as the standard method of notifications in a more discreet fashion, which is to be determined by the participants feedback in the post-study interview. However, it could also mean that a finer method of measurement is needed to record reaction times, such as a camera that can record milliseconds. The results of both the reaction time and the words per minute could also require more participants to see more interesting results. Results of participants' reaction times can be seen in Appendix IV.

5.2. Pre- and Post – Study Interview Results

5.2.1. Pre – Study Interview

During the pre-study interview participants were asked **if they like to receive notifications on their computers**? and **if they could change something about the why notifications are currently displayed what would it be**? The goal of the pre-study interview was to identify participants views of notifications before the study and the *Pepper's Ghost Illusion* were explained in order to get a non-biased response.

Question 1) Do you like to receive notifications (i.e. email, Facebook, calendar etc.) on your computer? Explain.

Half of participants (5 of 10) responded “sometimes” they like to receive notification on their computers. Most of these participants said that they sometimes liked the notifications on their computers depending on the application the notification is coming from, such as, email and calendar applications or some common messengers used for work like Slack. Facebook, and other social media sites, notifications are commonly turned off due to volume and lack of important content. Some participants stated that the type of notification they liked to receive depended on the platform they were using; social media is preferred on mobile devices and “important” notifications like emails and calendar are preferred on computers. Participants Also said that their preference depended on the task they were currently performing. Two of the participants who said “sometimes” said that they dislike notifications but keep them on because of time sensitive information such as calendar events or important emails. The consensus between the “sometimes” participants was that notifications were necessary but distracting.

Two of the ten participants responded that they like receiving notifications on their computers. One of these two participants said that they liked to be kept notified without needing to constantly check different applications or websites. The other said that they like having email and calendar notifications and that they liked to choose which applications they wanted to see notifications from.

The final three participants responded “no.” They do not like to receive notifications on their computers because they find the notifications too distracting and will not check them anyway. Another said that they do not like receiving notifications on their computers but like getting them on their phones and only use their computers to respond to certain notifications. Lastly, the third participant said that they do not like to receive notifications and they like to explicitly check applications and websites for them.

The goal of this question was to see if the participant's feedback was consistent with past findings. The results show this is true, participants find notifications distracting but also necessary as an awareness tool. My hypothesis was that participants would respond consistently with past research and that *Pepper's Ghost Illusion* could be used as a more discrete method of keeping user's informed.

Question 2) If you could change something about the way notifications are currently displayed what would it be? Explain.

The majority of participants (6 of 10) responded to this question that they would prefer notifications were less intrusive and more passive. The main complaint that participants have with current notification systems is that they are distracting to their work flow. Participants expressed a preference for a subtler form of notifications such as soft cues in their peripheral vision, auditory cues or less movement. Participants did not know exactly how they would like to see more subtle ways to be notified but definitely wanted to see an improvement.

Three other participants responded that they would like to have a system where their computer knows when they are busy and only shows relevant notifications. They would like to see each notification be filtered, notifying based on context. They also wanted to see different notification awareness, such as different auditory cues, based on the importance of the information.

The last participant responded to this question saying that notifications are fine the way they currently are.

These results compliment what was found in previous research that users like to be kept aware of information coming in but find notifications distracting. Participants mostly find notifications necessary but they want to see more passive means of notifying and are interested in different forms of informing.

5.2.2. Post – Study Interview

The post-study interview yielded the most interesting results in understanding each participants perceptions and preferences. The main goal of the post-study interview was to gain the participants view and feedback of *Pepper's Ghost Illusion* used in this context.

Question 1) Which method (on primary screen or overlay) did you prefer to display notifications?

Five participants preferred the overlay method and the other five preferred the primary screen method. Four of the five participants that preferred the primary screen said that they only chose the primary screen because it was easier to read. From these results, participants liked the overlay method to notify them of incoming information however, if they need text on the notification then the illusion will have to be improved for the text quality. Participant P1 said, "If the notifications were colour coordinated and less text, based it would be a very powerful integration." Participant P10 said, "I prefer the primary screen method but if I just wanted to see that I was getting a notification of some sort then the overlay might be better because it was less invasive. These responses indicate that the results of the preference is due to the legibility of the test on the overlay display. The responses from the next question in the interview drew some light on how the text quality can be improved by the placement of the notification. The closer the notification is from the point where the overlay glass meets the illusion display the clearer it appears. This effect is discussed further below.

