THE EFFECT OF FLAT PANEL MONITOR ARMS ON COMFORT, POSTURE AND PREFERENCE IN AN ARCHITECTURAL PRACTICE

A Thesis

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by

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ABSTRACT

This study investigated the effects of installing a flat panel monitor arm for a sample of 27 computer users at an architecture firm. Three surveys were conducted: a baseline pre-intervention survey, and one-month and 3-month follow-up post-installation surveys.

Subjective data was collected in this study through online surveys. Objective measures included physiological measurements and observations, with the help of the Rapid Upper Limb Assessment.

Results from the first wave of data collection of all subjects (N=27) revealed that there was an obvious issue of musculoskeletal discomfort experienced by many of the subjects. Initial data also found that subjects were at a moderate risks for developing musculoskeletal disorders as the average RULA score was 3. After the installation of the flat panel monitor arms, there was a significant difference in the change of index values for the symptoms of Upper Limb Musculoskeletal disorders between waves 1 and 2 (p=0.045), and between waves 1 and 3 (p=0.022) . A significant difference was also seen in the level of satisfaction between groups over the course of the study. The changes in response were significant at the 0.05 level, between waves 1 and 2 (p=0.045) and between waves 1 and 3 (p=0.004). The difference in change of responses when subjects were asked how often they have their computer monitors at a comfortable viewing height was significant between waves 1 and 2 (p=.031), and between waves 1 and 3 (p=0.36). Lastly, there was a significant difference found in the change of distance between subjects torso and desk (p=.044)

There were no significant differences in the RULA scores between groups or surveys. Reports of eye discomfort and headache were widespread among the subjects but there was no significant difference in the prevalence of complaints by body region

between those in the control and test groups for any of the 3 surveys, and there was no significant difference within a group between responses in each survey.

BIOGRAPHICAL SKETCH

Kathryn M. Boothroyd grew up in Endwell, NY and graduated from Maine-Endwell Senior High School. She received her Bachelors of Science degree with Honors from Cornell University in May 2006 for the study of Human Factors and Ergonomics in the department of Design and Environmental Analysis. She remained at Cornell University to complete her Masters degree, also concentrating in Human Factors and Ergonomics. This thesis was completed as part of the requirement for the Masters of Science degree Kathryn with receive in May 2008.

This thesis is dedicated to my family – Mom, Dad, Tom, Cara and Dan.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

Chapter 1: Introduction

Today's office work is heavily reliant on the use of computers. As daily computer use has increased so associated work-related upper extremity musculoskeletal symptoms and visual discomfort complaints have become a public health burden (National Research Council, 2001). Visual discomfort and eye strain are often more prevalent than upper extremity musculoskeletal symptoms among office workers, however, frequently the two health outcomes coexist (Dain, 1988; Menendez, Robertson, Amick, Harrist, Bazzani, Derango, & Moore, 2006; Sheedy, 1996). Not only can computer use lead to discomfort or injury, it also can diminishes the quantity and quality of work that can be produced and it can be a drain on employers from lost productivity and increased workers' compensation costs.

The factors and risks of soft-tissue injuries to muscles, nerves, tendons, joints, cartilage, and intervertebral discs related to the work environment, collectively are termed Work-Related Musculoskeletal Disorders (WMSD), and the ergonomic risks associated with these have been extensively researched over the past few decades (National Institute for Occupational Safety and Health [NIOSH], 1997). The majority of the studies reviewed in this thesis have concluded that proper positioning of the person in relation to their equipment in their work setting is the most effective strategy for preventing musculoskeletal strain and visual discomfort. To allow workers to achieve neutral postures that minimize injury risk, modern office furniture and ergonomic accessories need to accommodate the continuing changes in computer technology and the increasingly diverse anthropometry of the working population. Given the large number of ergonomic accessories it is important to determine the effectiveness of different ergonomic interventions in reducing the risks of discomfort and injury so that optimal decisions are made in designing an effective workplace.

Symptoms of visual discomfort include eyestrain, tired eyes, irritation, redness, blurred vision and double vision, and together these are also referred to as computer vision syndrome (CVS) (Blehm, Vishnu, Khattak, Mitra & Yee et al., 2005). CVS can arise when the visual demands of reading the computer screen exceed the abilities of the computer viewer (American Optometric Association, 1998). Many different factors have been shown to affect the symptoms of CVS, including proper lighting, work breaks and the ergonomic positioning of the computer monitor (Blehm et al, 2005).

The present study evaluated the impact of an ergonomic intervention for a sample of employees in an architecture firm. The intervention involved training the users and installing a flat panel monitor arm (FPMA), designed for liquid crystal display (LCD) screens, on the positioning of the screen, the postural risks for WMSDs, CVS, and user comfort and satisfaction with their computer workstation.

1.1 Prevalence of Work-Related Musculoskeletal Disorders

According to a recent US Census Bureau Current Population Survey in 2003, more than half (56%) of working American adults and about 90% of office workers use a computer at work, totaling over 76 million employees (Cheeseman Day, Janus & Davis, 2005). This was a 16% increase since the previous data was released in 1997 (ibid). Additionally, it has been reported that 40% of office employees work on their computers at least 4 hours a day (ibid).

The U.S. Department of Labor defines a Work Related Musculoskeletal Disorders (WMSD) as “an injury or disorder of the muscles, nerves, tendons, joints, cartilage, and spinal discs” (U.S. Department of Labor Bureau of Labor Statistics

[BLS], 2006). According to the Bureau of Labor Statistics, in 2004 over 522,000 injuries were reported in the U.S. associated with WMSDs alone, ranking second only to the number of back injuries and three times the number of WMSDs reported in 1984 (ibid). In two recent studies, the prevalence of musculoskeletal symptoms among computer users has been reported to be as high as 61% for neck and shoulder symptoms, and between 30-39% for arm and hand symptoms (Gerr et al., 2002; Greene, DeJoy & Olejnik, 2005).

Other WMSD symptoms commonly occur in the wrists, hands, arms, elbows and shoulders (NIOSH, 1997). These areas of the body are susceptible to repetitive motion injuries, especially in computer users who perform continuous typing and mousing tasks. The National Agriculture Safety Database (NASD), a division of NIOSH, states that 'repetitive motion injuries (also known as cumulative trauma disorders) occur when some action is usually bending or twisting, and performed over and over. Pain or other symptoms may develop slowly" (NASD, 2004).

In addition, the Bureau of Labor Statistics reports, "disorders associated with repeated trauma" account for about 60% of all occupational illnesses (ibid). Of these disorders, Carpal Tunnel Syndrome (CTS) is the condition most frequently reported and is the cause of the highest median days away from work (BLS, 2006). In 2001, 26,794 cases were reported with a median of 25 days away from work as a result of CTS compared to the 6 median days away from work for all non-fatal occupational illnesses also reported in 2001 by the Bureau of Labor Statistics (ibid). The highest incidence of CTS was reported in 1993 with 41,019 cases involving days away from work in private industry (ibid).

In addition to high reports of upper extremity WMSDs (522,528 cases in 2001 involving a median of 8 days away from work (BLS, 2006)), the most recently released US Census Bureau Report from 2001 states 70% of people who do daily work at a computer are affected by CVS and 88% of all computer users will eventually develop symptoms of CVS at some stage in their lives (NIOSH, 1995). In a 1992 study conducted by the American Optometric Association (AOA) , over 1300 optometrists were surveyed about their patients' symptoms. It was found from these surveys that 1 in 6 people in the US visit an optometrist concerning symptoms of eye strain from the use of computer monitors or other Visual Display Units (VDU) (Sheedy, 1992). Symptom frequency and intensity is amplified by increased VDU exposure (Travers & Stanton, 2002). CVS can affect computer users who spend as little as two hours at their computer workstation (Collins, Brown & Bowman, 1998; Costanza, 1994; Dain, McCarthy & Chan-Ling, 1988; Sheedy, 1992). These statistics illustrate the need for more research on prevention of computer related discomfort and injury especially since the number of computer users continues to rise. To better understand some of the risk factors associated with CVS, it is important to know about the principles of visual function.

1.2 The Human Visual System

Both the eye and brain work together for proper functioning of the human visual system. The optical component of the eye has been compared to a film camera; however, the rest of the visual system requires visual processing and interpretation by the brain (Boyce, 2003). For purposes of this research study on LCD screen use, the way in which the eye processes visual information is most important because the muscles involved and movements of the eye during the visual process are susceptible to strain and injury.

1.2.1 Eye Movements

Each eye has six extra-ocular muscles arranged in opposing pairs that attach to the eye and the eye cavity of the skull. These muscles are: superior rectus, superior oblique, medial rectus, lateral rectus, inferior rectus and inferior oblique muscles (see Figure 1.1). When the opposing muscles contract and release, the eye is able to move in different axes. There are several types of eye movements that occur, including tremors, which are continuous small oscillations in eye position that are necessary for proper vision. Saccades, or saccadic eye movements, are rapid eye movements with velocities up to 1000^{o} /second and smooth pursuit eye movements are much slower, about 40^{o}/ second. These types of eye movements occur in each eye, but are coordinated so that the lines of sights of the eyes remain focused on a common image.

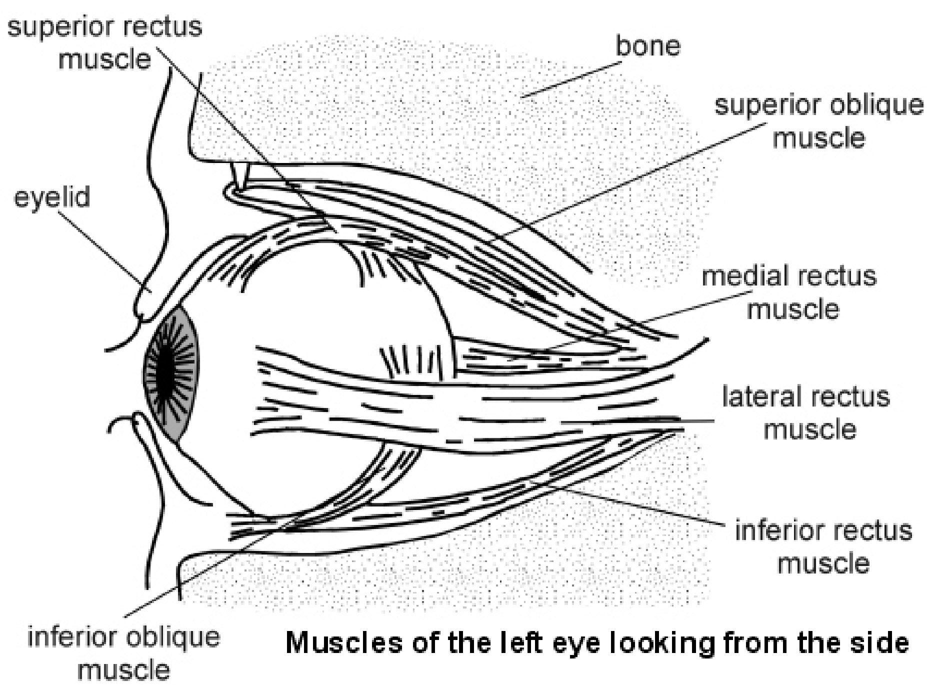

Figure 1.1 Side View of the Human Eye Muscles (Patient UK, 2006)

1.2.2 Field of Vision

Humans have a relatively narrow field of view resulting from the frontal mounting of the two eyes, but peripheral vision can be adjusted with movements of the head and eyes (Boyce, 2003). The diagram below (Figure 1.2) shows a normal field of view of a pair of human eyes. The white area in the middle represents what both eyes can see and the gray represent what only the left and right eyes can see individually. The black areas are cut-off visually by the bones of the eyebrow, cheeks and nose. Also, this area represents the visual field when the eyes and head are motionless (Webb, 1964).

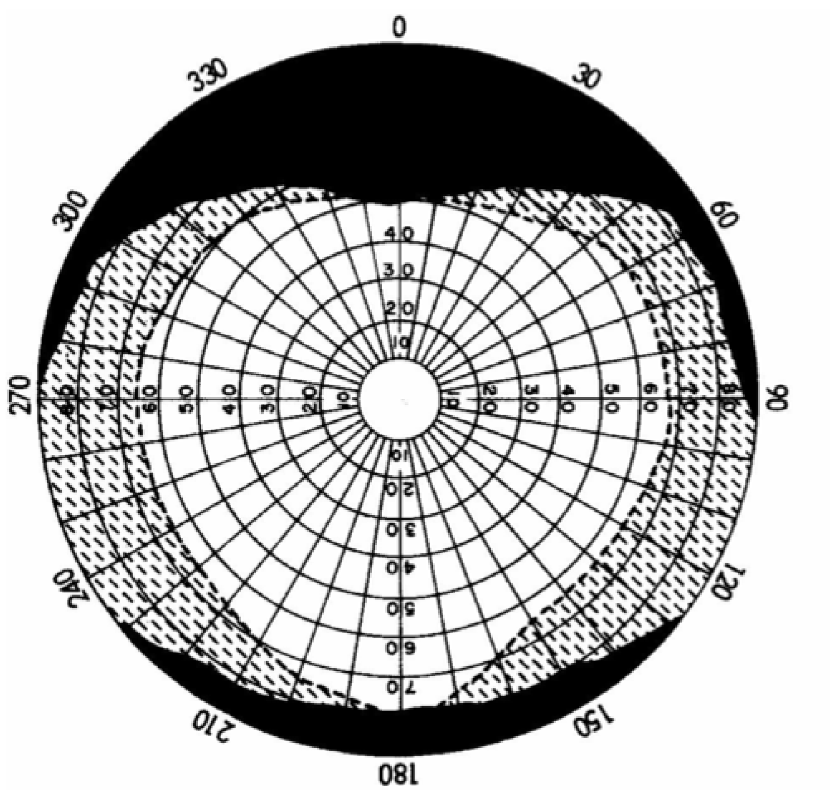

Figure 1.2 Binocular Visual Fields with Head and Eyes Fixed (Ruch & Fulton, 1960)

Research has shown that around a 15^o downward gaze angle is most comfortable for viewing distant objects, and for closer objects a greater angle below horizontal eye level is preferred (Hill & Kroemer, 1986). Figure 1.3 shows the optimum angles of gaze, or line of sight for viewing objects at near distances (Ankrum, 1996; International Standards Organization [ISO], 1998)

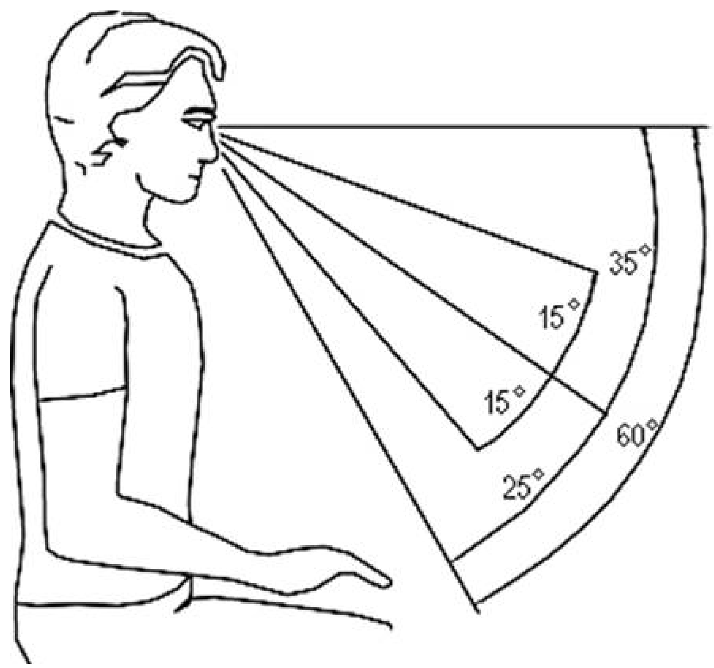

Figure 1.3 Gaze Angles for Viewing Near Objects (Ankrum, 1996)

<u>1.2.2 Optics of the Eye</u>

Figure 1.4 shows a cross section of an eye. The eye is almost completely spherical, about 24 mm in diameter and is made up of three concentric tissue layers: the sclera, choroids, and the retina (Boyce, 2003). The sclera is the outer-most layer that protects the eye and appears white everywhere except in part of the front where it is transparent. This transparent area is known as the cornea and is where light enters

the eye. The next layer inward is the choroid, which contains blood vessels that supply necessary oxygen and nutrients to the retina (ibid). Closer to the front of the eye, the choroid becomes the ciliary body, which produces watery fluid in the aqueous humor between the cornea and lens (ibid).

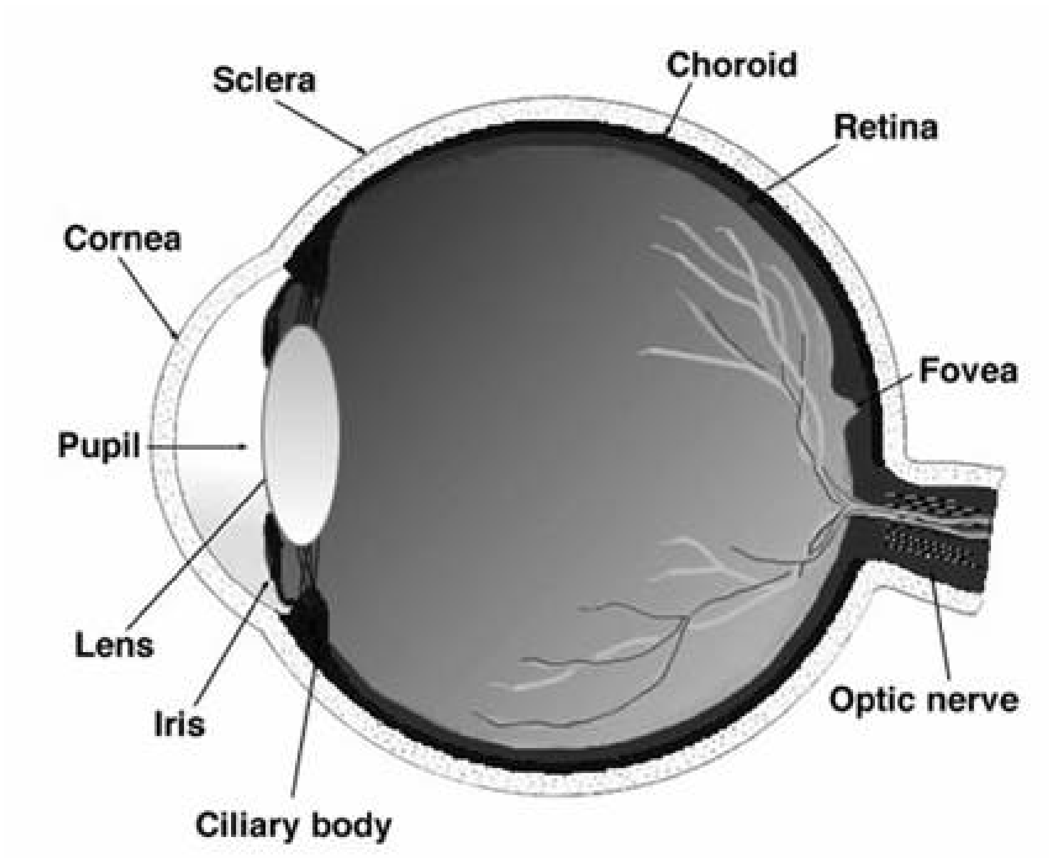

Figure 1.4 Anatomy of the Adult Human Eye (Kolb et al., 2005)

The iris contains pigmentation in its outer layer, distinguishing the color of the eye, and the inner layer of the iris contains blood vessels (Boyce, 2003). In the middle of the iris is an opening called the pupil, which allows light to enter the eye (ibid). The pupil can change in diameter from about 2 mm in bright light to about 8 mm in low light (ibid). There are two sets of muscles in the iris that control the movement of the pupil. The first set, known as the sphincter muscles, are located directly around the pupil. The dilator muscles run radially around the iris. The pupil size changes based on the amount of light reaching the retina, the distance of the image from the eye, the age of the observer, and emotional factors (ibid).

