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Assessing Computer Vision Syndrome Risk for Pilots

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Introduction

Background of the Problem

The use of visual displays has been present in aviation since the 1980s and continues to increase in number and scope, and evolve at a rapid pace. Displays used are often computer displays or specialized displays based on computer display technology, and thus may create some of the same adverse effects which afflict frequent computer users (Allerton, 2009). The scope of this study is limited to assessing whether computer vision syndrome (CVS) is a risk to pilots in the cockpit and in the flight simulator. The intention of the paper is to determine whether those in the aviation field already experience CVS symptoms and whether pilots are at risk for developing CVS.

Statement of the Problem

This study explored the problem of computer vision syndrome and whether the phenomenon can occur in aviation fields, specifically in video-intensive cockpits and simulator environments. This research first identified the problem of computer vision syndrome. It then attempted to identify the causes and how these are applicable to the aviation industry. Next, potential mitigations were identified. Finally, the research concluded with a qualitative study which may indicate a relationship between CVS to environmental factors common in aviation contexts.

There is a plethora of evidence to support that CVS is a major occupational risk for all people, especially those who view computer-type displays for long periods of time (Haas, 2010). Pilots use specialized versions of these same displays in modern aircraft as the central source of flight data (Sparks, 2011). The symptoms of CVS largely deal with fatigue of the affected person. Fatigue can cause errors on the flight deck. Errors can lead to accidents. The Flight

Safety Foundation (2002) states that pilot duties can be significantly hampered or disabled temporarily by the mildest of headaches.

As computer display technology becomes more ubiquitous in the cockpit, the same risks confronting frequent computer users in office settings may also be a significant risk to pilots, who rely on their vision as the most important sensory mechanism (Koonce, 2002). This problem is significant because pilot performance in the cockpit is paramount to the safety of crewmembers, fellow pilots, passengers, and people on the ground. Since human factors errors elements such as fatigue are the leading cause of aircraft accidents, we must ensure proper steps are taken to mitigate risks which may decrease pilot performance (Krause, 2003). In their analysis of CVS, Torrey (2003) stated "as recent studies have shown, even when the symptoms are negligible, they can affect performance and productivity in a big way" (p. 51). He says the problem can be so debilitating, that employees can be forced to shut down completely which is certainly not a desired scenario on the flight deck (Torrey, 2003). Pilot error is the cause of over 75% of general aircraft accidents and one of the contributing factors is poor go/no-go decisions related to stress and fatigue (Ison, 2005).

CVS has been called the number one occupational hazard of the 21st century (Torrey, 2003). It affects all occupations, from graphic designers to insurance adjusters to flight controllers, and secretaries (Torrey, 2003). Additionally, 88% of computer workers will develop CVS at some time in their lives (Torrey, 2003). Read (2013) claims that the issue of pilot fatigue is far from solved and it appears the only move that will eliminate pilot error is the radical change of taking the pilot out of the cockpit completely.

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Review of Relevant Literature

Although thorough inquiry has been conducted on CVS, little has been done to transfer this knowledge to aviation-specific domains such as the effects on pilots viewing computer-generated graphics on flight displays or exposure to flight simulator displays. This review of literature will first document what is already understood of CVS in regards to risk factors, symptomology, causes, and ways previous research has found to mitigate the problem. The role of computer displays in both the cockpit and in the simulator will then be detailed. Finally, the limited research regarding aviation-related computer displays and fatigue will be discussed.

CVS Overview

First, a thorough understanding of CVS must be outlined. According to the American Optometry Association, CVS is “a group of eye and vision-related problems that result from prolonged computer use” (American Optometric Association [AOA], 2013a). Blehm, Vishnu, Khattak, Mitra, and Yee (2005) further classify the phenomenon as a repetitive strain disorder resulting from operating a computer and looking at a computer monitor. Some definitions of CVS include the specification that the vision problems are related to near-work; however there is some controversy over this claim that near-work is an over-simplification and should include prolonged exposure in the definition (AOA, 2013b; Yan, Hu, Chen, & Lu, 2008). Although much research on CVS was performed during the proliferation of the personal computer at work in the 1990s, recent research insists that more modern technologies, such as tablet computers, smart phones, e-readers, and other LCD-display devices are also technologies which should be considered when considering when assessing risk for CVS (Haas, 2010).

CVS Symptoms

According to the AOA (2013a), common symptoms of CVS are eyestrain, headaches, blurred vision, dry eyes, neck pain, and shoulder pain. Yan et al. (2008) define CVS a little differently and place the symptoms into three categories, eye-related symptoms, vision-related symptoms, and posture-related symptoms as summarized in Table 1. These are similar to the classification of Blehm et al. (2005) who cite the symptoms as ocular-surface mechanisms, accommodative mechanisms, and extraocular mechanisms. For the purposes of this research, symptoms will be classified consistently with the research of Yan et al. (2008).

Table 1

Categories of CVS Symptoms

Eye-related symptoms	Dry eyes, watery eyes, irritated eyes, burning eyes
Vision-related symptoms	Eyestrain, eye fatigue, headache, blurred vision, double vision
Posture-related symptoms	Sore neck, shoulder pain, sore back

Note. This study considers three different categories of CVS symptoms including eye-related, vision-related, and posture related symptoms. Table adapted from Yan et al. (2008).

In addition to the symptoms illustrated in Table 1, Watt (2003) also includes light sensitivity as a symptom of CVS. Jon Torrey (2003) notes muscle spasms as another symptom. The Public Employees Occupational Safety and Health Program for the New Jersey State Department of Health and Senior Services also lists color fringes, deterioration in the ability to see fine detail, and severe eye discomfort lasting into the following day as symptoms (Conrad, 1992). The U.S. Department of Labor adds dizziness to the list of symptoms (U.S. Department of Labor, 2013). Additionally, those suffering from CVS may have red eyes, perceived color distortion, or slow refocusing (Madhan, 2009).

Blehm et al. (2005) and the AOA (2013a) agree that although workers at video displays had symptoms during video-intensive work, the symptoms were transient in nature and disappeared after the work day or work week.

CVS Physiological Risk Factors

According to the AOA (2013a), symptoms may be caused by inadequate lighting, computer screen glare, uncorrected vision problems, and ergonomics issues like distance to the screen and poor seating posture. However, this, too, may be an oversimplification. There appear to be both physiological risk factors and environmental risk factors. Most physiological factors described below deal or contribute to a lack of lubrication for the eyes. The eyes are very complex organs and rely on constant lubrication by the tear-secreting glands (Yan et al., 2008). Lubrication of the eyes is essential to maintain proper optical properties of the visual system as well as proper oxygen levels to the eyes (Yan et al., 2008). The following sections attempt to provide a thorough detail of physiological risk factors.

Blink rate. The rate at which humans blink has been found to differ dramatically when viewing a computer display. The average spontaneous eye blink rate (SEBR) at rest is 15-16 blinks per minute (Yan et al., 2008). During levels of high concentration and visual demand, such as reading a computer display, SEBR drops to 5-6 blinks per minute (Yan et al., 2008). Fewer blinks means less lubrication is being provided to the eyes for cleaning and refreshment (Yan et al., 2008).

Sex and age. Females have a naturally higher rate of dry eye than males (Blehm et al., 2005). One study found that women had 2.69 cases of CVS when compared with one male case (Rahman & Sanip, 2011). As age increases, tear production decreases, especially in post-menopausal women (Blehm et al., 2005).

Systemic diseases and medications. Certain diseases may further aggravate the ocular symptoms that accompany CVS. Sjögren's Syndrome, rheumatoid arthritis and autoimmune diseases can contribute to dry eyes (Blehm et al., 2005). Further, medications such as antihistamines, psychotropic medications, anti-hypertensive medications, and diuretics can contribute to the dry eye problem (Blehm et al., 2005). There are several diagnosed problems with the glands that produce the tear film. One is anterior blepharistis which causes an inflammation of the eyelids affecting the glands that produce liquid tears, and may contribute to dry eyes and CVS ocular symptoms (Blehm et al., 2005).

Corrective lens use. The use of contact lenses can contribute to dry eye and CVS because contact lenses rely on a thin layer of lubricant between the lens and the eye. If not properly lubricated, the lens may create friction between the lens and the eyelid, creating discomfort (Blehm et al., 2005). Additionally, those who wear eyeglasses are at high risk for CVS. Rahman & Sanip (2011) found that eyeglasses were a major predictor for CVS of nearly 2:1.

Cosmetics. Over-application of cosmetic products surrounding the eyes may block the openings of the meibomian glands, preventing the eyes to be properly lubricated (Blehm et al., 2005).