Question 2) Which method was easier to read (primary screen or overlay)?

Nine of the ten participants commented that the double effect of the illusion, caused by the thickness of the glass, made text more difficult to read. The thickness of the glass causes a reflection on both the front of the pane of glass and on the back. The reflection on the back of the pane is slightly off center from the reflection on the front creating a slight double image. The legibility was also an effect of the size of the text. With larger text the double effect is less noticeable and the text more legible. In the previous setups with *Pepper's Ghost* the image is typically life size and seen at a distance, diminishing the doubling effect. Previous setups have also mostly been to portray "holographic" people interacting with live people on stage. The audience can still recognize who the visual representation of the illusion is supposed to be, but the slight details can be lost. Text however, especially small text, needs the fine details to be readable.

In addition, often when a participant said they could not read or had difficulty reading the overlay notification, the notification appeared on the left side of the overlay glass. I believe this is because the visual quality of the overlay decreases, the further the illusion appears from the point where the overlay glass meets the display for the illusion the light reflected is diminished (Figure 3.7). The best quality of the illusion is closest to the screen where the most light is reflected. In the study setup, this is the right hand of the screen. This is consistent with the data collected in the study, 34 out of 50 (5 overlay notifications per 10 participants) overlay tasks were consistently read on the right-hand side with ease. Five out of 50 of the overlay notifications could not be read by participants, all 5 appeared on the left-hand side of the screen where the illusion has the weakest visual quality. Eleven out of 50 participant's results responded that the they could read the overlay notification but with difficulty. Seven out of 11 results appeared on the left, 3 out of 11 appeared in the middle and 1 was on the right. Participant P4 said that, " if the overlay was of a consistent visual quality, [they] would have almost no reason for disliking the overlay." From these results we can say that for notifications a good location to display using *Pepper's Ghost Illusion* is closest to the screen where the illusion has the best quality for legibility. Results of participants' legibility for the overlay tasks can be seen in Appendix III.

Question 3) Was one method (primary screen or overlay) more distracting to your task then the other?

The main complaint with notifications in previous research is that they are distracting and pull too much of the users focus from their primary tasks. The main goal of this question was to see how and in what ways the participants found each method distracting. As in the first question, participants responded with a split decision. Four of the participants said they found the primary screen method more distracting and four responded that they found the overlay more distracting. The final two responded that they found neither method more distracting then the other. The four participants that found the overlay more distracting said it was due to the quality of the text and legibility. These participants said that since it was difficult to read the overlay notifications in some areas they had to focus more on the notification which caused them to lose their place in the transcribing task. Participant P5 stated that the overlay, “was more distracting when the notification was in the [left] corner. It was hard to focus on it.” The participants wished that there had been consistent quality of the overlay notifications then they might have preferred the overlay method. However, the participants who found the primary screen more distracting said that they preferred the overlay because of its transparent quality. Participant P7 stated that the primary screen notification was more distracting because it blocked the text but the overlay was transparent the text behind the it was not blocked. Since the notification was softer they didn’t have to change their focus as much in order to acknowledge it. They could readjust their focus with little effort to mark their place in the text they were transcribing and acknowledge the notification then continue their task. The participants that found the primary notification more distracting said that these notifications more distracting because they were more jarring. Participant P1 said that they found the notifications on the primary screen, “too intrusive, made me frustrated and annoyed." The notification would demand their attention more than the overlay, not allowing them to mark their location in the transcription text and causing more time to continue their task after the notification. Some of these participants also stated that some of the primary notifications blocked their current location in the transcribing text, meaning that they could not continue their task while the notification was displayed. This shows that though *Pepper's Ghost Illusion* for notifications had issues it also might have had a positive impact on participants as a subtler form of notifying them of information. On further discussion with participants in the interview, suggestions to improve the overlay notification were asked. Some participants said the location of the notification should be constant to further reduce distraction like the current method of notifications. The reason I chose random locations for notifications was to test reaction time, if the pop-ups appeared in the same location participants would begin to anticipate them and skew the results for reactions. One participant suggested that an improvement on the overlay notifications would be to remove the text and display a different colour for the type of notification that is coming in. With this method, the benefits of the overlay could still be kept while removing the main complaint of the difficulty reading the text.