After the light passes though the transparent sclera and pupil, it then reaches the crystalline lens. The lens has a higher refractive index which bends the light rays and the lens can also change its shape by the contracting and retracting of ciliary muscles to adjust focal length (Boyce, 2003). When objects are farther away, the lens flattens, and when objects are closer, the lens fattens (ibid).

Next, the light that passes through the lens enters the vitreous humor, which is filled with a jelly-like substance located between the lens and retina (Boyce, 2003). When the light reaches the retina it is absorbed by photoreceptors and converted to electrical signals as nerve impulses (ibid). There are two groups of photoreceptors, known by their shape as rods and cones (ibid). There are about 120 million rods in the retina and all have the same light spectrum sensitivity (ibid). There are three types of cones that have specific light spectrum sensitivity, short-, medium- and long-wavelength (S-, M-, L-cones, respectively). There are only about 8 million cones and are mostly concentrated in one area, called the fovea (ibid).

Variations in amount of light arriving at the photoreceptors are converted into electrical discharges in different frequencies which are transmitted through the optic nerve to the brain where the visual image is perceived (Boyce, 2003; Schapero, Cline & Hofstetter, 1968).

1.2.3 Vision

Normal visual function, known as emmetropia, occurs when the ciliary muscles of the lens are relaxed and parallel light rays are focused on the retina. The eye is most relaxed when it is receiving light from greater than 10 meters away due to the natural curvature and focal point of the lens (Hetlands, 1999). Normal visual processing is referred to as having '20/20 vision'. According to the AOA, the 20/20 scale is the US standard for measuring vision. The first number in the scale indicates the distance at which a person should clearly see an object from and the second number is the actual distance between the object and person for them to see the object clearly. With 20/20 vision, a person can see what is expected to be seen clearly from a distance of 20 feet. There is no such thing as perfect vision and it is possible to have better than 20/20 vision (e.g. 20/15). The 20/20 vision scale is used to measure the capabilities of the visual system, or visual acuity. Visual acuity is defined as the ability to resolve detail for a target image with a fixed contrast between the image and background (Boyce, 2003).

As previously mentioned, the lens has the ability to change shape by the ciliary muscles that surround it. In doing so, the optical power of the eye can change for changing target distances (Boyce, 2003). Focusing from far to near is known as accommodation and is brought about by the contraction of the ciliary muscle and increase in the lens surface curvatures (Glasser & Kaufman, 1999). Focusing from near to far is called disaccommodation and is brought about by relaxation of the ciliary muscle and the lens (ibid). Accommodation and disaccomodation are necessary for images to remain focused on the retina of the eye, which is imperative for proper vision (Boyce, 2003). Another component needed for the eye to focus an image on the retina is having a thin tear film on the cornea (ibid). The tear film keeps the cornea clean, smoothes out imperfections on the surface, and begins optical refraction process. The cornea, with adequate tear film, is responsible for about 70% of the optical power of the eye and the remaining 30% is provided by the lens (ibid). In order to keep divergent light rays entering the eye in focus on the retina, the lens of the eye must continually adjust and there must be a sufficient amount of tear film on the cornea (Hetlands, 1999). The resting point of accommodation (RPA) is the eyes' default accommodation distance. This distance is where the eyes focus when there is nothing to focus on, for instance, when in total darkness (Ankrum, 1996). The eye focusing range changes with age, as the flexibility of the lens decreases (Boyce, 2003). The near point of accommodation, or the closest distance that an object can be placed while still in focus, for a child is usually about 5–7.5 cm (2–3 inches), for a young adult, 10–15 cm (4–6 inches), for a 45-year-old adult is about 50 cm (20 inches) and for an 80-year-old adult, it is about 1.5 m (60 inches) (Abraham, Kuriakose, Sivanandam, Venkatesan, Thomas, & Muliyil, 2005).

Refractive errors are typical visual impairments that are caused when light is focused incorrectly as it is directed on the retina. Refractive errors can be caused due to issues with the curvature of the lens or distances between the cornea, lens and retina (Shoemaker, 2002). Myopia or near-sightedness is a refractive error that occurs when light that enters the eye comes into focus in front of the retina causing retinal images to be blurred. A person with this condition cannot see clearly at a distance whether or not the ciliary muscles for accommodation are relaxed or activated. Myopia occurs in approximately 30.5 million Americans age 40 and over, but typically decreases with age (ibid).

Hyperopia is another refractive error that causes blurred vision and occurs when light focuses behind the retina when the lens is relaxed. In order to see more clearly, the muscles of the lens must be continuously activated (Hetlands, 1999). This visual impairment is somewhat less common than myopia with about 12 million Americans over age 40 diagnosed (Shoemaker, 2002). However, the prevalence of hyperopia increases with age and is seen more in Caucasian Americans than Black or Hispanic Americans (ibid).

Under normal conditions, the eyes also move to keep lines of sight converged on one target, or move to switch fixation from a target at one distance to another target at a different distance and in the same direction (Boyce, 2003). This automatic focusing response is known as vergence (Ankrum, 1996). The extra-ocular muscles that surround each eye helps to rotate them about a single point in the center of the eye. The eyes undergo convergence when the extra-ocular muscles rotate the eyes inward toward the nose (ibid). This action is needed when looking at relatively close object. The eyes turn inward toward the nose when the object moves closer to the face allowing the images to be focused on the retina (ibid). The eyes can also diverge, or rotate away from the nose when focusing on objects moving farther away (ibid). The eye movements for vergence are relatively slow, typically about 10^o/second, but can be quick movements or smooth movements (Boyce, 2003)

The resting point of vergence (RPV) is where the eyes are naturally set to converge when there isn't an actual object to focus on (Ankrum, 1996). The average RPV is about 45 inches from the face (ibid). However, when images are too close the extra-ocular muscles that control the rotation of the eye can be strained, even more so than strain in ciliary muscles from accommodation (Jaschinksi-Kruza, 1988; Owens & Wolf-Kelly, 1987).

The RPV and the RPA are the two neutral eye positions for optimal vision. An average RPV distance of an image is around 60 cm - 80cm (24 - 32 inches), and an average RPA is about 75cm (30 inches) (Canadian Center for Occupational Health & Safety [CCOHS], 2003). Images at distances past the RPV and RPA do not require accommodation or convergence, however resolving fine images may become more difficult when images are farther away (ibid). However, viewing distances closer than the RPV or RPA require more muscular effort of the ciliary muscles for accommodation and of the extra-ocular muscles for convergence (ibid).

Adaptation is another process of the visual system that occurs naturally when the eye adjusts to different perceived amounts of light (Boyce, 2003). Distinct changes occur in the eye for adaptation so images may be viewed with optimal light. These natural changes include neural adaptation in the nerves of the retina, photochemical adaptation in the photoreceptors and a change in the amount of light allowed in the eye by the diameter of the pupil. As previously mentioned, the constrictions and dilations of the pupil are determined by the iris (ibid). The diameter of a pupil can range from 1.5-8 mm for younger adults, but may decrease with age (ibid).

If the visual system is not completely adapted to the luminance levels surrounding the visual target, its capabilities are limited (Boyce, 2003). The length of time it takes the visual system to adapt depends on the amount of the change in luminance (ibid). Most changes can be made only with neural adaptation in less than one second (Kolb et al., 2005). Larger changes in luminance require photochemical adaptation, which may take minutes to complete (Boyce, 2003). The direction of the change in luminance also affects the rate of adaptation. Dark adaptation refers to how quickly the eye becomes sensitive to an image in the dark after being exposed to bright light. There is an increase in retinal sensitivity with longer times spent in the dark. Additionally, quicker dark adaptation occurs with less intense and shorter time exposures to pre-adapted light (ibid). Dark adaptation can take up to about 30 minutes; however, light adaptation can occur in a matter of seconds (Kolb et al., 2005). Light adaptation is sensitivity of the eye with a change from low luminance levels to high luminance levels (Boyce, 2003).

1.2.4 The Aging Eye

Optical and physical properties of the eye have been shown to change with age (Glasser & Campbell, 1999) that can affect visual acuity. The ability to adapt to changes in light usually decreases after the age of 40 (Boyce, 2003). As a person ages, RPA tends to move farther away (Ankrum, 1996; Grandjean, 1987) and the ability to accommodate diminishes resulting in the condition called presbyopia (Glasser & Campbell, 1999; Kasthurirangan & Glasser, 2005; Strenk, Strenk & Koretz, 2005; Weale, 1989).

Presbyopia, or being unable to focus on near objects, usually starts between the ages of 38-45 years and is known to occur in 100% of the population sometime by age 55 (Dunaway & Berger; Weale, 2005).

One of the theories for the onset of presbyopia is that there is a thickening of the lens and increase in spherical size of the eye with age (Glasser & Campbell, 1998; Glasser & Campbell, 1999; Kinge, Midelfart, Jacobsen & Rystad, 2000). As the lens becomes thicker, flexibility and its ability to accommodate will diminish. Additionally, as the size of the eye changes, the focal point of the lens also changes. A refractive error and blurred vision can result if light that enters the eye comes into focus in front of the retina (Boyce, 2003).

Two studies conducted by Glasser and Campbell revealed that optical and physical changes occur in the eye as it ages. In their first study, Glasser and Campbell (1998) studied 27 human eyes ranging in age from 10-87 and looked at the focal length and change in spherical shape of the eye with the use of a scanning laser. Results showed that the focal length of the lenses increased with age. Additionally, younger lenses were found to be more flexible and have a wider range of change in focal length. Lenses older than 60 years showed no change in focal length when stretched (Glasser & Campbell, 1998). In a follow up study looking at 19 pairs of isolated human eye-bank lenses ranging in age from 5 to 96 years, results showed that the human lens becomes heavier and larger in cross sectional area (Glasser & Campbell, 1999).

In another study measuring changes in the eye over a 3 year period of 224 university students (mean age 20.6 years), lenses were shown to thicken by 0.07 mm ($p<0.05$) and the vitreous lengthened by 0.27 mm ($p<0.05$) over time (Kinge et al., 2000). Refractive change towards myopia (light entering the eye comes into focus in front of the retina) was found to have a statistically significant relationship to time spent on reading scientific literature ($p \leq 0.001$) and on practical near-work ($p \leq 0.05$) (ibid). However, no relationship was found between refractive change and time spent at working with video display terminals (VDT). In this study, it was concluded that intensive near-work could initiate myopia or lead to its progression in young adults and that time spent on near-work seems to play a significant role in the process (ibid). Although for this group of subjects VDT use did not significantly influence the refractive change, further research on this relationship should be considered since VDT and computer monitor use can be considered near-work.

Another natural occurrence of the eye due to aging is discoloration and clouding of the lens, also known as cataracts (National Eye Institute [NEI], 2006). Age-related cataracts is also multi-factorial disease, as ultraviolet exposure, diabetes, drug ingestion, smoking and alcohol consumption have been found to be risk factors (Seddon, Fong, West, & Valmadrid, 1995).

As the clouding, or loss of transparency of the lens increases vision becomes impaired. Typically, the proteins that make up the lens are arranged in a certain way that allow light to effectively pass through it to the retina (NEI, 2006). During the aging process, the proteins of the lens can shift, decreasing the opacity of the lens and making it more difficult for light to be transmitted (ibid). The lens also naturally becomes more yellow/brown in color as it ages (ibid). Over time, as the intensity of the color of the lens increases, a brownish tint to vision ensues. The tint of the lens may inhibit color distinction and make it more difficult to read, but does not affect sharpness of the image transmitted to the retina. Symptoms of cataracts can also include increased sensitivity to light, a need for brighter light, and halos around lights (MayoClinic, 2007).

It is estimated that about half of Americans older than 65 have some degree of cataracts and up to 70% older than 75 (MayoClinic, 2007). Distance vision and problems with glare are also typically a result of cataracts (ibid).

Drying of the eyes is another common age-related eye problem (MayoClinic, 2007). "Deficiencies in tear quantity or quality, which can be caused by low tear production or excessive tear evaporation, result in an unstable tear film and dry eye syndrome (DES)" (Lemp, 1995). Adults over 40 are more likely to experience dry eyes because of decreased production of tear film. Tears are a mixture of water, fatty oils, proteins, electrolytes, bacteria-fighting substances and growth factors that regulate various cell processes and keep the eye clear of debris. Good vision is almost impossible without proper tear film because dry spots on the cornea can occur and cause irritation, discomfort and poor vision (MayoClinic, 2007). Dry eye symptoms can be debilitating and affect psychological health and overall sense of well being (Schaumberg, Sullivan, Buring & Reza Dana, 2003).

In a study that surveyed 39,876 women in the United States, it was found that DES increased with age (from 5.7% $<$ 50 years old to 9.8% $\geq$ 75 years old) (Schaumberg et al., 2003). The age-adjusted prevalence of DES was 7.8%, or 3.23 million women aged $\geq$ 50 in the US (ibid).

In a more recent study of DES that questioned 690 people about how much their everyday activities were limited by symptoms of dry eye, results indicated that those who reported to have DES (n=190) were more likely to have problems with reading ($p < .0001$), carrying out professional work ($p=0.0001$), using a computer (p<0,0001), watching television (p=0.04), driving during the day (p<0.0001) and driving at night (p<0.0001) (Miljanović, Reza Dana, Sullivan & Schaumberg, 2006).

The Bureau of Labor Statistics (2006) estimates that by the end of this decade, workers aged 55 and older will comprise 20% of the work force (compared to 13 percent in 2000). This older work force trend introduces new implications for risks of WMSDs and Computer Vision Syndrome, due to the changes in the eye listed above.

1.2.5 Corrective Lenses

Wearing appropriate vision corrective lenses and proper positioning of office workstation equipment can reduce symptoms of Computer Vision Syndrome and musculoskeletal disorders (Balci & Aghazadeh, 1998; Basrai & Aghazadeh, 2004). Uncorrected or under-corrected hyperopia, presbyopia, and problems with eye coordination and eye focusing can be major contributing factors to VDT related eye stress (Sheedy, 1992).

One study investigated the effects of computer monitor location (15^{o} and 40^{o} below horizontal eye level) on subjective assessment and performance for subjects (n=14) with and without bifocals (Balci & Aghazadeh, 1998). It was found for 1 hour tasks that consisted of reading words from computer screens and typing out that subjects with bifocal lenses had significantly higher neck discomfort and lower performance than non-bifocal subjects in both monitor locations (ibid). Overall for male and female subjects, the 40^{0} angle monitor caused less discomfort in the neck, shoulders, forearms, and wrists, less tiredness and eyestrain and higher performance than the 15^{0} angle monitor (ibid).

The head inclination and angle of gaze (angle of sight below horizontal eye level) to the monitor were measured with a goniometer in another study of the effects of monitor position of lens wearers (Basrai & Aghazadeh, 2004). The results revealed that neck and back discomfort, and eyestrain were significantly affected by the placement of the VDT monitor and the type of glasses worn (ibid). Bifocal users reported more eyestrain than people with single vision glasses, and more musculoskeletal discomfort was experienced with monitor positions located at 'eye-level' and 'shoulder-level' to the user compared to 'sunken-level' (computer imbedded into the work surface) into the work surface (ibid). Specific monitor angles were not provided.

The results of these two studies similarly concluded that lower angles of the computer monitor produced less discomfort and users with bifocal glasses experienced more discomfort when performing computer based tasks. The possible reason for these results may be that users had to position their bodies in an awkward posture in order to properly view the computer screen which caused discomfort. Also, it is possible that the distance of the screen was in a location not suitable for bifocal use. Bifocal lenses are to be used to see near distances usually closer than 16 inches from the eye and the recommended distance of a computer monitor for a bifocal wearer is about 5 to 15 inches past a bifocal viewing distance (Sheedy, 1999).

Computer glasses or occupational progressive lenses are becoming more popular because of their effectiveness for viewing mid-distances and near distances for typical office workstation needs. In fact, computer glasses designed for the computer workplace have been shown to be effective in reducing vision-related symptoms of computer users (Butzon, Sheedy, & Nilson, 2002). In a study that consisted of 26 subjects the effects of computer glasses on symptoms of presbyopia were investigated. All subjects were given an eye examination in the previous year, wore prescription corrective lenses, had symptoms of presbyopia and were given one of two interventions. Two interventions, computer glasses and an ergonomic self-assessment tool (ESAT), were given in alternating order for three weeks to all subjects. It was found that the computer glasses were significantly more effective at reducing the frequency and severity ($p < 0.008$) of the symptoms than the ESAT, and 24 of 26 subjects judged the computer glasses to be more effective. Subjects attributed 80.7% of presbyopia symptom reduction to the computer glasses and 19.3% to the ESAT. Although the ESAT was judged effective, it was not as effective as the computer glasses. Additionally, Torrey (2005) estimates that 70-75% of all computer users could ease CVS symptoms with the use of similar lenses.

1.3 Computer Use and Vision Effects

Research has revealed that a number of health disorders are associated with the use of computers, but the majority of symptoms are related to visual strain (Bergqvist, Wolgast, Nilsson, & Voss, 1995; Ustinaviciene & Januskevicius, 2006). Uncorrected refraction errors, imbalance of eye muscles, and prolonged use of the eye are the cause of eye fatigue and discomfort, collectively known as asthenopia (Yanoff & Duker, 2004), and can be related to the workstation equipment design, the task performed and the overall workplace environment (Bergqvist & Knave, 1994)
"Asthenopia is defined as a complex of subjective factors, while visual strain is reflected by both subjective and objective factors" (Ustinaviciene & Januskevicius, 2006).

Additionally, as the number of people who work at computers and visual display unit increases, the levels of complaints and symptoms of ocular discomfort and ocular muscle strain have also increased (NIOSH, 1995; AOA, 1998). In a recent study looking at visual strain in 404 office employees, 88.5% of subjects who used a computer complained of various visual symptoms (Ustinaviciene & Januskevicius, 2006).

Blehm, et al. complied a review of literature dealing with the relationship between computer use and visual discomfort. They found that the most commonly reported symptoms of CVS could be categorized as symptoms dealing with asthenopia, the ocular surface, vision and extra-ocular (not directly related to the eye) (2005). The symptom categories and more specific symptoms are listed in Table 1.1 below.

Table 1.1: Computer-Related Vision Symptoms

Symptom Category	**Symptoms**
Asthenopic	Eyestrain
	Tired eyes
	Sore eyes
Ocular surface	Dry eyes
	Watery eyes
	Irritated eyes
	Lens problems
Visual	Blurred vision/ Refraction Error
	Slowness of focus change/ Accommodation
	Double vision
	Presbyopia
Extra-ocular	Neck pain
	Back pain
	Shoulder pain

Besides changes in accommodation, visual acuity and convergence points resulting from the use of computers (Bergqvist, Wolgast, Nilsson & Voss, 1995), one of the greatest causes of CVS is drying of the eye (Miljanovic et al., 2007; Schaumberg et al., 2003).

The onset of dry eyes is partly due to a decrease in blinking (Blehm et al., 2005; Miljanovic et al., 2007; Schaumberg et al., 2003). Blinking is important for maintaining and protecting the surface of the eye by keeping it properly moistened with tears (Acosta, Gallar & Belmonte, 1999). Most individuals normally blink between 10–20 times per minute when relaxed while not working at a computer (Acosta, Gallar & Belmonte, 1999). After completing a visual task (card game) on the computer screen for 10 or 30 minutes, subjects (n=20) in one study were found to significantly decrease their blink rate. Low blink frequency values during the computer playing period were similar for periods of 10 minute play (7.3±1.4 blinks/min, n=15) and 30 minute play (6.1± 1.2 blinks/min, n=12). This showed about a 40% decrease from the mean resting blink rate (12.4±1.2 blinks min) (ibid).

