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An Investigation Of The Relationship Between Visual Effects And Object Identification Using Eye-tracking

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AN INVESTIGATION OF THE RELATIONSHIP BETWEEN VISUAL EFFECTS
AND OBJECT IDENTIFICATION USING EYE-TRACKING

by

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ABSTRACT

The visual content represented on information displays used in training environments prescribe display attributes as brightness, color, contrast, and motion blur, but considerations regarding cognitive processes corresponding to these visual features require further attention in order to optimize the display for training applications. This dissertation describes an empirical study with which information display features, specifically color and motion blur reduction, were investigated to assess their impact in a training scenario involving visual search and threat detection. Presented in this document is a review of the theory and literature describing display technology, its applications to training, and how eye-tracking systems can be used to objectively measure cognitive activity. The experiment required participants to complete a threat identification task, while altering the displays settings beforehand, to assess the utility of the display capabilities. The data obtained led to the conclusion that motion blur had a stronger impact on perceptual load than the addition of color. The increased perceptual load resulted in approximately 8-10% longer fixation durations for all display conditions and a similar decrease in the number of saccades, but only when motion blur reduction was used. No differences were found in terms of threat location or threat identification accuracy, so it was concluded that the effects of perceptual load were independent of germane cognitive load.

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CHAPTER 1:   INTRODUCTION

1.1   Direction of Information Display Development

From the cathode ray tube (CRT) television to liquid crystal displays (LCDs), there has been much innovation and technological research to develop modern displays (Chen & Lin, 2004; Marmaras, Nathanael, & Zarboutis, 2008). The LCD is increasing in popularity over the CRT display because of the LCD's "compact size, improved viewing angle, high-gain, better optical diffusion, and lower price" (Chen & Lin, 2004). All of this was made possible through innovation and research. However, although it is commercially logical to continuously produce displays of higher quality, the importance of display quality in training environments remains questionable and merits further consideration. Depending on the application, recent advancements in color representation, contrast, and clarity may not provide additional benefits to the viewer beyond aesthetics. Research has attempted to quantify limits of human perception of contrast and motion blur, but this research is outdated and may no longer be applicable to current technological standards (Chen & Lin, 2004; Hammett, 1997; Kokoschka & Haubner, 1985; Sanders & McCormick, 1993). Consequently, display technology has developed far beyond the limits of its predecessors (bestbuy.com, 2011), but the impact of these newer displays on training is questionable. Additionally, studies regarding the effectiveness of different display characteristics in terms of information transfer and user preference using CRT displays suggest that improving some aspects of the technology will not provide any further benefits (Chen & Lin, 2004; Kokoschka & Haubner, 1985; Legge, Rubin, & Luebker, 1987). Unfortunately, similar studies with LCD's are scarce (Chen & Lin, 2004), indicating an area of information display and training research that is lacking in scientific investigation.

1.2   Current Implementations of Information Display Research

Many aspects of a display have been individually considered in terms of their effect on user perception and information transfer (Oyama & Shiramatsu, 2002), such as display size, resolution, aspect ratio, frame rate, motion blur, and contrast. For example, larger displays have become more and more pervasive due to the economical availability of lower priced technologies (Kreng & Wang, 2009). Although it may seem like larger displays are commercially preferred, the appropriate size depends on the viewing distance (Oyama & Shiramatsu, 2002). According to a study by Oyama and Shiramatsu (2002), viewing distance of three times the height of the display was found to provide the best overall experience, while a 16:9 aspect ratio was preferred over 4:3. In addition, based on the preferences on viewing distance and aspect ratio, 1,000 scanning lines were necessary to meet the resolution requirements. Most modern displays are capable of resolutions of 1,080 scanning lines, considered high-definition (HD), and come in the 16:9 aspect ratio, but the distance from which the display is viewed can vary according to user preference, whereby closer viewing requires higher resolution to create a clearer image. These results allow for the appropriate size, viewing distance, and resolution of a display to be selected for different applications, as these are general features of a display that can be distinguished before the display is even turned on and limit the positioning and location of the display. The ability to produce the image is only part of the metric of usability; the capability of the display to change pixels in a timely manner, dependent on frame rate and response time, can impact the usability of a display.

Consideration of frame rate and resolution have been investigated by Smets and Overbeeke (1995) who showed that frame rate is more important than resolution for a search-and-act task (puzzle solving). It was additionally shown that different frame rates do not impact what the user learns, but alters what the user considers to be the 'quality' of the video (Gulliver, Serif, & Ghinea, 2004). Gulliver et al. (2004) also found that increased visual immersion (a feeling of connectedness to the content) can result in

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greater information transfer, albeit degrading the user's perception of 'quality'. These studies demonstrate the interplay between quality and information transfer, whereby the improvement of one may hinder the other. For example, some modern displays use a technique called "motion blur reduction" to calculate and add frames between animation frames in order to make motion appear more continuous, effectively doubling or quadrupling the frame rate. However, the ability to distinguish detail is not solely dependent on the amount of motion blur present during an animation (Hammett, Georgeson, & Gorea, 1998); contrast is what allows for an object or image to differentiate itself from its surrounding via brightness and color.

A study by Chen and Lin (2004) suggests that the contrast ratio significantly affects visual recognition and higher contrasts result in better visual recognition, which can be applied to identification tasks. They also indicate that the greater preference was given to higher contrast ratios. It is of interest to note the low contrast ratio necessary to achieve their results, 3:1. Their study coincides with the results from a decade prior by Sanders and McCormick (1993) that indicated a contrast ratio of 3:1 and higher are adequate for visual recognition. Another decade prior to this conclusion, an article reported that ratios above 100:1 had little impact on the user's ability to distinguish details or letters (Kokoschka & Haubner, 1985). From these studies, it is inferred that contrast ratios between 3:1 and 100:1 are sufficient for visual recognition including letter and word recognition. To determine how contrast ratio affects usability, reading tasks are often investigated, as was done by Legge, Rubin, and Luebker (1987), who found that reading speed increases considerably with increasing contrast at low contrast levels, but reading speed is unaffected at higher contrasts. Despite these results, modern display contrast ratios are much higher and finding a display with low contrast is rare. For example, commercial displays have contrast ratios ranging from 4,000:1 to 3,000,000:1 (bestbuy.com, 2011). Based on these articles, display technology is likely exceeding the limits of human visual perception and consequently developing imperceptible advancements in technology. If the display technology is surpassing the limits of human visual capacity,

then the probability of these additional display capabilities resulting in perceptible differences, whether preferential or procedural, is low.

Culminating all of these display properties together into a visual system, the psychological component of complexity becomes important to consider. According to Oliva, Mack, and Shrestha (2004), "visual complexity is mainly represented by the perceptual dimensions of quantity of objects, clutter, openness, symmetry, organization, and variety of colors". In their work, they compared how participants grouped images in order of complexity with or without being given a prompt as to how to identify complexity. Both groups ordered the images in a similar fashion based on the number of objects, number of colors, and structure, suggesting that participants reported similar notions of complexity without direction. Given that complexity is closely related to cognitive load mechanisms (a measure of the amount of information in one's working memory), these dimensions should be taken into consideration when designing an instructional interface. For examples, Patrick, Carter, and Wiebe (2005) had participants view different aspects of a simple two-dimensional graphic and a rich three-dimensional graphic and found that the color and complexity attributes of the graphic guided attention differently even though the graphics were similar. The authors suggest that color and complexity of an image can affect attentional focus and optimize cognitive load by optimizing visual search processes and redirecting cognitive resources. However, color represents additional information for the user to process, thus manifesting as an unnecessary complication resulting in information overload (Patrick et al., 2005). Therefore, optimizing cognitive load with respect to incorporating color is likely to be a factor of using image designs that guide attention without overly complicating the information to be transferred.

Also, the level of complexity of the information presented to the user during a search task could result in significant differences in terms of user performance. The image complexity can be compounded by the ability of the information display to generate higher detail and additional colors that may lead to

more of less effective visual search. Overcomplicating the information is likely to require additional cognitive load in order to retain the added information, leading to a decrease in visual search performance. However, if the surplus of information does not encumber the user's cognitive ability, it may be beneficial to the user's ability to correctly identify objects. To ensure that appropriate technology is being employed for a search and identification task, a study needs to be performed that utilizes modern technological devices and examines how one display condition can be used with another in order to maximize the efficiency of a user's search and identification task.

1.3   Proposed Area of Study

The goal of this study is to determine if the presence of color contrast and ability to decrease motion blur impact training. Due to significant research in cognition and the effects of display parameters on learning, which suggest that higher contrast does not affect visual performance and that complicated a display may have adverse effects on cognitive load, it appears unlikely that the added resources utilized to develop improved displays positively impact object identification, although visual search may be improved. To test these theories, an eye tracking system can be used to test how display conditions affect visual search by measuring fixation duration and the amount of cognitive processing involved in threat identification. In addition, self-reported cognitive load measures and simulation interaction scores can indicate if object identification accuracy and information transfer are dependent on perception.

1.4 <u>Hypotheses</u>

H1: Participants using a color display will experience higher cognitive load during training compared to the control group, indicated by increased self-reported mental effort.

H2: Participants using motion blur reduction will experience higher cognitive load during training compared to the control group, indicated by self-reported mental effort.

H3: Participants using both a color display with motion blur reduction will experience higher cognitive load during training compared to the control group and the other two experimental groups, indicated by self-reported mental effort.

H4: Participants using a color display will have higher perceptual load compared to the control group, indicated by larger average pupil diameters.

H5: Participants using motion blur reduction will have higher perceptual load compared to the control group, indicated by larger average pupil diameters.

H6: Participants using both a color display with motion blur reduction will have higher perceptual load compared to the control group, indicated by larger average pupil diameters.

H7: Participants using a color display will experience higher perceptual load during training compared to the control group, indicated by increased fixation duration.

H8: Participants using motion blur reduction will experience higher perceptual load during training compared to the control group, indicated by increased fixation duration.

H9: Participants using both a color display with motion blur reduction will experience higher perceptual load during training compared to the control group and the other two experimental groups, indicated by increased fixation duration.

H10: Participants using a color display will have higher perceptual load compared to the control group, indicated by a lower number of saccades.

H11: Participants using motion blur reduction will have higher perceptual load compared to the control group, indicated by a lower number of saccades.

H12: Participants using both a color display with motion blur reduction will have higher perceptual load compared to the control group, indicated by a lower number of saccades.

H13: Participants using a color display will display increased accuracy of threat identifications compared to the control group, indicated by higher threat assessment scores.

H14: Participants using motion blur reduction will display improved accuracy of threat identifications compared to the control group, indicated by higher threat assessment scores.

H15: Participants using both a color display with motion blur reduction will display improved accuracy of threat identifications compared to the control group and the other experimental groups, indicated by higher threat assessment scores.

H16: Participants using a color display will acquire a higher level of learning compared to the control group, indicated by scores on the knowledge tests.

H17: Participants using motion blur reduction will acquire a higher level of learning compared to the control group, indicated by scores on the knowledge tests.

H18: Participants using both a color display and motion blur reduction will acquire a higher level of learning compared to the control group, indicated by scores on the knowledge tests.

CHAPTER 2: LITERATURE REVIEW

2.1 Display Technology

To support the idea that display technology has undergone significant evolution throughout the past decade, this section will discuss current capabilities and published research involving various aspects of information display configuration and operation. Some aspects, such as brightness motion blur, are still applicable and, in some respects, still capable of improvement. Other features, such as the addition of color primaries and expanding the color gamut capabilities of a display, are possibly surpassing what is perceptibly noticeable and are complicating design with little or no return on investment. This section will focus on how these display characteristics can or cannot be applied in a training environment, specifically during a search and identification task.

2.1.1 Brightness

The brightness of a display is what allows the viewer to actually see what is being portrayed by the display; it is a measure of how much light is present. This aspect of a display is partially dependent on ambient lighting, which can be very high for outdoor applications. High levels of ambient lighting require higher levels of display brightness in order for the display to be readable (Chen & Lin, 2004). If the display is sufficiently bright, then there should be little or no difference in visual recognition if the ambient lighting changes, as shown by Chen and Lin (2004); although at high levels of display brightness, a slight increase in visual recognition resulted from lower ambient illumination levels. The levels of ambient illumination they worked with were 200 lux (lumens per square meter) (considered low)

and 450 lux (considered the normal office ambient illumination level) (Chen & Lin, 2004). This effect goes along with Weber's law, which states that intensity must be increased to see a difference when the background intensity is already high (Ruppertsberg, Bloj, Banterle, & Chalmers, 2007). Generally, a display should be at least three times as bright as its surrounding luminance levels (Sanders & McCormick, 1993). For this reason, display brightness can be critical for display use because it is the primary determinant of the visibility of the display, especially outside, and it is for that reason that improvements are continuing to be made.

Even though fluorescent lamps (used as the backlighting source for most LCDs) have achieved 100 lumens per watt as of 2006, this value was matched by a low-power, phosphor coated blue light-emitting diode (LED) (Mills, 2006). LED light is caused by electroluminescence, where light is generated directly via electricity instead of thermal radiation via heating like in incandescent bulbs (Schubert, Gessmann, & Kim, 2003). Due to the nature of pn-junctions, LEDs require a DC current in order to generate light (current flows one way). The wavelength of the LED emission is dependent on the forward current applied, such as with InGaN, which is known for its high brightness (Svilainis, 2008). One of the primary benefits of using LEDs is that they are very energy efficient and can easily be mass-produced. This will tend to bring the cost of LED technology down and allow for greater application where energy may be scarce. An additional benefit of LED's is their size; since they are very small (sizes range from millimeters to less than a millimeter), they can fit into smaller devices, take up less area, and ultimately allow very small regions of very intense brightness. This last capability is an essential component to contrast since it partially depends on the brightness of an object compared to its immediate surroundings.

2.1.2   Contrast

Contrast, with regards to displays, can be generally defined as the difference in color or brightness between nearby pixels. An extension of this is perceived contrast, which is what the mind interprets as contrast. To obtain the same perceived contrast, higher brightness requires higher contrast since they are interdependent. Apparent brightness is dependent on background brightness; it is how the mind interprets luminous intensity. A phenomenon called simultaneous contrast, depicted in Figure 2-1, occurs when objects of the same brightness appear to have altered brightness due to their surrounding background (McNamara, 2001). In order for the squares in the centers to look similar, their brightness must be reduced according to their surroundings. It is for this reason that contrast is strongly dependent on the surrounding features. Contrast allows and object to be differentiated from its surroundings, therefore making this display attribute important to a visual search task; if an object is not easily distinguished from its background, the ability to locate this object diminishes.