CVS Environmental Risk Factors

There are also multiple risk factors that contribute to CVS that are found in the environment or within an occupation.

The nature of displays. All displays show images via pixels on a screen. Experts claim that the human eye has difficulty steadily focusing on these images and the eye must work very hard to maintain focus (Torrey, 2003). Torrey (2003) also states that the eyes continually focus

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and refocus subconsciously while looking at a computer display. Repeated thousands of times per day, the refocusing of the eye creates eyestrain (Torrey, 2003).

The format, layout, and color of text on displays can also affect the ocular muscles negatively. Contrast is important, as light images on a dark screen are harder on the eyes than dark images on light background (Blehm et al., 2005). Spacing between the characters is also important. At least one-half character space should be used between words and one character space between lines of text (Blehm et al., 2005). Upper and lower case letters should also be employed for reduced strain when compared with words in all capital letters (Blehm et al., 2005).

Increased exposure. Some studies show that only two hours exposure to a video screen or digital display per day can lead to CVS (Asian News International, 2012). Thus, even small amounts of exposure can create safety risks. Traditional studies on office workers classify high-risk users as those that are exposed four or more hours per day (Blehm et al., 2005).

Lighting, contrast, and glare. Poor illumination may exacerbate the lack of blink rate. In a study performed by Tsubota, Toda, and Nakamori (1996) illumination was lowered and blink rate slowed from the control of 17.2 blinks/minute to 7.1 blinks/minute with an illumination of 120 lux and 30 lux, respectively. At the lower luminance level and blink rates, volunteers expressed difficulty in reading (Tsubota, Toda, & Nakamori, 1996).

Conversely, other studies show that most office environments are too bright due to the evolution of tasks that are performed in the office. According to Conrad (1992), most office environments were set up to have illumination levels around 700-1000 lux when work was typically done with physical paper. However, since the type of work has changed from physical paper to computer video displays, lighting was not decreased accordingly. According to Conrad (1992), illumination for offices with video displays should be between 200 and 700 lux. Conrad

(1992) states, "room lighting should be only as bright as necessary for all tasks done in the room".

The type of illumination may be a contributing factor to CVS. Although it was found that sodium lamps had the least contribution to eye fatigue, for task lighting incandescent lamps with warmer color temperatures were found to minimize symptoms (Blehm et al., 2005). Regardless of lighting type, all lights should be free from flicker (Conrad, 1992).

Glare is a critical factor for CVS. Lighting and display orientation should be positioned to produce the least glare possible. Glare from the video screen has shown to increase eyestrain (Blehm et al., 2005). Desk, keyboard, and other office surfaces should be matte in texture so as not to reflect light (Conrad, 1992). Glare can also cause the operator to subconsciously duck, twist, or contort their body leading to neck and backaches (Conrad, 1992).

Temperature and humidity. Low humidity levels can cause eye irritation (Conrad, 1992). In addition, increased air flow and increased temperature can speed evaporation of the tear film (McGinnigle, Naroo, & Eperjesi, 2012).

Noise. Excessive noise should be avoided, as this can be a contributing factor for CVS. In the office setting, impact (dot-matrix) printers should be placed in an acoustically-isolated environment so as not to contribute to CVS problems (Conrad, 1992).

Ergonomics and furniture. Ergonomics factors, such as display position, seating, furniture, and viewing angle can be a large factor when considering CVS risk. There is a difference in the position of most computer displays when compared with writing or reading physical paper. Human eyes are most relaxed when viewing objects over a long (>20 feet) distance in the daylight (Yan et al., 2008). As computers are at much closer distances, human eyes will tire more easily after working at close distances for long periods of time (Yan et al., 2008). Angle of the display also plays a factor, because displays which are placed at equal or higher angles to the viewing angle increase the exposed surface area of the eye (Yan et al., 2008). Increased surface area means evaporation occurs more readily and the eyes tend to dry out rapidly (Yan et al., 2008).

Furniture should be arranged to meet current office ergonomic standards. The screen should be between 10-20 degrees lower than horizontal eye level. Distance to the screen should be maintained between 20-26 inches (AOA, 2013b). Another furniture consideration is to ensure the monitor exhausts directly into the air. All displays create hot, dry exhaust so care should be taken that this exhaust does not blow onto the operator, as dry eyes can result (Conrad, 1992).

Radiation. All displays emit radiation in the form of visible light, ultraviolet (UV), infrared (IR), radio-frequency (RF), and x-ray emissions (AOA, 2013b). Although all display devices create emissions, little evidence exists that they emit unsafe levels of radiation (AOA, 2013b). The U.S. Occupational Safety and Health Administration (OSHA) found computer displays emit levels of radiation below the current standard, and in some cases were indistinguishable from ambient environmental radiation levels (U.S. Department of Labor, 2013). Even if there is no health hazard of this radiation, these emissions cause an electrostatic field around the display, which can attract dust on the screen and decrease clarity and increase glare (AOA, 2013b).

Task. If focus is being shifted between a display and a physical document flat on a desk, there can be increased accommodation and convergence problems due to the iris muscles' requirement to refocus continually (Blehm et al., 2005). Over a few hours, this can cause headaches due to the stress caused on the eye muscles (Yan et al., 2008). Yan et al. (2008) points out that computer use has evolved from office-based work to nearly every occupation including academic, business, and entertainment. Further studies should be performed by psychologists and behavioral scientists related to the differences and similarities of different tasks, such as pilot tasks in a cockpit (Yan et al., 2008). The AOA (2013b) claims that most display tasks are repetitive and can become stressful both mentally and physically after an extended period of continuous work.

Display resolution and refresh rate. The modern displays tend to do a better job at preventing CVS than older displays due to higher resolution and faster refresh rates. Studies conducted found that higher resolutions (more pixels per inch) displays were found to create fewer problems with understimulation and accommodation (Blehm et al., 2005). Most modern screens have a resolution that is similar to the eye as written text (Blehm et al., 2005). The refresh rate of a display is how many times per minute that the display “repaints” the image on the screen (Chen, 2011). This measurement, measured in Hertz, has an impact on how our eyes view the display. Extremely low refresh rates between 8 and 14 Hz are known to cause epileptogenic seizures (Blehm et al., 2005). Chen (2011) states modern refresh rates can be very high, up to 240 Hz and are ideal for displaying fast moving objects. Many standard cathode-ray tube displays only operate at the refresh rate up to 50 Hz (Sparks, 2011). Newer LCD monitors are capable of 75 Hz or faster (Blehm et al., 2005). LCD screens have since become the standard, as they are superior in brightness, space conservation, and high refresh rates (Blehm et al., 2005).

CVS Diagnosis

The AOA (2013a) suggests diagnosis of CVS to be a four-fold method. First, the patient history must be taken into account. Has the patient suffered from the symptoms of CVS prior? Is the patient healthy? Is the patient currently on medications or being treated for disease? Are there any special environmental factors that may be applicable that may exacerbate the symptoms such as poor air quality? Second, the AOA (2013b) states visual acuity measurements are taken and can be compared with previous measurements to determine the extent which vision may have been affected. Third, a refraction calculation may be taken which identifies the extent at which deficiencies should be compensated (nearsightedness, farsightedness, astigmatism) (AOA, 2013b). Last, the eyes must be tested for how well they work together. Eyes are checked for consistency with movement, focus, and compensation patterns between the eyes. The tests above may or may not be done with eye drops (AOA, 2013b).

Computer Screens in Cockpits

In 1998, Rockwell Collins announced they had invested ten years of research and development to introduce an LCD display that could pass the viewing angle and clarity requirements for FAA certification ("LCD Technology Crucial," 1998). This requirement came about due to the increasing amount of information pilots had to process and analyze during flight. Prior, LCD displays were only used for non-essential flight deck applications ("LCD Technology Crucial," 1998). Although this upgrade began for the Boeing 737 and Boeing 777, the technology was soon deployed to military fixed-wing, military helicopter, and high-end business jets ("LCD Technology Crucial," 1998). Rockwell Collins worked in cooperation with multiple vendors including LCD Lighting and the Sharp Corporation. Liquid crystal displays were much desired and overwhelmingly sought out for their high resolution, lower power and cooling requirements, and their supreme visibility even in sunlight ("LCD Technology Crucial," 1998). In addition, the footprint of the LCD was remarkably less than CRTs. This initial LCD display had a depth of only eight inches, compared with a traditional CRT with a depth of 14 inches ("LCD Technology Crucial," 1998). Additionally, as the size of a CRT gets larger, the depth must also increase unlike LCD technology (Sutton, 1998).