The final two questions asked in the post study interview were to discover what the participants specifically liked and disliked about each method: the overlay and the primary screen. Most of the responses were covered in the above questions but I felt it was still important to explicitly ask to further understand the participants reasoning and to discover other likes and dislikes.

Question 4) What did you like and dislike about the overlay method?

All of the participants stated that they did not like that they had difficulty reading some of the overlay notifications. As stated previously, the difficulty reading the text is from the doubling effect from the thickness of the glass in the illusion combined the reduced quality of the notifications the further they appear from the source of the illusion on the glass. Some participants commented that if the visual quality of the notifications was consistent, as good as when they are close to the source of the illusion, then there would be no need for a dislike of the overlay method. Future work on this topic would be to explore various methods of reducing the defective qualities of the illusion for notifications such as looking at methods of exploring different thicknesses of the glass to further reduce the doubling effect.

Participants stated that they liked the transparent quality of *Pepper's Ghost Illusion,* as previously mentioned, because they could easily see past the notification and continue their task. They stated that they could mark their location in the transcription text and slightly change their focus to acknowledge the notifications. Participants stated they considered the overlay method as a more subtle option for viewing notifications. Each of the participants that said they wanted a more subtle alternative to current notifications liked the *Pepper's Ghost Illusion* as less invasive method in the post study interview. One of the most interesting responses from this question in the interview was an observation from one of the participants. This participant said they like when they moved their head, the notification appeared to move with them. They said that the effect was interesting because they could, "look behind the notification to the screen behind". An interesting topic for future research will look into how this effect can be utilized in a display setup with *Pepper's Ghost Illusion*.

Question 5) What did you like and dislike about the primary screen method?

Most of the participants responded that they liked best that the notifications on the primary screen was easy and clear to read. This is fairly obvious since the most disliked quality of the overlay method was the difficulty with the clarity of the text making it more difficult to read. Participants also commented that they liked the familiarity of the notifications on the primary screen. The method was familiar to participants since it was made to mimic the standard form of notifications used today so they would be little to no adapting with the primary screen method. Participants also like that the notifications were of a consistent quality no matter the location on the screen.

The main dislike that participants had with the primary screen method is that the notifications would block the text that they were transcribing. They felt that they had to wait for the notification to disappear before they could continue with their task. Participants said that they felt this pulled their attention too much from their task and caused them more time to resume. Participants felt that the primary screen notifications were more jarring from their task.

5.3. Observations

As each of the studies were conducted I stood behind and to the right of the participants to take notes. One thing I observed during the study sessions was that when a notification appeared on the primary screen I could read it from the ~4 feet distance I stood back from the screen. However, I could not read any of the notifications on the overlay screen from my distance. The camera was placed roughly on level with the participant and could record what the notification said but from my distance I could not. This could provide a means of privacy for notifications while users work, not having to be concerned about sensitive information being displayed.

5.4. Conclusions

In this chapter, I present the findings from the study and interviews conducted for this thesis. The results from the study showed that there was no difference in reaction time or performance between the primary and overlay method. The more interesting results were discovered in the post study interview. The interview revealed that *Pepper's Ghost Illusion* as a notification system was seen as a more subtle and interesting approach to display notifications. However, improvements need to be made to make it an effective method.

Chapter 6

CONCLUSION

The main goal of this thesis was to explore **how the *Acquario* display, a novel display mechanism for viewing notifications using an old technique, *Pepper's Ghost Illusion*, to evaluate reaction time and preference for users.** Chapter 1 opens with the background and motivation for this work. Notifications have been reported in several studies as very valuable in providing awareness of incoming information to the user. However, notifications have also been reported as distracting and cause the user to pull focus from the participants primary task. Chapter 2 describes previous literature on notifications and *Pepper's Ghost Illusion*. Then I look at the design and implementation of the system used to explore the thesis topic in Chapter 3. The study is then described in Chapter 4 and the results explored in Chapter 5. In this chapter, I summarize the contributions from this work and provide directions for future avenues of research on this topic.

6.1. Contributions

The main contributions of this thesis are the presented setup method for *Pepper's Ghost* with a digital background and the insights gained from the participant interviews. The results from the study (presented in Chapter 5) highlight the participants perceptions of the notifications overlaid on a digital display. This work also provides a study methodology using *Pepper's Ghost* and how the setup can be utilized for a study.

6.1.1 Revisiting the Research Questions

Research Question 1 (RQ1). Does Pepper's Ghost Illusion allow for more subtle notifications?