Figure 2-1: Example of simultaneous contrast.

Typically, a higher contrast ratio will result in improved visual performance and subjective preference (Chen & Lin, 2004). Kokoschka and Haubner (1985) reported that a contrast ratio of 100:1 has minimal impact on visual performance, whereas Chen and Lin (2004) said that a contrast ratio greater

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than 3:1 does not increase visual performance significantly. The reported values of contrast ratio are independent of frame rate and are typically measured with a white and black image on the display. It is interesting to note that these reports (and similar ones) are many years old; these are the few reports that discuss how contrast can affect visual performance within applications. Also, it is understood that these articles used display technology available at that time; CRT displays with capabilities that are significantly different than modern displays. Further investigation on the relationship between contrast and visual performance are necessary due to recent advances in LCD technology. Although a 2001 study (Näsänen, Ojanpää, & Kojo) stated that visual perception becomes faster with increasing contrast, as indicated via decreased reading speed with decreasing contrast, other studies stated that once a certain contrast ratio is exceeded, there is little, if any, improvement in reading speed (Legge et al., 1987) or letter identification (Pelli, Burns, Farell, & Moore-Page, 2006). These issues bring into question the value of high-contrast displays and their utility for applications for reading and, inherently, written information transfer.

Various measures of readability include "reading rate, identification of misspelled words, searching for pre-specified letters/words within word lists or passages, etc." (Humar, Gradisar, & Turk, 2008). The Le Courier legibility table, which ranks the readability of text based on text color and background color, utilized subtractive primaries (cyan, magenta, and yellow colors that create black when combined), which, according to (Humar et al., 2008), "is not appropriate for integrative color computer displays" (which use red, green, and blue that create white when combined). Figure 2-2 gives a demonstration comparing the top ten combinations for ease of readability. It is interesting to note that the readability of the text in the tables is different if this document is read via print versus computer screen, hence the motivation behind this suggested improvement!).

Figure 2-2: Le Courier legibility table and suggested improvement (Humar et al., 2008).

The tables presented in Figure 2-2 demonstrate not only the importance of contrast towards readability, but how these attributes are heavily dependent on color choice (Humar et al., 2008). It is also apparent from that study that color combinations can also interact with one another; such a phenomena is called 'chromatic induction', which describes how the perception of a color is dependent on the colors surrounding it (McFadden, Kaufmann, & Janzen, 1994; Widdel & Post, 1992). An example of this effect is presented in Figure 2-3, where the two green squares are actually the same color, but appear to have different brightness due to their surround colors. Designers must therefore be aware of color-coded information that may be affected by this phenomenon (Ponton, 2008).

Figure 2-3: Example of chromatic induction.

Applications where readability is a primary concern is not in written documents in particular, but in environments where colors and graphics are more heavily utilized: web pages and presentations for instance. In these media, background colors are incorporated behind or around texts to make the presentation of information more interesting or pleasing to the user. It is these type of combinations that can likely occur in training materials where graphics and text can be combined or overlapped, thus making the readability important to the transfer of information.

2.1.3   Color

Readability, however, is merely and advanced form of object recognition; recognizing shapes as letters and groups of shapes as words. Hence, a natural extension of readability is visual search, which is also heavily dependent on coloration. Using color can reduce the need for visual search and allow more time for comprehension instead of searching. Alternatively, color may result in information overload for the user by unnecessarily complicating the instructional materials (Patrick et al., 2005). A particular application of this is the use of visual aesthetics on web pages, whereby changes in the colors, text style

and size of the content will affect the user's perception of the content (Hoffmann & Krauss, 2004; Zettl, 2004).

In addition to the decisions developers must make regarding the use of particular colors, displays and graphics card also limit the variety of colors available. There are a plethora of colors that cannot be displayed because they lie outside the color gamut (a mapping of colors visible to humans; see Figure 2-4); there are also colors within the gamut that cannot be displayed, because the resolution of the graphics card is finite (Ruppertsberg et al., 2007). Shown in Figure 2-4, the larger rounded shape lists all of the colors are visible to a normal human eye and the smaller highlighted triangle are the colors capable of being produced with a standard red, green, and blue (sRBG) CRT display. It is clear from the figure that the sRGB only covers a portion of the entire color gamut, indicating that many of the colors detectable to the human eye are not represented by the display.
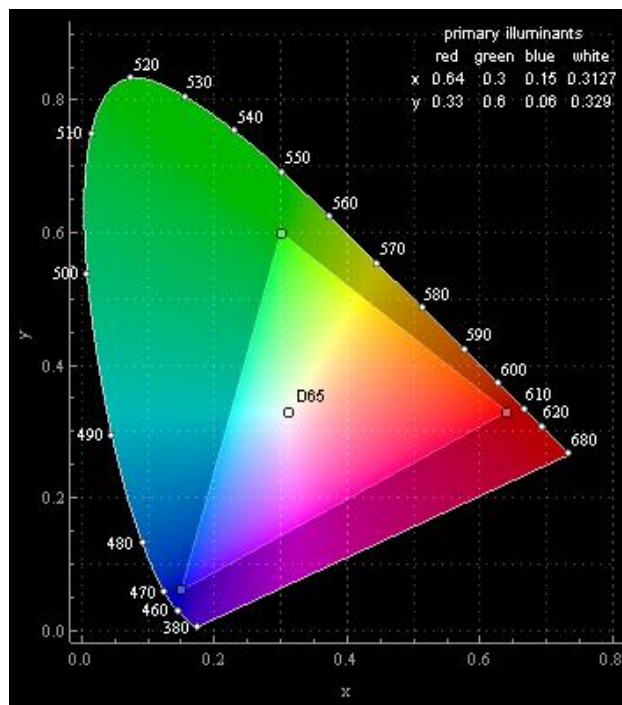
Figure 2-4: CIE chromaticity diagram with sRGB color gamut emphasized.

The size of the highlighted portion of Figure 2-4 is dependent on the integrated colors used to produce the images. When the highlighted area is increased due to improvements of the primaries used, the display is considered to be a wide gamut display. The wider gamut will result in greater accuracy in terms of reproducing the colors found in nature as opposed to a smaller color gamut. Multi-primary displays or displays with highly saturated pure primary colors (LED, Laser) allow for a wider color gamut (Kim, 2006). They increase the size of the gamut by allowing for larger areas of the color gamut to be covered; multi-primary displays result in a 4-sided polygon whereas pure primary colors will push the boundaries of the shapes towards the limits of human visibility.

Generally, if there is a mismatch between the originating color gamut and the gamut available to a display based on hardware, the result will be a distortion of the color reproduction of the image (Berns, Motta, & Gorzynski, 1993; Ján & Luo, 2001; Jiménez Barco, Díaz, Jiménez, & Rubiño, 1995). To overcome this, a gamut mapping algorithm can be applied in order to manipulate the source image to fit within the color gamut of the display, although this manipulation could also result in image artifacts (Kim, 2006). A method is proposed by Kim (2006) whereby a mixture of primary colors will result in a standard color gamut, resulting in a perfect color match for the various standards without signal artifacts. This method also allows for the increase in contrast as well as brightness.

A technique called Multi-standard Color Gamut Processing (MCGP) can be applied to a wide color gamut display in order to match the standard color gamut without video processing while also improving brightness (Kim, 2006). Due to the methods of MCGP and Dynamic Color Gamut Processing, a display's brightness can be increase by a factor of 1.6 (Kim, 2006).

The brightness and color of a static image can affect how it is interpreted, but when images are displayed in rapid succession to create an animation, alternative artifacts are introduced. Objects in motion will move across the retina of the eye, which can incur motion blurring effects (Bedell, Tong, &

Aydin, 2010). Therefore, when animations are used with a display, the frame rate and resolution of the display become important to the information transfer capabilities.

2.1.4   Frame Rate and Resolution

When an image is stationary, detectors (like the retina) can utilize temporal summation in order to improve the signal-to-noise ratio. However, if an object is in motion or is moving across a detector, the resulting image will become blurred due to the fact that each point of the image is being processed at multiple locations (Bedell et al., 2010). If a detector can follow the movement of the image, the likelihood that the image point will be processed at multiple detector points is reduced and the extent of blurring can be reduced (Tong, Patel, & Bedell, 2005, 2006). Further investigation by Kanai, Sheth, and Shimojo (2007) show that the perception of a moving object itself may dynamically evolve following the onset of motion.

Theoretical assumptions concerning the superiority of dynamic visual display (DVD) over static visual display (SVD) are based on that DVDs can direct learners' attention to the relevant information in the instructions (Guan, 2002). Park and Hopkins (1992) reviewed 27 studies that investigated the effects of DVDs versus those of SVDs and only found 15 of them demonstrated the benefits of DVDs. Based on the review of research findings regarding the effects of DVDs, they recommended using DVDs in relation to the following conditions: 1) demonstrating sequential actions in a procedural task; 2) simulating causal relationships among the components of complex systems; 3) demonstrating visually invisible system functions and behaviors such as blood flow in the human body or current in electronic systems; 4) providing a visually motional cue, analogy or guidance to show time-dependent processes; and 5) directing attention to the essential information to be learned (Park & Hopkins, 1992).

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There is no definitive differentiation between a group of images displayed in quick succession and animation. The rate of image change incurs perceptual changes; faster frame rates result in the appearance of more fluid animation (to a limit). In one study, participants viewed animations at either 5, 15, or 25 frames per second; it was found that information transfer was independent of the frame rate (Gulliver et al., 2004). The different frame rates did not impact how much information the user was able to retain, but it did affect how the user perceived the quality of the animation. A higher frame rate results in more fluid animation and can be considered by the user to be of higher quality, and it requires significantly more information in terms of signal transfer and representation, but no additional information is transferred to the user regarding the content and concepts of the animation.

Although Smets and Overbeeke (1995) showed that frame rate is more important than resolution for many tasks, research has concluded that resolution does in fact play a part in information transfer. One's perception of resolution is moderately affected by the distance at which the display is viewed. If one views a television from far away, they will likely not be capable of discerning one pixel from another, but this becomes much easier when the viewer is inches away from the display. To clarify, an experiment used a viewing distance of 3H (where H is the height of the display) and an aspect ratio of 16:9 provided the most preferred viewing experience (Oyama & Shiramatsu, 2002). In addition, it was found that these conditions required about 1000 scanning lines (1080 by modern convention) for the best perceived resolution (Oyama & Shiramatsu, 2002).

A positive relationship was found between subjective preference and window resolution, whereas decreasing resolution led to a decrease in subjective preference, but the decreasing window resolution also resulted in an increase task performance times (Booth, Bryden, Cowan, Morgan, & Plante, 1986). This could be interpreted as difficulty in discerning information from a low resolution image or animation; the more difficult it is to draw information from a display, the more cognitive effort is required

in order to understand it. This concept was further illustrated by Watson et al., who demonstrated that search time and accuracies were faster for a high resolution display in comparison to that of lower resolution (Watson, Walker, Larry, & Reddy, 1997).

2.2   Training

When applying the aforementioned display characteristics into a training environment, it is necessary to understand how the content of a display manifests in the user's memory. The level of complexity that the display inherently has not only depends on the content, but on the display's capabilities such as resolution and color. Similarly, the interpretation of display properties such as motion blur and contrast can result in undesired consequences, like improper identification due to cognitive overload or difficulty distinguishing details due to loss of object clarity.

2.2.1   Complexity

A visual pattern is described as complex if its parts are difficult to identify and separate from each other (Oliva et al., 2004). "Visual complexity is mainly represented by the perceptual dimensions of quantity of objects, clutter, openness, symmetry, organization, and variety of colors" (Harper, Michailidou, & Stevens, 2009). In an effort to organize information and guide the user's attention to relevant materials, design features may inadvertently result in visually complicated presentations that overwhelm the user instead of helping him or her (Harper et al., 2009). Therefore, to minimize the potential for information overload, graphics should not display more information than is required for the task at hand (Canham & Hegarty, 2010).

For example, an experiment was performed measuring eye-tracking fixation counts, indicating that different characteristics like shape and color resulted in different fixation counts (Patrick et al., 2005). Although no particular difference in information retention was seen, students stated that the 3D graphics had more detail and were more realistic than the 2D graphics. This research provides support towards the

idea that adding detail to an image will affect attentional focus, but not necessarily benefit information retention. For a search task, attentional focus is a key component to locating and identifying an object, so the addition of detail may prove advantageous in these circumstances.

The complexity of an interface can also have an effect on task performance, particularly visual search and identification tasks. For a search task, complex or poorly designed graphics can manifest as an increase in gaze direction shifting, indicated poor visual search performance (Burns, 2000). If the fixation duration increases, it could be due to the user's difficulty to draw information or the user drawing a significant amount of information, indicating an increase in image complexity (Jacob & Karn, 2003). In either case, if the goal of a search task is to quickly identify an object, then the complexity of the graphic needs to be considered. To reduce complexity, higher contrasts and longer presentation durations improved object recognition according to Schütz, Braun, and Gegenfurtner (2009), meaning that object recognition improves the longer an object can be clearly differentiated from its surroundings. This reinforces the idea that color and motion blur reduction will improve object identification by providing additional contrast and clarity to the display.

2.2.2   Perception and Preference

In order to achieve the display attributes such as high contrast and motion blur reduction, modern displays can be employed. However, according to Chen and Lin (2004), ergonomic evaluations using liquid crystal displays have been relatively few. This was likely the result of the fact that CRT televisions dominated the display market until the early 2000's (Chen & Lin, 2004). Since then, there has been an explosion of productivity in terms of display quality and integration that rarely been evaluated in training environments, particularly in terms the effectiveness of new display capabilities such as motion blur

reduction and improved contrast. Such properties as resolution, brightness, color, contrast, motion blur all can contribute to how a viewer interprets and understands a graphic, so an experimental technique to obtain objective user data is to make measurements using an eye-tracking system. Eye-tracking systems provide details regarding the user's attentional focus based on gaze direction and fixation duration as well as cognitive load based on fixation duration and pupil dilations.