At the time of this research, the LCD display still reigns supreme. A cockpit full of these displays is commonly referred to as a "glass cockpit" (Garmin G3000, 2013). One critical factor with LCDs is the expected life of the backlight. The backlight sits behind the glass cells and acts as the illumination element. The LCD backlight in the Boeing 777 is made by Honeywell, Inc. and is anticipated to meet or exceed 30,000 operating hours (Smith-Gillespie & Syroid, 1994). The Boeing 777 was the first commercial transport aircraft to use active-matrix liquid crystal displays (AMLCD) as flight management systems (FMS) displays (Sutton, 1998). In many cases the replacement for the backlight lamp is an approved line maintenance function which simplifies and lowers the cost of replacement (Sparks, 2011).

The next generation of LCD glass cockpits use touch screen capability to further streamline and simplify the pilot experience. Garmin is currently marketing two touch-capable systems, the G5000 and the G3000 (Garmin G3000, 2013; Garmin G5000, 2013). Both systems remove the buttons along the bezel of the screen in favor of integrated touch buttons located directly on the screen, which Garmin calls "touchkeys" (Garmin G5000, 2013). Garmin claims a simplified human-factors approach by limiting the hand/eye movements required to manipulate the avionics suite. The G5000 is currently available for FAR Part 25 business jets (Garmin G5000, 2013). The G3000 is the little brother suite, which is designed for light turbine aircraft, but retains some knobs and buttons for easy transitions (Garmin G3000, 2013).

Computer Screens in Simulators

The purpose of the flight simulator is to allow for a virtual flight experience and allows the pilot to control the simulated aircraft based on the visual scene (Henley, 2003). Simulation

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was pursued because of the low-cost, low-risk, convenience, and independence to weather factors (Lee, 2005). Simulating the visual scene outside the cockpit of the simulator has improved drastically since the 1980s. Prior to 1980, most simulation systems replicated the out-the-window (OTW) scene by using high resolution cameras mounted on a gantry to move along detailed terrain models to reflect the altitude and attitude of the pilots simulated aircraft (Lee, 2005). As computing power dramatically rose in the 1980s, the use of computer graphics imagery (CGI) became a more efficient way to simulate OTW scene (Lee, 2005). At first these visual scenes were poor resolution and did not closely resemble a real OTW scene, however as graphics and computing power increased, the fidelity of the OTW visuals followed (Lee, 2005).

The cathode-ray-tube (CRT) was the first type of computer display to be used in simulation systems because it was already in use with televisions and computer systems at that time (Allerton, 2009). The CRT works by shooting electrons from the cathode in the rear of the display to the front of the display, the anode. The electrons are "steered" by two magnetic coils in the center of the unit. They are directed at one pixel on the screen, and shoot all pixels in succession (Allerton, 2009). When an electron comes into contact with the phosphor coating on the screen the pixel glows momentarily. This process repeats rapidly and constantly. When each pixel on the screen is either illuminated, one refresh cycle has completed. Refresh rate refers to how many times the cycle repeats per minute (Allerton, 2009). The typical refresh rate for the standard television was 60 times per minute (60 Hertz). The CRT, however, had many disadvantages. It was bulky, costly, and required significant power and cooling (Allerton, 2009).

The LCD followed as competition in the computer and television marks drove down prices and began a technological race (Allerton, 2009). LCD technology uses liquid crystal molecules to change each pixels state from absorptive to transmissive based on the electrical current applied (Allerton, 2009). A back or edge light is used to illuminate the screen. The backlight can be fluorescent but recently, especially in the television market, the illuminative element has shifted to LED lights for longer life and higher efficiency (Giamello, 2012). There are many advantages to LCD displays, especially for simulation applications. First, they are much lighter than CRTs and require about half the power and cooling as CRTs. The resolution has dramatically increased. However, traditional LCD displays have shape limitations. They come in a rectangular size, of mostly 4:3 or 16:9 aspect ratios (Allerton, 2009). This poses a challenge with using these as flight instruments in simulation, because often the pilot's legs and knees conflict with the size of larger displays (Allerton, 2009).

Another type of display technology used frequently in simulation is the projection system. They come in a myriad of resolutions, sizes, and technologies. First, the LCD projector is based upon the same technology as the LCD monitor (Zaccaria, 2009). However, the backlight is a high-powered lamp of xenon gas, mercury vapor, or LED light sources ("Guide to projector lamps," 2013). This image is then projected and magnified through the lens and onto the projection surface (Zaccaria, 2009).

Digital Light Processing (DLP) is a technology that was designed by Texas Instruments in 1997 (Ouellet, 2007). Unlike the LCD projector, however, DLP uses a small microchip called a Digital Micromirror Device (DMD) containing thousands of mirrors. These mirrors are mounted on microscopic moving platforms, which either tilt towards the light or away from the light to reflect light towards the lens ("DLP: Wide-Screen," 2004). Color is obtained by a spinning color wheel which rotates the primary colors (red, green, and blue). Some manufacturers make use of additional segments of color in the color wheel to optimize the color output ("DLP: Wide-Screen," 2004). Some people, however, have reported sensitivity related to the rapid succession of colors displayed caused by the spinning color wheel (Wong, 2008). Advanced and more costly DLP projectors do not use a color wheel, but the light is split into three or more colors, and each color is assigned to a different DMD. This eliminates the possibility of eye fatigue caused by the rapid succession of a color wheel ("Video projection options," 2007).

Liquid crystal on silicon (LCOS) technology is a hybrid between DLP and LCD technologies. Like DLP it is a reflective technology, however the mechanics are similar to LCD. LCOS is “an LCD assembly formed directly on the silicon substrate that contains the addressing circuits for each pixel” (Chen, 2011). In other words, light is projected and reflects from reflective LCOS panels which use polarization to turn on and off pixels. Color is achieved by initially splitting the light into primary colors using a prism or x-cube, then recombining before the lens (Yu, 2004).

Like flat-screen displays, a disadvantage of projection technology has been that the displays must be projected onto a flat surface and limited by size and aspect ratio (Allerton, 2009). However, these disadvantages have been largely overcome in the past ten years. Warping is the ability to project an image onto a non-planar surface. This occurs by determining the topography of the projection surface and the projector then pre-distorts the image inversely from the surface topography. This pre-distortion allows the image to appear normally once projected ("Seiko Epson," 2012). The end result is the ability to project images onto curved surfaces without distortion. One example of this technology is the Christie Digital Systems Edgeless Graphics Geometry (EGG), which uses a concave display with a cutout near the bottom at which the operator sits. The surface is contoured to provide an immersive experience for the participant (Christie Digital Systems, 2013).

The second game-changer in display projection is called edge-blending. This is the ability to use multiple projectors to seamlessly create a large image without "seams" between the end of one projector image and the beginning of an adjacent one (Song, Gong, Huang, Han, & Ding, 2010). This is accomplished using overlaps using complicated mathematical algorithms to achieve a seamless image (Song et al., 2010). In the most modern applications, computers are specifically to align and calibrate projectors in the system, rectify color differences between the projectors, and ensuring edge-blending is optimized (Song et al., 2010).

Perhaps the most sophisticated flight simulation system at the time of this writing is the Barco RP-360 dome simulator. It was unveiled in July of 2011 and consists of a large dome which surrounds the pilot. Outside the dome, multiple projectors display an image onto the dome using edge-blending and warping technologies to result in a smooth, un-distorted, 360 degree field of view (Dron, 2011, p. 24). The RP-360 simulation system uses Barco SIM 10 projectors which project a resolution of 4096 x 2400, or 10 megapixels (Barco, Inc., 2013). It uses LCOS display technology to produce a smooth image without detectable pixels. The system is powered by a 2 kilowatt Xenon lamp with a life expectancy of 1,800 hours (Barco, Inc., 2013). The RP-360 is built per the customer's specifications, but can be ordered with up to 14 SIM 10 projectors (Barco, Inc., 2013). The launch customer for the RP-360 is Elbit Systems and is intended to train Israeli pilots on the Lockheed Martin F-16I in 2012 (Dron, 2011).