Another study investigated eye blink rates before and after subjects were given a computer based task. First, the blink rates during a 10 minute conversation were recorded of 30 patient subjects with DES (median age 44.8 years, range 18-67). During the conversation, the mean eye blink rate was 16.8 blinks/min. Then subjects' blink rates were measured during an initial VDU task and again after 30 minutes of VDU work. There was a significant reduction in blink rates during the initial VDU use (6.6±4.8; $P<0.001$) and during re-measurement after 30 min (5.9±4.6; $P<0.001$) (Schlote, Kadner, & Freudenthaler, 2004). These two studies also support results of previous research by Tsubota & Nakamori, 1995 and Freudenthaler, Neuf, Kadner, & Schlote, 2003 that the decrease in blink rate is a result of computer or VDU usage.

Computer use not only decreases blink rates, it also results in increased exposed ocular surface that has been associated with reduced tear film (Acosta, Gallar & Belmonte, 1999). If the eye is viewing a computer monitor at a horizontal gaze, approximately 40% more of the ocular surface is exposed compared to reading at a downward angle below the horizontal (Tsubota & Nakamori, 1995). When the eye is looking at a downward angle, the eyelid covers more of the ocular surface, minimizing tear evaporation (ibid). In a study measuring the effects of exposed ocular surface area and blink rates on tear evaporation it was found that the ocular surface area increased as subjects (n=15) looked at a downward angle (1.2 ± 0.27 cm^2), to horizontal (2.2 ± 0.39 cm^2) to an upward gaze (3.0 ± 0.33 cm^2) (Tsubota & Nakamori, 1995). Specific eye gaze angles were not recorded. The corresponding tear evaporation rates were 7.0 ± 3.5 g/s (downward gaze), 17.6 ± 6.6 g/s (horizontal gaze), and 23.7 ± 6.3 x 10(-7) g/s, respectively. This study revealed that the tear evaporation per square meter increased proportionally with ocular surface area (ibid). Therefore it is suggested that as more ocular surface is exposed the risk of developing dry eye is enhanced.

1.4 Monitor Considerations

Viewing distance and monitor height (vertical gaze angle) are important variables that affect eye discomfort in computer based work because the position of the computer monitor affects the user's viewing angle and the degree of ocular exposure (the amount eye not covered by the eye lid) (Bergqvist & Knave, 1994; Lie & Fostervold,1995; Fostervold, Aarås & Lie, 2006). In addition, the position of the monitor has been shown to be associated with reports of upper extremity discomfort (Babski-Reeves, Stanfield & Hughes, 2005; Burgess-Limerick, Plooy, Fraser & Ankrum, 1999; Kumar, 1994; Straker & Mekhora, 2000). Research has been conducted on different monitor heights, distances and tilts in order to find a position that minimizes the risk of developing visual or musculoskeletal discomfort.

1.4.1 Monitor Distance

The viewing distance of the computer monitor determines the amount of accommodation and convergence of the eyes (Jaschinski-Kruza, 1988). The shorter the viewing distance of the image the greater force the ciliary muscles have to exert on the crystalline lens to focus the image (Fisher, 1977; Jaschinski-Kruza, 1988). It is generally accepted that the shorter the viewing distance of the image the greater the amount of visual strain resulting from the increased tension of the ciliary and extra-ocular muscles (Weston, 1949; Jaschinski-Kruza, 1988).

Although research conducted on the preferred range of viewing distances of the monitor has produced conflicting results, it is generally accepted that distances beyond the viewers Resting Point of Accommodation (RPA) produces less eyestrain than those in front of their RPA (Jaschinski-Kruza, 1988). One study looked at the reported eyestrain of subjects with different RPA by asking subjects to perform a search and comparison task for two hours at a monitor distance of 100cm and then at 50 cm. At each distance they were also asked to complete 4 questionnaires about visual strain experienced during the experimental period. The results of this study found that there was greater preference and significantly less eyestrain reported for all subjects when using the monitor at 100 cm away compared to 50 cm (ibid).

Another study looking at the change of monitor distance and its effects on eye strain found that as the monitor at a closer distance to subjects also produced more eye strain (Jaschinski, Heuer & Kylian, 1998). In the first wave of this study, subjects (n=22) performed their typical computer tasks for four days, each day with a new monitor configuration (ibid). Results showed that a monitor placement approximately 18 cm below eye level and at a distance of 92 cm produced less eyestrain and discomfort than when the monitors were at eye level height and a distance of 63 cm. When the subjects were forced to work at a shorter distance than their preferred viewing distance they reported more visual strain (ibid). It was concluded from this study that a lower height and farther distance of the monitor was preferred, but allowing the individual to make adjustments to find the optimal monitor position would be best for reduction in visual strain and discomfort (ibid).

When viewing a computer monitor or other visual display units, the eyes undergo convergence and accommodation repeatedly to keep focus on changing images (Ankrum, 1996). At distances closer than the RPA and convergence, the muscles of the eye are put under more strain to keep the images in focus leading to risks of discomfort (ibid). Therefore, it is recommended that the monitor be approximately an arms length away from the computer user for easy accessibility (Ankrum, 1996; Jaschinski-Kruza, 1988).

1.4.2 Monitor Height

The complexity of the visual system, in addition to the musculoskeletal system of the head, neck and upper limbs has contributed to controversy regarding the appropriate height of the computer monitor because of individual preferences and abilities. Results of research on optimal computer monitor viewing height have revealed opposing results. Additionally, research has indicated that a trade-off exists between visual strain and musculoskeletal strain with regards to monitor height (Psihogios, Sommerich, Mirka & Moon, 2001).

In some studies looking at the effects of monitor height on musculoskeletal discomfort, higher monitor positions (horizontal eye level and above) were found to have more positive results for reducing the musculoskeletal discomfort of the neck and back (Straker & Mekhora, 2000; Psihogios et al., 2001). However, in other studies higher monitor positions have also been associated with visual stress, reduced visual acuity (Bergqvist & Knave, 1994; 0 to -20$^{o;}$ Lie, Aaras & Fostervold, 2006) and musculoskeletal discomfort (Bergqvist, Wolgast, Nilsson & Voss, 1995; Lie et al., 2006). A more recent study showed no significant difference in the amount of muscle strain when viewing monitors at different heights (Straker, Pollock, Burgess-Limerick, Skoss & Coleman, 2006).

The results of a field study that investigated affects over 12 months of vertical monitor placement for 150 office worker (Lie et al., 2006) supported the use of a lower monitor placed at -30^{o} to horizontal eye level as opposed to a monitor -15^{o} to horizontal eye level (Lie et al., 2006). Statistical analysis of single symptoms showed a significant group by time interaction for discomfort in the neck and shoulder ($F(1,83)=4.41$, $p=0.039$, $f=0.23$[1]), discomfort in the back ($F(1,59)=7.99$, $p=0.006$, $f=0.37$) (ibid). In the same study, subjective symptoms of musculoskeletal discomfort in the upper limbs and headaches significantly decreased over the 12 month study period. Subjects who were given a monitor at -15^{o} to horizontal eye level were shown to have reduced functional capacity of the ciliary and extraocular muscles after prolonged VDU work and significantly more self-reported sick days in the last 6 months of the study compared to the group of subjects with even lower monitor positions (Lie et al., 2006). These results validate results from laboratory studies showing reduced symptoms in computer work using a downward line of sight angle (-30^{o}) (Kumar, 1994; Ankrum, Hansan & Nemeth,1995; Lie & Fostervold, 1995).

Straker and Mekhora (2000) looked at the effects of body angles, posture, muscle activity, discomfort and preference for different monitor heights. Twenty minute computer tasks were assigned to subjects (n=20) at two different monitor positions. The top of the monitor level with the subjects' eyes was considered the 'high monitor position' and when the bottom of the monitor was level with the top of

[1] This is the effect size for the F value.

the desk and angled 25^{o} back, this was considered the lower monitor position. A significant interaction effect of the monitor positions and body posture angles ($F_{3,57}$=20.58, p=0.0001) showed that 'lower monitor positions' resulted in greater (more flexed) postural angles of subjects' head, neck and trunk. Therefore, this study supports higher monitor positions in order to reduce the risk of musculoskeletal discomfort from improper head and neck posture.

In addition to subjective data for musculoskeletal discomfort, musculoskeletal stress has been measured objectively by the amount of muscle activity using the normalized electromyographic (EMG) (Sommerich, Joines & Psihogios, 2001). Increased muscle activity over time can lead to localized muscle fatigue, which has shown to be a contributor to the development of muscle tension in VDU workers (Hagberg, Silverstein, Wells, Smith, Hendrick, Carayon & Pérusse, 1995). A study that recorded spinal and upper limb muscle activity in 36 subjects found that there was no significant difference in muscle activity of the spine (cervical erector spinae) and neck muscle (upper trapezius) while working with either high or low (high: top of monitor at subject's horizontal eye level; low: bottom of monitor at desk height) computer display heights (Straker et al., 2006). However, other studies by Sommerich, Joines and Psihogios (2001) and Straker and Mekhora (2000) found that neck and back muscle activity were greater for lower monitor positions compared to high monitor positions. Low monitor position was considered 35^{o} below horizontal eye level in the study by Sommerich et al. (2001) and the bottom of monitor at desk height in the study by Straker and Mekhora (2000). The top of the monitor positioned at subjects' eye level was considered a high monitor position in both studies.

Opposing study results regarding muscle activity and musculoskeletal discomfort due to monitor height indicate the need for further research. However, the majority of research supports the recommendations for positioning the monitor at a higher position (top of monitor at horizontal eye level) to reduce muscle activity. On the other hand, research suggests that lower positions (monitor below eye level) help to reduce the symptoms of CVS and sometimes can also reduce neck and back strain.

Lower monitor positions (below horizontal eye level) have been found to be beneficial for reducing visual strain (Bergqvist & Knave, 1994; Bergqvist et al., 1995; Jaschinski, Heuer & Kylian, 1998; Lie, Aaras & Fostervold, 2006) and for allowing a natural reading gaze around 45° below horizontal eye level, established by Kroemer and Hill (1986). When viewing images at this angle, approximately 40% less of the eyeball's surface is exposed than looking straight ahead (Rupp, 1987) reducing symptoms of CVS, such as tear evaporation and dry eye (Blehm et al., 2005).

Jaschinski et al. (1998) also conducted a study to investigate the effects of monitor positions on visual strain, but found contradicting results. A highly significant correlation between monitor height and gaze angle ($r=0.52$, $n=22$, $p<0.01$) was found, meaning subjects who performed computer tasks with a horizontal gaze (top of monitor at eye level) reported more eyestrain than those with lowered gaze angles (18 cm below horizontal, on average) (Jaschinski et al.,1998). In the second phase of this study, subjects ($n=22$) were allowed to freely adjust the position of their monitor for computer based tasks. It was recorded that the average gaze angle below the horizontal was between 0^o and 16^o (ibid.).

The recommendations to minimize visual discomfort have been shown to conflict with the recommendations to minimize musculoskeletal discomfort. These issues from the mentioned examples indicate the need for further research on the effects of monitor height for visual criteria, posture, discomfort and preference, and for extended periods of time. Further research should be conducted to determine what height, depth and tilt angle the computer monitor should be positioned relative to the user to reduce the risk of developing musculoskeletal disorders and CVS.

1.4.3 Monitor Display

Readability and legibility of the computer monitor or VDU are crucial in the reduction of CVS and other musculoskeletal disorders. In fact, screen legibility has been shown to significantly influence the occurrence of symptoms of ocular discomfort ($p=.04$) (Collins, Brown, Bowman & Carkeet, 1990) Therefore, the quality of the monitor display with regards to the character size, structure, style, contrast, and stability, directly affects visual performance.

It is important that when reading from a monitor that a combination of upper and lower case words, preferably with a serif font, are used for easy interpretation and readability (Henifin, 1983). The spacing between characters and lines should allow for at least one-half character space between words and one character space between lines for best quality (Costanza, 1994).

The contrast between backgrounds and characters on a computer monitor is necessary to consider for efficient reading ability. A negative screen contrast, with a light background and dark letters, reduces any reflected images and the luminance difference between the screen and surrounding environment. Negative contrast was also found to have a lower error rate and increase productivity (2% to 31.6% performance rate) for visual search and proofreading tasks (Bauer & Cavonius, 1980; Snyder et al., 1990; Ankrum, 2005).

The risk of developing symptoms of CVS can be reduced by setting a lower room brightness (low illuminance < 200 lux). The preferred range of illuminance is between 200-500 lux (20-50 foot candles). When at a low brightness level, image stability is improved and character flicker is reduced. This causes some contradiction with the lighting levels needed to perform paper-based tasks. In order to support both computer and paper tasks, a combination of indirect lighting and desk task lightings creates a good lighting option for workers. Indirect lighting is most preferred in offices

(Hedge et al., 1995), however task lighting can add additional and direct light for paper based tasks (Hedge, 2000). This combination was shown to be effective in a study of German office workers conducted by Cakir (1991) (See Section 1.5.1).

The visual performance has also been found to be affected the quality of the images projected on a screen based on the number of distinct pixels in each dimension, also known as screen resolution. Search reaction times, eye movements and visual comfort were measured in a study comparing monitor resolutions of 62 dots per inch (dpi) and 89 dpi. It was determined that search reaction times and fixation durations when viewing documents were significantly increased with the lower resolution (Ziefle, 1998). The results of this study support that there is a significant interaction between eye fatigue in low-resolution conditions. Advances in technology and the introduction of LCD flat panel monitors, that have higher screen resolution than traditional CRT monitors, have helped to alleviate this issue (Thomson, 1998). Finally, regular cleaning to remove dust can also help with the legibility and readability of the computer screen (AOA, 1998).

1.4.4 Monitor Size

Only a few studies have been conducted to examine the effects of monitor size on performance, preference, musculoskeletal and visual strain. Some studies that include monitor size as a variable also have examined the differences in monitor and computer technologies. A study comparing 4 different sizes of notebook computers to a 17-inch (43 cm) VDT found that neck flexion, neck muscle activity, and eye discomfort increased as screen size decreased (Villanueva, Jonai, & Saito, 1998). Computer task performance significantly decreased as the size of the screen decreased (ibid), however this may have been the result of other factors such as keyboard size and posture. Another study by Sommerich et al. (2001 found that muscle activity was less for a larger monitor (19”) at the 35^{o} below horizontal eye level compared to a standard size monitor (14”). However, no significant difference for factors of strain, performance and preference for computer based tasks with constant character size was found with different monitor angles.

These previously mentioned studies found that monitor size affects muscle activity. Increased muscle activity over time can lead to localized muscle fatigue contributing to the development of muscle tension in VDU workers (Hagberg, Silverstein, Wells, Smith, Hendrick, Carayon & Pérusse, 1995). Therefore, further research should be conducted to find the effects of monitor size on performance, preference, musculoskeletal and visual strain.

1.4.5 Computer Use and Performance

The use of the computer and VDUs has been shown to cause visual and musculoskeletal health concerns (Bergqvist & Knave, 1994; Bergqvist et al., 1995). In addition to the health related symptoms listed above, performance, such as reading from the computer screen, has been shown to be less preferred and 30% - 40% slower than reading the same information from a printed document (Muter & Maurutto, 1991; Zaphiris & Kurniawan, 2001).

Ziefle (1998) also investigated effects of reading performance on paper (225dpi) and two different resolution computer monitors (120 dpi and 60 dpi). The same 19” CRT monitor was used with black characters on a white background and subjects viewed material 20 inches (50 cm) away. It was found that proofreading was significantly better ($F(19, 38)=8.17$, $p< 0.05$) and reading speed was significantly faster ($F(2, 38) = 9.41$, $p<0.05$) with the hard copy (201 words/minute) than with the high and low resolution screens (182 words/min and 179 word/min, respectively) (ibid)

Another study addressed workload and performance effects of paper-based and computer-based assessments for university students (Noyes, Garland & Robbins, 2004). Thirty student volunteers (15 male, 15 female) were asked to read an article, complete a multiple choice question and a survey on workload and effort on paper or at a computer workstation. No significant difference for test scores was found between groups completing tasks at the computer or on paper. However, a significant difference in the perceived effort ($t(28) = 2.13$, $p<0.05$) was found indicating subjects at the computer reported more effort required in the reading comprehension compared to the paper-based test. This result was supportive of results from a previous study that found a significant negative relationship between workload and comprehension scores ($r= -0.39$, $p<0.05$) (Mayes, Sims & Koonce, 2001).

These studies suggest that there is an increased effort, lower preference and performance rate with computer-based tasks compared to paper-based tasks. However, other research studying musculoskeletal discomfort and posture between the two conditions recommend the use of the computer over paper (Straker, Pollock, Burgess-Limerick, Skoss & Coleman, 2006). Straker et al. (2006) measured the spinal and upper limb muscle activity in 36 young adults while reading from an electronic screen at two different heights (involving mouse use for navigation) and from a book (involving page turning) in order to investigate common office work situation involving both computer and paper work. Paper tasks resulting in greater mean spinal and upper limb muscle activity compared to the monitor at desk level. In fact, the difference in muscle activity at 4 specific areas of the spine was highly significant ($p<0.001$) between paper and computer tasks.

Although research suggests that there is a greater preference to perform certain tasks on paper rather than at the computer, the use of the computer in the workplace is continually on the rise (Chesseman Day et al., 2005). Performing tasks at the computer can allow for better posture and less muscle activity (Straker et al., 2006), potentially reducing the risk for musculoskeletal injuries. Furthermore, most of the studies conducted thus far about the difference between computer and paper work have been on CRT monitors, which have lower resolution power than LCD monitors currently available. As technology continues to advance and screen resolutions increase, reading speed and performance are predicted to equal that of hard copy documents (Neilsen, 1998).

1.5 Environmental Factors of WMSDs

Environmental factors, such as lighting, workstation equipment and its orientation to the user dramatically influence the risk of musculoskeletal and ocular discomfort or disorders. Some standards or recommendations exist to give guidance for proper ergonomic working conditions. However, in many instances, there isn't a single optimal set-up or workstation design that is adequate for all users. Instead, it is most important that any workstation can be configured so that any user is in a neutral postures and their equipment 'fit' their body type and tasks. The Business and Institutional Furniture Manufacturer's Association (BIFMA) defines 'fit' in their guideline for VDT furniture used in office work spaces as "the selection and design of furniture and equipment requires a fit to be achieved between a range of task requirements and the needs of users. The concept of fit concerns the extent to which furniture and equipment (work chairs, work surfaces, visual display units, input devices, etc) can accommodate individual users' needs" (Michael, 2002). In order to accommodate proper fit to the widest range of users and tasks, adjustable furniture and workstation configuration is most logical.

1.5.1 Glare and Lighting

Conflict exists in office lighting recommendations because of the differences in lighting needed for paper based tasks and computer tasks (Hedge, 2000). Paper based tasks require a higher level of illuminance, about 500 to 1000 lux for optimum visibility, compared to computer tasks (ibid). For traditional cathode ray tube (CRT) monitor workstations, ambient lighting of 150–500 lux is generally suggested (Helander & Rupp, 1984). Bangor (2000) found that the ambient illumination level of 300 lux was best compared to 0, 600, and 1200 lux for performance, image quality and visual fatigue. Preference for computer tasks was previously found to be about 100 ±250 lux (Shahnavaz, 1982), which would be too low if paper based tasks also needed to be performed at the same workstation.