2.3   Eye-Tracking

Eye-tracking systems typically operate by using an invisible light source and a camera system to measure the reflection of the light source off of the retina of the user. This measurement system allows for the determination of pupil size in real time. For instance, the Tobii 1750 remote video eye-tracker measures mean binocular pupil diameter with precision 0.10 mm and mean binocular pupil dilations with precision 0.15 mm (Jeff, 2010). Eye-trackers have been used for many years as an indicator of cognitive activity and is considered to be an appropriate method for examining conceptual change processes during text comprehension due to its long research tradition in examining cognitive processes and its extremely accurate online results (Ifenthaler et al., 2008). Collecting eye movement data varies with respect to intrusiveness, but some methods allow for significantly less interference than other psychophysiological measures like heart rate, EEG, or skin conductance. Eye movement measures are a promising and minimally intrusive method for obtaining objective cognitive information about a user in real-time (Liu & Chuang, 2010). As Liu and Chuang (2010) state, "an individual's eye movements reveal a continual stream of information that can be used to indicate her or his mental state. The positions and the number of fixations, the fixation duration, and the saccade length are the most common variables in eye movement measures". Additional physiological parameters, such as eye-blinks and pupil size, have also been investigated in terms of their psychophysiological representations.

"Generally blinks, pupil dilation, and percentage of eye closure are descriptive of fatigue and cognitive processing, whereas fixations and saccades measure interface difficulty and areas of interest which capture the user's attention" (Ponton, 2008). Eye movements allow for the objective deciphering of user perception, attention, and cognitive processes (Gulliver et al., 2004). The level of cognitive processing can be considered to be partially linked to image complexity; the harder an image is to comprehend, the more mental resources are necessary in order to make sense of it. One experiment in

particular showed that there was a positive relationship between fixation duration and background complexity and between fixation duration and number of targets in the array (M. Bauer et al., 2001). In other words, higher complexity resulted in longer fixation durations because the images required more time to process and understand.

2.3.1   Blinks

Eye-blinks have been used in order to quantify fatigue (Caffier, Erdmann, & Ullsperger, 2003; Eriksson & Papanikotopoulos, 1997; Yamada, 1998), cognitive processes (Boksem, Meijman, & Lorist, 2005; Poole & Ball, 2004; Veltman & Gaillard, 1998; Yamada, 1998), and stress (Andreassi, 2000). Many articles have shown that an increase in cognitive activity will result in fewer blinks per unit time (L. Bauer, Goldstein, & Stein, 1987; May, Kennedy, Williams, Dunlap, & Brannan, 1990; Poole & Ball, 2004; Yamada, 1998). Alternatively, reports have shown the opposite effect due to stress: elevated stress patterns were indicated by an increased blink rate (Andreassi, 2000).

Although blinks have been associated with a variety of psychological effects, pupil size has gained the most notoriety in terms of real-time measurement of cognitive load. Blink rate, although valid, require multiple blinks over the span of tens of seconds in order to find trends in the data; in other words, the resolution of the data is insufficient for correlating cognitive loads during complex or short tasks. An alternative measure results in much higher data resolution and has also met with much success in terms of assessing cognitive load in real time; pupil response.

2.3.2   Pupil Response

"Pupillometrics" is a term invented by Hess (1965) to describe a research field (started in 1960) that encompasses the effects of psychological influences, perceptual processes, and mental activities upon the pupil size. The method used to measure pupil response is referred to as pupillometry. Pupil size, or the diameter of the pupil, is associated with the intensity of cognitive activation (Guan, 2002). Attributes of pupil response measurements that set them apart from blinks are that pupil measurements occur at a much faster scale (tens of hertz) and that pupils respond to a stimuli within seconds. A study by Verney, Granholm, and Marshall (2004) indicated that there are three stages of a pupil response to a stimulus: an early factor from approximately 0 to 0.7 s; a middle factor from approximately 0.7 to 1.5 s; and a late factor from approximately 1.5 to 3.0 s. The middle factor was interpreted as reflecting target processing and the late factor was interpreted as reflecting resources allocated to mask processing; the early factor is still under investigation as to what it corresponds to. An observation that was made in regards to the early response was pupil dilation in response to a dark stimulus with a bright background. This response was contrary to what the researchers expected because they believed that the bright portion of the stimulus would incur a pupil constriction as a reflex to bright light (Verney et al., 2004). This result reinforces the idea that experimentation must be performed in a controlled environment. Many artifacts that result in pupil restriction and dilation can be minimized, but it is naïve to believe that all indirect stimuli have been accounted for. As such, the use of pupil response should be approached with great caution (Lin, Imamiya, & Mao, 2008).

That is not to say that pupil response measurements are inadequate or inaccurate; studies have been able to successfully correlate pupil response to cognitive load. According to Ikehara and Crosby (2005), eye movement and skin conductance were both capable of detecting changes in task difficulty. It has also been shown that the size of the pupil progressively increases as short-term memory demands are

increased (Piquado, Isaacowitz, & Wingfield, 2010), at least until the point of memory overload (Granholm, Asarnow, Sarkin, & Dykes, 1996; Kahneman & Beatty, 1966; Peavler, 1974). When pupil response is analyzed on a larger time scale, an alternative means of data analysis has been proposed by Marshall, the Index of Cognitive Activity (S. P. Marshall, 2002), which is typically reported as, "the average number of abrupt discontinuities in the signal per second over a designated period of time" (Sandra P. Marshall, Pleydell-Pearce, & Dickson, 2003). The results of the study showed that the changes in pupil dilation, which in turn indicated changes in the Index of Cognitive Activity, identified when the user applied different strategies, thus allowing for the identification of performance before and after the change in cognitive activity (Sandra P. Marshall et al., 2003).

The diameter of the pupil affects the depth-of-field; larger pupil size decreases the depth-of-field (Atchison & Smith, 2000). For large pupil diameters, aberrations degrade image quality. For small diameters, image quality is diffraction limited. 2-3 mm gives the best balance between these two effects (Atchison & Smith, 2000). For display viewing, changes in the depth of focus do not cause image degradation because the display is at a fixed distance and required no perception of depth.

2.3.3   Fixations

Often measured in conjunction with pupil response, fixations can be used to identify where the user is focusing his or her attention, often defined with a search area. Weighting can be applied to these fixations to develop a "weighted search area" which shows where and how long the user looks at a particular section of the display (Chi & Lin, 1997). This allows developers to determine which parts of an interface are being used, if some parts are distracting, or if one aspect is too complex. As Liu and Chuang (2010) state, "the duration of eye fixations, the number of fixations, and the amount of refixations reveal

patterns describing how a user's attention is directed to a given region or visual area of the computer [display]".

Atkins, Moise, and Rohling (2006) have found that fixations occur in two phases; the first phase (search phase), is while the user is observing multiple regions of a display in order to locate a particular object or target; the second (recognition phase), is where the user uses the object features and information about the object in order to identify the object. If the suspicious object is not the intended target (a distraction), the user will still allot time to viewing and comprehending it (Liu & Chuang, 2010), so distraction reduction is of particular importance in terms of information layout.

But how long will a person have to look at an object in order to understand and identify it? Although some results differ from one another, it has been shown that people can recognize a complex image within 50-80 ms (Guyonneau, Kirchner, & Thorpe, 2006; Kirchner & Thorpe, 2006; Thorpe, Fize, & Marlot, 1996), and can identify simpler objects within 10 ms (Schütz et al., 2009). These studies show that very minimal viewing time is necessary to recognize objects. It is important to keep in mind that these experiments were performed by varying the brevity of the display of a letter on the display; they did not require the fixation direction to move within the short time frame. If an experiment were to incur fixation movement within a short timescale, this would be considered a different type of phenomena known as a saccade.

2.3.4   Saccades

"Saccades are the rapid ballistic movements of the eye from one point of interest to another, whose trajectory cannot be altered once begun" (Linda & Robert, 2000). Saccades differ from fixations because saccades are movements between fixations, although is some argument regarding the length of

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time a fixation needs occur in order for the movement to be considered a saccade: Jacob and Karn (2003) suggest that a fixation between 100-200 ms identifies a saccade, whereas Rayner (1998) suggests 200-250 ms. In daily life, humans use a combination of saccades and fixations to follow moving objects in order to keep the image clear (Schütz et al., 2009). Saccadic eye movements are used to bring objects of interest to the fovea and smooth pursuit eye movements are used to stabilize moving objects of interest on the fovea. Thereby spatial resolution is maximized and retinal smear minimized (Schütz et al., 2009). Some researchers argue that no cognitive processing occurs during a saccade and thus they reveal little or no information about the user (Poole & Ball, 2004), but other researchers correlate the length of the saccade to the interface complexity (May, et al., 1990; Rayner & Pollatsek, 1989).

2.4   Summary

Display technology has been reviewed in terms of recent advancements in brightness, contrast, color reproduction, frame rate, motion blur, and resolution. Display brightness has been improving by using novel materials and configurations, such as replacing florescent tubes with high-efficiency LEDs to generate equal luminous intensity using less power. Improvements in contrast have not been investigated using modern equipment, so their benefits are still subjective. Color reproduction and motion blur reduction have been enhanced, although these results are also subjective in nature.

Incorporating these display aspects into usable applications reveals issues with perception and complexity, whereby quality and color usage can result in usability and performance effects. To make objective measurements, eye-tracking systems have been successful in determining what aspects of a presentation incur higher cognitive demands, more attention, and more distraction.

CHAPTER 3:   THEORY

3.1   Operational Principles of Displays

In 1992, almost two decades ago, Lessin (1992) pointed out that LCDs are "equivalent to or better than CRT [displays] in many aspects, including: weight, power consumption, viewability, response time, color gamut, and cell brightness". Satisfactory performance for indoor and portable display applications requires a brightness of ~100 cd/m2 at an operating voltage of between 5 and l5 V, an efficiency of 5 lm/W and a continuous operational lifetime of at least 10,000 hours (Burrows, Forrest, & Thompson, 1997). Plasma display panels, by comparison, have setbacks in comparison LCDs: low luminous intensities (1 lm/W) and low efficiency (0.5%) due to the multitude of loss mechanisms (Hagelaar, 2000). Another competitive technology, organic light emitting diodes (OLEDs) have the benefit of being ultra-thin and flexible, but suffer from aggregation (Yase et al., 1996), crystallization (E. Han, Do, Fujihira, Inada, & Shirota, 1996; Eun Mi Han, Do, Yamamoto, & Fujihira, 1996) and interdiffusion (E. M. Han, Do, Yamamoto, & Fujihira, 1995) of the component films which all contribute to device degradation.

3.1.1   Cathode-Ray Tube (CRT)

In a CRT display, the image is produced by a magnetically guided stream of electrons that excite a layer of phosphor material on a screen to produce light, known as cathodoluminescence (Chigrinov, 1999). When an image is to be produced, the electrons are transferred in a scanning motion, line by line, to create the image. Otherwise, the beam is deactivated and the image is removed. This

activation/deactivation mechanism results in the flickering effect seen on CRT displays (Humar et al., 2008). A general schematic is presented in Figure 3-1.
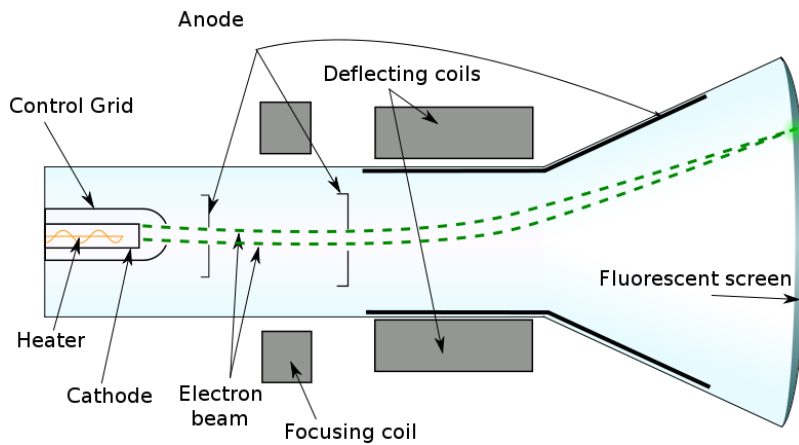
Figure 3-1: General schematic of a cathode ray tube display (Wikimedia, 2011).

The phosphorus layer consists of triads of phosphors that emit light in three colors, usually red, green, and blue (Hendee & Wells, 1997). Some CRT displays use a shadow mask to limit the cross-talk between illuminated pixels and to create a well-defined pixel shape (Hendee & Wells, 1997). The electron beam spot size is slightly larger than the holes in the shadow mask to ensure that the pixel is more evenly and fully illuminated (Hendee & Wells, 1997). Variations can include different arrangements of the electron gun(s), different pixel layouts in the phosphor display, and the shape and density of the holes in the shadow mask (Hendee & Wells, 1997).