Pilot Risk: What is Known Now

The AOA (2013b) claims visually and physically fatiguing work may result in lower productivity, increased error rate, and reduced job satisfaction. Further, the U.S. Federal Aviation Administration (FAA) claims that "fatigue continues to be one of the most treacherous hazards to flight safety, as it may not be apparent to the pilot until serious errors are made

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(Federal Aviation Administration, 2013a, p. 938). The flight deck is an extremely stressful environment when considering workload, noise, vibration, and instrument scanning. When scanning between the instruments and the environment outside, our eyes must continually refocus, which causes fatigue (Novacek, 2003). Brightness on avionics displays must also be adjustable. A light that is too bright causes a phenomenon called blooming, in which the eye constricts to lessen the brightness of the light, but adjacent instruments appear to dim due to the constriction (Novacek, 2003). Fatigue is the result. Similarly, a light or display that is too dim can impair our color vision and lead to eyestrain and fatigue (Novacek, 2003). For these reasons, Novacek (2003) recommends all displays and lights in the cockpit are fully-adjustable. Additionally, it has been suggested that the use of a heads-up-display (HUD) may alleviate CVS symptoms as it eliminates the need to switch focus between the instrument panel and a distant object (Novacek, 2003).

Methodology

The research model used for this study was an ex-post-facto design to determine a) frequency of exposure to computer displays in the cockpit and in the simulator and b) to determine if there is a relationship between exposure to computer displays and incidents of CVS symptoms. The study hypotheses are as follows.

- H_1: There is a statistically significant relationship between exposure to computer displays and the rate of CVS symptoms in pilots.
- H_0: There is not a statistically significant relationship between exposure to computer displays and the rate of CVS symptoms in pilots.

Sample Selection

The United States Federal Aviation Administration (FAA) publishes a list of registered pilots on their website. This file is a spreadsheet consisting of pilots registered with the FAA numbering 8,404,418 at the time of this paper (FAA, 2013b). For convenience of mailing the surveys and faster delivery/response, a filter was applied to only show U.S.-based (including U.S. Territories) pilots. After the filter was applied 528,425 U.S.-based (including territories) pilots remained. These represented the potential recipients of the survey. A Microsoft Excel macro was then written to select and copy to another spreadsheet every 2000th record. This yielded 264 results. The same macro was then modified to select every 2001st record and was run, also yielding 264 results. A total of 528 surveys were mailed. Therefore, every U.S.-based (including territories) pilot had approximately a one in 1,000 chance of receiving a survey. Responses were requested to be mailed or emailed back to the researcher.

An *a priori* sample size calculation was predicted using the G*Power statistical software version 3.1.7. G*Power software then calculates the recommended sample size of 167.

Survey Design

The survey was designed to include three total pages including the solicitation letter. A full copy of the survey can be found in Appendix A. The first section, "General Questions" was designed to determine whether pilots wear glasses during flight/simulation and whether those glasses are coated with anti-glare material. The second section, "Flying Questions" was designed to determine level of exposure and incidents of CVS symptoms while flying the aircraft the pilot flies most often. Question 1 asked about the pilot's frequency of flying an aircraft. The potential answers were based on a five-point Likert scale with the following responses:

Never	Rarely	Occasionally	Frequently	Very Frequently
☐	☐	☐	☐	☐

Figure 1. Section II, Questions 1, 3, 4, and 5 Responses.

For the second question the pilot was supplied with graphical and textual definitions of "traditional instrumentation" versus "computer-based instrumentation" as in Figure 2. Question 2 was designed to place the cockpit into three categories of computer-display prominence to determine exposure to displays while in the cockpit.

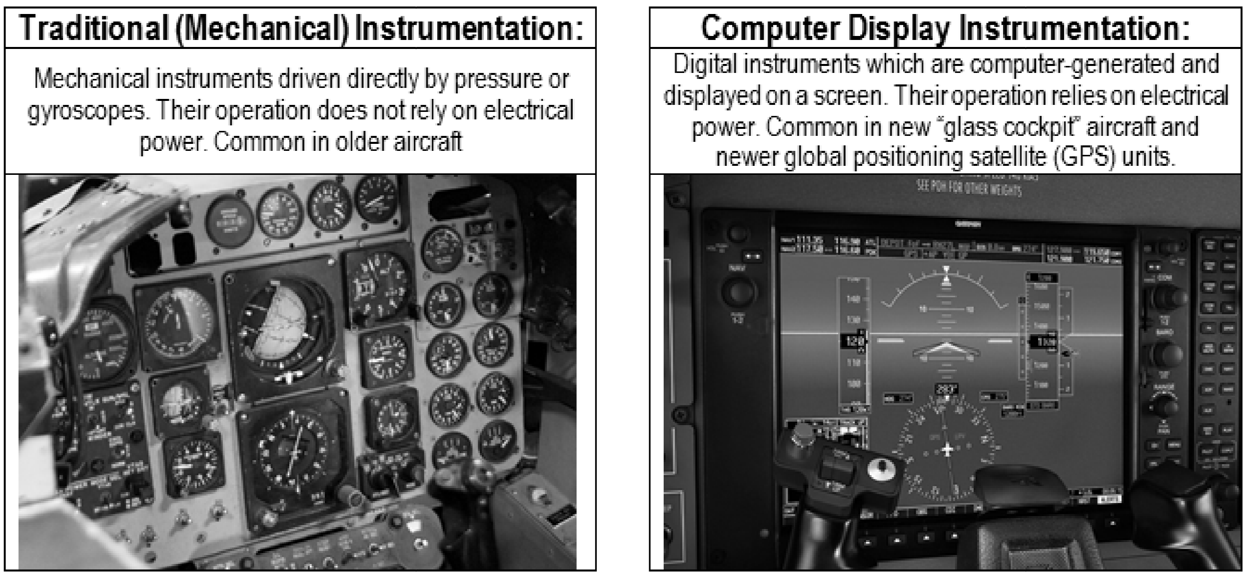

Figure 2. Section II, Question 2 Definition Clarification (actual survey used color graphics). Responses for Question 2 are on a 3-point Likert scale as seen in Figure 5.

Mostly or Completely Traditional Instrumentation	Evenly Mixed	Mostly or Completely Computer Display Instrumentation
☐	☐	☐

Figure 3. Section II, Question 2 Responses.

Section III of the survey asked similar questions related to the exposure and incidents of CVS while using a flight simulator. No question is asked related to ranking the cockpit because simulators use computer displays for OTW scene at a minimum.

The survey was developed by the researcher and it was reviewed and endorsed by persons familiar with the use of computers, associated side effects of their use, and ergonomics. After reviewing a draft of the survey, multiple comments and suggestions were made. One suggestion was to include questions regarding prescription eyeglass use. As Rahman & Sanip (2011) suggest, eyeglasses use may be a contributing factor to CVS, thus the question was added to the survey. Also, according to the work of Blehm et al. (2005) glare may be reduced by anti-glare coating on prescription eyeglasses. It was suggested these be added to assess whether these factors contributed significantly to the occurrences of CVS. Another suggestion that was made was to add a picture which illustrated the difference between traditional instrumentation and computer display instrumentation, as the text alone was vague and subject to improper interpretation. Further, definitions were provided explaining dynamic, computer displays versus analog instruments. The last modification that was made due to peer review was the solicitation letter. Clear language was added to the solicitation letter that the survey was part of academic study and that responses would be completely anonymous.

As completed surveys were received they were entered into SPSS for analysis. Each survey was assigned a number, and return envelopes were discarded. This ensured all surveys are entered into the SPSS tool and only once. As promised in the survey solicitation, all respondents were kept anonymous and only identifiable by the assigned survey number.

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Statistical Analysis

The statistical methodology for this research was to determine whether there was a statistically significant relationship between exposure to computer displays and the three symptom categories of CVS. Statistical analyses could be performed on the data once all surveys were collected. To determine whether a relationship exists, a chi-squared test for independence was conducted on two variables examined. Multiple tests were conducted to analyze different symptom categories and potential relationship between different variables.

Results

A total of 178 completed, valid surveys were received and inputted into the SPSS tool. Due to overall low frequencies in the “frequently” and “very frequently” categories, the “never” and “rarely” categories were translated into “no”, indicating the person did not have symptoms. Respondents indicating “occasionally”, “frequently”, or “very frequently” were translated to “yes” answers indicating presence of that particular category of symptoms. In addition, for simulator frequency (Part III, Question 1), “never” and “rarely” answers were considered “no” simulation use and “occasionally”, “frequently”, and “very frequently” were translated into “yes” meaning the person does use a simulator. The tables that follow represent the frequencies of responses directly from the surveys. The chi-square results follow.

Table 2

General: Eyeglass Use and Anti-Glare Coating

	Eyeglasses		Anti-Glare	
	Frequency	%	Frequency	%
No	76	42.7	34	19.1
Yes	102	57.3	58	32.6
Don’t Know	-	-	14	7.9
Not Applicable	-	-	72	40.4
Total	178	100	178	100

Note. All participants responded to these questions.