During the post-study interview the majority of the participants reported that the overlay method of notifications provides an unobtrusive way of displaying information. Some participants reported that the transparent quality of the notification and the overlaid effect kept the participants informed but did not pull their focus from the transcription task. The biggest issue with the current setup of the overlay method was that the doubling effect made the notifications difficult to read.

Research Question 2 (RQ2). Can Pepper's Ghost Illusion be effectively used with a digital background?

Pepper's Ghost Illusion has been very successful at providing a means to produce "holographic" images in physical environments. Chapter 4, section 3.1 explored the multiple setups attempted to find a solution to using *Pepper's Ghost* with a digital background. The main concern when creating the setup is the lighting levels of both displays, the background must be lower and the overlay set to the highest level. The distance the glass is from the overlay display also effects the visual quality of the "ghost". The further the glass is, the less light gets reflected and severely reduces the quality of the image displayed.

Research Question 3 (RQ3). Do users have the same reaction time with an overlay notification as with a standard notification?

The results from the data collected was consistent between setups. Words per minute and reaction time was recorded through the duration of the study. The words per minute remained the same before and after a notification regardless of the display it appeared on. This was likewise for the reaction time, participants recorded less than one second to notice a notification whether it was on the primary screen or the overlay.

6.2. Limitations

The main limitation of this study is the legibility of the text on the notifications created with *Pepper's Ghost Illusion*. This was due to the double effect from the thickness of the glass, improvements on the setup should be explored in future work. Another limitation is the setup of the illusion itself. The illusion requires a cumbersome setup for a desktop application and may not be desired by users for a notification application. This could have been avoided using a Heads-Up Display (HUD) such as the Mircosoft Hololens or Google Glass; however, the aim of this work was to explore a non-wearable solution to "holographic" displays.

The method chosen to measure reaction time can also be improved. I chose to only have the participant verbally acknowledge the notification to make the study less complicated and to simulate a real work environment. Reaction time can be recorded more precisely by have the participant perform an action such as pressing a button, clicking the notification, or eye tracking. Even the method used in this study could be improved with a higher frame-rate video recording (e.g., in milliseconds). This could show a more significant difference between the two methods of displaying notifications.

An increase number of participants could also improve the statistical power of the quantitative findings; a broader sample of participants (e.g., beyond computer science graduate students) may highlight preference differences in the post-study interview. This work is limited by the participants recruited, graduate students from computer science, and are not an accurate representation of the general population.

6.3. Future Work

This work lays a foundation for how *Pepper's Ghost Illusion* can be used as an application and opens doors for future research to explore. Future work needs to explore how thin the overlay glass can be made to reduce the double effect on the text and make notifications more legible. In the work by Luo et al. the researchers created *Pepper's Ghost Illusion* with a plastic cone made of polyethylene terephthalate (PETG) 0.5mm thick [15]. They found that if the plastic is too thin there is noticeable colour artifacts due to wave interference. Future work can explore an effective method of using PETG plastic as an overlay with a digital background to reduce the double effect and examine legibility of text. The difficulty of using plastic this thin is creating a minimal frame setup so there is no occlusion, hindrance or distortion in the plastic. If there is any distortion the quality of the illusions will be affected.

This work lays the foundations for future research into applications using *Pepper's Ghost Illusion*. In Section 5.3 I discussed an observation on the legibility of notifications over the participant's shoulder. Notifications with *Pepper's Ghost Illusion* were legible to the participant however, I could not read them standing a few feet over their shoulder. Future work could explore how *Pepper's Ghost* can be used for privacy concerns. Notifications of a private nature could be protected from passersby in a public setting. Applications can also explore the overlaid effect of the illusion. Participants commented that they could "look behind the notification", and that the notification appeared to move with their heads. This effect could be explored in other applications, such as games.

6.4. Conclusions

The results from this work shows that there is a potential for *Pepper's Ghost* to be applied as a notification system, providing a subtle unobtrusive method of notifying users according to some participants. While there are some limitations, these can be addressed in future work.

Pepper's Ghost Illusion is an approximation of a holographic display overlaying information on a screen without the addition of a heads-up display. The participants' views and feedback on *Pepper's Ghost* can, in theory, be applied to future work using real holograms. The results from this thesis provides a base for how users view applications with *Pepper's Ghost Illusion* and how it can be improved. Even with the limitations discussed, this work provides a foundation for future work with the *Pepper's Ghost Illusion*.