3.1.2 Liquid Crystal Displays (LCDs)

Three major configurations for liquid crystal alignment (Wu, 2009): twisted nematic (Schadt & Helfrich, 1971), multi-domain vertical alignment (Schiekel & Fahrenschon, 1971), and in-plane switching (Soref, 1974). Figure 3-2 (Wu, 2009) describes how the twisted nematic configuration works. When no electric field is applied across the polymer layer, the liquid crystals will tend to align themselves according to a rubbing direction used on the walls of the cavity containing them. The light from the backlight passes through a polarizer and the angle of polarization changes depending on the orientation of the liquid crystals. If an electric field is applied, the liquid crystals reorient and have no effect on the polarized light passing through it. Upon passing through the polymer layer, the polarized light encounters another polarizer which will determine how much light passes through based on its orientation with respect to the polarization of the light encountering it.
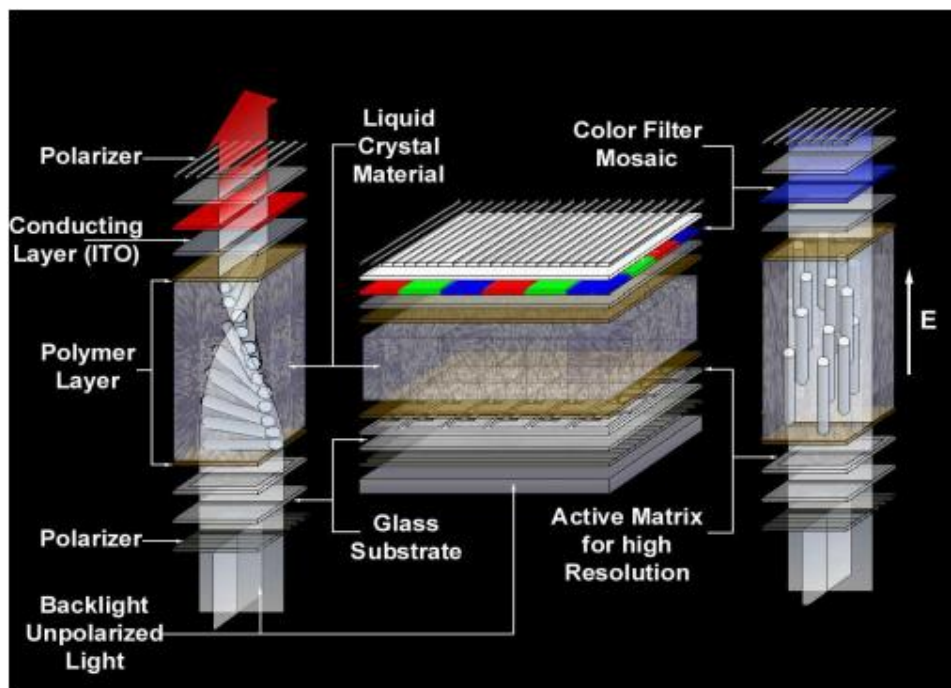
Figure 3-2: Configuration of a twisted nematic liquid crystal display (Wu, 2009).

Figure 3-3 describes how an in-plane switching liquid crystal display works in a similar manner to twisted nematic except that the liquid crystals reorient themselves within a specific plane (perpendicular to the direction of light propagation) as opposed to out of the plane.
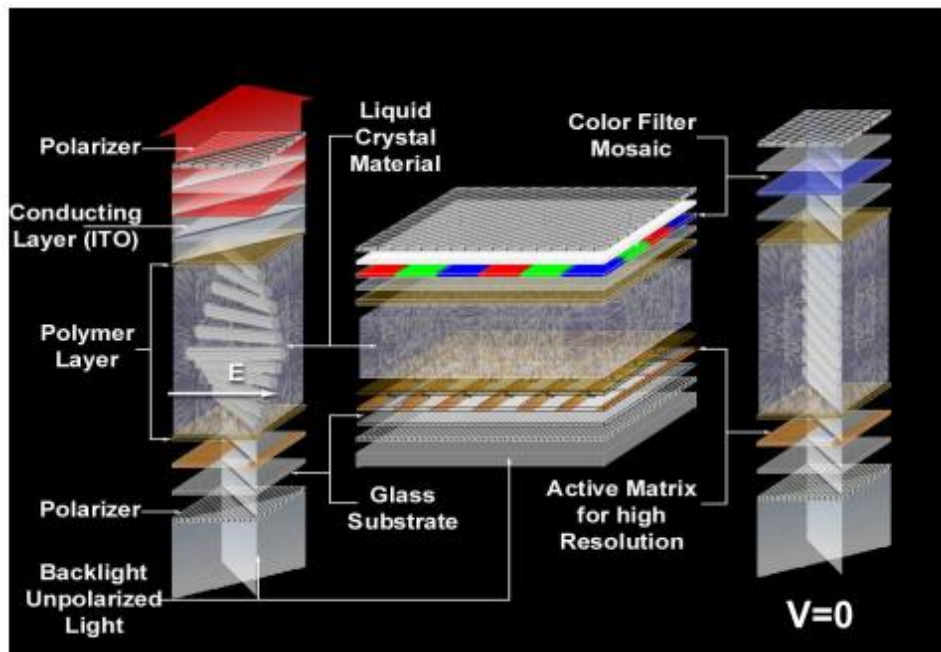
Figure 3-3: Configuration of an in-plane switching liquid crystal display (Wu, 2009).

There are various operational modes for LCDs including transmissive, reflective, and transflective. Transmissive displays rely on a backlighting system as the source of light which, when generated, passes through the liquid crystal and out the front of the display. Reflective displays rely on ambient lighting as the source of light that enters through the front of the display and reflects off of a reflective backing behind the pixels. Transflective displays utilize a combination of these technologies by having both a backlight as well as a mirrored backing to reflect incoming ambient lighting.

To generate frame rates above 60Hz, imaging software takes two adjacent frames and calculates the necessary image to transition between the two adjacent frames. If one frame is placed between each adjacent frame, a frame rate of 120Hz is achieved; three frames between adjacent frames results in 240Hz. It is believed that these higher frame rates reduce motion blur, thus this technique of adding frames is also referred to as motion blur reduction.

3.1.3   Light Emitting Diode (LED) Displays

Light emitting diodes (LEDs) use III-V semiconductors to emit light when there is a voltage applied, resulting in electron-hole pair recombination (Curtin & Infante, 1997). LEDs are current-driven as opposed to voltage driven and consume about 5 mA per diode (Chigrinov, 1999). LEDs are efficient at producing light (3 lm/W), require low voltages (1-2 V), and consume very little power (Chigrinov, 1999). OLEDs have similar efficiency at 2-3 lm/W, but require higher voltages to operate (10-15 V) (Chigrinov, 1999).

Inorganic LEDs cannot be controlled with matrix-addressed technology, but OLEDs can when a DC electric field is used, as shown in Figure 3-4 (Chigrinov, 1999). OLEDs are made up of several layers to allow the injection of holes from ones side and electrons from the other side of the active layer (Chigrinov, 1999). The light-emitting layer for OLEDs is very thin (about 100 nm) (Chigrinov, 1999) and can also be made to be quite flexible. OLED lifetimes are limited to a few thousand hours (Chigrinov, 1999).
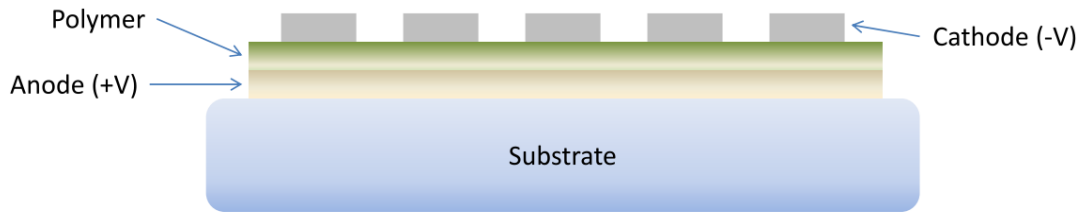
Figure 3-4: Schematic of a matrix-addressed OLED adapted from Chigronov (Chigrinov, 1999).

LED Backlighting can be done either using edge-lit or local dimming methods. Edge-lit displays have a row of LEDs along one side of the display and rely on using a reflector or diffuser to equally distribute the light across the display. For local dimming, the LEDs are spread throughout the area of the display and are illuminated only when a pixel within a specified area of that LED is required to be on. This allows for greater control of contrast.

3.1.4   Plasma Display Panels (PDPs)

In plasma display panels, a gap is made between two perpendicular electrodes and filled with a gas that reacts to an applied voltage to produce an abundance of UV light. The light reacts to colored phosphors which then emit light (usually red, green, and blue) towards the viewer (Chigrinov, 1999). Figure 3-5, obtained online from howstuffworks.com (2002) depicts a general layout of a plasma display panel. Important features to note are the address and display electrodes, the phosphors, the gas chambers for each pixel bordered by "ribs", and the MgO layer. A PDP consists of two glass plates with a gap in between them (100–200 mm). This gap gets filled with a gas that is later to be electrified in order to produce a bright discharge of light. To produce the voltage necessary, electrodes are situated in a grid-like pattern and then activated one row at a time so each pixel within the row gets activated when needed

(Bogaerts, Neyts, Gijbels, & van der Mullen, 2002). Pixel size for a PDP is around 0.33 mm per triad. If higher resolution is desired, luminance and thus contrast ration suffers (Chigrinov, 1999).
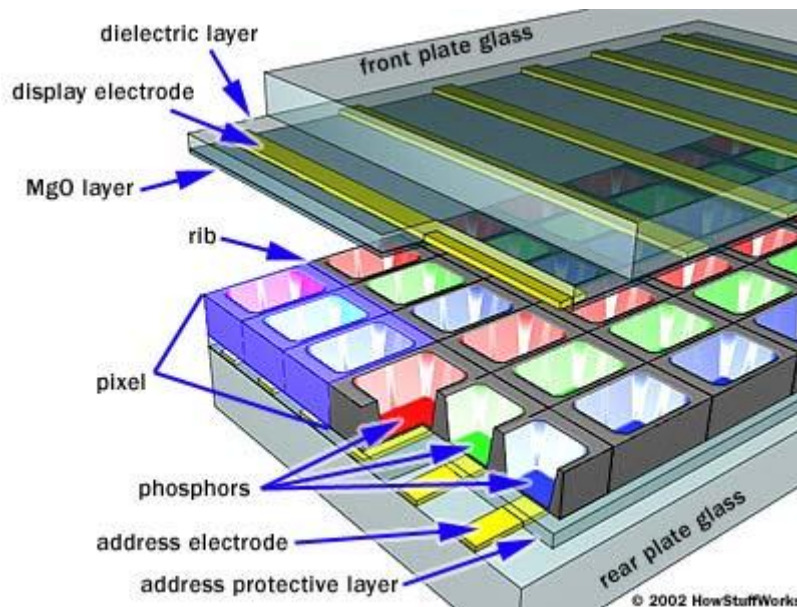
Figure 3-5: Schematic of a plasma display panel (HowStuffWorks.com, 2002).

The discharge gas, commonly comprised of rare gases (xenon, neon, helium), will usually incorporate a 5% composition of xenon for its high UV emission (about 10% efficient) (Bogaerts et al., 2002). If color is to be used with the PDP, than a process similar to the CRT is used, whereby a specific phosphor is excited in order to emit the appropriate color (Bogaerts et al., 2002). The discharge operation can be carried out with either DC or AC currents: in DC mode, the electrodes and the discharge gas are in direct contact with one another, whereas the AC configuration has a dielectric layer sandwiched between the electrode and the gas (Bogaerts et al., 2002).

Advantages of PDPs include large area, wide viewing angle, fast response times, and greyscale (Chigrinov, 1999). Disadvantages of PDPs include low contrast ratio (in comparison to CRT displays and LCDs), high controlling voltages (150-200V), and power consumption (Chigrinov, 1999).

3.2   Display Specifications

Information displays come in a variety of styles and flavors with a broad range of specifications that differentiate one from another. In order to understand how these aspects will be used to determine the display qualities that lead to improved training efficiency, the specifications themselves must be understood. The aspects that will be focused upon are brightness, color gamut, contrast, and motion blur.

3.2.1   Brightness

Brightness has been defined to be the "dimension of color that is referred to a scale of perceptions representing a color's similarity to [a series] of achromatic colors ranging from very dim (dark) to very bright (dazzling)" (Burnham, Hanes, & Bartleson, 1963). In general, it is the human perception of the luminance of a light source. Phototransduction is the process by which light generates the initial visual signal in the retina (Toyoda, Murakami, Kaneko, & Saito, 1999). The transduction mechanism of rods is so sensitive that it takes fewer than 100 absorbed photons to half-saturate the response (Toyoda et al., 1999). Depending on the ambient light condition, photoreceptor cells adapt to light stimulus; dark ambient conditions increase light sensitivity whereas bright ambient conditions decrease sensitivity (Toyoda et al., 1999).

Flicker occurs when the refresh rate of a display is slower than the frequency at which the image is rendered by the eye (Svilainis, 2008). The minimum frequency at which flicker occurs is called the "critical flicker frequency" (CFF), also known as the Ferry-Porter Law (Burnham et al., 1963), as defined by Equation 3-1 (Svilainis, 2008). In the equation, *a* refers to the ambient light levels (12.5 to 1.5 for high

to low ambient light levels), b is a constant of value 37 Hz, and L_a is the average luminance of the source in cd/m^2 (or nits).

$$CFF = a \log L_a + b \qquad\qquad (3\text{-}1)$$

If the backlight refresh rate is slower than the camera exposure time, the pulse width modulation (PWM) of the backlight will be cut off leading to image distortion (Svilainis, 2008). The refresh rate must be greater than the camera's exposure time to eliminate flicker. Refresh rates of 400-1000 Hz are usually used (Svilainis, 2008).

The relative luminance of a display is defined by its white point (the point on a color gamut map that creates the simulation of white light (Wen, 2005). There are N-3 degrees of freedom for a display using N primary colors with a given white point (Wen, 2005). Meaning, if there are additional primaries used to create a white light, each additional primary will allow for finer tuning of the white point.

3.2.2 Color Gamut

Color can be defined as the attribute of visual experience that can be described as having quantitatively specifiable dimensions of hue, saturation, and brightness (Burnham et al., 1963). In other words, it is what the observer perceives as photon energy. Hue is considered to be the "dimension of color that is referred to a scale of perceptions ranging from red through yellow, green, blue, and [cyclically] back to red" (Burnham et al., 1963). Saturation is expressed as the "dimension of color that is referred to a scale of perceptions representing a color's degree of departure from an achromatic color (one lacking a distinguishable hue) of the same brightness" (Burnham et al., 1963).

A computer display differs from printed text because the computer display is integrative (based on adding light together) and ink on paper is subtractive (limiting the amount of light being reflected or transmitted) (Humar et al., 2008). RGB (Red, Green, and Blue) are called additive primaries and CMY (Cyan, Magenta, and Yellow) are called subtractive primaries (often referred to as CMYK where 'K' stands for black). The combination of RGB produce white whereas the combination of CMY produce black (Burnham et al., 1963), as shown in Figure 3-6. A display with more than three primaries is usually called a multi-primary display, which complicates the design and manufacture and increases complexity and costs (Wen, 2005).

Figure 3-6: RGB and CMY color combinations.