Table 3
General: How often do you fly an aircraft?

	Frequency	%
Never	2	1.1
Rarely	22	12.4
Occasionally	55	30.9
Frequently	48	27.0
Very Frequently	51	28.7
Total	178	100

Note. All participants responded to this question. Data derived from Part II, Question 1 of the survey. Part II, Question 1: How often do you fly an aircraft?

Table 4
Flying: Type of Instrumentation

	Frequency	%
Mostly or Completely Traditional	89	50.0
Evenly Mixed	36	20.2
Mostly or Completely Computer Display	50	28.1
Total	175	98.3

Note. 175 (98.3%) participants responded.

Table 5
Flying: Dry, Watery, Irritated, or Burning Eyes (Eye-related)

	Frequency	%
Never	100	56.2
Rarely	52	29.2
Occasionally	20	11.2
Frequently	2	1.1
Very Frequently	1	0.6
Total	175	98.3

Note. 175 (98.3%) participants responded to this question.

Table 6
Flying: Eyestrain, Eye Fatigue, Headache, Blurred Vision, Double Vision (Vision-Related)

	Frequency	%
Never	108	60.7
Rarely	47	26.4
Occasionally	19	10.6
Frequently	1	0.6
Very Frequently	0	0.0
Total	175	98.3

Note. 175 (98.3%) participants responded to this question.

Table 7
Flying: Sore Neck, Sore Back, Shoulder Pain (Posture-Related)

	Frequency	%
Never	74	41.6
Rarely	56	31.5
Occasionally	40	22.5
Frequently	6	3.4
Very Frequently	1	0.6
Total	177	99.6

Note. 177 (99.6%) participants responded to this question.

Table 8
Simulator: Frequency of Simulator Usage

	Frequency	%
Never	67	37.6
Rarely	42	23.6
Occasionally	48	27.0
Frequently	17	9.6
Very Frequently	3	1.7
Total	177	99.5

Note. 177 (99.5%) participants responded to this question.

Table 9
Simulator: Dry Eyes, Watery Eyes, Irritated Eyes, Burning Eyes (Eye-Related)

	Frequency	%
Never	59	33.1
Rarely	33	18.5
Occasionally	15	8.4
Frequently	2	1.1
Very Frequently	0	0.0
Total	109	61.1

Note. 109 (61.1 %) participants included in this table.

Table 10
Simulator: Eyestrain, Eye Fatigue, Headache, Blurred Vision, Double Vision (Vision-Related)

	Frequency	%
Never	59	33.1
Rarely	33	18.5
Occasionally	14	7.9
Frequently	4	2.2
Very Frequently	0	0.0
Total	110	61.7

Note. 110 (61.7%) participants included in this table.

Table 11
Simulator: Sore Neck, Sore Back, Shoulder Pain (Posture-Related)

	Frequency	%
Never	52	29.2
Rarely	34	19.1
Occasionally	21	11.8
Frequently	3	1.7
Very Frequently	0	0.0
Total	110	61.8

Note. 110 (61.8%) participants included in this table.

Table 12
Contingency Table: Instrumentation Type x Eye-Related Symptoms

	Symptoms Exhibited		
Instrumentation Type	No	Yes	Total
Mostly or All Traditional	83	6	89
Evenly Mixed	30	6	36
Mostly or All Computer Display	39	11	50
Total	152	23	175

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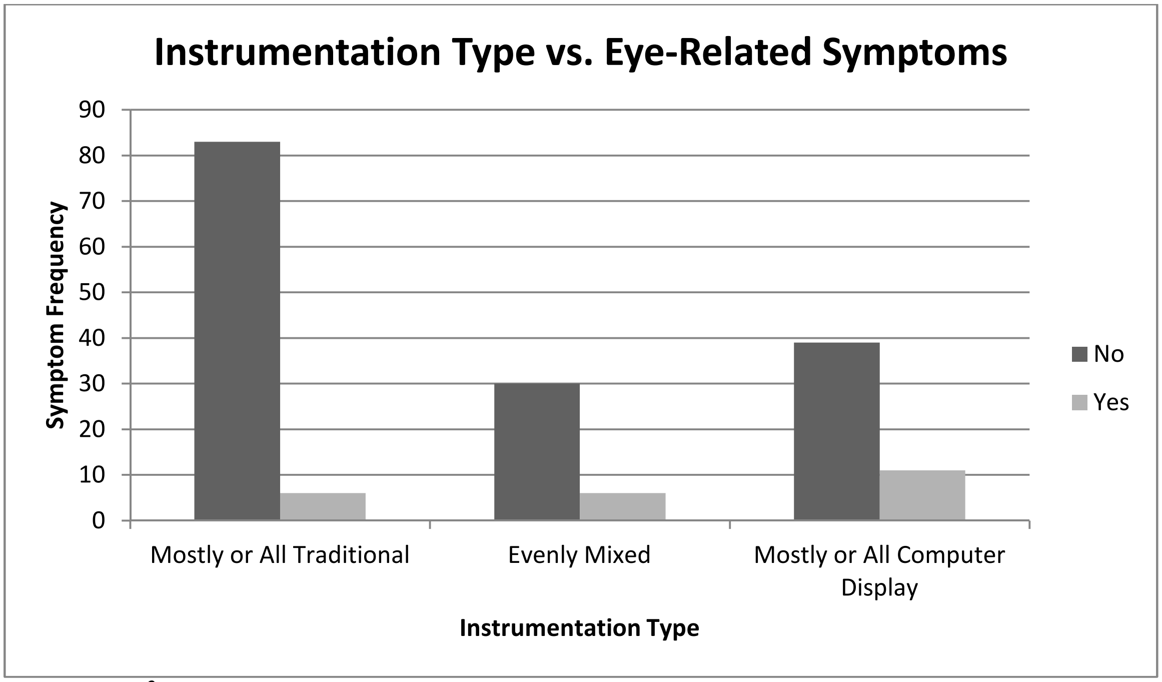

Figure 4. χ^2 distribution comparing instrumentation type and eye-related symptoms experienced by survey participants.

For this analysis, χ^2 (2,175) = 7.002, $p = 0.03$, thus the H_0 is rejected. Eye-related symptoms and instrumentation type are statistically related. This can best be seen in Figure 4. As the instrumentation becomes more computer-display-based the eye-related symptoms rise drastically.

Table 13

Contingency Table: Instrumentation Type x Vision-Related Symptoms

Instrumentation Type	Symptoms Exhibited: No	Symptoms Exhibited: Yes	Total
Mostly or All Traditional	81	8	89
Evenly Mixed	31	5	36
Mostly or All Computer Display	43	7	50
Total	155	20	175

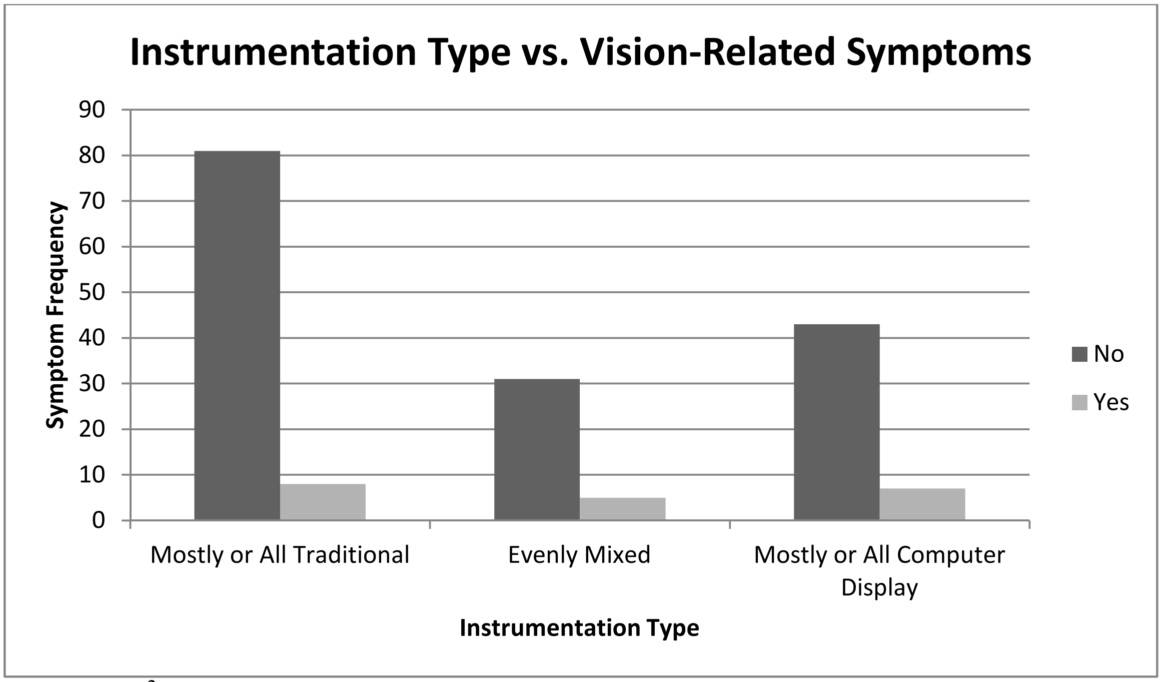

Figure 5. χ^2 distribution comparing instrumentation type and vision-related symptoms experienced by survey participants.