The Illuminating Engineering Society (1989) and the America National Standards Institute (1993) has set standards for office lighting. They both recommend that luminance ratios should not exceed 1:3 or 3:1 between the task and visual surroundings, nor should the ratio exceed 1:10 or 10:1 between the task and closer visual surroundings. These standards have taken offices with computers in to consideration, however the Human Factors and Ergonomics Society (2002) has recently set more rigid standards. They recommend that any luminous source within the computer user's field of view should not exceed three times the mean of the screen luminance. Computer screens can emit from 2 – 3 cd/M^2 for dark background displays to nearly 300 cd/M^2 for white background displays (Sheedy, Smith & Hayes, 2005).

Five types of glare are often distinguished as direct, reflected, discomfort, disability and blinding. Direct glare is a bright light in one's field a view at a level greater than retinal adaptation. Sunlight and exposed ceiling lights are two examples of sources of direct glare. Reflected glare can change depending on the surface it bounces off. Typical work surfaces can cause reflected glare to be specular, spread, diffuse or compound. Glare that does not impair the vision, but results in sensation of discomfort is known as discomfort glare. A reduction of visibility of a target, reduction in visual performance or temporary blindness is a result of either disability or blinding glare (U.S. Department of Occupational Safety and Health Administration [OSHA], 2006).

Glare found on a computer screen can cause annoyance and interference with work, in addition to eyestrain (Garcia & Wierwille, 1985). The amount of lighting, or illuminance, veiling glare and the position of the computer monitor in relation to the sources of light influence the amount of computer screen glare (Hedge, 2000). Improper lighting and glare contribute to eyestrain and effect visual function (Sheedy et al., 2005). Reports of eyestrain have been shown to increase as the amount of computer screen glare increases (Hedge et al., 1996).

Screen glare can be reduced by adjusting the source or the position of the monitor in relation to the source. Direct glare from the sun entering through office windows and light reflected off bright clothing, white paper or whiteboards can all be adjusted to reduce computer screen glare (Hedge, 2000).

Effective measures to minimize glare and reduce the risk of musculoskeletal discomfort or eye strain have been found to also include using different types of office lighting (Hedge, 2000) A study in a German office of over 800 subjects found that the most preferred type of office lighting system consisted of a combination of indirect lighting where the light from the luminaries is directed upwards and reflects down from the ceiling and wall surfaces (ibid), and desk task lighting, more focused light (Cakir, 1991). Having a two component lighting system can adequately both writing and reading tasks or be adjusted to a light level appropriate for computer tasks.

Two lighting systems of different luminous flux or total amount of light, measured in foot candles, were studied to find the effects of glare and preference for computer users (Hedge et al., 1995). One lighting system used parabolic fixtures (approximate illumination of 50 foot candles to 70 fc) and the other used indirect lighting (approximate illumination of 30 to 50 fc) in an office setting. Subjects (n=90) who were given indirect lighting had significantly less reports of daily tired eyes and eye focusing problems, much less screen and workspace glare, and a significantly greater preference compared to subjects with parabolic lighting (ibid).

In another study investigating workstation lighting, subjects were given a constant ambient illuminance of 350 lux (approximately 32 fc) and tested indirect and direct lighting, six task lighting conditions and three document illumination levels (Yearout & Konz, 1989). It was found that subjects preferred a combination of indirect and direct illumination, and task document brightness at 190 cd/m^2 (+890 cd/m^2) (ibid). Figure 1.5 below shows a recommended office equipment orientation in relation to light sources.

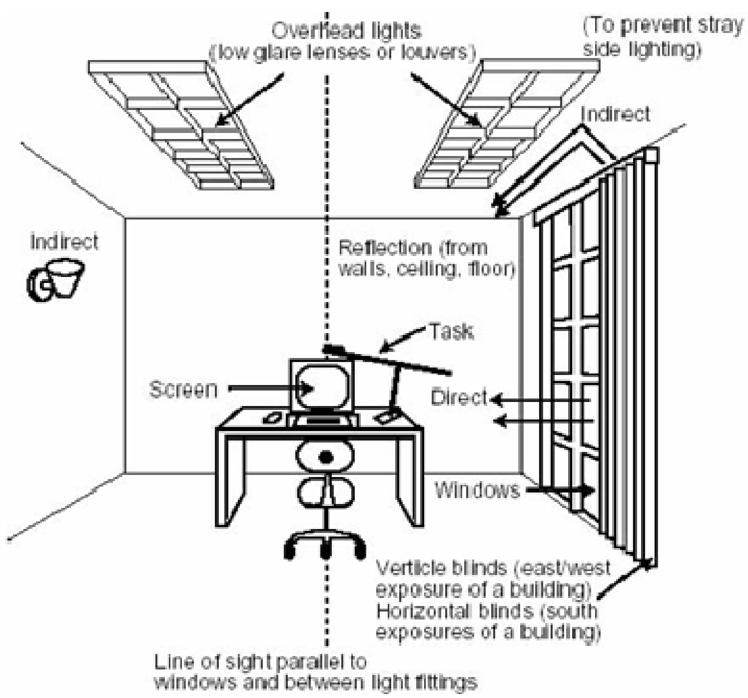

Figure 1.5 Recommended Office Equipment Orientations (OSHA, 2006)

U.S. Department of Occupational Safety & Health Administration (OSHA) (2006) recommends office task lighting between 20-50 foot candles (fc) and up to 73 fc for offices with LCD monitors since they emit less light (see Section 1.5.2). When appropriate changes in light levels can not be, anti-glare filters can be used in order to increase contrast and reduce reflection (Blehm et al., 2005). A study reported that screen filters reduced the occurrence, duration and intensity of eye and musculoskeletal complaints after 1 month of use for 40 subjects (Hladky & Prochazka, 1998). The filter and control group (n=20) were not significantly different for age, gender, years of VDU experience, work task, self-reported overall health, eye conditions, and workstation layout (ibid). Furthermore, OSHA suggests using mesh and optical glass glare filters, or opaque hoods to increase the contrast between characters and background (OSHA, 2006).

Flexibility and variety of lighting types, brightness and control will accommodate different user needs and tasks.

1.5.2 Liquid Crystal Display (LCD) Monitors

There are many benefits of using a thin film transistor (TFT)- liquid crystal display (LCD) monitor compared to traditional cathode ray tube (CRT) monitors, including better visual performance (Menozzi, Lang, Naepflin, Zeller & Krueger, 2001; Ziefle, 2001), image quality, greater viewable area, and energy efficiency (Hedge, 2003). Research has also found that computer users prefer LCDs over CRTs (Chen & Lin, 2004, Menozzi et al., 2001, Ziefle, 2001).

Visual performance was measured in a study by Ziefle (2001) by comparing search task times on a LCD and CRT monitor. Overall search times were found to be significantly shorter for LCD monitors ($F(1,21) = 7.7$, $p<0,05$) and search times per line were 22% shorter compared to CRTs. Mean eye fixation time, or time spent focusing on the screen, was significantly lower in tasks performed on LCD screens compared to CRTs ($F(1, 21) = 9.8$, $p < 0.05$), as well as the number of fixations per line ($F(1,21) = 6.8$, $p < 0.05$) to read the same information (ibid). These statistics indicated less oculomotor effort (eyestrain) for the LCD condition compared to the CRT. Furthermore, 18 of the 24 subjects from the Ziefle study preferred the LCD over the CRT display (ibid).

Preference and performance results between CRT and LCD conditions were also supported in the study by Menozzi et al. (2001). 34% fewer errors occurred in LCD tasks and reaction times were significantly shorter (Menozzi et al., 2001) compared to the CRT. Also, screen type (CRT and TFT-LCD) significantly affected subjective rating ($F(1,18)=31.37$, $p<0.01$) of 24 subjects (24 male, mean age 19.9) in the study by Chen and Lin (2004).

LCDs monitors also provide greater productivity and possible reduction in CVS symptoms because they are flicker free, where as CRT monitors have to refresh the displayed image causing flicker. “Flicker is regarded as on of the crucial factors responsible for CRT performance decrements and the emergence of asthenopic discomfort” (Ziefle, 2001).

LCDs have uniform screen brightness because every pixel is active. This eliminates geometric distortion at the screen edges and helps to reduce specular glare (Hedge, 2003). “CRTs are subject to peripheral distortion of the image as the electron beam becomes progressively more tangential to the monitor screen phosphors at the edges, hence CRT screens typically have a black dead space around them” (ibid). The reduction in display area also signifies less viewable area of the CRT screen.

In addition to improving the work performance and increasing visual health, LCD monitors save energy compared to the amount needed for a CRT monitors (KSBA, 1998). LCDs were proven to be more economically efficient by saving over 60% more energy than CRT monitors (ibid). Another study reported that a 15" LCD uses around 25 watts when operational and around 3 watts when in standby mode, compared with an equivalent viewing area 17" CRT that uses 80 watts when operational and 5 watts in standby mode" (Hedge, 2003). LCD screens recover from standby faster and emit less heat, thereby saving energy (ibid). A further benefit of using an LCD monitor is that it does not emit electromagnetic radiation that is associated with the scanning electron beam and is required for a CRT monitor (LCD Research Committee [LIREC], n.d).

LCD monitors are more economical since they require about 20% less surface area than traditional CRTs (KBSA, 1998). Therefore, a LCD monitor can provide more usable work surface area and a wider variety of workstation configurations (LIREC, n.d). LCDs are also lighter in weight then CRTs (Hedge, 2003), allowing them to be mounted to an articulating arm with less difficulty and more easily adjusted to positions for proper viewing and sharing information (Quilter, 2001).

Additionally, LCDs are more difficult to view from acute side angles, giving better screen privacy and potentially helping maintain proper alignment of the user's body with the screen (Hedge, 2003; Hollands, Parker, McFadden & Boothby, 2002).

1.5.3 Workspace Configuration

Risk factors for WMSDs and CVS can be diminished by properly configuring the workstation to the individual user and task. For example, if the keyboard and monitor are not aligned the user may have to twist their body to see the screen. This may occur when there is not enough space at the workstation to allow proper positioning of the workstation components, or simply if the user is unaware of the implications of poor workstation configuration and ergonomics. Figure 1.6 shows a properly aligned monitor and keyboard to the computer user.

Figure 1.6 Properly aligned workstation keyboard and monitor to user (Ergotips, 2002)

Crenshaw (2000) addressed the placement of computer components for optimum work surface utilization and health. She discussed that a flat panel monitor mounted on an adjustable arm is a good option for allowing users' primary work area and frequently used objects to be located close to the body and within the Neutral Reach Zone (See Section 1.5.6). Figure 1.7 shows the primary work area within a reachable distance with the use of a flat panel monitor and adjustable arm, but the picture to the right with a traditional CRT monitor is not adjustable. The adjustable monitor arm for a flat panel LCD also allows the user to more easily reposition the monitor out of primary work area to provide more desk space for other tasks (Crenshaw, 2000).

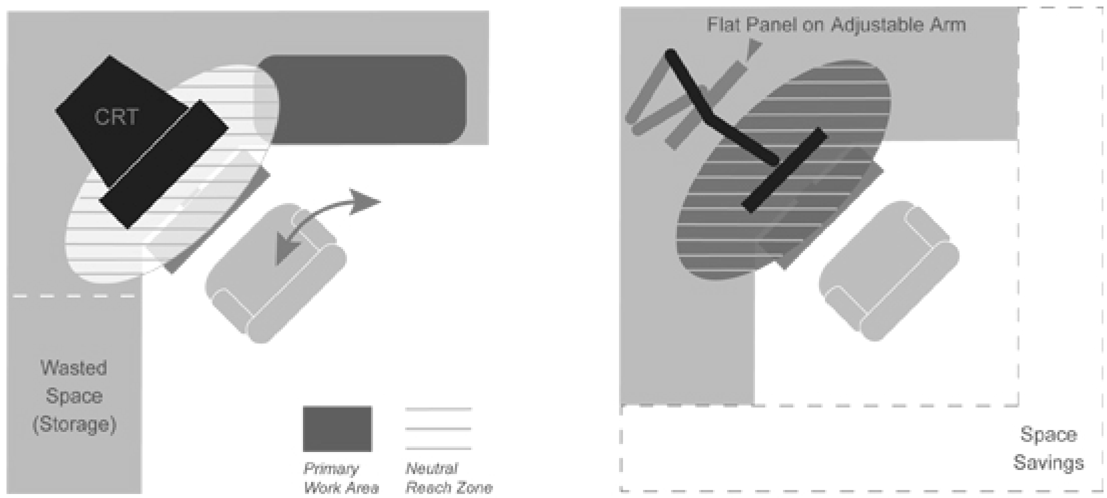

Figure 1.7 Workspace Areas and Neutral Reach Zone (Crenshaw, 2000)

Injury risk and prevention of future WMSDs has shown to be much lower with implementing proper work station configuration, ergonomic intervention and training (Greene et al., 2005). The risk of low productivity or work absence has also been show to be diminished through knowledge and ergonomic work station implementation.

1.5.4 Document Holders

Additional office equipment and tools exist that can help prevent musculoskeletal strain, such as a document holders (OSHA, 2006). Bauer and Wittig (1998) found that subjects (n=8) preferred positions of a document holder to be to either side at the same height and distance as the computer monitor compared to below the monitor. The position of the document holder was also noted to have an influence on the posture changes of the head (head inclination), head rotation and eye movements (Bauer & Wittig, 1998). With proper positioning, a document holder can reduce the risk of developing neck, shoulder and eye strain by reducing muscle activity (ibid) Documents positioned too far from the monitor may lead to awkward head positioning or repetitive head movements. The document holder position should also be alternated (i.e. left to right side of the monitor) in order to prevent strain (OSHA, 2006).

1.5.5 Keyboard Position

Proper keyboards and their positioning can have a large impact on the injury risk for neck, shoulder, wrist and hand. Keyboards should be of appropriate size and key-spacing to accommodate most users. Generally, the optimal horizontal spacing between the centers of two keys should be 0.71-0.75 inches (18-19 mm) and the vertical spacing should be between 0.71-0.82 inches (18-21 mm) (OSHA, 2006).

Keyboard location and body posture have been shown to influence the risk of WMSDs, as well. One study found an association between keyboard use and seated posture, on the risk of neck, shoulder, hand and wrist WMSD (Marcus, Gerr, Monteilh, Ortiz, Gentry, Cohen, Edwards, Ensor and Kleinbaum, 2002). In this observational study, 632 newly hired employees who worked a minimum of 15 hours at the computer per week were followed for up to 3 years and were asked to record discomfort in a daily diary. Measurements of workstations and physical exams were also taken of subjects. This data revealed that subjects who had lower keyboard heights (elbow height below the height of the "J" key) had a moderately lower incidence of neck and shoulder discomfort. Horizontal location of the "J" key >12.5 cm from the edge of the desk was also associated with a lower risk of hand and arm discomfort (Marcus et al., 2002).

Keyboard trays allow the user to adjust the keyboard so that arms and wrists can be in a relaxed position close to the body while still at an appropriate distance from the monitor (OSHA). The keyboard should be located below seated elbow height and gently sloped away from the user, known as negative tilt. Negative tilt of the keyboard encourages neutral wrist position, as well as relaxed muscles in the neck, back, shoulders and arms (Hedge, Morimoto & McCrobie, 1999). Keeping the wrist from being extended, flexed, or laterally bent decreases the chance of strain or even CTS. Carpal Tunnel Syndrome occurs when the median nerve, which runs from the forearm into the hand, becomes compressed at the wrist. Compression can occur when the wrist is in a non-neutral position causing the carpal tunnel to narrow or when the tendons become inflamed (National Institute of Neurological Disorders and Stroke [NINDS], 2006). Keyboard trays can be easily adjusted to fit the height and tilt for different users and can usually be stowed away beneath a desk to allow for desk work (Gerr, Marcus & Monteilh, 2004).

Proper keyboard tilt and position can help to reduce the risk of contact stress in the wrist, which can occur internally or externally. Internal contact stress, when a tendon, nerve or blood vessel is bent around a bone or tendon, can result from awkward wrist positions when using a keyboard. External contact stress may be experienced when wrists or forearms are leaning on the edges of work surfaces, as seen in Figure 1.8 below. Numbness or loss of feeling is often associated with contact stress. Tendons can easily be damaged when repetitive motions are performed with awkward wrist positions.

Figure 1.8 Contact Stress from a table edge (OSHA)

1.5.6 Work Surface Depth and Neutral Reach Zone

Most work, either at a computer work station or performing other tasks, should be done within a neutral reach zone. This is the area highlighted in grey in Figure 1.9. where users should locate frequently used devices and perform tasks for easy accessibility by the forearm and with the upper arm in a neutral position (Sanders & McCormick, 1993).

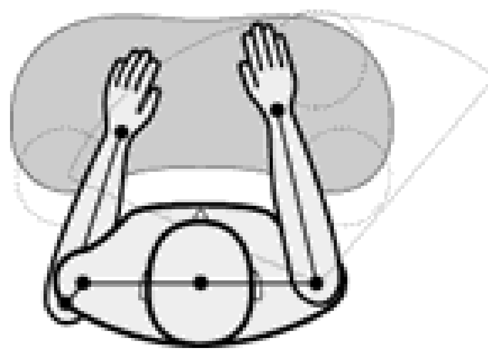

Figure 1.9 Neutral Reach Zone (Sanders & McCormick, 1993)

This area is appropriate for placing a keyboard, mouse, monitor, and other necessary task items and can be used to rest the forearms. Leaning the forearms directly on the work surface has been reported by subjects as an important feature for comfortable computer worktable design (Karlqvist, 1998). However, this only works for forward leaning postures.

Other factors affecting the required work surface area are the type of tasks being performed and the tools needed for those tasks, plus any additional technology or resources needed.

1.5.7 Work Surface Height

Work surface height influences users' posture, the working height of the task, documents or computer monitor, and thigh clearance beneath the work surface. When sitting at a work surface, the body should be in a neutral posture to allow for prevention of strain or discomfort. As mentioned earlier, an important feature of a comfortable workstation found in a study by Karlqvist (1998) is the possibility of leaning the forearms directly on the work surface. Also, there is lower muscle activity in the upper extremities when the forearms are supported during computer related tasks (Aaras et al, 1997). The work surface should be adjusted to a height where the shoulders are relaxed, the upper arms vertical and the forearms horizontal and parallel to the work surface in a relaxed position. An easily adjustable work surface and in combination with chair arm support has been shown to be effective in reducing the risk of musculoskeletal disorders in the neck and shoulders while performing computer work (Delisle, Lariviere, Plamondon & Imbeau, 2006).

Adjustable surface height could impact the range of monitor and document heights, allowing for flexibility between users and tasks. Adjustability of the work surface would also allow for adequate thigh clearances for a range of users and help to avoid awkward postures and exertions (OSHA,2006).

<u>1.5.8 Workstation Chair</u>

To minimize the potential of musculoskeletal discomfort while seated, a properly adjusted chair that allows for neutral posture and is appropriate for the task is critical. Workstation chairs should provide adequate support of the back, legs, buttocks, and arms, which can be done most effectively for a variety of users if chair components are adjustable. The backrest, seat pan, arm rests and base should adjust to best suit the user.

The US Occupational Health and Safety Administrations reports that the back rest should conform to the natural curvature of the spine and provide lower back (known as the lumbar region) support. This can best be accomplished by having a vertically adjustable back rest where the outward curve of the chair can fit to the small of the user's back. The back rest should allow users to recline between 105^{o} and 120^{o} from the top of users' thighs (OSHA). Horizontal adjustments of the back rest or of the seat pan is an important component of the chair design. When correctly positioned, the users' back should be up against the back rest, with their buttocks and thighs fully supported on the seat pan without the front of the seat pan applying pressure to the backs of their knees. Furthermore, the seat should allow users' feet to rest flat on the ground or footrest, armrests should allow relaxed shoulders, and the base should consist of five legs with casters for easy mobility and stability (OSHA).