Color gamut was defined by the CIE in 1931 as a standard (T. Smith & Guild, 1931). It is a mapping of colors visible to the human eye and can be used to quantify the capability of a display to reproduce colors. Larger area implies that the display is capable of producing a larger variety of colors. The CIE Chromaticity diagram is reproduced again in Figure 3-7.
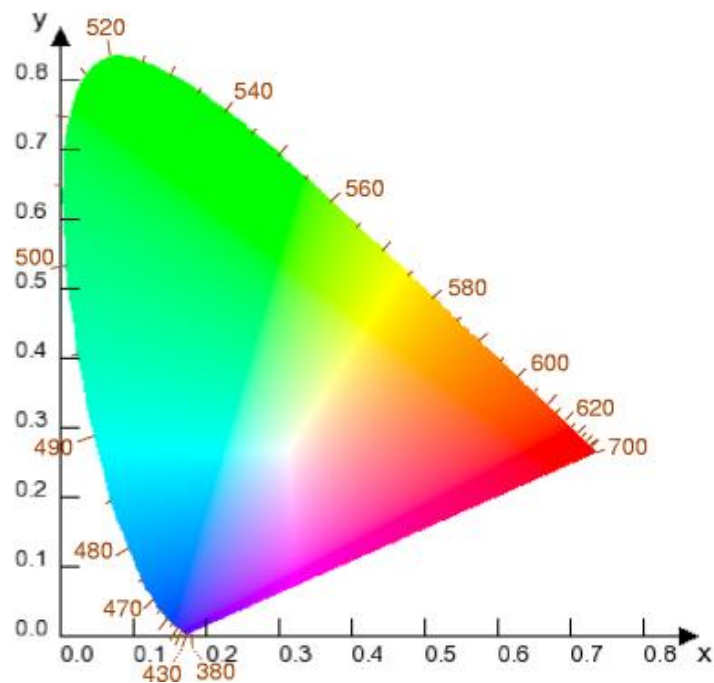
Figure 3-7: CIE chromaticity diagram (all-science-fair-project.com, 2011).

Most analyses of color data are subjective and difficult to analyze because of the multiple physiological factors involved (Ntuen & Gong, 1997). When describing a color used in an experiment, one must exactly identify the color (chromaticity coordinates, white temperature, gamma value) (Humar et al., 2008). Chromaticity coordinates (given as (x,y), (u,v), or (u',v') depending on color space) refer to the points on the chromaticity diagram (Figure 3-7) that correspond to the peak wavelength of the primaries used in the display. LEDs and OLEDs have higher saturations than CRTs, PDPs, and LCDs because the spectral widths for the primaries of LEDs and OLEDS are much narrower (Wen, 2005), this results in LEDs and OLEDs having a much larger area in the chromaticity diagram. If an object is filmed with a multi-spectral camera, the color conversion can be designed such that the image replication is very close to the original object to reduce metamerism (failure to correctly reproduce color) (Koenig, Ohsawa,

Yamaguchi, Ohyama, & Hill, 2002; Murakami, Ishii, Obi, Yamaguchi, & Ohyama, 2004; Ohsawa, Koenig, Yamaguchi, & Ohyama, 2002).

3.2.3   Contrast

Contrast sensitivity describes the ability of the observer to discern subtle differences in shades of gray present in an image (Hendee & Wells, 1997). High brightness contrasts tends to reduce hue contrast; equal brightness tends to maximize hue contrast (Burnham et al., 1963). Contrast can be quantified as a ratio of the difference between two luminances divided by one of the two luminances (usually the larger of the two). Image polarity is defined by the brightness of a color relative to its surrounding color. If the surrounding color is brighter than the inner color, it has a positive polarity, otherwise it is negative (Humar et al., 2008). In the two expressions listed in Equation 3-2, L_s is the luminance of the background, L_0 is the luminance of the object (Hendee & Wells, 1997).

$$C = \frac{L_s - L_0}{L_s} \quad C = \frac{L_0 - L_s}{L_0} \tag{3-2}$$

The luminance of the object and the background determine which expression to use; if the object luminance is less than the background, the first expression is used, if it is more than the background, the second is used. That way, the contrast is always positive. Alternatively, the contrast ratio is typically used, as defined in Equation 3-3, where L_{max} and L_{min} are the luminances emitted by the areas of greatest and least intensity respectively.

$$C_r = \frac{L_{\max}}{L_{\min}} \tag{3-3}$$

Although widely used particularly in LCDs specifications, the full-field contrast ratio of display devices, whereby the brightness of white and black are compared, is not a complete descriptor of the devices contrast capabilities (Badano, Flynn, & Kanicki, 2002).

The human eye is best configured for observing images of positive polarity, like black text on a white background. In addition, when objects are spread further apart from each other and there is noticeable space in between them, finer details are capable of being observed (Townsend, Taylor, & Brown, 1971). Bunching objects together, often referred to as "crowding", limits a person's ability to discern fine details, thus resulting in a degradation of visual performance (Chung & Mansfield, 2009). Instead of distances objects from each other, a similar effect is observed as long as the objects are very dissimilar from each other (Chung & Mansfield, 2009).

3.2.4 Motion Blur

Translation can occur either in a plane perpendicular to the observer (left, right, up and down) or parallel to the observer (back and forth) (Epstein & Rogers, 1995). Translation refers to an object that moves within a plane with respect to its surroundings, like a car driving past an observer (Lowe, 2004). Rotation can occur either with its axis of rotation parallel to the observer (for instance, looking at a windmill from the front) or perpendicular to the observer (such as looking at a windmill from the side) (Epstein & Rogers, 1995). Transformation is as the name implies, changes in the physical attributes of an object such as size, shape, or color (Lowe, 2004). Transition involves the appearance or disappearance of entities (either fully or partly) (Lowe, 2004).

The human visual system can detect motion as slow as 1-2 min of arc per second or as fast as 200 degrees before suffering from motion blur (W. J. Smith, 1991). If a motion video were to be observed frame by frame, they may look more blurry than they would if they were shown in rapid succession (El-Sana, Asis, & Hadar, 2002). Motion blur is typically manifested in cinema since it uses a frame rate of 24 frames per second, resulting in objects suffering from motion blur (El-Sana et al., 2002).

If an object moves at a constant velocity v_0 in the image plane, its displacement is given by $x = v_0 t$ where t is time. The smearing function is given by Kopeika (1998) in Equation 3-4.

$$f_x(x) = \frac{1}{(v_0 t_e)} = \frac{1}{d} \tag{3-4}$$

In Equation 3-4, the length of the blur is represented by d and t_e is the image exposure time. Therefore, to reduce the size of the blur, the object velocity and image exposure time should be minimized. The human-eye physiology and the motion blur effect lead to the conclusion that visual acuity is reduced for objects are in motion and finer details become more difficult to see (El-Sana et al., 2002).

Motion sharpening refers to the phenomenon whereby blurred images appear sharper in motion than their static analogues (Hammett, 1997). Previous findings have shown that sharp images undergo blurring in motion whilst blurred images appear sharper in motion (Hammett et al., 1998). Whilst sharpening increases with speed, it is practically invariant with contrast (Hammett, Georgeson, Bedingham, & Barbieri-Hesse, 2003).

The effects of motion blur generally do not cause any significant impact until velocities are above 2 deg/s, with one study reporting on the loss of visual acuity at velocities up to 200 deg/s (Ramamurthy, Bedell, & Patel, 2005).

3.3   Cognition

Cognition involves processes with the mind to absorb and interpret information. Therefore, this section discusses theoretical concepts related to cognitive processes, particularly: perceptual load, cognitive load, and working memory. Definitions and concepts are provided as well as experimental evidence supports these theories.

3.3.1   Working Memory Load

During any task, working memory is responsible for maintaining access to any information that is necessary for completing that task, whether the information exists in long-term memory or is external to the individual (Ericsson & Delaney, 1999). Essentially, working memory can be equated with consciousness (Sweller, van Merrienboer, & Paas, 1998), whereby information is temporarily stored so it can be immediately used and manipulated. Working memory is most commonly used to process information in the sense of organizing, contrasting, comparing, or working, so its applicability to this study is how the identifying characteristics of the objects are stored and how much working memory that information requires. In terms of instructional design, a limit of seven units of information at any one time should be imposed for effective instruction (Baddeley, 1992; Miller, 1956). Furthermore, because working memory is also used to manipulate the information that is stored, one can only process two or three items of information simultaneously (Sweller et al., 1998). However, for the object identification task proposed in this document, there are neither conceptualizations nor in-depth thought processes determined to be involved in the identification process, so the limitations imposed by working memory can be further explain via cognitive load theory.

3.3.2   Cognitive Load Theory

Cognitive load theory (CLT) emphasizes that the limitations of working memory can impede knowledge acquisition and schema construction (F. Paas, Renkl, & Sweller, 2004). It is an instructional theory that aims to provide parameters for optimizing cognitive load, or the load that performing a particular task imposes on the learner's cognitive system (F. G. Paas, Van Merriënboer, & Adam, 1994), associated with learning complex cognitive tasks (F. G. Paas, Tuovinen, Van Merriënboer, & Aubteen Darabi, 2005). CLT suggests that for information retention and memory recall, instructional materials should be presented in alignment with cognitive processes (Huang, Eades, & Hong, 2008). The ultimate goal of CLT is to provide guidance on how to relate changes in instructional design to the learner's cognitive limitations (F. Paas et al., 2004). CLT can be applied to the following example described by Vogel-Walcutt, Nicholson, and Bowers (2009). Novice learners whom are presented with new material will attempt to store as much information into their working memory as possible regardless of relevance, whereas experts will likely store only relevant information. The working memory capacity of the novices will become overloaded with less relevant information than the expert user, thus affecting their learning ability.

Incorporating instructional design into CLT, there are three types of cognitive load as defined by Sweller, van Merrienboer, and Paas (1998): intrinsic, extraneous, and germane. Intrinsic cognitive load refers to the amount of mental difficulty involved with completing a task or understanding a concept (Sweller et al., 1998). The amount of procedural elements and relationships within a task that have to be constantly used within working memory determine the difficulty of the task (Bétrancourt, Dillenbourg, & Clavien, 2008; Nimwegen, 2008). Extraneous cognitive load is caused by the unnecessary details given to an instructional material which can detract from learning by using up working memory (Bétrancourt et al., 2008; Nimwegen, 2008; Sweller et al., 1998). Germane cognitive load describes the amount of mental

effort required to process information and associate it with prior knowledge (Sweller et al., 1998). In terms of the object identification task considered with the proposed experimental research, intrinsic cognitive load would be the most relevant, but it is assumed that its effects will be minimal.

To extend these constructs further, an additional type of working memory load known as perceptual load is also necessary to consider. Whereas CLT is primarily concerned with how objects in working memory are manipulated, conceptualized, and transferred into and out of long-term memory, perceptual load theory focuses on how descriptive and aesthetic qualities of an object interact with working memory. Combining CLT with perceptual load, the design and qualities of an object will play a role as to which attributes are considered or focused upon, thus storing the information into working memory where it can interact with long-term memory. This overlap can best illustrated by looking at how perceptual load is understood.

3.3.3 Perceptual Load

Perceptual load can refer to either the amount of attention a stimulus requires in order to be identified (Lavie, 2006), or the number of different-identity items in a stimulus that need to be perceived (DeLeeuw, 2009). Based on these definitions, reducing perceptual load requires an object to be identified using as few characteristics as possible and reducing the amount of time needed to view and interpret these qualities. In a search and identification task, reducing perceptual load implies that a stimulus would require less attention in order to be identified; this can be interpreted as an improvement in task performance if the goal is to identify an object as fast as possible.

An assumption has been made by Wei and Zhou (2006) that there are dimension-specific attributes like shape and color that require minimal visual processing. This notion is further examined

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using the dimension-weighting theory of visual selection (Krummenacher, Müller, & Heller, 2001; Krummenacher, Müller, & Heller, 2002; Müller, Heller, & Ziegler, 1995), which proposes that recognition is based on an attentional mechanism that gives specific attributes of an object more emphasis and concentration than others. It has been argued that the various visual attributes of a stimulus are not weighted equally (Krummenacher et al., 2001; Krummenacher et al., 2002; Müller et al., 1995), meaning that some dimensions (such as color, shape, or texture) are given more attention and hence are assigned a stronger weights.

Relating this theoretical construct to the proposed experimental work, altering the color and motion blur of an object is thought to introduce additional dimension with which to weight the identification task. For example, when the objects are displayed without color and with motion blur, the identifiable qualities of each tank will be gray-scale shading and the shapes of various components of each tank. With motion blur reduction disabled and the tanks in motion, motion blur will cause the distinguishing characteristics of the tanks to blend together slightly, thus affecting both the gray-scale and shapes of the tanks. With motion blur reduction enabled, these hindrances should not be present and should allow for easier identification. In terms of coloration, color will allow for additional identifying information about each tank to be stored in working memory, but likely not enough to overload it, so more weight can be given to the color, which may be easier to distinguish from a gray-scale if motion blur is involved.

3.4   Summary

Overall, each type of display has positive and negative attributes: CRT's are inexpensive, but can be heavy, bulky, and have limited resolution capabilities; LCD's are reasonably priced, compact, and energy efficient, but have a multitude of variations in terms of capability based on their design which complicate their application; PDP's are comparable in price to LCD's and exhibit minimal motion blur, but are limited to large displays and are not energy efficient. Of these displays, LCD's will be considered for the purposes of the proposed experimentation due to their applicability and multitude of variations.

In terms of experimentation, brightness will not be considered because research has already been performed regarding its impact on usability and the assumption that improvements are known to exist in terms of materials and brightness. Contrast ratio technology has reached a level such that LCD's exhibiting ratios below 4,000:1 are difficult to find, whereas ratios above 100:1 are believed to not incur dramatic effects in terms of visual performance. However, in terms of color and motion blur reduction, these attributes can be easily manipulated and are presently being introduced as new commercial technology.

Cognitive load and perceptual load will both be contributing to working memory load. Therefore, a cognitive load questionnaire will be administered to gauge the effect of cognitive load on task performance. Due to the overlapping of perceptual load and cognitive load, differentiating between will be attempted by correlating the fixation data with the cognitive load questionnaire.

The effects of display characteristics of LCD's on cognitive processes is relatively under-represented in the literature, therefore the research intended via this proposal is expected to provide new insight for information display research to bring new concepts to light.