For this analysis, χ^2 (2,175) = 1.065, p = 0.58, thus data failed to reject the H_0. The proportion of frequency of vision-related symptoms is the same among three categories of instrumentation type. There is no statistically significant relationship between type of instrumentation and experience of vision-related CVS symptoms.

Table 14

Contingency Table: Instrumentation Type x Posture-Related Symptoms

	Symptoms Exhibited		
Instrumentation Type	No	Yes	Total
Mostly or All Traditional	73	16	89
Evenly Mixed	25	11	36
Mostly or All Computer Display	32	18	50
Total	130	45	175

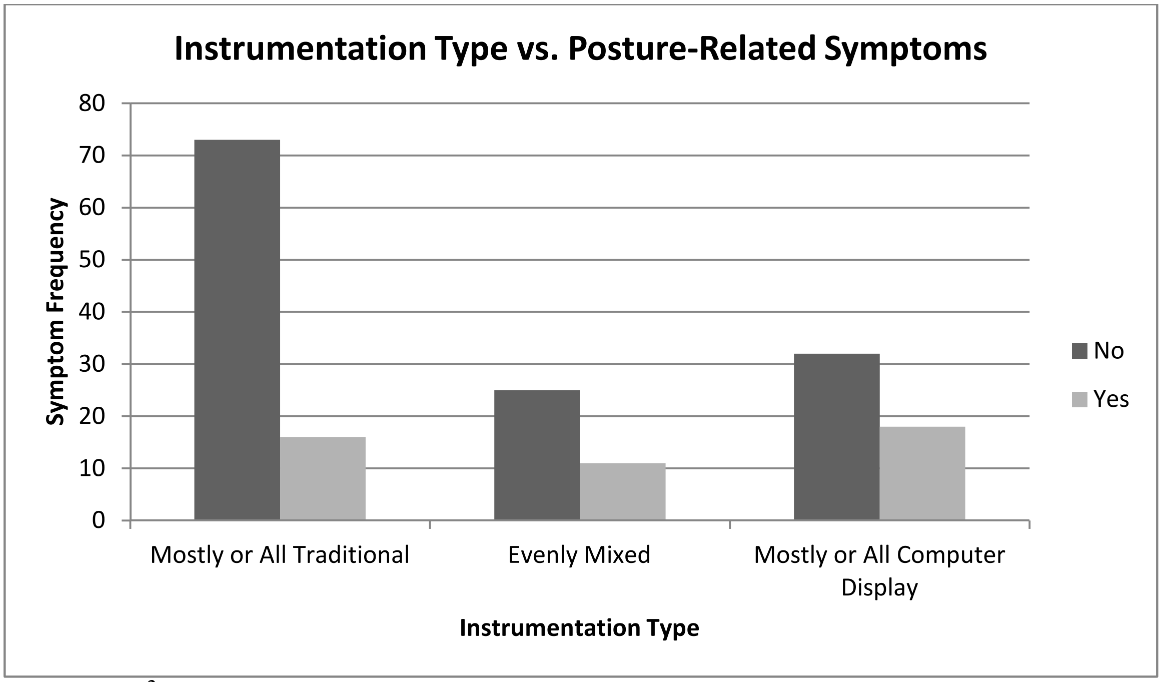

Figure 6. χ^2 distribution comparing instrumentation type and posture-related symptoms experienced by survey participants.

For this analysis, χ^2 (2,175) = 6.00, p = 0.049, thus the H_0 is rejected. Posture-related symptoms and instrumentation type are statistically related. This can best be seen in Figure 6. As the instrumentation becomes more computer-display-based the posture-related symptoms rise drastically.

Table 15

Contingency Table: Simulator Usage x Eye-Related Symptoms

	Symptoms Exhibited		
Usage	No	Yes	Total
No	37	5	42
Yes	55	12	67
Total	92	17	109

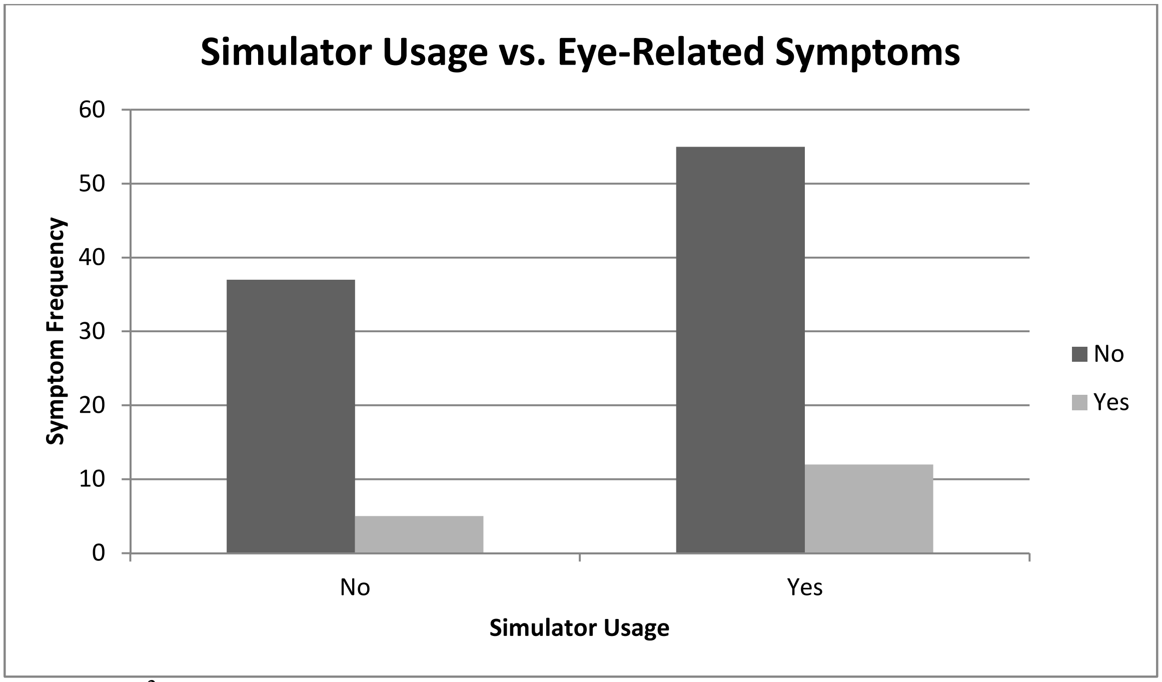

Figure 7. χ^2 distribution comparing simulator usage and eye-related symptoms experienced by survey participants.

For this analysis, χ^2 (1,109) = 0.707, p = 0.70, thus the data failed to reject the H_0. The proportion of frequency of eye-related symptoms is the same among both simulator users and non-users. There is no statistically significant relationship between type simulator usage and experience of eye-related CVS symptoms.