The effects of adequate workstation posture and chairs on upper extremity discomfort were found in a study by Amick, Robertson, Derango, Palacios, Allie, Rooney and Bazzani (2002). Their research revealed that test subjects who were given an ergonomically designed chair and training experienced lower musculoskeletal symptoms over the workday (after 2 months of intervention implementation) compared to the control subjects or test subjects who only received the training. There was no group effect pre-intervention. Additionally, there was a significant increase in symptom levels for all subjects in the baseline assessment ($p<0.0001$) indicating an improvement in the 2 month intervention period. In a follow up study, the group who received the ergonomic adjustable chair with training significantly lowered symptom growth over the workday ($p=0.012$) after 12 months. Results from training alone showed no significant difference over a workday ($p=0.461$).

1.5.9 Ergonomic Training

In the same study mentioned above which investigated effects of ergonomic training and adjustable ergonomic workstation furniture, no effect of symptom reduction was seen in the training only group over the course of a workday (Amick et al., 2003). However, over the 12 month study, average pain levels reported by the two test groups (chair with training, training only) were reduced over the workday.

Other research looking at the effects of ergonomic interventions including training on musculoskeletal discomfort for office workers have been shown to be positive. In one study, the results showed that an average 40% decrease in reports of musculoskeletal symptoms maintained 12 months after an ergonomic intervention that included ergonomic workstation equipment and training (Rudakewych, Valent-Weitz & Hedge, 2001). Discomfort in eyes, shoulders, arms, hands, wrists, legs, thighs, neck and back were investigated in this study and all reduced in the intervention for the test group (ibid).

In another study evaluating the effectiveness of an active ergonomics training program for computer users, it was found that the training improved users' work postures, work practices, risk factor exposure and pain levels (Goodman, Greene, DeJoy, Olejnik, 2005). This study evaluated 87 subjects who worked at a computer for a minimum of 10 hours per week. The subjects were divided into two groups; a control group with no intervention and a test group that participated in a six-hour ergonomic training session at their work place. Test subjects who, at the baseline assessment had symptoms of WMSD, significantly reduced back pain intensity ($z = -2.03$, $p < 0.05$), pain frequency ($z = -2.70$, $p < 0.01$), and pain duration ($z = -3.25$, $p < 0.01$) post-intervention compared to the control group subjects who reported baseline pain.

It is important that training accompany an ergonomic intervention because many office workers are unaware of ergonomic issues, how to use the equipment properly and how to make adjustments for their specific work, tasks and neutral postures.

The adjustment suggestions provided with fully adjustable workstation furniture is often not followed, as seen in a study by Grandjean, Hunting & Pidermann (1983). Most users adjusted their equipment too high than what was recommended. In the same study it was noticed that computer users leaned back in their chairs causing their arms to be extended upward and forward in a non-neutral posture. This also led to lowering of the eyes and increasing the distance from the eyes to the monitor. These postures lead to an increased risk of musculoskeletal disorders.

1.6 Task Related Risk Factors of WMSDs

Research has revealed that the amount of time spent at the computer, awkward postures, and ineffective workstation configuration are ergonomic risk factors associated with WMSDs. Static body postures, as well as highly repetitive movements, are other leading ergonomic risk factors for work-related injuries. Chronic exposure to ergonomic risk factors may produce cumulative trauma to musculotendinous tissue, which can result in the onset of a WMSD. Chronic problems and long-term disability may result if not appropriately addressed (Bernard, 1997; Gerr et al, 2002; Occupational Health & Safety Agency for Healthcare in British Columbia [OHSAH], 2003).

1.6.1 Repetitive movements

Repetitive motion injuries, also known as cumulative trauma disorders (CTD) occur when an action is repeated over and over (NASD, 2004). Specific research on musculoskeletal disorders have revealed that repetitive hand activity has been associated with symptoms and disorders in the upper extremities (Latko, Armstrong, Franzblau, Ulin, Werner & Albers, 1999; Bao, Spielholz, Howard & Silverstein, 2006) Repetitive hand activity can be defined by external forces (Stetson, Keyserling, Silverstein, Leonard & 1991), hand/wrist movements (Fallentin, Juul-Krustensen, Mikkelsen, Anderson, Bonde, Frost & Endahl, 2001), the repetitive use of the hand (Keyserling, Stetson, Silverstein & Brouwer, 1993) and forearm muscle activities (Cook, Rosecrance, Zimmermann, Gerleman & Ludewig, 1998). Measurement methods have included self-reporting, on-site/off-site observations and direct measurement (Bao et al., 2006).

The most commonly body parts that are affected by repetitive movements include the fingers, hands, wrists, elbows, arms, shoulders, back and neck (NASD, 2004). Repetitive motion injuries for computer users have been found to occur from mousing, typing, other key entry work, repetitive hand tool use, and repetitive actions (NIOSH, 1997).

In a study by Ranney, Wells & Moore (1995), it was found that 54% (N=146) of subjects showed evidence of musculoskeletal injury in the upper extremities from repetitive work in physical assessments. Subjects reported to have muscle pain and tenderness in the shoulders and neck (31%), as well as forearm and hand pain (23%) on the extensor side. Sixteen subjects were diagnosed with CTS and 12 others were found to have tendon disorders, such as DeQuervain's tenosynovitis. Researchers also concluded from study results that muscle tissue is highly vulnerable to overuse (Ranney et al., 1995). Silverstein et al. (1986) found that jobs that require high repetition had a 2.8 odds ratio of injury compared to low repetition. The odds ratio of injury increased to 30.3 if the job required high repetition and high force (force greater than 6 kg) (Silverstein et al., 1986; Ranney et al., 1995).

1.6.2 Work Breaks and Time Spent at the Computer

The consecutive amount of time spent using a computer may also be a risk factor for WMSDs for computer users. Most of the research, especially studies with larger numbers of subjects, shows an increase in the WMSD prevalence with more time spent at the computer. Taking short breaks when using the computer through out the day has also been shown in some studies to help reduce the risk of discomfort. However, other research did not find statistically significant evidence for these conclusions.

One study by McLean, Tingley, Scott and Richards (2001) found that taking frequent, scheduled breaks during a computer work session will help slow the development discomfort for areas of the body such as the neck, back, shoulder, and wrist. Test subjects were asked to perform a three hour computer session with ‘microbreaks’ and it was shown that neck, back, shoulder and wrist pain were reduced significantly ($p<0.001$). It was also concluded in this study that fixed scheduled break were more beneficial than only taking breaks when it was felt necessary. Finally, microbreaks showed no evidence of a detrimental effect on worker productivity.

In a study by NIOSH, short, frequent breaks demonstrated a decrease in worker discomfort and increase in productivity compared to the historical 15-minute morning and afternoon break (Sellers, 1995). Working for more than four hours at a computer or VDU has been found to have significant associations with symptoms of Computer Vision Syndrome (Sanchez, Perez, Velez and Jimenez, 1996). Visual fatigue and possibly other symptoms can be sufficiently prevented with looking away from the monitor into the distance, or out a window, at lest twice an hour (Cheu, 1998).

Similarly, in a study of 205 computer users investigating the amount of time spent on computer based tasks in relation to pain experienced in the head, neck, shoulders, and back found that pain was more frequent among those using a computer for more than 4 hours per day (Fahrbach & Chapman, 1990).

Previous research has revealed insignificant results between associations of upper extremity discomfort and amount of computer use. In a study of 333 office employers, hours of work at a computer workstation per day were not significantly associated with arm, hand and wrist discomfort (Sauter, M.S. Gottlieb, K.C. Jones 1983). Another study of discomfort, demographic characteristics, and computer use among 539 data entry operators, neither months in current job nor weekly hours at the computer workstation were associated with upper extremity discomfort (Sauter, Schleifer & Knutson, 1991).

Bergqvist et al. (1995) conducted a study were 353 office workers were divided into three groups based on the number of hours spent at the computer. It was found that there were no differences for neck, shoulder, hand or arm outcomes between the groups who spent <5 h per week; 5–20 h per week; or ≥20 h per week. However, there was a significant difference in prevalence of arm and hand musculoskeletal outcomes between computer users who worked >20 hours/week and had limited rest break opportunity and no lower arm support compared to those who spent <5 hours/week at the computer (OR=4.6, 95% CI=1.2–17.9).

Furthermore, Evans & Patterson (2000) performed a study investigating neck and shoulder pain in 170 computer users. It was found that 65% of the subjects reported neck or shoulder pain, however no statistically significant associations between prevalence of pain and hours per week of computer use were found.

Although all research does not reveal statistical significance results in terms of amount of time working at a computer and the level of risk of developing pain or risk of WMSD, it seems that shorter lengths of time and taking breaks from computer work would be helpful for improving comfort and would not negatively impact worker productivity.

1.7 Factors and Cost

Numerous factors leading to the development of these injuries have already been investigated. Posture of the torso and upper extremities, keyboard and monitor positioning, and workstation configuration are some examples of risk factors (Hedge, Morimoto, McCorbie, 1999; Gerr, Marcus, Ensor, Kleinbaum, Cohen, Edwards, Gentry, Ortiz, Monteilh, 2002; OHSAH, 2003). These factors not only affect the well-being and health of the worker, but can be detrimental to the level of performance, cause absenteeism and have a high cost for workers' compensation. In fact, the National Research Council and Institute of Medicine found that the total cost of compensation costs, lost wages and lost productivity due to WMSDs were somewhere between $45 to 54 billion annually (NRC/IOM, 2001). Furthermore, the Bureau of Labor Statistics reported that in 2006, the incidences of absences from work for full-time architecture or engineering employees due to illness or injury was 1.9 times per week. In the same report, it was found that architecture and engineering employees lost .9% of hours typically worked due to illness or injury (BLS, 2006). Therefore, it is vitally important that it is understood how the components of a well planned computer workstation and proper positioning can maintain employee health and prevent potential injuries or financial burden (Salvendy, 1997).

Additional factors that have been found to impact the ergonomic needs of office employees, such as psychological factors, work organization, job design and the ambient work environment including air temperature, quality and lighting (Punnet, 1997). However, these additional factors where not the focus of the present study.

1.8 Background of Risk Assessment

The Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993) and was chosen as the ergonomic assessment technique for this study because it quickly evaluates individuals' exposures to postures, forces and muscle activities that have been shown to contribute to WMSDs. RULA was developed to perform ergonomic assessments of workplaces and particularly to assess the development of upper limb disorders, making it an appropriate method for the current study. Use of this ergonomic evaluation approach results in a risk score between one and seven, where higher scores signify greater levels of apparent risk. A low RULA score does not guarantee that the workplace is free of ergonomic hazards, and a high score does not assure that a severe problem exists. The risk score can be used as an action level, which indicates the priority for ergonomic change for a given task. Lower scores and action levels indicate posture is acceptable if not maintained for long periods of time. Higher scores and action levels designate immediate change and investigation is necessary (McAtamney & Corlett, 1993).

1.9 Research Method Validation

In a field study that tested whether monitor placement in a workplace had an effect on the posture and discomfort similar to the effects found in laboratory setting experiments, it was found that the evidence was consistent in both settings (Psihogios, Sommerich, Mirka & Moon, 2001). It was generally preferred by subjects that the monitor be at about a mid-level gaze angle and similar posture discomfort ratings were reported (ibid).

Another research study set out to evaluate the association between subjective and objective indicators of visual strain and to determine the relationship of function visual strain and symptoms of CVS. The study consisted of 404 subjects in an office setting and groups were divided in to those who performed or did not perform work at the computer. Subjective perceptions of visual strain from computer work were confirmed by objective data collected by ophthalmologic and psycho-physiological measurements. It was also concluded from the study that changes in eye function measured at the beginning and end of the day could be used as a good objective index of visual strain and nerve strain. (Ustinaviciene & Januskevicius, 2006)

1.10 Study Rationale

The overall purpose of this study was to evaluate the effectiveness of a LCD monitor arm for employees of an architectural firm by using objective and subjective methods. As of now, there has not been a systematic study of the effects of installing LCD arms in a computerized environment. The present research tested the effects of an adjustable LCD arm on the risk of musculoskeletal disorders comfort, posture and preferences among architectural employees.

Research conducted thus far has not shown an optimal computer monitor position to prevent both WMSDs and CVS. One design issue that has been studied is what the optimal height may be for a computer screen (Sommerich, Joines, & Psihogios, 2001; Seghers, Jochem & Spaepen, 2003; Fostervold, Aaras, & Lie, 2006). Some studies have concluded that more research be done on the adjustability of computer monitors to allow the user to easily position the monitor to a location for legibility and comfort. Another objective of this research was to investigate the relationship between adjustments of their monitor and subjective ratings of discomfort.

1.11 Hypotheses

The following hypotheses have been formulated based on the empirical research reviewed. They are all based on the assumption that an ergonomic intervention will take place: namely, the installation of an LCD monitor arm for test subjects and an ergonomic training program for all subjects.

Hypotheses:

1. The risk of musculoskeletal discomfort in the upper extremities, as measured by RULA scores, will significantly decrease following the installation of a LCD monitor arm along with an ergonomic training program and it will be lower compared to control subjects.
2. The frequency, intensity and interference to work of upper extremity musculoskeletal symptoms will decrease following the installation of an LCD monitor arm along with an ergonomic training program and it will be less compared to control subjects who do not receive a monitor arm.
3. The frequency, intensity and interference to work of symptoms related to headache, neck ache and eye strain will decrease following the installation of an LCD monitor arm along with ergonomic training program and it will less compared to control subjects.
4. Subjects receiving the LCD monitor arms will position their screen at a more comfortable viewing height and distance compared to subjects in the control group.

5. The workstation work surface will increase in usability, such as more area for paper based tasks, following the installation of the LCD monitor arm.
6. Comfort ratings for the workstation, workspace and computer screen will increase after the installation of the articulating LCD monitor arm and be greater for test subjects compared to control subjects.
7. Satisfaction ratings for workstation, workspace and computer screens will increase following the installation of the monitor arm and these will be greater for the test group and be greater compared to the control group.
8. RULA scores are predicted to correlate positively with the frequency of upper extremity discomfort and the frequency of eye and head discomfort in the baseline and control subjects, but not for the test subjects following the intervention.

Chapter 2: Methods

2.1 Experimental Design

A mixed design field experiment was conducted to test the effects of a flat panel monitor (FPM) arm. Three waves of data collection occurred. Wave 1 was a baseline survey and observation taken in March 2006 of all subjects before they were randomly assigned to test and control groups. After groups were assigned, test subjects had a flat panel monitor arm installed and all subjects received ergonomic training. Waves 2 and 3 of data collection occurred post installation in June, and again in October 2006, when surveys and observations were repeated. Figure 2.1 depicts the experimental design. This protocol was approved by the University Committee on Human Subjects.

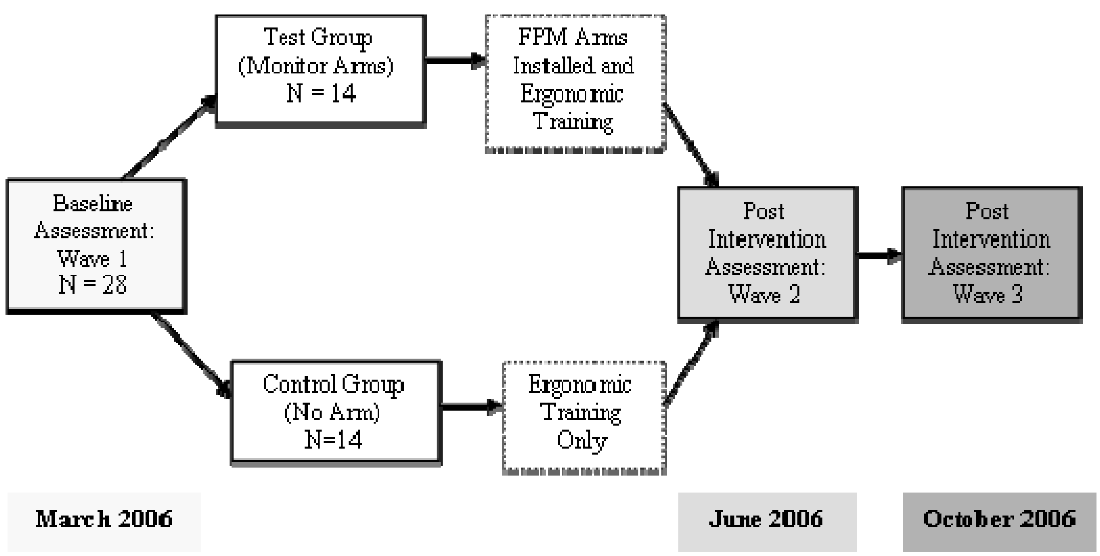

Figure 2.1 Research Design

2.2 Subjects

Employees of a New York City architecture and design firm, Mancini Duffy, were asked to participate in this study if they worked 3 or more days a week at the office, performed at least 70% of their work during a typical day at their computer work stations and used an ergonomic adjustable keyboard tray. Of those employees eligible to participate, twenty eight (16 women and 12 men ranging in age from 20- 60 years) volunteered for the first wave of data collection. Five subjects were from Accounting, one from Facility Planning/Special Services, nine from Marketing and Business and thirteen Project Architects. Office telephone extensions were used as assigned identification numbers that were used to compare the survey responses and the physical data collected.

All subjects were observed and had measurements taken of their body in relation to their computer work station. Twenty-seven of twenty eight subjects responded to an online web survey. The subject who did not respond was contacted and eliminated from the remainder of the study.

Four subjects of the study did not use a keyboard tray or mouse platform, but rather placed both on the desk surface. One of these four had a tray, but was unable to use it because the cord attached to the keyboard was not long enough for it to be put on the tray. Another subject added the keyboard tray in the second wave and a third subject did not participate in the second or third wave of data collection. Twenty four subjects used their keyboard tray. Six of the subjects who used the keyboard trays did not use the mouse platform attached to the tray. Instead, they utilized the mouse on the desk surface.

For the post-installation wave 2, 23 responded to the online survey and were observed and measured. Twenty subjects responded to wave 3, the final online survey and were again observed and measured (See Table 2.1). The phone extension identification numbers remained the same throughout the three waves of data collection.

Table 2.1: Subject Gender by Wave of Data Collection

	Wave 1	**Wave 2**	**Wave 3**
Females	16	13	12
Males	12	10	8

2.3 Ergonomic Intervention

For subjects in the test group, a flat panel monitor arm (Humanscale Model M7) (See Figure 2.2) was installed at their workstation and affixed to the existing monitor and desk. The monitor arm has three joints that allow for horizontal adjustability, which can be extended up to 18.5" from the base of the arm to the monitor . In addition, the height can be adjusted and has a 60^{o} lateral and vertical monitor tilt capability. The arm is made of 100% recycled aluminum and weighs about 10lbs. The monitor arm has the ability to hold a flat panel monitors' weight of 7lb-35lbs and can also rotate 60^{o} laterally and vertically for tilt adjustments.

All subjects received ergonomic training that consisted of general overview of workstation components that can be adjusted and how they can be adjusted to allow for neutral postures. This was administered by an outside source and not the researcher.2.4 Work Environment

All subjects in the study were located in the same, third floor office of the Mancini Duffy Architecture and Design firm in New York City. Twenty four subjects' were at cubicle workstations in an open office area randomly throughout the floor. Four subjects were located in private outer perimeter offices.