CHAPTER 4:   EXPERIMENT

4.1   Materials

- An LCD display whose display properties can be modified (namely color and motion blur reduction). The Samsung UN32D6000SF was used for these purposes.

- Computers capable of running the UAV training simulation and eye-tracking system simultaneously

- Training tutorials to explain the UAV scenario and the tasks to perform

- An eye-tracking system to measure fixation direction and duration

- IRB Approval (see APPENDIX A)

- An informed consent form (see APPENDIX B)

- A biographical questionnaire (see APPENDIX C) to obtain data regarding gender, age, and ethnicity of the participants

- A prior knowledge questionnaire (see APPENDIX D) to determine prior experience with UAV simulations

- A cognitive load questionnaire (CLQ) (see APPENDIX E) to gain subject data regarding cognitive load levels throughout the experiment

- A declarative/procedural knowledge test (see APPENDIX F) regarding training

The computers, UAV training system, and training tutorials were available for use at the ACTIVE lab at the Institute for Simulation and Training. The additional materials were purchased or created once the study was approved. The layout of the simulation station is depicted in Figure 4-1, which shows the eye-tracking system (two cameras and an IR light source) and a monitor (the monitor displayed was not the actual monitor used for the experiment).
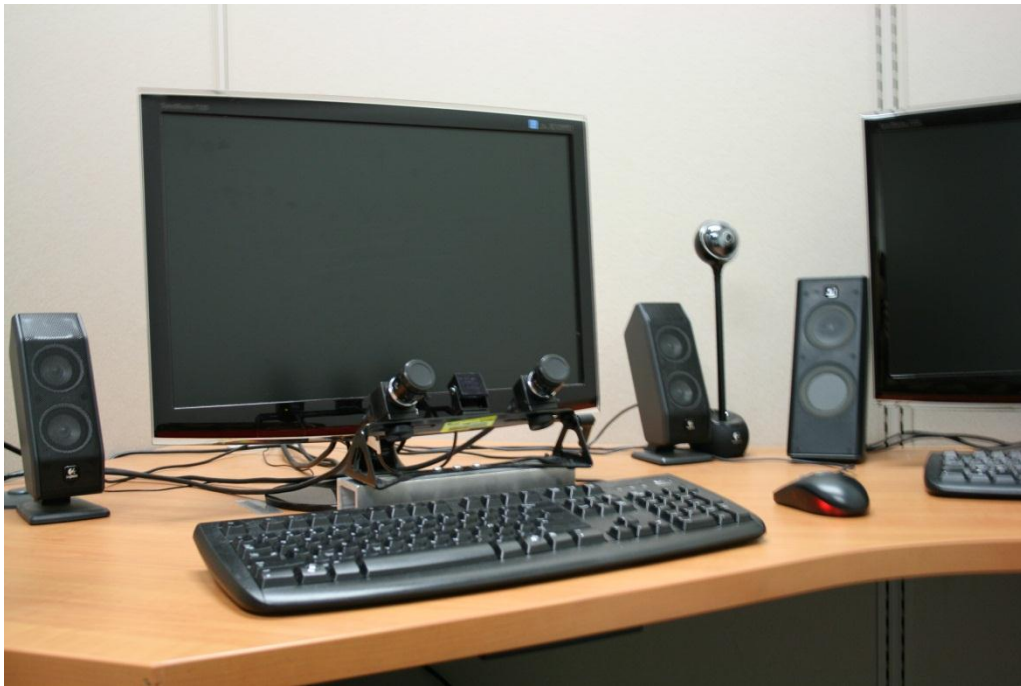
Figure 4-1: Simulation station including eye-tracking cameras and computer monitor.

Behind a wall within the same room, the experimenter controlled all aspects of the experiment, including running instructional materials, initiating the simulations, and recording eye-tracking data.

4.2   Participants

Participants were required to be between 18 and 40 years of age and be U.S. citizens due to the nature of the training scenario (upper age limit was imposed due to differences in pupil response depending on age). Participants were required to have normal color vision with no history of color blindness and to be able to read a display at a comfortable distance away from it. Persons requiring bifocals, trifocals, or very strong prescription glasses were unable to be calibrated with the eye-tracking system and were thus excluded from the study. Experimental conditions were sequentially assigned to participants so that each experimental condition had an equal number of participants. Biographical and prior knowledge information were gathered and taken into effect during this study. Participants were compensated with $10 upon the completion of the experiment with course credit. It was not believed that this amount of compensation would incur any performance effects during the experiment.

4.3   Method

The subjects participated in a threat identification task within an unmanned aircraft vehicle (UAV) simulator wherein the user was taught to locate and identify objects as threats. There were approximately 10 threats to identify amidst non-threats during each training scenario (excluding the practice scenario). An example of the UAV layout is presented in Figure 4-2, which depicts the viewing angle, type of environment, and a selection of tanks that are available to use during the identification task.
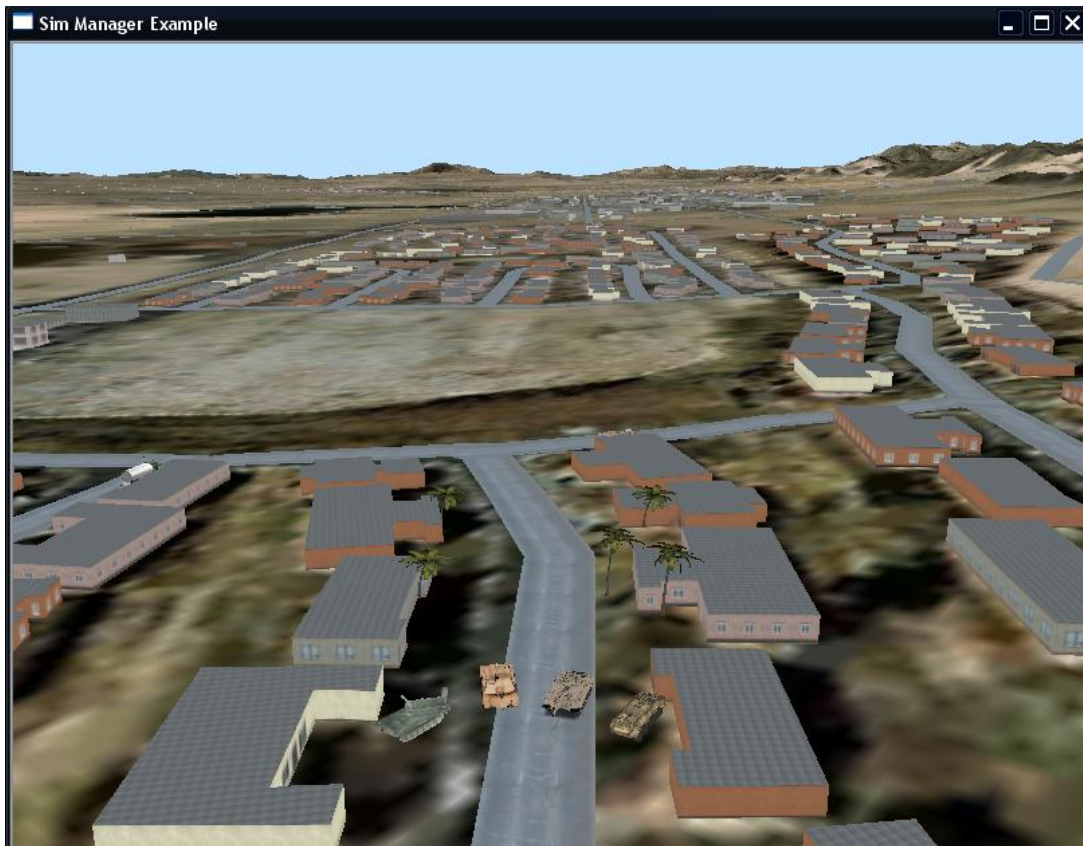
Figure 4-2: UAV simulation display with four tanks visible.

As objects appeared during the simulation, the participant was required to single-click on the threat level he or she wished to assign and then single-slick the object to identify it as a threat. The UAV scenario was designed such that there was a multitude of available objects such as buildings, cars, and crowds of people that the user must search through in order to identify specific objects.

The display conditions that were employed were whether the scenario was presented in full color (RGB) or in black and white (B&W), and whether or not motion blur reduction was enabled or disabled (MBR on or off). Each of these parameters was adjusted individually as shown in Table 4-1.

Table 4-1: Sets of display conditions to be used during experiments.

Motion Blur Reduction

		Off	On
Color	B&W	Group 1 (control)	Group 2
	RGB	Group 3	Group 4

The task was completed three times by each participant, once with the display set to have B&W and MBR off for practice, once with altered display conditions for a training session, and once with altered display conditions for an assessment session. All participants were required to practice interacting with the training simulation using the condition assigned to group 1, as these conditions was considered neutral. The participants in group 1 were referred to as the control group because they interacted with the training simulation throughout the experiment with no change in display conditions. Comparisons between the control group and groups 2, 3 and 4 were meant to isolate the perceptual elements and allow for the determination of whether changing perceptual load will affect cognitive processing (indicated by fixation duration), cognitive load (indicated by the cognitive load questionnaires), threat identification accuracy (indicated by the number of correct threat identifications during each scenario), and training effectiveness (indicated by the post-training knowledge tests). Measurements included cognitive load questionnaire scores, fixation duration, scores of correct and incorrect threat identifications, and scores from the knowledge tests.

4.4   Procedure

The participants were informed regarding the tasks involved in the experiment but not of the display variables: color and motion blur reduction. Withholding information regarding the display conditions was done to avoid any suggestions of the experimental design or indications of what results were expected, which could have manifested as a change in the participant's task performance. The participants were also asked questions regarding their eligibility to participate in the experiment, including participation in similar experiments and prior experiences with military training. Once the participants were deemed eligible to participate and provided their consent to proceed with the experiment, they were asked to fill out a biographical questionnaire to obtain data regarding gender, age, and ethnicity and a prior knowledge questionnaire to determine any prior experience with training systems similar to those used in the experiment. Once these were filled out, the participants were seated at the experiment station and the eye-tracking equipment was calibrated and validated using standard procedure.

The participants were presented with a training tutorial video (Intro Trainer) to familiarize them with the tasks to be performed with the display set to RGB with MBR on for all participants. Once the participants finished watching the training tutorial video, the participants were given a CLQ to indicate their subjective level of cognitive load during the tutorial. After a score was given, the practice scenario was loaded for the participants and the simulation was run with the display set to B&W with MBR off for all participants. Upon completing the practice scenario, a CLQ was completed by the participants. The participants then completed two phases: the training and assessment phase. Within each phase, the participants watched a training video and then completed a scenario based on the training video. The training videos had the display set to RGB with MBR on for all participants, whereas the simulators had the display settings set according to Table 4-1. The training phase involved watching a training video

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(Trainer 1) and completing a training scenario. The assessment phase involved watching a second training video (Trainer 2) and completing an assessment scenario. Each activity (training video and scenario) was followed by a CLQ. Finally, the participants completed a declarative/procedural knowledge test. Approximate time to complete this experiment was 75 minutes (itemized procedural elements are listed in Table 4-2).

Table 4-2: Approximate experimental procedure times.

Task	Time Required (minutes)
Informed consent and questionnaires	10
Eye-tracking calibration	15
Intro trainer video (RGB, MBR on) and CLQ	5
Practice scenario (B&W,MBR off) and CLQ	5
Trainer 1 video (RGB, MBR on) and CLQ	5
Training scenario 1 (see Table 4-1) and CLQ	10
Trainer 2 video (RGB, MBR on) and CLQ	5
Assessment scenario 2 (see Table 4-1) and CLQ	10
Knowledge tests and CLQ	10

CHAPTER 5:   RESULTS AND DISCUSSION

5.1   Results

Statistical analyses were performed using a two-tailed MANOVA with α=0.05 and n=20 for each group. Assumptions of equal variance and a normal distribution were confirmed using a Levene's test and a Kolmorgorov-Smirnov test, respectively. Comparisons between groups were performed to determine statistical significance of each experimental condition. Of all of the measures collected, Table 5-1 lists the only measures that resulted in any p-values less than 0.05: fixation duration and number of saccades. Note that not all comparisons resulted in p<0.05; the insignificant values are listed with a single asterisk and values showing a trend towards significance (p<0.10) at shown with a double asterisk.

Table 5-1: List of p-values for fixation duration and saccade measurements.