Table 16

Contingency Table: Simulator Usage x Vision-Related Symptoms

	Symptoms Exhibited		
Usage	No	Yes	Total
No	38	4	42
Yes	54	14	68
Total	92	18	110

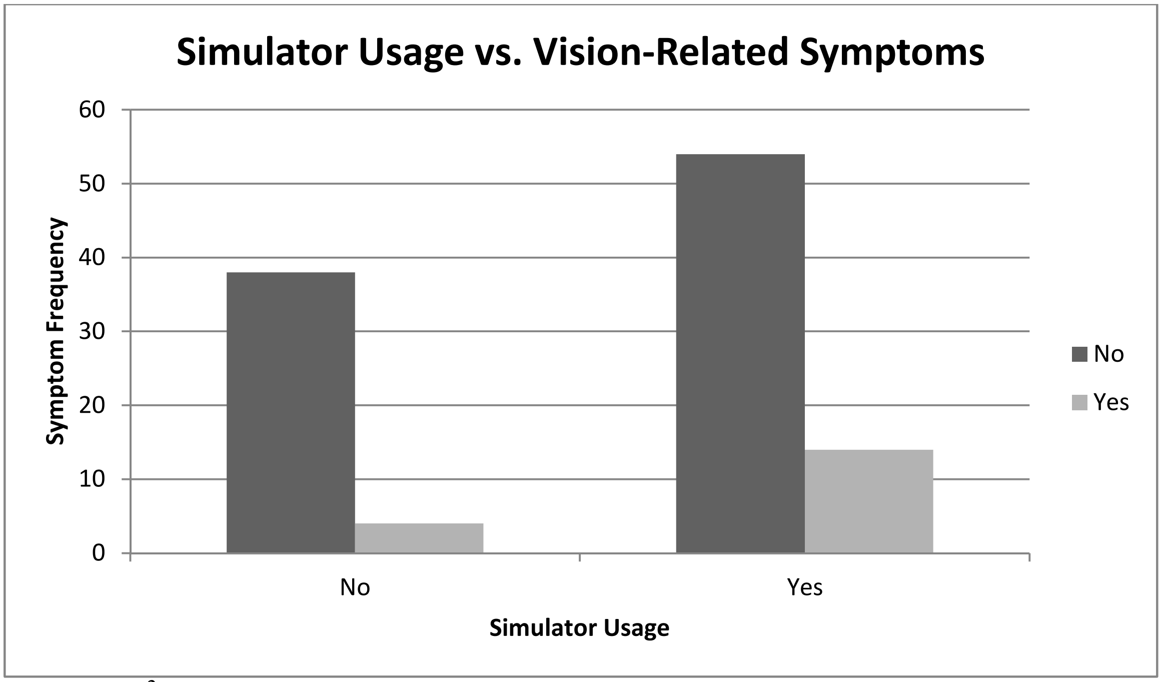

Figure 8. χ^2 distribution comparing simulator usage and vision-related symptoms experienced by survey participants.

In this analysis, χ^2 (1,110) = 1.584, p = 0.21 (with Yates' correction), thus the data failed to indicate a justification to reject the null hypothesis.

Table 17

Contingency Table: Simulator Usage x Posture-Related Symptoms

	Symptoms Exhibited		
Usage	No	Yes	Total
No	35	7	42
Yes	51	17	68
Total	86	24	110

For this analysis, χ^2 (1,110) = 1.057, p = 0.587, thus this failed to reject the H_0. The proportion of frequency of posture-related symptoms is the same among both simulator users and non-users. There is no statistically significant relationship between type simulator usage and experience of posture-related CVS symptoms.

Analyses were performed for eyeglass use as well as anti-glare coating with the various CVS symptom categories; however, no statistical relationships at the p = 0.05 were encountered.

Overall, it was found that two categories of CVS symptoms (eye-related and posture-related) had a statistically significant relationship to exposure to computer displays in the cockpit. A statistically significant relationship was not found between exposure to computer displays in the cockpit and vision-related symptoms. Also, no statistical significant relationship was found between the three categories of CVS symptoms and usage of a flight simulator.

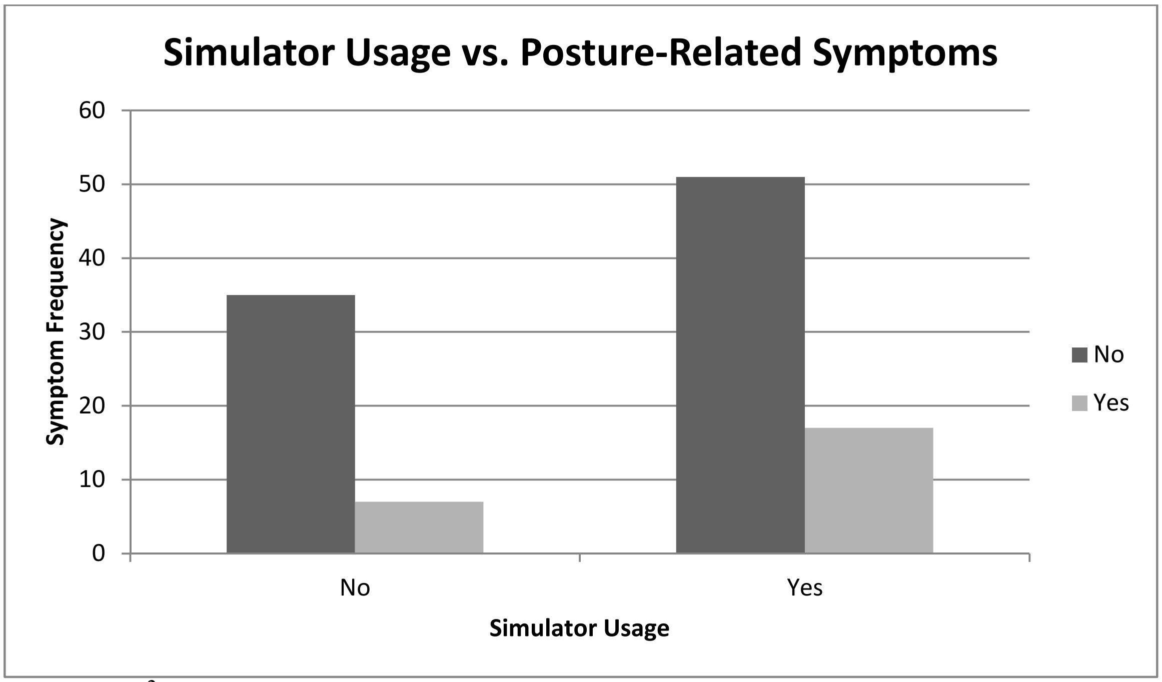

Figure 9. χ^2 distribution comparing simulator usage and posture-related symptoms experienced by survey participants.

Discussion

Perhaps the reason for low reporting of headaches is due to pilots who experience headaches are often denied medical certification. If CVS were to be found an important medical issue it could potentially ground pilots; pilots may be more reluctant to seek medical help when experiencing symptoms.

Another potential explanation for pilots largely reporting “never” or “rarely” on most topics is some may have thought they were being targeted for the sale of something. One respondent included a note indicating that he was not interested in anything the researcher had to sell, and to discard the completed survey if that was the case.

Pilots are taught to “scan” their instruments along with scanning the OTW visual scene for other aircraft and obstacles (Gardner, 2007). This practice trains the pilot to divide attention between instruments and the visual scene out the window (Gardner, 2007). Potentially the result of “scanning” produces the same result as the 20/20/20 rule, and gives the eyes frequent breaks from viewing the computer displays. More investigation may be necessary to see if this is, in fact, applicable in simulated environments.

Since most displays in the aircraft and simulator are modern LCD panels, the accommodation issues that plagued cathode-ray tube display viewers in the past may have been overcome by better technology. High refresh rates and resolutions near eye-limiting may have come to the aviation context after the technology had been perfected.

Further study is suggested as to how flight deck designers use human factors analysis and ergonomics knowledge to design cockpits that prevent pilot fatigue. Detailed study of the tasks of pilots and optimization of cockpit ergonomics design may explain the low frequency of CVS symptoms. Perhaps one reason why there was a disconnect between the findings of this study and those of office workers is that pilots often are tasked to evaluate visual cue data rather than textual displays observed by office workers. The type of focus, concentration, and strain may differ between these environments.

Other studies have had difficulty relating symptoms to computer display use. One study of computer users in Nepal was unable to find a statistically significant link and noted that symptoms in VDT users were vague and difficult to assess due to a myriad of difficult-to-isolate variables (Shrestha, Mohamed, & Shah, 2011). Additionally, fatigue has traditionally been very difficult to measure and assess due to the subjective feelings involved (Chistoloulou, 2012; Yan et al., 2008).

Finally, another explanation for pilots reporting few incidences of CVS is that the implementation of computer displays in the cockpit may already have been understood and addressed by manufacturers, ergonomics researchers, avionics designers, and those implementing the technology. It is possible, despite the lack of documentation, that the industry has already addressed the risks and took action to mitigate the effects on CVS for pilots.

Conclusion

The purpose of this research was to find a statistically significant relationship between exposure to computer displays in aircraft and simulators and symptoms relating to CVS. The study was successful in finding a statistically significant relationship between exposure to computer-display-based cockpits and eye and posture related CVS symptoms. However, no statistically significant relationship was found with vision-related symptoms and computer display-based cockpits. Similarly, no statistically significant relationship was found between simulator usage and experience of CVS symptoms.