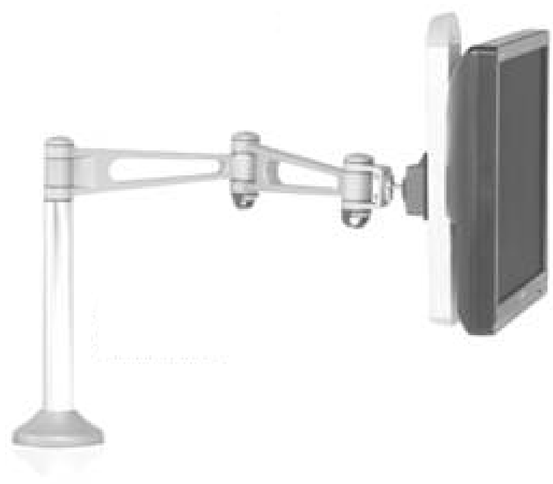

Figure 2.2 Flat Panel Monitor Arm (Humanscale Model M7B)

All subjects used the same computer, 19" liquid crystal display (LCD) monitor and an adjustable chair (Aeron by Herman Miller). Subjects in the study used a keyboard tray (Humanscale 2G mechanisms with 900 board (19"), an 8" swivel mousing surface on right and left sides, gel palm support and 22" track). Two subjects chose not to use their tray although equipped. Two other subjects were in the process of getting a tray installed for their desk and one additional subject was not able to use her tray because cords for the keyboard were too short.

Workstation configurations and desk dimensions varied slightly. Twenty-two subjects worked at a desk with a 90^{o} angle (Appendix A) while five subjects were at desks with a rounded cutout where the keyboard tray was placed (Appendix B).

2.5 Research measures

2.5.1 Survey

For each of the three waves of data collection subjects were emailed a link to an online web survey to be filled out individually prior to the physical measurements data collection. In each survey, information was gathered about each subject's comfort and satisfaction levels with workstation equipment, workstation usage, the comfort of eleven upper body regions, and information about headache and eye strain. Many of the questions allowed to subject to choose from a few pre-selected answers or allowed a rating using a Likert scale. Appendix F, G and H show the online surveys for the three waves.

The use of subjective data collection was validated in a research study by Lindgegard et al (2005). They investigated the concordance between ratings of comfort and exertion by subjects and observations of workplace layout and posture collected by an ergonomist. They found that concordance between the subject ratings from the questionnaire and observations were fairly good overall. Ratings and observations of the workstation chair and keyboard were very close (0.60, 0.58), as well as ratings of the screen and mouse in the questionnaire and observations (0.72, 0.61). "Concordance between ratings of perceived exertion and observations of working postures indicated good agreement (0.63-0.77) for all measured body locations (neck, shoulder, wrist and trunk)" (Lindegard et al., 2005). This study concluded that observations and questionnaires could both be used as cost effective and reliable methods to identify high exposure to poor workstation layout and working posture.

2.5.2 Physical Measurements

Initial physical measurements were recorded by the researcher on March 21st and 22nd, 2006 at the Mancini Duffy office in NYC. A standard measuring tape was used to measure the following distances: from the eye to the monitor; from the center torso to the bottom of monitor; from the center torso to the desk; the horizontal distance from the center of the mousing wrist to the center of the shoulder; and the mousing wrist to the center torso. The dimensions of utilized space and total work surface area of subjects' desks were measured. Photographs were also taken (Appendix A-E) while subjects performed typical workstation tasks.

The second wave of physical measurements was taken on June 13th, 2006 and the third wave of physical measurements was taken on October 10th, 2006. The same measurements of the workstation components and the subjects were taken for each wave of data collection. All measurements were recorded on an observation checklist in each wave of data collection (See Appendix I)

2.5.2a Demographics

In the online survey administered in wave 1, background information was collected on subjects' age, gender, corrective lens use, length of time worked at their desk and the amount of time spent on different tasks at their desk. A sample question is shown below.

2.5.2b Workstation Satisfaction and Comfort

For all three online surveys, work station satisfaction and comfort were questioned. Subjects were asked if they had adequate amounts of work space, how often they were comfortable with the distance of their monitor, and the level of satisfaction with the arrangement of workstation equipment.

2.5.2c Musculoskeletal Discomfort, Frequency and Interference

The last portion of each survey questioned the frequency of discomfort, the level of discomfort and the amount of discomfort interference of specific upper extremities. Frequency of discomfort was measured on a scale consisting of answers: never, 1-2 times last week, 3-4 times last week, once every day and several times a day. The level of discomfort was measured from slightly uncomfortable to very uncomfortable. The amount of interference was measured with answers: not at all, slightly interfered, and substantially interfered. Questions regarding frequency and interference of symptoms were based on surveys previously conducted by Hedge et al. (1996) dealing with predictors of sick building syndrome.

2.5.2d Flat Panel Monitor Arm Usage and Opinion

Additional questions were asked in the second online survey for subjects who received the flat panel monitor arms. The questions asked their opinion of the monitor arm and how often they used it. Questions were asked of all subjects on their opinion of the ergonomic training the received since the first wave of data collection.

In the final online survey, subjects in the test group were asked again about their opinions of the flat panel monitor arm and also if it assisted in their interactions with colleagues.

Each of the three online surveys, for all subjects, concluded with an open-ended question for general comments. All survey questions were programmed to be validated to avoid missing responses. Twenty one subjects completed all three web-based surveys by November 2006.

2.5.3 Risk Assessment

The Rapid Upper Limb Assessment (RULA), developed by McAtamney and Corlett (1993), was used to assess risk factor exposure at the computer workstation (See Appendix J). This method was chosen as the ergonomic assessment technique for this study because it quickly evaluates individuals' exposures to postures, forces and muscle activities that have been shown to contribute to Work Related Musculoskeletal Disorders. RULA scores are based on the postural angles of the user's neck, back, and upper extremities, such as the wrist and forearm; how long postures are sustained; and how often the postures occur during the observed period. The risk score can indicate an action level and determine the priority for ergonomic change for a given task. Possible total scores range from 1, low injury risk, to 7, indicated poor posture or long durations and a very high risk for injury. Table 2.2 shows the relationship of total RULA scores and the implications to the working environment.

Table 2.2: Interpretation of RULA Scores (McAtamney and Corlett, 1993)

RULA SCORE	Implication for Work Environment
1-2	Posture is acceptable if it is not maintained or repeated for long periods of time.
3-4	Further investigation is needed and changes may be required.
5-6	Further investigation and changes are required soon.
7	Further investigation and changes are required immediately.

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Additional studies have been conducted by McAtamney and Corlett (1993) that have shown a significant relationship between RULA scores and perceived discomfort for both individual areas of the body and for the overall upper body, furthering the reliability of RULA. In their first experiment, a validation of the tool with an experiment of experienced visual display unit operators in a laboratory setting was conducted. Sixteen subjects (1 male, 15 female) were given a data entry task of 40 minutes in one of two postures. They were asked to perform 8 tasks total (four in each posture) with a height adjustable chair and monitor stand. Before and after each test subjects were asked to report any pain, aches or discomfort. The aim of the study was to determine if the RULA method could reflect whether or not the postures were acceptable and to determine the relationship between the self reports of discomfort with the objective RULA scores. The relationship of the individual RULA body part scores to the development of pain or discomfort was statistically significant for the neck and lower arm scores ($p<0.01$), but was not for the trunk, upper arm or wrist. Additionally, functional units, or grouped individual body area in the same region (i.e. upper arm, lower arm, wrist and hand), were found to be highly statistically significant with the reports of pain and discomfort ($p<0.01$).

Also, RULA has been compared to other assessment techniques to prove its validity, such as in a study conducted by Fountain (2002) that examined the relationship between RULA scores and self-reports of discomfort. The results showed a statistically significant difference between perceived discomfort and the RULA scores, demonstrating that RULA was able to identify 'high' risk postures. Also, a study by Drinkaus, Sesek, Bloswick, Bernard, Walton, Joseph, Reeve & Counts (2003) compared the RULA assessment to the Strain Index. The Strain Index uses both qualitative and quantitative variables, such as task duration and speed of task, to determine a risk level. The Strain Index also focuses on hand operations, where the RULA looks at body angles of the whole upper extremities. Little agreement was found between the outputs of the two tools, but it was noted by the authors that the RULA assessment would be more appropriate for measuring tasks that appeared to involve sedentary work and more awkward seated postures.

Furthermore, in the McAtamney and Corlett original study using the RULA method, the reliability was tested by comparing the scores given by 120 subjects of images of operators performing a variety of tasks. The comparisons of results showed a high consistency of scoring among the subjects. Exact data is not provided.

In the present study, RULA data was collected based on keyboarding and mousing tasks. During the assessment process and observation, specific tasks were not assigned to the subjects. However, subjects were instructed to either continue with the work on the computer they were doing at the time or to perform a typical computer task, such as checking their email. In this study, the RULA was used for assessing one side of the body, typically the one that is exerting the most force or experiencing the most strain or discomfort. In the present study, the side of the body assessed with the RULA method was based on which hand the subjects used their computer mouse. Since most people in this study used their right hand for mousing, the right side of the body was assessed more frequently.

Many studies have used the RULA method created by McAtamney and Corlett, however, there have only been few studies have actually examined the validity and reliability of this method as an assessment tool compared to subjective data. Due to the lack of research, this study will also compare RULA scores, self-assessments, and objective measurements as an added proof of validity for the RULA method.

2.6 Experimental Procedure

Approximately a week before the scheduled data collection, an email was sent to Rachel Casanova, a contact at Mancini Duffy, who then forwarded the email to subjects asking them to follow a link to an online survey created by the researcher.

The survey asked for subjects' last four digits of their phone extension since all subjects had a desk phone, which was used as subject identification to link subjective and objective data.

Measurements were taken at the workstation of each of the subjects. The subject's identification number was recorded on an observation checklist (See Appendix I). Next, with the subject in a typical computer working posture, the researcher took the physical measurements. Observations were made then made to about the workstation components and work surface utilization. The use of foot rests, document holders, keyboard trays and mouse trays were also noted. Then, observations of subjects' working posture was made and recorded in the RULA form (See Appendix J). Finally, photographs were taken of each subject for future reference of posture and work space utilization.

The same procedure was administered twice more with an online survey preceding the field research. The difference between the baseline data collection and the two post installation data collection waves was that additional questions were asked informally by the researcher for subjects who received the flat panel monitor arm. Comments and concerns of the subjects were recorded by the researcher for all waves of data collection.

2.7 Data Analysis

All data initially were coded into Microsoft Excel spreadsheets and subsequently imported into in a multivariate statistical package (SPSS version 15) for analysis. An Upper Limb Musculoskeletal Disorder (ULMSD) index was created by summing the frequency of symptoms of neck, left/right shoulder, left/right upper arm, left/right forearm, left/right wrist and left/right hand. This index ranged from 11 through 55, with higher scores indicating more and more frequent symptoms. A computer vision syndrome (CVS) index was the sum of the frequency of headaches, tired eyes, and eyestrain to create a scale from 3 through 15, with higher scores indicating more frequent symptoms.

Chi-Square tests were used to test the significance of the differences between the test and control groups. Values found between waves 1 and 2 and between waves 1 and 3 were calculated for responses to individual questions and also tested with a Chi-square. Pearson correlations were computed to assess the significance of associations between RULA scores and subjective discomfort ratings. An independent samples t-test was used to compare demographic variables between groups.

Chapter 3: Results

3.1 Sample Characteristics

In wave 1, the sample consisted of 16 women and 12 men who were randomly assigned to test and control groups. Fifteen subjects were assigned to the control group and 13 were assigned to the test group. The demographic characteristics of the groups were compared to ensure no selection bias. There were no statistically significant differences between the groups for age, tenure, work days, work hours, and the amount of time spent working with paper, on the work surface and at the computer. The mean group responses are shown in Table 3.1 and the results of the independent sample t-test are shown in Table 3.2.

Table 3.1 Wave 1 Sample Characteristics

	Test		**Control**	
	Mean	Std. Deviation	Mean	Std. Deviation
Tenure	4.46	.66	4.40	1.29
Work Days	4.62	.768	4.87	.64
Work Hours	6.15	1.35	6.53	1.81
Age	37.31	10.13	40.0	10.52
Paper Hours	2.85	1.86	3.00	2.56
Work Surface Hours	3.23	2.74	3.00	2.39
Computer Hours	4.54	1.13	4.80	1.94

Table 3.2 Independent Samples Test for Sample Characteristic

t-test for Equality of Means

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI	
						Lower	Upper
Tenure	-.154	26	.879	-.062	.399	-.882	.759
Work Days	.945	26	.353	.251	.266	-.295	.798
Work hours	.622	26	.539	.379	.610	-.875	1.634
Age	.987	26	.498	2.692	3.919	-5.363	10.748
Paper Task Hours	.179	26	.859	.154	.859	-1.612	1.920
Work Surface Hours	-.238	26	.814	-.231	.970	-2.224	1.763
Computer Task Hours	.428	26	.672	.262	.611	-.995	1.518

Twenty three subjects were measured and observed in the second wave, although twenty five filled out the online survey. Twenty subjects were measured, observed and filled out the survey for the third wave of data collection. Of the subjects in the last wave of data collection, 8 were men and 12 were women. The number of subjects in each wave of data collection is shown in Table 3.3 below.

3.1.1 Gender Effects

A one-way ANOVA test was performed to see effects of gender on indices created for ratings of musculoskeletal discomfort. No significant gender effects were found from this test.

Table 3.3 Number of Subjects by Wave

	Wave 1	Wave 2		Wave 3	
	All	Test	Control	Test	Control
Men	12	2	7	5	6
Women	16	9	4	7	3
Total	28	11	11	12	9

3.1.2 Work Allocation

The majority of all subjects (89.3%) spent a total of 5-8 hours at the office per day. Questions regarding the number of hours spent on paper tasks, computer tasks and work surface tasks were only asked in the baseline survey. Of the sample, 67.9% (19) Ps had been at their current work station for more than 6 weeks and 78.6% (22) worked 5 days a week, 7.1% (2) worked 4 days a week, and 10.7% (3) worked 3 days a week. The breakdown of work tasks was that 96.4% (27) reported spending 3 or more hours a day on computer tasks; 75% (21) spent 1-3 hours per day on paper tasks; and 57.1% (16) working more than 1 hour per day on their work surface (Figure 3.1).

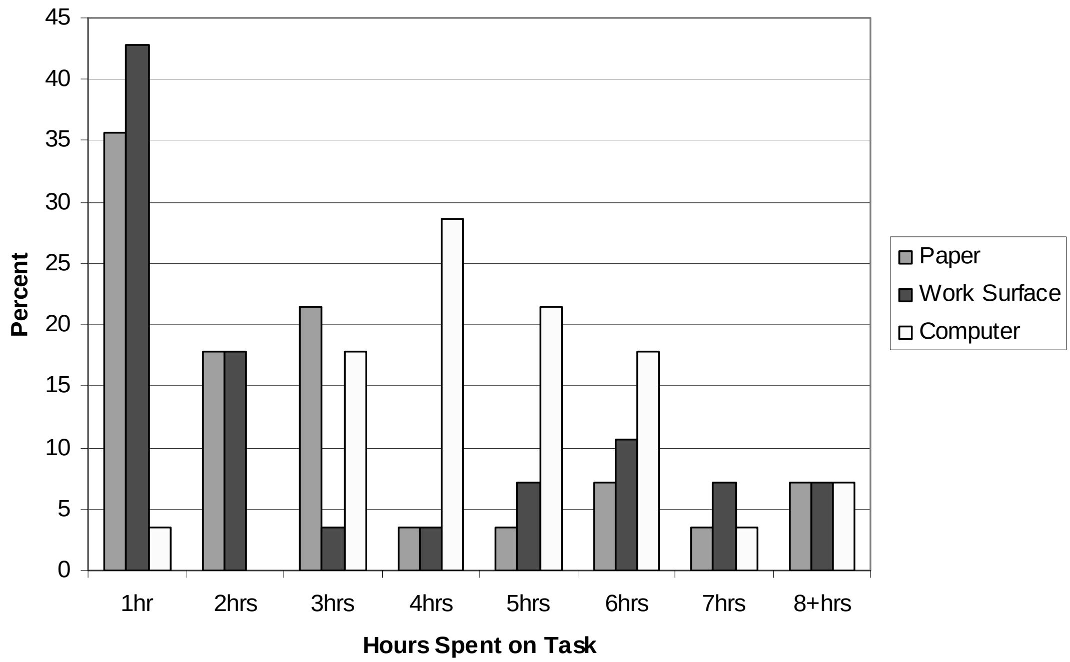


Figure 3.1: Percent of Paper, Work Surface, and Computer Tasks Wave 1

3.1.3 Corrective Lenses

There was no significant difference between groups of the number of subjects who wore corrective lenses. It was reported that about half in each group wore some type of corrective lens (See Table 3.4). Six subjects reported that they used regular glasses in addition to contact lenses. Additionally, some subjects reported that they wore more than one type of corrective lens.

Table 3.4: Types of Lenses Worn by Groups

	None	**Regular Glasses**	**Trifocals**	**Reading Glasses**	**Bifocals**	**Contact Lenses**
Control	7	4	1	2	0	4
Test	7	4	0	0	2	3

3.2 Group Comparisons

3.2.1 Viewing Height Comfort

The test group in waves 2 and 3 reported being able to find a comfortable view height for their monitors more frequently than the control group. As seen in Table 3.5, 4 (30.8%) of the test group in wave 1 said their monitor was always at a comfortable viewing height. By the second wave, 8 (66.7%) reported their screen was always at a comfortable viewing height and in the third wave this increased to 9 (90%) subjects. Of the control group, 6 (40.0%) reported that their screens were always in a comfortable viewing height in the baseline data collection. In the second wave and third waves the number of subjects who always had their monitors at a comfortable viewing height decreased to, 2 (13.3%) subjects and 3 (30%) subjects, respectively.

There was a statistically significant difference in mean responses for test and control groups in wave 3 (p=.023). Additionally, the change in responses for the test and control group were found to be significantly different between waves 1 and 2 (χ^2=6.97, df=2, p=.031), but not between waves 1 and 3 (χ^2= 6.67, df=2, p=0.36).

Table 3.5 Frequency for Screen at Comfortable Viewing Height

	Test Group			**Control Group**		
Response	**Wave 1**	**Wave 2**	**Wave 3**	**Wave 1**	**Wave 2**	**Wave 3**
Never	0	0	0	1	0	0
Hardly Ever	0	0	0	0	0	0
Some of the Time	1	0	0	1	1	1
Most of the Time	**8**	4	1	**7**	**8**	**6**
Always	4	**8**	**9**	6	2	3

3.2.2 Viewing Distance Comfort

There was not a statistically significant difference in mean responses for test and control groups in any of the three waves. There was also a trend for the frequency of comfortable viewing distance to increase among the test group. In wave 1, test and control subjects were similar in their responses to viewing distance. Post installation in wave 2, 100% (N=12) of the test group reported that their monitor was in a comfortable viewing distance ‘most’ or ‘all of the time’. The number of responses for having the monitor at a comfortable viewing height ‘all of the time’ increased to 70% for the test subjects in the final wave (Table 3.6).