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Appendix I

Pre-Interview questionnaire

1) What's your age?

____

2) What is your gender?

____

3) What is your major/ occupation?

____

4) How many years of experience do you have with computing systems?

____

5) I have previous experience with the *Pepper's Ghost Illusion*?

___ Yes ___ No

6) Do you like to receive notifications (i.e. email, Facebook, calendar etc.) on your computer? Explain

____

____

____

7) If you could change something about the way notifications are currently displayed what would it be? Explain

____

____

____

Appendix II

Post-Interview questionnaire

1) Which method (on primary screen or overlay) did you prefer to display notifications? Why

2) Which method was easier to read (primary screen or overlay)?

3) Was one method (primary screen or overlay) more distracting to your task then the other?

4) What did you like AND dislike about the overlay method? Explain

5) What did you like AND dislike about the primary screen method? Explain

6) Comments:

Appendix III

Participant	round 2 - overlay		round 5 - overlay		round 6 - overlay		round 8 - overlay		round 10 - overlay	
	read	position	read	position	read	position	read	position	read	position
1	yes	right	No	left	yes	right	yes	right	yes	right
2	no	left	yes	middle	yes - with difficulty	left	yes - with difficulty	left	yes	right
3	yes	right	yes	right	yes - with difficulty	left	yes	right	yes	right
4	yes - with difficulty	left	yes - with difficulty	middle	yes - with difficulty	middle	yes - with difficulty	middle	yes - with difficulty	right
5	yes	right	no	left	no	left	no	left	yes	right
6	yes	left	yes	right	yes	right	yes - with difficulty	left	yes	left
7	yes	left	yes	right	yes	left	yes	left	yes	middle
8	yes	right	yes	middle	yes - with difficulty	left	yes	left	yes	right
9	yes	right	yes	right	yes	right	yes	right	yes	right
10	yes	right	yes	middle	yes	middle	yes	right	yes - with difficulty	left

Table 1. Legibility results for the overlay method from the study.

Appendix IV

Participant	round 1 - primary	round 2 - overlay	round 3 - primary	round 4 - primary	round 5 - overlay	round 6 - overlay	round 7 - primary	round 8 - overlay	round 9 - primary	round 10 - overlay
	reaction time	reaction time	reaction time	reaction time	reaction time	reaction time	reaction time	reaction time	reaction time	reaction time
1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1	< 1
2	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
3	< 1	< 1	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
4	1	1	< 1	< 1	1	< 1	1	1	< 1	< 1
5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1	< 1
6	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1
7	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
8	< 1	< 1	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
9	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
10	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Table 2. Reaction time results from the study.

Appendix V

Participant	initial type speed	round 1 - primary		round 2 - overlay		round 3 - primary		round 4 - primary		round 5 - overlay		round 6 - overlay		round 7 - primary		round 8 - overlay		round 9 - primary		round 10 - overlay	
	WPM	WPM		WPM		WPM		WPM		WPM		WPM		WPM		WPM		WPM		WPM	
		before	after	before	after	before	after	before	after	before	after	before	after	before	after	before	after	before	after	before	after
1	35	34	33	35	35	35	34	33	33	34	33	34	34	34	34	34	34	34	34	35	35
2	42	57	58	50	50	48	48	47	47	45	45	47	47	47	43	44	44	43	43	42	42
3	19	29	29	25	26	25	25	24	24	22	22	21	21	20	20	19	19	19	19	19	19
4	32	37	37	37	37	34	34	34	34	33	33	31	31	32	31	32	32	32	31	32	32
5	24	26	26	24	24	23	23	24	23	23	23	23	23	23	23	23	23	23	23	24	24
6	34	43	43	40	40	40	39	37	36	35	35	34	34	36	35	37	37	36	36	34	34
7	82	101	99	90	90	93	93	87	87	91	92	90	90	87	87	83	82	83	83	82	82
8	64	78	78	71	70	69	69	67	66	66	66	65	65	65	65	65	65	64	64	64	64
9	18	5	5	7	7	9	10	10	11	11	11	13	13	15	14	16	16	17	17	18	18
10	46	28	29	34	34	37	37	39	39	41	41	43	43	44	44	45	45	45	45	46	46

Table 3. Participant’s results for words per minute during the study.