CVS plagues about 90% of office workers and the problem could easily translate to the aviation field if pilots are exposed to risk factors similar to those of office workers (Blehm et al., 2005). Perhaps most important is the need to focus on cockpit and simulator ergonomics and time of exposure to these displays to keep occurrences of symptoms low. Eye, vision, and posture related problems can contribute to pilot fatigue and fatigue is a known direct cause of aircraft accidents (Cobb & Primo, 2003). Further, the findings of this study are likely to be applicable to any type of computer display circumstance common among the general population such as the use of laptops, desktops, tablets, automotive displays (e.g. navigation systems or

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status displays), and similar applications. As society becomes more dependent upon and more widely utilizes computer systems, their effects on the human body must be better understood so that negative effects can be mitigated. Moreover, this information may provide manufacturers the data they need to make new systems more user-friendly and less physically and mentally tasking.

Recommendations

Everyone is at risk for developing CVS considering the prevalence of modern electronic devices such as computers, tablets, laptops, smartphones, and smart watches (Asian News International, 2012). LCD displays and their equivalents are used in vehicle navigation screens, vehicle dashboards, office desk phones, printers, ATMs, and nearly every other facet of our lives. However, pilots are especially at risk considering the rapid evolution of the cockpit into landscape of computer displays. The study shows evidence that computer-display-based cockpits and eye- and posture-related symptoms of CVS are related. It can be addressed by education, screening by vision professionals, and general awareness. In this study, only 102 (57.3%) respondents reported wearing eyeglasses. Further study and larger sampling is suggested to determine if anti-glare coatings help pilots mitigate CVS symptoms.

Clinicians should be aware of CVS, symptoms and prevention. Considering the nature, responsibility, and liability of flying passenger aircraft clinicians should be vigilant to seek out potential CVS risk factors and early symptoms. Aviation medical examiners should be acutely aware of the problem, and add CVS symptoms to their list of medical questions asked before the exam. If suspicious circumstances show on the questionnaire, the medical examiner should ask further questions to assess the safety of the pilot. Pilots experiencing headaches should not be penalized for reporting headaches, sore eyes, and other CVS symptoms. This may only encourage the concealment of these serious issues and failure of a proper diagnosis.

CVS should also be part of the adult learning experience for pilots. Pilots must train in simulators, attend continuing education, and be certified to fly specific aircraft. Awareness training should be included in this continuing education. The topic could easily be added to a pilot's annual company training and be delivered via web-based training. Pilots should be aware of the dangers, risks, and human limitations that involve our ability to see. Attitudes and egos must be kept in check so that pilots don't make poor go/no-go decisions despite the pressure of the industry to perform.

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Appendix A: Mailed Survey

Dear Pilot,

I am a graduate student at Embry-Riddle Aeronautical University attempting to finish my Master of Aeronautical Science degree. For my thesis research, I am studying the effects of newer, computer-generated display screens on pilots. If you would fill out the following survey it would be greatly appreciated by me and future researchers of aviation display technology.

Your responses are completely anonymous. Please return the survey using the pre-stamped envelope enclosed or by emailing the completed survey to ***cemst7@yahoo.com*** before September 18th, 2013.

Thank you kindly for your participation,

Curt E. Mowry

Colorado Springs, CO

Note: Your name and address information was found on the Federal Aviation Administration (FAA) pilot registry available to the public at this website: http://www.faa.gov/pilots/lic_cert/

Survey: Pilot Exposure to Computer Displays

Part I: General Questions

1) Do you wear eyeglasses?
- ☐ No
- ☐ Yes

2) If you answered "Yes" to question 1, are your eyeglasses coated with an anti-glare coating?
- ☐ No
- ☐ Yes
- ☐ I don't know

Part II: Flying Questions:

1) How often do you fly an aircraft?

Never	Rarely	Occasionally	Frequently	Very Frequently
☐	☐	☐	☐	☐

< Please Turn Over for More >

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For the purpose of question 2, please consider the following:

Traditional (Mechanical) Instrumentation:	**Computer Display Instrumentation:**
Mechanical instruments driven directly by pressure or gyroscopes. Their operation does not rely on electrical power. Common in older aircraft	Digital instruments which are computer-generated and displayed on a screen. Their operation relies on electrical power. Common in new "glass cockpit" aircraft and newer global positioning satellite (GPS) units.

2) How would you classify the instrumentation of the aircraft you fly most often?

Mostly or Completely Traditional Instrumentation	Evenly Mixed	Mostly or Completely Computer Display Instrumentation
☐	☐	☐

3) How often do you experience **dry eyes, watery eyes, irritated eyes, or burning eyes** while flying or immediately following flying the aircraft you fly most often?

Never	Rarely	Occasionally	Frequently	Very Frequently
☐	☐	☐	☐	☐

4) How often do you experience **eyestrain, eye fatigue, headache, blurred vision, or double vision** while flying or immediately following flying the aircraft you fly most often?

Never	Rarely	Occasionally	Frequently	Very Frequently
☐	☐	☐	☐	☐

5) How often do you experience **sore neck, sore back, or shoulder pain** flying or immediately following flying the aircraft you fly most often?

Never	Rarely	Occasionally	Frequently	Very Frequently
☐	☐	☐	☐	☐

Part III: Simulator Questions

1) How often do you use a flight simulator?

Never (*)	Rarely	Occasionally	Frequently	Very Frequently
☐	☐	☐	☐	☐

***If you answered "Never", you may end the survey.**

2) How often do you experience **dry eyes, watery eyes, irritated eyes, or burning eyes** while using or immediately following using a **flight simulator**?

Never	Rarely	Occasionally	Frequently	Very Frequently
☐	☐	☐	☐	☐

3) How often do you experience **eyestrain, eye fatigue, headache, blurred vision, or double vision** while using or immediately following using a **flight simulator**?

Never	Rarely	Occasionally	Frequently	Very Frequently
☐	☐	☐	☐	☐

4) How often do you experience **sore neck, sore back, or shoulder pain** using or immediately following using a **flight simulator**?

Never	Rarely	Occasionally	Frequently	Very Frequently
☐	☐	☐	☐	☐

Thank you for your participation in the survey!

Appendix B: Anshel's Screening Questionnaire for Professionals (Anshel, 2007)

Computer Workplace Questionnaire

Work Practices:

1. Number of hours per workday of computer viewing. ____________
2. How long have you worked at a computer-based job? ____________
3. Type of work habits: (circle one)
   a) Intermittent- periods of less than 1 hour
   b) Intermittent- periods of more than 1 hour
   c) Constant- informal breaks, as required
   d) Constant- regular breaks
   e) Constant- no breaks, other than meals
4. How often do you clean your display screen? ________________

Environment:

Lighting in the work area: (check all that apply)
Fluorescent overhead only ☐
Incandescent overhead only ☐
Fluorescent and incandescent overhead ☐
Fluorescent overhead and incandescent direct ☐
Window light ☐ In front? ☐ Behind? ☐ To the side? ☐
Window light control: Curtains? ☐ Blinds? ☐ Vertical/Horizontal? ☐
Desk Lamp/Task Light ☐
Other (describe) ______________________________________
How would you rate the brightness of the room: Very bright /Medium/Dim?

Display Screen:

What color are the letters on your screen? ____________________
What color is the background of your screen? __________________
Viewing distance from your eye to display screen: __________ inches.
Can the monitor be tilted? Y N
Can the monitor be raised / lowered? Y N
Does the screen have a glare filter? Y N If so, is it glass/mesh?
Top of display screen (above, equal to, below) eye level?
If above or below, by how many inches? ____________________

Workstation:

Viewing distance from your eye to keyboard: ______________ inches.
Viewing distance from your eye to hard copy materials: ______ inches.
Reference material is (to the side, below) the screen? Y N
If to the side, is it next to the screen or keyboard? Y N
Is this height adjustable? Y N
Is the monitor supported on a (stand/desk/CPU)?
Is this adjustable? Y N
Is all of your hard copy material visible without significant movements? Y N

Symptoms:

Do you experience any of the following symptoms during or after COMPUTER work:

☐ Eyestrain	☐ Double Vision
☐ Headaches	☐ Neck/Shoulder/Wrist Ache
☐ Blurred Near Vision	☐ Color Distortion
☐ Blurred Distant Vision	☐ Light Sensitivity
☐ Dry/Irritated Eyes	☐ Backache

Do you wear glasses while working at the computer? Y N
If yes, are they (single vision, bifocal or progressive)? Y N
Do you wear contact lenses while working at the computer? Y N
If yes, are they (soft, gas permeable, or hard lenses)?