Table 3.6 Percent Responses of Comfortable Viewing Distance for Monitor

	Test Group			**Control Group**		
Response	**Wave 1**	**Wave 2**	**Wave 3**	**Wave 1**	**Wave 2**	**Wave 3**
Hardly Ever	7.7	0	0	0	0	10
Some of the Time	7.7	0	0	16.7	27.3	10
Most of the Time	**53.8**	**50**	30	**58.3**	**54.5**	**50**
Always	30.8	**50**	**70**	25	18.2	30

3.2.3 Reading Distance Comfort

There was not a significant difference in the responses for test and control group in wave 1 for frequency of finding a comfortable reading distance of the monitor. However, there was a significant difference in the responses in wave 2 (p=0.035), but no significant difference in wave 3. Table 3.7 shows that in wave 1, 4 (30.8%) of test subjects and 4 (26.7%) of control subjects reported that their screen was always at a comfortable viewing distance. Of the test subjects post installation, 5

(41.7%) in the second wave and 6 (60%) in the third wave thought their monitor was always comfortable for reading. Of the control subjects in the second wave, only 1 (9.1%) reported their monitor was always at a comfortable reading distance. 6 (54.5%) said it was most of the time and 4(36.4%) reported it was some of the time at a comfortable reading distance. The responses in the third wave for control subject were the same as the second wave, except that there was one less subject who responded.

Table 3.7 Percentage of Responses for Comfortable Reading Distance

	Test Group			**Control Group**		
Response	**Wave 1**	**Wave 2**	**Wave 3**	**Wave 1**	**Wave 2**	**Wave 3**
Never	0.0	0.0	0.0	6.7	0.0	0.0
Hardly Ever	7.7	0.0	0.0	0.0	0.0	0.0
Some of the Time	7.7	0.0	0.0	20	36.4	10.0
Most of the Time	**53.8**	**58.3**	40.0	**46.7**	**54.5**	40.0
Always	30.8	41.7	**60.0**	26.7	9.1	**50.0**

3.2.4 Screen Satisfaction

The greatest level of satisfaction reported by the test group was for their monitors after the installation of the flat panel monitor arm (See Table 3.11). Additionally, test group reports for 'very satisfied' of their computer screen rose considerably from the first wave (N=5, 38.5%) to the second wave (N=11, 91.7%). The responses for the control group wavered throughout the study, but were generally positive for screen satisfaction (Table 3.8).

The test group reported being significantly more satisfied with their computer screen in survey 2 ($\chi2$=19.39, df=2, p=0.000; test group = 91.7% vs. control group = 0% reported being 'very satisfied') and survey 3 ($\chi2$=7.37, df=2, p=0.025; test group = 80% vs. control group = 20% reported being 'very satisfied')

Table 3.8 Screen Satisfaction

	Test Group						**Control Group**					
	Wave 1		**Wave 2**		**Wave 3**		**Wave 1**		**Wave 2**		**Wave 3**	
Response	N	%	N	%	N	%	N	%	N	%	N	%
Very Unsatisfied	2	15.4	0	0	0	0	0	0	0	0	0	0
Fairly Unsatisfied	1	7.7	0	0	0	0	0	0	0	0	1	10
Fairly Satisfied	5	38.5	1	8.3	2	20	8	**66.7**	2	18.2	7	**70**
Very Satisfied	5	**38.5**	11	**91.7**	8	**80**	4	33.3	9	**81.8**	2	20

3.2.5 Screen Height Comfort

By survey 2 the test group reported being marginally significantly more frequently satisfied with their screen height ($\chi2$=5.90, df=2, p=0.052; test group = 66.7 vs. control group = 18.2% reported 'always') but this was very significant by the survey 3 ($\chi2$=7.57, df=2, p=0.023; test group = 90% vs. control group = 30% reported 'always').

3.2.6 Screen Comfort

There was a statistically significant difference between the test and control groups for wave 2 (χ^2=12.9, df=2, p= 0.002), but not for responses in waves 1 or 3.

There was no significant difference between the changes in response between any of the waves. The percents of responses for screen comfort are listed in Table 3.9.

Table 3.9 Percent of Screen Comfort

	Test Group			**Control Group**		
Responses	**Wave 1**	**Wave 2**	**Wave 3**	**Wave 1**	**Wave 2**	**Wave 3**
Very Comfortable	38.5 %	**83.3**%	**70**%	26.6%	9.1%	20%
Fairly Comfortable	**46.2**%	16.7%	30%	0%	**72.7**%	**70**%
Fairly Uncomfortable	15.4%	0%	0%	**66.6**%	18.2	10%
Very Uncomfortable	0%	0%	0%	6.6%	0%	0%
Not Applicable	0%	0%	0%	0%	0%	0%

3.2.7 Collaborative Work

In survey 3 test Ps were asked 'how often they meet with colleagues at their workstation to look at screen information', and 33.3% (N=3) said several times per day; 22.2% (N=2) said 1-2 times per day; 22.2% (N=2) said 3-4 times per week, and 22.2% (N=2) said 'hardly ever'. Related to this, 44.4% (N=4) of test Ps said the FPMA made it 'much easier' to show screen information to others, and 44.4% (N=4) said it was 'somewhat easier'.

3.2.8 Work Surface Area

Twenty-three subjects worked at a desk with a right angle corner and five subjects were at desks that had rounded corners (See Appendix A and B) where the keyboard tray was located. There was not a significant difference in the amount of available work surface area in the baseline survey between groups (test group = 21%, control group = 16%).

Fourteen (51.9%) subjects reported in wave 1 that the amount of work surface area at their personal workstation was inadequate. Seven of the respondents who had insufficient work surface area were project architects.

The number of subject responses for 'not enough' work surface area decreased in each of the two waves of data collection post intervention, however the number of responses for 'very ample' remained constant (See Table 3.10). There were 8 subjects in the test group who did not change their answers from wave 1 to 2. Two subjects said they had more space and two others reported to have less space from wave 1 to wave 2. Additionally, when the responses for workstation area were compared between test and control for each of the three waves, no significances differences were found.

Table 3.10 Responses for Amount of Work Area at Workstation

	Test Group						**Control Group**					
	Wave 1		**Wave 2**		**Wave 3**		**Wave 1**		**Wave 2**		**Wave 3**	
Response	N	%	N	%	N	%	N	%	N	%	N	%
Very Ample	1	7.7	1	8.3	1	10.0	1	8.3	0	0.0	0	0.0
Enough	6	46.2	6	50.0	6	60.0	8	66.7	7	63.6	5	50.0
Not Enough	6	46.2	5	41.7	3	30.0	3	25.0	4	36.4	2	50.0

3.2.9 Workstation Component Satisfaction

When asked about the satisfaction of their workstation workspace, subjects in both the control and test groups mostly responded as 'fairly satisfied' for all three waves of data collection (See Table 3.11). There was no statistically significant change in responses seen between the waves of data collection.

Table 3.11: Workspace Satisfaction

	Test Group						**Control Group**					
	Wave 1		**Wave 2**		**Wave 3**		**Wave 1**		**Wave 2**		**Wave 3**	
Response	N	%	N	%	N	%	N	%	N	%	N	%
Very Unsatisfied	1	7.69	0	0.0	0	0.0	1	8.3	2	18.2	1	10.0
Fairly Unsatisfied	1	7.69	3	25.0	1	10.0	2	16.6	1	9.1	2	20.0
Fairly Satisfied	**9**	**69.2**	**7**	**58.3**	**6**	**60.0**	**7**	**58.3**	**8**	**72.7**	**7**	**70.0**
Very Satisfied	2	15.3	2	16.6	3	30.0	2	16.6	0	0.0	0	0.0

In all three waves, most subjects reported that they were 'fairly' or 'very satisfied' with the rest of the components of their workstation, including their keyboard, chair, and mouse (Table 3.12, next page). There were no significant changes in responses between the three waves.

Table 3.12 : Percentage Satisfaction Responses for Workstation Components

		Very Unsatisfied	**Fairly Unsatisfied**	**Fairly Satisfied**	**Very Satisfied**
Keyboard	Test 1	23.1	23.1	**38.5**	15.4
	Test 2	8.3	33.3	16.7	**41.7**
	Test 3	20.0	20.0	20.0	**40.0**
	Control 1	0	8.3	**66.7**	8.3
	Control 2	9.1	**45.5**	36.4	9.1
	Control 3	10.0	30.0	**40.0**	20.0
Mouse	Test 1	23.1	**30.8**	**30.8**	15.4
	Test 2	8.3	25.0	**50.0**	16.7
	Test 3	20.0	30.0	10.0	**40.0**
	Control 1	0.0	8.3	**75.0**	16.7
	Control 2	0.0	18.2	**81.8**	0.0
	Control 3	0.0	30.0	**50.0**	20.0
Screen	Test 1	15.4	7.7	38.5	**38.5**
	Test 2	0.0	0.0	8.3	**91.7**
	Test 3	0.0	0.0	20.0	**80.0**
	Control 1	0.0	0.0	**66.7**	33.3
	Control 2	0.0	0.0	18.2	**81.8**
	Control 3	0.0	10.0	**70.0**	20.0
Chair	Test 1	7.7	23.1	**53.8**	15.4
	Test 2	0.0	8.3	**66.7**	25.0
	Test 3	10.0	10.0	**40.0**	**40.0**
	Control 1	0.0	8.3	**66.7**	25.0
	Control 2	9.1	18.2	**63.6**	9.1
	Control 3	0.0	0.0	**60.0**	40.0

3.2.10 Frequency of Monitor Movements

When asked how often the computer screen is moved to make room on the work surface, responses in the baseline study were mostly never or hardly ever (86%, N=24). Only 4 (14%) of the wave 1 subjects reported moving their screen a few times a week or about once a day.

The same question was asked in the second and third waves of data collection for all subjects. There was no significant difference in the different scores for the frequency of monitor movement between any of the waves, but as seen in Table 3.13, five test subjects reported increasing the frequency of moving their screen between waves 1 and 3 compared to only one of the control subjects. A greater number of control subjects responded with the same answers in all three waves compared to the test group responses.

Table 3.13 Change in Response for Monitor Movement from Wave 1 to 3

Change in Response	**Test**	**Control**	**Total**
Less Frequent Movement (-1)	2	2	4
No change (0)	3	7	10
More movement (1)	5	1	6
Total	10	10	20

3.2.11 Workstation Comfort

There was no statistically significant change in keyboard comfort between the three waves for the test and control groups. Overall, most respondents were fairly comfortable with the components of their workstation throughout the course of the study. However, 4 (40%) of the test group in wave 3 described their mouse as ‘fairly uncomfortable’ and 2 reported that their chair was ‘fairly’ or ‘very uncomfortable’ (Table 3.14).

Table 3.14 Responses for Workstation Component Comfort

		Very Comfortable	Fairly Comfortable	Fairly Uncomfortable	Very Uncomfortable
Keyboard	Test 1	7.7	**46.2**	30.8	15.4
	Test 2	8.3	**66.7**	25.0	0.0
	Test 3	30.0	**50.0**	20.0	0.0
	Control 1	0.0	**58.3**	33.3	0.0
	Control 2	0.0	**63.6**	27.3	9.1
	Control 3	10.0	**70.0**	20.0	0.0
Mouse	Test 1	7.7	**46.2**	46.2	0.0
	Test 2	8.3	**66.7**	25.0	0.0
	Test 3	10.0	**50.0**	40.0	0.0
	Control 1	8.3	**91.7**	0.0	0.0
	Control 2	0.0	**81.8**	18.2	0.0
	Control 3	10.0	**70.0**	20.0	0.0
Chair	Test 1	23.1	**46.2**	23.1	7.7
	Test 2	25.0	**58.3**	16.7	0.0
	Test 3	23.1	**38.5**	7.7	7.7
	Control 1	25.0	**66.7**	8.3	0.0
	Control 2	16.7	**66.7**	8.3	0.0
	Control 3	16.7	**66.7**	0.0	0.0

3.2.12 Storage

Although the difference in responses was not statistically significant, in wave 1 61.4% (N=8) of the test subjects reported to be unsatisfied with their storage. After the implementation of the ergonomic intervention, test subjects responded more frequently to being 'fairly satisfied' or 'very satisfied' with their workstation storage. Four test subjects reported a positive change in their storage and no one reported a negative change from wave 1 to 2. However, in the control group, the there were 3 subjects who reported a strong negative change in their storage satisfaction from wave 1 to 2 (See Table 3.15).

Table 3.15 Storage Satisfaction

	Test Group						Control Group					
	Wave 1		Wave 2		Wave 3		Wave 1		Wave 2		Wave 3	
Responses	N	%	N	%	N	%	N	%	N	%	N	%
Very Unsatisfied	4	30.8	2	16.7	1	10	1	8.3	1	8.3	2	16.7
Fairly Unsatisfied	4	30.8	4	33.3	5	50	6	50.0	5	41.7	4	33.3
Fairly Satisfied	5	38.5	6	50	2	20	4	33.3	3	25.0	3	25.0
Very Satisfied	0	0	0	0	2	20	1	8.3	1	8.3	1	8.3

3.2.13 Headaches

There was no statistically significant difference between the reports of headache frequency or between the headache indexes of the two groups for any wave. The responses for frequency of headaches are shown in Figure 3.2.

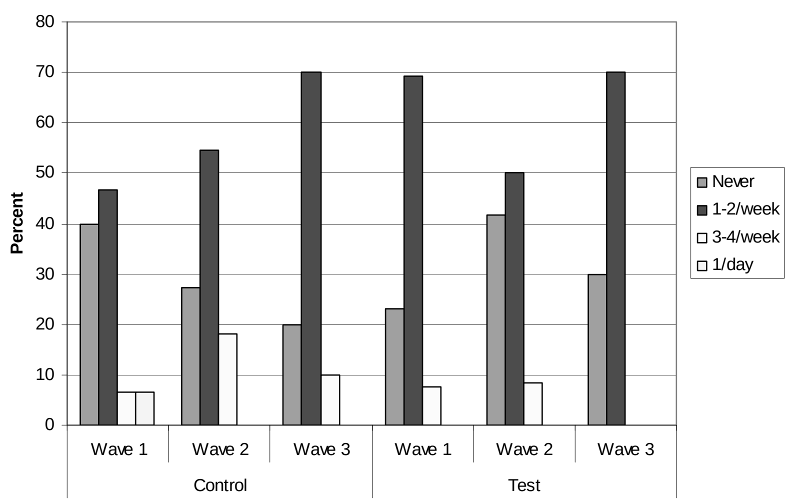


Figure 3.2: Percent Response for Frequency of Headaches (Mean ± S.E.)

3.2.14 Eyestrain and Tired Eyes

Although it was hypothesized that there would be a significant differences in the chance in response for eyestrain, none were found. There was also no significant difference between groups in any of the waves for responses to frequency of tired eyes. This may have been due to the fact that there were not many responses in total by the subjects. However, there was a tendency for less frequent experiences of eyestrain and tired eyes in both groups. The percent of responses for eyestrain and tired eyes are shown in Tables 3.16 and 3.17.

Table 3.16 Percent of Reported Eyestrain by Wave and by Group

	Control Group			**Test Group**		
	Wave 1	**Wave 2**	**Wave 3**	**Wave 1**	**Wave 2**	**Wave 3**
Never	33.33	72.73	50.00	15.38	41.67	60.00
1-2/last week	40.00	9.09	40.00	46.15	50.00	30.00
3-4/last week	20.00	18.18	10.00	23.08	8.33	10.00
1/day	6.67			15.38		
Several/day						

Table 3.17 Percent of Reported Tired Eyes by Wave and by Group

	Control Group			**Test Group**		
	Wave 1	**Wave 2**	**Wave 3**	**Wave 1**	**Wave 2**	**Wave 3**
Never	26.67	18.18		7.69	25.00	30.00
1-2/last week	20.00	72.73	70.00	53.85	58.33	60.00
3-4/last week	46.67		30.00	15.38	16.67	10.00
1/day	6.67	9.09		15.38		
Several/day				7.69		

3.2.15 Neck strain

No significant difference was found between the responses of the test and control group for frequency of neck strain. The percent of responses are shown in Table 3.18.

Table 3.18 Percent of Responses for Frequency of Neck Strain

	Control			Test		
	Wave 1	**Wave 2**	**Wave 3**	**Wave 1**	**Wave 2**	**Wave 3**
Never	13.33	27.27	20.00	15.38	33.33	30.00
1-2/week	60.00	54.55	80.00	53.85	58.33	60.00
3-4/week	20.00	18.18			8.33	10.00
1/day	6.67			15.38		
Several/day				15.38		

No statistically significant difference was found between the values for the Neck Strain Index for any of the waves of data collection. However, the mean value of the neck strain index for the test group decreased from wave 1 (NeckStrain Index = 10.4) to wave 2 (NeckStrain Index = 2.3).

3.2.16 Work-Related Musculoskeletal Disorder

Reports of musculoskeletal discomfort were widespread among the Ps but there was no significant difference in the prevalence of complaints by body region between those in the control and test groups for any of the 3 surveys. There were no significant differences within a group between responses in each survey (Table 3.19).

Of the total number (N=28) of subjects analyzed in wave 1, 92.6% (N=25) reported having some type of WMSD symptom in the back, neck or upper extremity. Substantial reports of upper extremity symptoms were as follows: 85.2% (N=23) in the neck, 44.5% (N=12) in the left shoulder, 48.1% (N=13) in the right shoulder, 33.3% (N=9) in the right forearm, 55.5% (N=15) in the right wrist. Symptoms on the right side of the body were more prevalent than on the left. All subjects with WMSD symptoms on the right side were right handed. Of the symptoms reported on the left, all respondents were left handed mouse users. Table 3.19 shows the responses for each area of the body that was questioned regarding frequency of discomfort.

Table: 3.19 Percentage of Musculoskeletal Discomfort for Each Survey and Group

	Control			Test		
	Wave 1	**Wave 2**	**Wave 3**	**Wave 1**	**Wave 2**	**Wave 3**
Neck	84.6	72.7	80	86.7	66.7	70
Shoulder (left)	53.8	36.4	30	40	41.7	30
Shoulder (right)	61.5	27.3	40	40	33.3	40
Upper arm (left)	23.1	18.2	20	13.3	0	0
Upper arm (right)	30.8	9.1	20	6.7	8.3	10
Forearm (left)	23.1	27.3	20	20	8.3	10
Forearm (right)	46.2	27.3	60	26.7	25	30
Wrist (left)	15.4	9.1	20	13.3	25	30
Wrist (right)	92.3	27.3	70	26.7	66.7	60
Hand (left)	23.1	18.2	20	13.3	0	20
Hand (right)	61.5	27.3	60	33.3	41.7	50

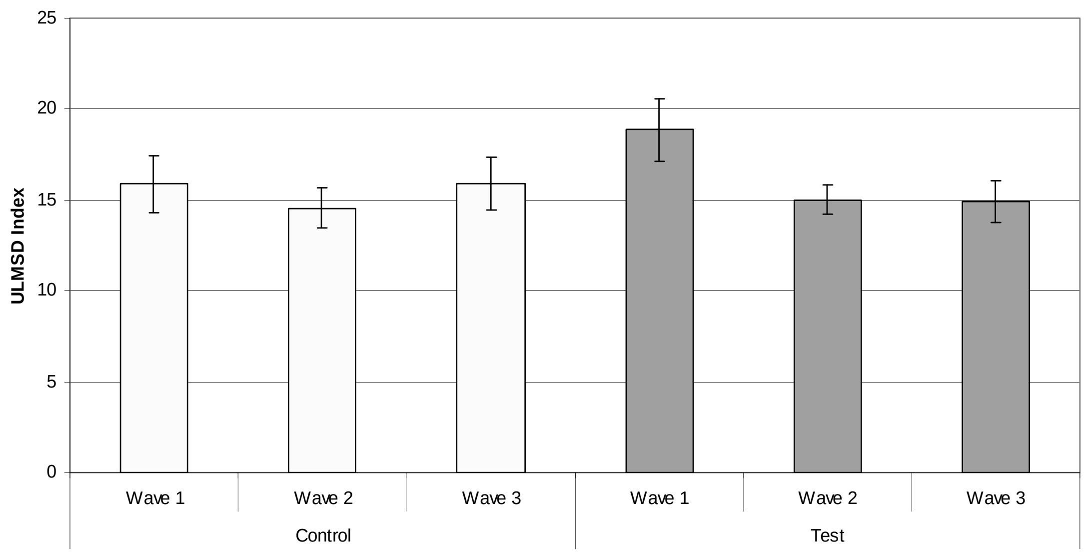
3.2.17 Upper Limb Musculoskeletal Disorder Index

The ULMSD index scores for each survey were compared using a Friedeman's test for each group. There was a significant decrease in ULMSD scores for the test group (χ_2=13.94, df=2, p=0.001) but not for the control group (Figure 3.3).