	Experimental Condition	Trainer 1 p-value	Trainer 2 p-value
Average Fixation Duration	Motion Blur Reduction	0.042	0.013
	Color	0.120*	0.037
	Color and Motion Blur Reduction	0.017	0.014
Number of Saccades	Motion Blur Reduction	0.145*	0.009
	Color	0.668*	0.162*
	Color and Motion Blur Reduction	0.057**	0.003

To visualize these results, Figure 5-1 and Figure 5-2 display the average fixation duration and saccade data, respectively. Letters in the figures indicate which measures are significantly different from one another, whereby "a" is different from "b" and "ab" is different from neither "a" or "b". It is

important to note that the practice conditions were the same for all participants, so none of these data resulted in significant differences from one another and thus are not labeled with letters.
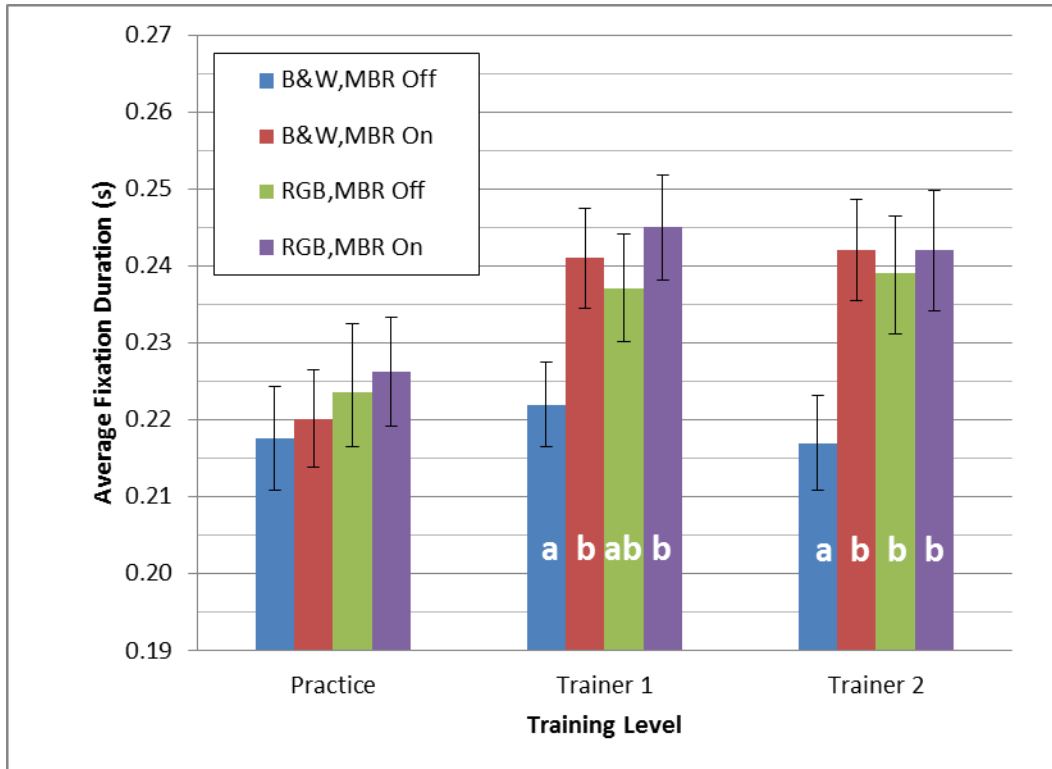
Figure 5-1: Average fixation durations during each simulation phase.
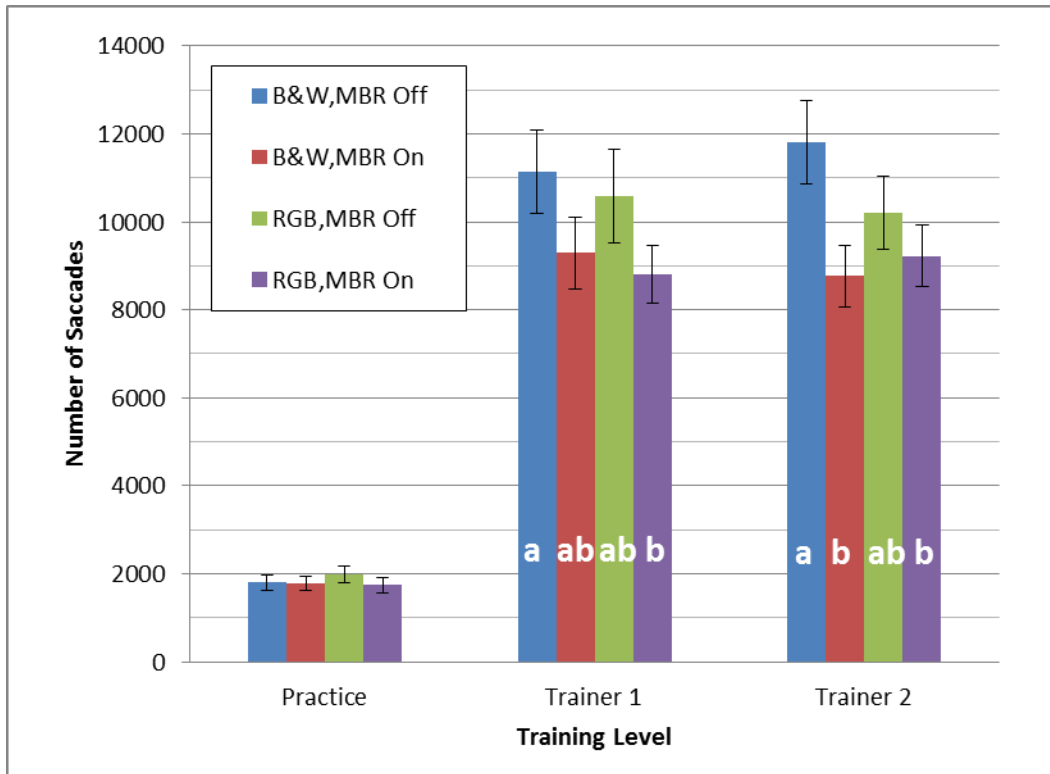
Figure 5-2: Average number of saccades during each simulation phase.

Although the analysis of the self-reported cognitive load measures failed to display statistical significance between groups, the data illustrates an important feature of the experiment: the difficulty of the experiment increased as it progressed. Figure 5-3 shows that, regardless of group, there is a general agreement that the difficulty of the experimental tasks increased as the experiment progress.
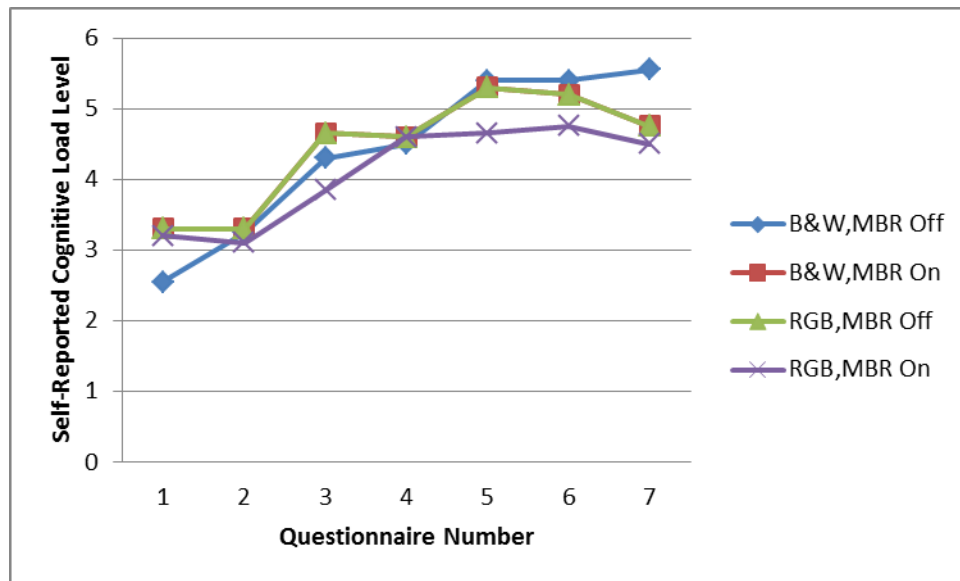
Figure 5-3: Self-reported cognitive load measures.

5.2   Discussion

This section will analyze the results that have been provided in section 5.1 and will suggest conclusions based on the data. It has been arranged to discuss the groups of hypotheses laid out in section 1.4 accordingly.

5.2.1   Self-Reported Cognitive Load

Self-reported cognitive load is a subjective means to ascertain the cognitive load levels that the participant feels he or she is under during separate portions of the experiment. Although these measures are dependent on the participant's own beliefs, they are useful for a few reasons. These measures have been commonly used in order to gauge cognitive load levels while objective means are still under

investigation. Additionally, if a user interprets a task as being mentally taxing, then it is likely that he or she maintained a high cognitive load; there is reason to believe that these measures are relatively accurate.

Although there were no statistical differences reported by comparing the self-reported cognitive load measures between groups, the data shown in Figure 5-3 clearly shows a common trend for all groups; the cognitive load levels increased as the experiment continued. This was attributed to the additional complexity of the tasks required to interact with the simulator. During the practice session, the user had to click on a threat level and then click on an object; no information regarding which threat levels to assign or what objects to target was provided. During the first training simulation, a specific list of objects were to be assigned a threat level of 1, 2, or 3 based on information provided in the preceding training video. The second training simulation had an additional requirement of assigning call-for-fire tasks to combinations of threats based on the threat level based on information provided in the preceding training video. Since each consecutive task added memory tasks (a list of specific things to remember), the resulting cognitive load levels were cumulative whereby they continually increased.

According to hypotheses H1, H2, and H3, it was believed that the experimental conditions would result in higher self-reported cognitive load levels as compared to the control. Analysis of the data led to the conclusion that cognitive load levels increased irrespective of the experimental condition, thus the null hypotheses failed to be rejected. It is important to note that the experimental conditions were all equivalent during the videos and were applied only during the simulations. Looking specifically at the self-reported measures during the simulations, all values were approximately equal as well. This gives support to two possible conclusions. First, that the experimental conditions resulted in no subjectively perceivable differences in cognitive load levels throughout the experiment; if differences existed, they could only be inferred using objective measures. This idea will be visited again during later sections involving objective data measures. Second, the effects of perceptual load are independent of germane

cognitive load, whereby the appearance of the tasks in terms of color or motion blur reduction has no measureable impact on overall cognitive load.

As an interesting side note, several participants volunteered information without coercion during debriefing regarding the difficulty in identifying objects without color information present. Generally, the participants whose display condition was in black and white claimed that that lack of color information made identifying the objects difficult because most of the tanks in the simulation looked similar in shape. This stated difficulty was not reflected in the self-reported cognitive load levels and can be assumed to be based solely on perceptual load. None of the participants whose display condition was in color made statements regarding the difficulty of differentiating tanks from one another.

5.2.2 Pupil Diameter

Pupil diameter was only measured during the simulations. Analysis of the data was performed 3 ways: average pupil size, relative change in average pupil size, and average index of cognitive activity (ICA). The average pupil size was thought to correspond to the increase in cognitive load, but individual differences in pupil size were thought to confound these results. Therefore, the relative change in average pupil size was calculated using the practice simulation as the baseline so that physical differences in pupil size would no longer influence the results. The index of cognitive activity is a value generated from the eye-tracking system software using an algorithm based on pupil measurements. Due to licensing issues, the index of cognitive activity data was only collected from the final 20 participants, but this data was analyzed regardless of experimental condition to see if any relationship could be found relating cognitive load levels (in general) to pupil response. None of these measures resulted in any significant differences

between groups, so hypotheses H4, H5, and H6 which postulated an increase in pupil diameter failed to reject the null hypotheses.

The lack of significance between groups can be due to a variety of factors. One possibility could be due to the slow pace of the simulation; objects were visible on screen for about 10 seconds, allowing for long periods of inactivity between identifications. If cognitive load levels were only elevated during periods of assigning threat levels, then averaging the data over the entire simulation would conceal these peaks. However, the self-reported measures indicated that cognitive load levels were increasing steadily as the experiment progressed, thus negating this argument due to the fact that the pupils should have been relatively increasing in diameter compared to the baseline.

Another reason for the lack of statistical significance could be due to the idea mentioned earlier that perceptual load is independent from germane cognitive load, which suggests that pupil response alone is incapable of differentiating between the two, at least over long time scales. This also reveals another result; the different display conditions resulted in similar changes in pupil response. This shows that changing the amount of color present on a screen has no measurement effect on the overall pupil size. Alternatively, if color actually contributed to a change in pupil size that was negated by an increase in cognitive load, then these results indicate that additional steps are necessary to ensure that these two factors do not overlap. To account for this, baselines should be taken with the experimental conditions present instead of using the control condition.

5.2.3 Fixation Duration

Hypotheses H7, H8, and H9 stated that a relationship exists between fixation duration and perceptual load; that greater image complexity generated by adding color information and improving

image clarity by employing motion blur reduction would result in longer fixations. The longer fixations would be required to process the additional information that was presented; color information and additional spatial information that would otherwise be obscured via motion blur. Statistical analysis indicated that increased perceptual load did require longer fixation durations, thus successfully rejecting each of the null hypotheses. However, given the inability to successfully reject the null hypothesis for H8 for both Trainer 1 and Trainer 2 for the color condition, further experimentation may be required to validate these conclusions.

Considering the data presented in Figure 5-1, it is clear that no obvious differences appear when comparing the fixations during the practice simulation. This is expected since all participants used the same display conditions (black and white with motion blur reduction disabled). During the training simulation (Trainer 1), all experimental conditions resulted in higher fixation durations than the control group; with all conditions displaying statistical significance except color condition (p=0.12). However, the assessment condition (Trainer 2) resulted in statistical significance for all group comparisons to the control (p<0.05). In all instances, the experimental condition resulted in longer fixation durations, approximately 8-10% higher than the control condition. This stands to imply that given a multitude of objects on a screen, the experimental conditions would result in fewer objects analyzed. Applying this to a military application, the ability to identify objects with shorter fixation durations could mean the difference between finding a threat or missing it completely. Assuming the goal of an unmanned aircraft vehicle is to assist in locating targets in the least amount of time, these results suggest that including color information and/or using motion blur reduction will actually lessen the efficacy of searching for threats. Instances where color information is not available, such as forward-looking infra-red (FLIR) or thermal imaging cameras, should allow for better search capabilities than a full-color or false-color system.

5.2.4 Saccades

Given that saccades are ballistic eye movements between fixations, an inverse correlation between the two measures is thought to exist. Since the fixation data suggested that increases in perceptual load were accompanied by longer fixation durations, it should also stand to reason that increases in perceptual load will result in a decrease on the number of saccades. This is believed to be result of the idea that longer fixations will result in fewer saccades.

The statistical analysis of the saccade data reveals a similar understanding of the experimental results obtained from the fixation duration data. According to Figure 5-2, the data for Trainer 1 propose that color or motion blur were not independently differentiable from the control condition, but combining color and motion blur reduction resulted in $p=0.057$, indicating a strong possibility of rejecting the null hypothesis for H12. For Trainer 2, motion blur reduction resulted in $p=0.009$ and combining motion blur reduction resulted in $p=0.003$, both of which indicate strong confidence in rejecting the null hypotheses for H10 and H12, but not for H11. Taking into account the discrepancies between Trainer 1 and Trainer 2, stronger evidence exists for rejecting the null hypothesis for H12 than for H10, suggesting that further work may be necessary to validate these conclusions.

These results lead to the conclusion that motion blur reduction has a greater impact on reducing the average number of saccades than incorporating color information, and that the combination of these factors has a cumulative effect resulting in the greatest decrease in the average number of saccades. These results are similar to the conclusions drawn from the average fixation duration data because the relative impact of each display condition was evident, although not nearly as strong.

5.2.5   Threat Assessment

Threat assessment scores were calculated a variety of ways in order to try and gain multiple understandings. Scores were divided into two groups: object identification, which scored a 1 for each threat correctly identified and a 0 to each non-threat identified as a threat, and threat assessment, which scored a 1 for a correct threat level assignment, a 0 for assigning an incorrect threat level to a threat, and a -1 for assigning a threat level to a non-threat.

For object identification, percentages were calculated by dividing the number of correct identifications by the total number of identifications made. These percentages would indicate the level of understanding gained from the training videos as well as the ease of which threats were differentiated from non-threats. This was used for analysis instead of using the total number of threats identified or the number of correct identifications because the system recorded every object that was clicked upon. These data varied much more widely than the percentages did since some threats (like mountainous regions) could be identified multiple times. If the experimental conditions made it impossible to differentiate between threats and non-threats, then the statistical analyses of the percentages would have indicated a difference between the groups. There were no significant differences between groups, it can be concluded that the addition of color information and/or the implementation of motion blur reduction did not affect the accuracy of object identification. Also, since the display conditions during the videos were the same for all groups, the same amount of information was presented to each group in order to make the identifications. This provides support to the idea that the object identification accuracy was based procedural knowledge and understanding of the material, which are attributed to germane cognitive load and not perceptual load.

The threat assessment scores also had to be treated as percentages for the same reason as the object identification scores; objects could be assigned threat levels multiple times, resulting in a wider variance of scores than percentages. To calculate these percentages, the number of correct threat assignments was divided by the number of correct object identifications. This resulted in an understanding of the participant's ability to apply his or her understanding of the threat levels to the objects that were identified. The comparisons between groups would then allow for an investigation as to how perceptual load affect germane cognitive load; whether perceptual load caused any changes in the user's ability to recall information. Statistical analyses of these results all failed to reject the null hypotheses for H13, H14, and H15, thus providing evidence that perceptual load has minimal impact on the ability to correctly identify object and on the ability to apply procedural knowledge during a simulation.

5.2.6   Knowledge Test Scores

Similar to the threat assessment measures, the knowledge test scores were administered in order to determine if there were any differences in the amount of knowledge obtained during the training simulations based on the display conditions. Since the cognitive load measures and threat assessment scores all failed to indicate any statistically significant differences between the display conditions, it is understandable that the knowledge tests scores also failed to reject the null hypotheses for H16, H17, and H18. This provides further evidence that the effect of display condition was to only affect perceptual load and that this load is independent of germane cognitive load. Also, that all knowledge regarding threat identification was gained from the training video and not necessarily from the simulation. The results

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from the motion blur reduction analysis also confirm findings from (Gulliver et al., 2004), who showed that information retention was not affected by frame rate.

CHAPTER 6:   SUMMARY

This dissertation presented information regarding the use of information displays in a training environment and ways in which display technology can be used to alter instructional mechanisms. Of particular interest for this dissertation were how color and motion blur reduction contributed to the perception of the information being displayed and how this perception affected the user's ability to locate objects and to recall information. A literature review was performed regarding the use of eye-tracking equipment to measure perception and cognitive load, gauge interface usability characteristics, and train users in an instructional environment. Recent advancements in display technology were also investigated to understand what capabilities were available with display technology as well as what direction future research was heading towards.

Theoretical concepts of cognition and information displays were discussed to guide the principles of the completed experimentation. From these theoretical concepts, hypotheses were derived to test how display properties affected training efficacy and to find what aspects of an information display were pertinent to transferring information more effectively and for improving the efficacy of a search task. Generally, the hypotheses stated that increased cognitive loads resulting from increased perceptual loads were expected to generate improved memory recall and search task ability.

The experiments were able to show that perceptual load was independent of, or at least had minimal effect on, cognitive load. The self-reported cognitive load measures, pupil dilations, and index of cognitive activity measures all indicated minimal differences between groups in terms of their cognitive loads. The self-reported cognitive load measures indicate a common increase in cognitive load as the experiment progressed, but this increase in cognitive load did not result in any changes in the participant's ability to perform tasks successfully. Average fixation durations during the training and assessment

simulations resulted in significant differences between the control group and the experimental conditions. In most cases, the average fixation duration increased when color or motion blur reduction were incorporated into the simulation. These attributes were assumed to increase the complexity of the information presented to the user during the simulation and were thus responsible for increasing the user's perceptual load. A direct correlation between the increased perceptual load and increased fixation durations was made, coupled with the fact that the object identification accuracy, threat assessment scores, and knowledge test scores were similar between all groups, led to the conclusion that the increased perceptual load was detrimental to the efficacy of the simulation interaction. Requiring 8-10% longer fixation durations for equal identification accuracy was viewed as a fairly significant reduction in task performance.

Saccade data, in addition to the fixation data, was able to suggest that the impact of motion blur reduction on perceptual load was greater than the addition of color information. Furthermore, the effects of combining color and motion blur reduction resulted in a cumulative effect, whereby the statistical significance caused by perceptual load was strongest for this condition. This provides support for the idea that perceptual load effect may generally be cumulative, but this would require further investigation to validate.

As a direct result of this experiment, recommendations can be made in terms of the display requirements suggested for improved search task performance. Generally, any display that is capable of removing color information and provided a small amount of motion blur would be best suited to reduce the amount of time necessary to identify object. This should alleviate any requirement that high-end display technologies must be implemented for search tasks and that investing in technology to make color images available are also unnecessary for these types of situations.

If this work were to be continued, the impact of other display dimensions could be explored, including: contrast, frame rate, color gamut, brightness, resolution, screen size, hue, and edge enhancement. It is expected that some of these properties will compare to those found with motion blur reduction due to their ability to make objects appear more clearly without affecting the color information: contrast, frame rate, resolution, and edge enhancement. The color gamut and brightness are believed to have a larger impact on preference rather than perceptual load, whereas hue is likely to impact perceptual load since color information is being altered. Extending this idea further, experiments could be conducted using a false color format, where colors are based on intensity levels or on some scale. Also, a study could be conducted comparing realistic environments versus simulated environments. Realistic environments will include greater amounts of detail and would thus be introducing much higher levels of perceptual load. It may also be shown that the more realistic environments are more dependent on the display properties such as color and motion blur reduction due to the increased level of detail.

Overall, this research was successful in finding a significant positive correlation between perceptual load, average fixation duration, and the number of saccades made during a search task; higher perceptual loads led to longer fixation durations and more saccades. It was also surmised that perceptual load had minimal impact on reported cognitive load levels. These results are useful for implementing improved display conditions for search tasks, such as those found in military training applications, and for prescribing possible areas of research in display technology to further understand the user impact that display conditions have upon the user.

APPENDIX A: IRB APPROVAL LETTER

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Jonathan L. Rosch**

Date: **June 24, 2011**

Dear Researcher:

On 6/24/2011, the IRB approved the following human participant research until 6/23/2012 inclusive:

Type of Review:	UCF Initial Review Submission Form
Project Title:	The effects of display quality on perception during an identification task
Investigator:	Jonathan L Rosch
IRB Number:	SBE-11-07734
Funding Agency:	
Grant Title:	
Research ID:	N/A

The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 6/23/2012, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Kendra Dimond Campbell, MA, JD, UCF IRB Interim Chair, this letter is signed by:

Signature applied by Joanne Muratori on 06/24/2011 01:23:45 PM EDT

IRB Coordinator

APPENDIX B: INFORMED CONSENT

INFORMED CONSENT
Effects of display quality on an identification task

Principal Investigator(s):   Jonathan L. Rosch
Sub-Investigator(s):   Jennifer J. Vogel-Walcutt, Ph.D.
Investigational Site(s):   IST, 3280 Progress Dr., Orlando, FL 32826

Introduction: Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in a research study. You are being invited to take part in a research study which will include up to 100 people at UCF. You have been asked to take part in this research study because the researcher is interested to know how people interpret object data using military computer simulated tasks. You must be an American citizen, 18 years of age or older, and be capable of seeing a full range of colors to be included in the research study. You can read this form and agree to take part right now, or take the form home with you to study before you decide.

What you should know about a research study:
- Someone will explain this research study to you.
- A research study is something you volunteer for.
- Whether or not you take part is up to you.
- You should take part in this study only because you want to.
- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide it will not be held against you.
- Feel free to ask all the questions you want before you decide.

Purpose of the research study We are investigating the effects display quality during military computer-based simulation tasks.
What you will be asked to do in the study: In this study, you will watch a short training presentation and complete military threat detection tasks using a computer-based simulator. Measurements will be made using a non-intrusive eye-tracking system which only records data regarding where you are looking and the size of your pupils. Video of yourself will be shown on the screen during the eye-tracking system calibration process, but no video will be recorded and no part of the apparatus will come into contact with you.

Location: IST, 3280 Progress Dr., Orlando, FL

Time required: We expect that you will be in this research study for a total of 1 hour.

Risks: There are no foreseeable risks or discomforts associated with the simulator.

Benefits: There are no expected benefits to you for taking part in this study.

Compensation or payment: Compensation will be given as credit for class through SONA. SONA decides how many credit points are awarded for each hour of experimental participation. The results of the research study may be published, but your name or the names of your students will not be used.

Confidentiality: We will limit your personal data collected in this study to people who have a need to review this information. We cannot promise complete secrecy.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints, or think the research has hurt you talk to Jonathan Rosch, Graduate Student, Institute for Simulation and Training by email at jrosch@ist.ucf.edu or Dr. Vogel-Walcutt, Research associate, Institute for Simulation at (407) 823-1366 or by email at jjvogelwalcutt@yahoo.com.

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901. You may also talk to them for any of the following:
- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You want to get information or provide input about this research.

APPENDIX C: BIOGRAPHICAL QUESTIONNAIRE

BIOGRAPHICAL QUESTIONNAIRE

1. **Age** _____

2. **Gender** (please circle)   a. Female   b. Male

3. **Race/Ethnicity** (please circle one only):

a. Caucasian   b. Africa-American   c. Asian-American   d. Hispanic   e. Other

4. **SES/combined income of house hold** (circle one only):

a. $0-29,999   b. $30,000-59,999   c. $60,000-89,999   d. $90,000 +

5. **Marital status** (circle one only):

a. Single   b. Married   c. Divorced   d. Widowed   e. Living with partner

6. **What is your current working status?** (You may circle more than one)

a. Staying at home   b. Work full-time   c. Work part-time   d. Student   e. Retired

7. **What is the highest degree that you have obtained?** (Circle one only)

a. Some High School   b. High School Diploma   c. Some College

d. Bachelor's Degree   e. Some Graduate Experience   f. Completed Graduate Degree

8. **What is your primary language?** (Circle one only)

a. English   b. Spanish   c. Other

9. **What is your hand preference?** (Circle one only)

a. Right-Handed   b. Left-Handed   c. No Preference

10. **Do you require corrected vision?** (Circle one only.)   Yes   No
    If so, do you wear glasses or contacts? (Circle one only.)   Yes   No
    And if so, are you wearing them now? (Circle one only.)   Yes   No

11. **Have you ever served in the military or ROTC?**   (Circle one only.)   Yes   No
    If so, with whom and when? _____

12. **How often do you play video games** (computer or console)? _____ hours/week

13. **How often are you on the computer?** _____ hours/week

14. **How would you describe your degree-of-comfort with computers?** (Circle one only.)

a. Poor   b. Fair   c. Average   d. Above Average   e. Proficient

APPENDIX D: PRIOR KNOWLEDGE QUESTIONNAIRE

PRIOR KNOWLEDGE QUESTIONNAIRE

1. **What do you know about Unmanned Aircraft Vehicles?**

_____

_____

_____

_____

_____

2. **What do you know about Threat Identification?**

_____

_____

_____

_____

_____

3. **What do you know about Call for Fire tasks?**

_____

_____

_____

_____

4. **Have you ever used a military simulator? If so, please explain your experience.**

_____

_____

_____

_____

_____

APPENDIX E: COGNITIVE LOAD QUESTIONNAIRE

COGNITIVE LOAD QUESTIONNAIRE

In solving or studying the preceding problem I invested: (Circle one only)

1. Very, very low mental effort

2. Very low mental effort

3. Low mental effort

4. Rather low mental effort

5. Neither low nor high mental effort

6. Rather high mental effort

7. High mental effort

8. Very high mental effort

9. Very, very high mental effort

APPENDIX F: DECLARATIVE/PROCEDURAL KNOWLEDGE QUESTIONNAIRE

DECLARATIVE/PROCEDURAL KNOWLEDGE QUESTIONNAIRE

(1-3) To complete each mission, the UAV Operator is responsible for which three (3) items listed below? (Circle three.)
a. Identifying targets
b. Destroying targets
c. Determining the threat level of targets
d. Detecting targets

4. What determines the instructions you will give to your supporting forces?
a. The number of people in the area
b. The threat level of the targets
c. The proximity of the targets to friendly forces
d. The time it takes to report the threat level

5. Which of the following is _NOT_ an example of the instructions you may give your supporting forces?
a. Call for neutralization of the target
b. Investigate and take action if necessary
c. Engage target immediately
d. Mark area as a possible threat

(6-12)For each scenario in questions 4-10, determine the appropriate instructions you would report to supporting forces on the ground?

6. A mountainous region
a. Investigate and report findings
b. Mark area as a possible threat
c. Remote sweep of the area
d. Engage target immediately

7. A foe tank next to a small group of people
a. Investigate and report findings
b. Call for neutralization of the target as time permits
c. Remote sweep of the area
d. Call for immediate neutralization of the target

8. A small group of people in a mountainous region
a. Investigate and report findings
b. Mark area as a possible threat
c. Remote sweep of the area
d. Call for immediate neutralization of the target

9. A small group of people in an unpopulated area
a. Investigate and report findings
b. Mark area as a possible threat
c. Remote sweep of the area
d. Call for immediate neutralization of the target

10. A small group of people next to a car parked in an abnormal location
a. Call for neutralization of the target
b. Mark area as a possible threat
c. Remote sweep of the area
d. Investigate and take action if necessary

11. A foe tank
a. Call for neutralization of the target as time permits
b. Investigate and take action if necessary
c. Remote sweep of the area
d. Call for immediate neutralization of the target

12. A foe tank next to a car parked in an abnormal location
a. Investigate and report findings
b. Mark area as a possible threat
c. Call for neutralization of the target as time permits
d. Call for immediate neutralization of the target

DECLARATIVE/PROCEDURAL KNOWLEDGE ANSWER KEY

1. a
2. c
3. d
4. b
5. c
6. a
7. b
8. a
9. a
10. d
11. a
12. c

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