Additionally, the change in ULMSD score between waves 1 and 2 were calculated and found to be significantly different between the test and control group (χ^2=6.2, df=2, p=0.045) (Table 3.20). Additionally, the change in responses for the test and control groups between waves 1 and 3 were found to be significantly different (χ^2=7.6, df=2, p=0.022) for the index values of ULMSD (See Table 3.21).

In the first wave, the overall ULMSD index values varied from 11 to 35 with a mean value of 16.7 (S.D. 5.4). Since the greatest index value that could be attained was 55, this indicated a generally moderate level of discomfort for the subjects. In wave 1 the highest ULMSD score was a 35 and in wave 2 this decreased to a score of 20.

There was only one test subject that was found to have increased the score for ULMSD from wave 1 to wave 2. All other test subjects' ULMSD score decreased from the pre installation to the post installation phases (N=11). Figure 3.3 shows the mean ULMSD Index scores and mean standard errors for each waves of data



collection.

Figure 3.3: ULMSD Index Scores for each Group for each Survey (Mean ± S.E.)

Table 3.20 Change in Response for ULMSD between Wave 1 and 2

Change in Response	**Test**	**Control**	**Total**
Decrease (-1)	11	5	16
No change (0)	0	3	3
Increase (1)	1	3	4
Total	12	11	23

Table 3.21 Change in Response for ULMSD between Wave 1 and 3

Change in Response	**Test**	**Control**	**Total**
Decrease (-1)	8	2	10
No change (0)	2	6	8
Increase (1)	0	2	2
Total	12	10	20

3.2.18 Computer Vision Syndrome Index

There was a significant decrease in CVS (CVS Index) scores for the test group (χ_2=8.86, df=2, p=0.012) but not for the control group between the wave 1 and 3. The greatest index value that could be obtained was 15. The range of index scores in wave 1 for the test group was 4 to 10. This decreased in wave 2 to a range of 3 to 9, and decreased again in wave 3 with a range of 3 to 7 (See Figure 3.4).

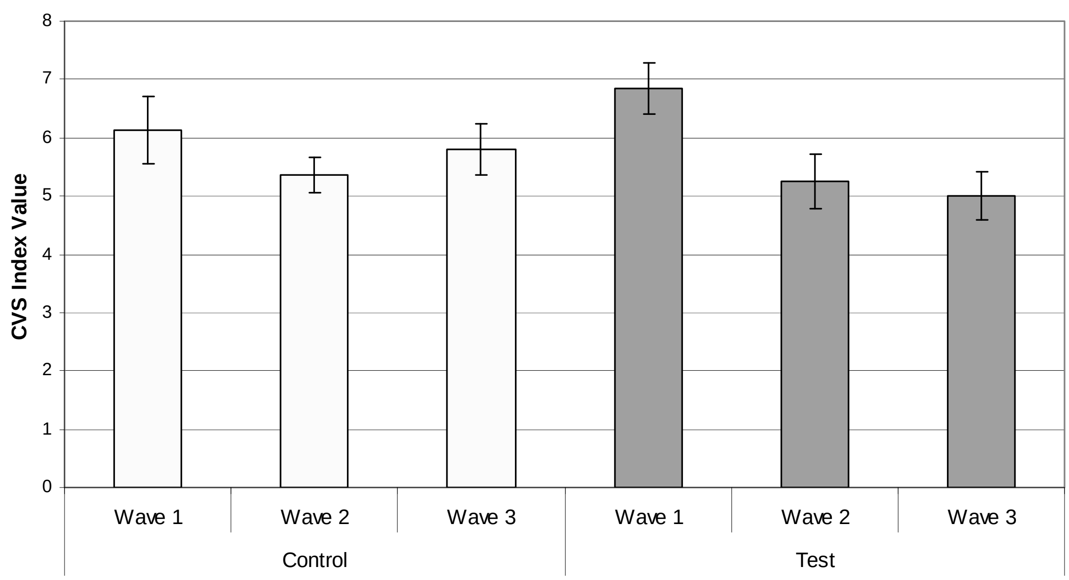


Figure 3.4 CVS Index Scores for each Group for each Survey (Mean $\pm$ S.E.)

3.2.19 Glare

There were no significant changes in the responses for glare problems between or within groups. The number of test group subject who reported always having glare problems decreased over the course of the study from 15. 4% to 0% in wave 3. In addition, the number of test subjects who reported never having a problem with glare increased from wave 1 (30.8%) to wave 2 (50%) (Figure 3.5). However, these differences were not found to be statistically significant. Responses are also shown in Appendix K.

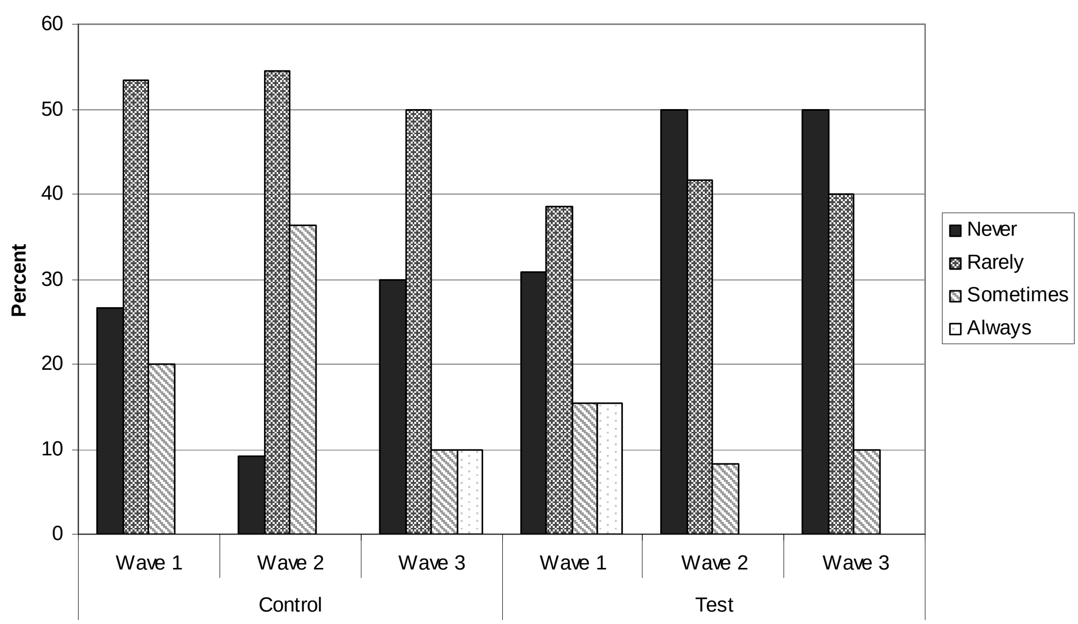


Figure 3.5: Responses of Glare Problems for All Waves

3.2.20 Rapid Upper Limb Assessment

The risks of musculoskeletal disorders were analyzed based on Rapid Upper Limb Assessment scores. It was predicted that the scores would be lower for the test subjects following the installation of the Flat Panel Monitor Arm. However, there were no significant differences in the RULA scores between groups over the three waves. Figure 3.6 shows the mean and standard deviation of the RULA scores by wave.

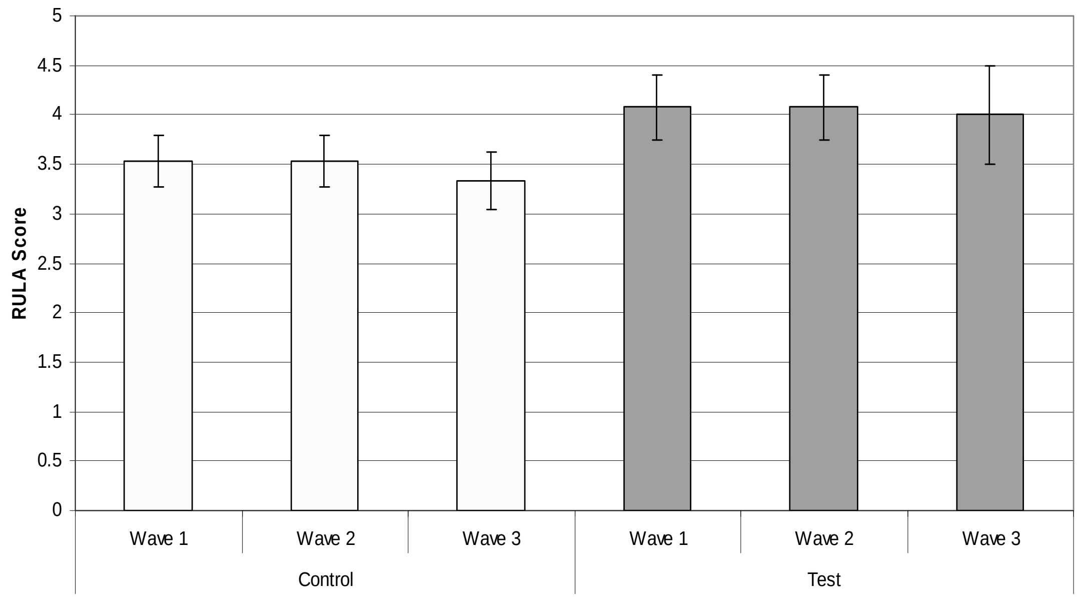


Figure 3.6: Mean RULA Scores by Waves

The change in RULA scores between waves or the difference between test and control groups were not statistically significant; the assessment of subjects indicates that most subjects were exposed to some risk level for Work-Related Musculoskeletal injury throughout the duration of the study.

Only in the third wave of data collection was one control subject given an overall score lower than three. That individual was given a score of 2, meaning their posture was acceptable and no changes needed to be made to reduce the risk of injury or discomfort. In the initial observation, most subjects (N=20) had a score of three or four, meaning postures should be further investigated as some risk of injury is present.

For the second wave of data collection, 11 subjects total were given a RULA score of three or four, 8 (61%) of which were test subjects and 9 (75%) were control subjects. Again in the third wave, the majority of subjects (14), 5 (62.5%) test subjects and 9 (81%) control subjects, were scored with a three or four.

3.2.21 RULA Component Scores

The differences between component scores of the RULA were not found to be statistically significant for any of the waves.

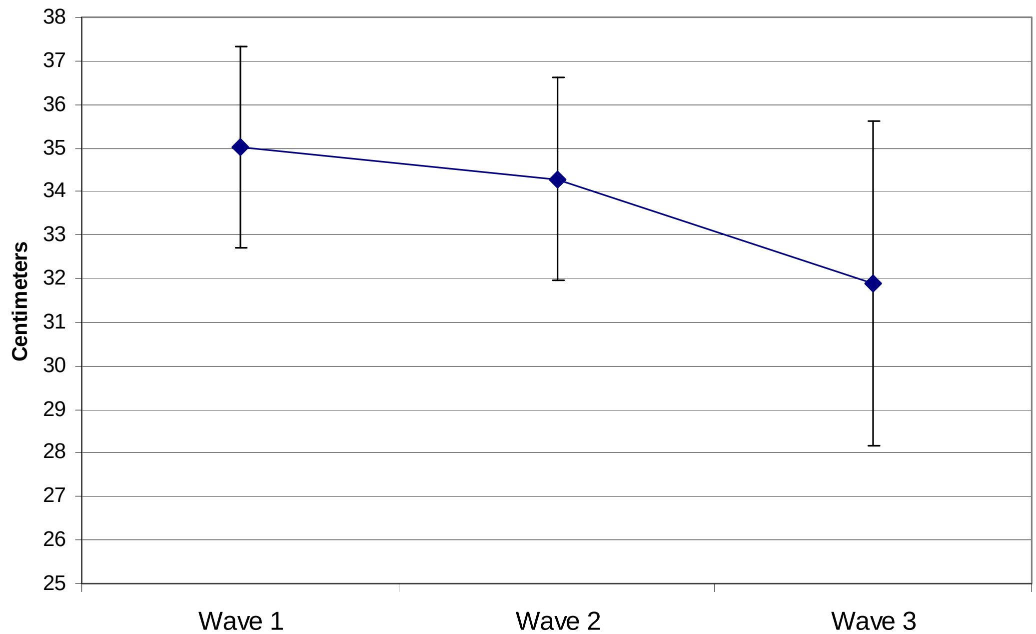
3.2.22 Distances to Workstation

The distances measured from subjects' eye to monitor and torso to monitor did not change significantly over the course of the study and none of the measurements were found to be significant between groups for any wave of data. Table 3.22 shows the mean and standard deviation of the distances measured.

Table 3.22 Distances Measured at the Workstation (cm)

		Eye to Monitor			**Torso to Monitor**			**Torso to Desk**		
		1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Test	Mean	73.96	71.32	76.68	73.86	69.32	73.99	33.81	38.63	34.93
	S.E.	11.35	9.14	15.21	10.95	6.68	14.91	14.88	12.24	19.15
Control	Mean	77.37	78.49	73.79	77.27	69.09	73.66	35.36	29.21	29.46
	S.E.	16.08	11.43	16.18	12.98	12.29	16.21	10.77	8.41	13.13

However, irrespective of group, an overall mean difference was found for the distance from the subjects' torso to desk. The mean difference is significant at the .05



level (F[1.14]=4.88, p=0.44: survey 1 = 34.7 ± 3.5 cm; survey 2 = 32.4 ± 2.3 cm; survey 3 = 28.9 ± 3.4 cm. No other measures were significantly different between surveys or groups (Table 3.22). Figure 3.7 shows the mean distances and standard error of the means between waves for all subjects. Exact numbers are shown in Appendix L.

Figure 3.7: Distance from Torso to Desk by Wave for all subjects

3.3 Opinion of Flat Panel Monitor Arm

Reactions to the installation of the Flat Panel Monitor Arm were positive in the test group, and 100% reported liking it in both wave 2 and 3 (See Table 3.23).

Table 3.23 Opinion of FPMA by Test Subjects Post-installation

	Wave 2		Wave 3	
Response	**Frequency**	**Percent**	**Frequency**	**Percent**
Really like	**11**	**91.7**	**8**	**88.9**
Somewhat like	1	8.3	1	11.1
Somewhat dislike	0	0.0	0	0.0
Really dislike	0	0.0	0	0.0
Total	12	100.0	9	100.0

Additionally, two (16.7%) subjects in the test group reported that the Flat Panel Monitor Arm (FPMA) they were given for the study created much more space at their workstation, and 10 test group subjects reported having a little more space at their computer workstation (Table 3.24).

Table 3.24 Response to Amount of Area Created by Use of FPMA Post-installation

	Wave 2		Wave 3	
Response	**Frequency**	**Valid Percent**	**Frequency**	**Valid Percent**
No Effect	0	0.0	1	11.1
Much More	2	16.7	3	33.3
Little more	**10**	**83.3**	**5**	**55.6**
Little Less	0	0.0	0	0.0
Much Less	0	0.0	0	0.0
Total	12	100.0	9	100.0

In wave 2, half of the test group subjects (N=6) reported moving their monitor a little more often after the installation of the arm.

Two test group subjects reported no effect of the monitor arm on the number of times they adjusted their computer screen position. One subject reported that they adjusted the screen much more often with the monitor arm in place. Two subjects reported to move their screen a little less often and one subject reported to move their computer screen much less often with the monitor arm (See Table 3.25).

Table 3.25 FPMA Influence on Monitor Adjustment

	Wave 2		**Wave 3**	
Response	Frequency	Percent	Frequency	Percent
No Effect	2	16.7	1	11.1
Much more often	1	8.3	3	33.3
Little more often	6	50.0	4	44.4
Little less often	2	16.7	0	0.0
Much less often	1	8.3	1	11.1
Total	12	100.0	9	100.0

Overall, the test group reported that using the monitor arm made it easier to adjust the position of the monitor screen. In wave 2, all test group subjects (N=12) reported that the FPMA was either easy or very easy to adjust. In wave 3, 7 out of 9 subjects reported that the arm helped ease the positioning of the monitor screen (Table 3.26).

Table 3.26 Reported Ease of Flat Panel Monitor Adjustments

	Wave 2		**Wave 3**	
	Frequency	Valid Percent	Frequency	Valid Percent
Very Easy	3	25.0	**4**	**44.4**
Easy	**9**	**75.0**	3	33.3
Difficult	0	0	2	22.2
Total	12	100.0	9	100.0

3.4 Ergonomics Training

When asked about their opinion of the ergonomic training received as part of the study intervention, subjects in the test group reported it to be more useful than those in the control group. All subject received the same ergonomic training (Table 3.27).

Table 3.27 Opinion of Ergonomic Training

Response	**Test**	**Control**
Not useful	0%	9%
Fairly useful	25%	55%
Very useful	42%	9%
No opinion	33%	27%

3.5 Open Ended Questions

Wave One: Comments
"I just had Lasic surgery last week of January. I am noticing eye strain/poor vision at night when I go home and try to read signs in the distance. Because of the surgery, I have extended my viewing range for paperwork and reading the monitor."
"I have pain on my lower back almost every day."
"When you've been in a given workplace cockpit for a while you grow accustomed to its nuances of comfort and discomfort. Over time, you forget previous cockpit arrangements and your current arrangement eventually becomes 'all you know'."
"I don't necessarily have headaches, or eye issues weekly -- but they definitely occur with frequency -- Weekly was the only choice though.

Also - I suffer from back pain frequently as well -- however, that was not part of this survey. "
"Body aches are more typically in my upper, mid- and lower back."
"Occasionally minor loss of sensation in legs."
"Understanding ergonomics, I do try to make adjustments as often as necessary. "

In waves 2 and 3 of the study, subjects were asked to make additional comments any issues they felt relevant to the topic of ergonomics and test subjects were additionally asked their opinion of the LCD monitor arm.

When asked about the opinions of the LCD monitor arm, subjects wrote the following:
"Love it. "
"Good for showing others screen."
"Makes room for several sheets of paper to be viewed at a single time while still facing the monitor. Desk is easier to clear off. Cleaning staff can get under monitor, desk is less dusty. Overall a good addition. "
"It's much more interactive than before which is helpful in both adjusting the screen as well as showing the screen to others at my desk. "
"A little extra storage under monitor. Easier to adjust height but doesn't move often."
"The addition of the LCD arm and the reinstallation of the keyboard tray has greatly improved the ability to sit in an ergonomically correct position and freed up valuable desk space. The location of the mouse pad and the inability to adjust its height is a problem. It sits under the desk surface with barely enough clearance for my knuckles."

"Sometimes screen is not square (90 degrees) and must be adjusted; it also can bounce when a group of people walk by."
"It's hard to move it up and down."
"Maybe make it adjust smoothly [with] less force." *Current design is cumbersome to adjust laterally - I typically have the arm extended to the left at its maximum extension. It takes two people to readjust the location of the vertical shaft as the mounting bracket has to be loosened from under the desk surface.*

Other general comments that were made by subjects in the control group included:
"[There isn't] much room under monitor, no keyboard tray, [but] good ergonomic training. "
"[I] Wish I had more storage."

Chapter 4: Discussion and Conclusion

The use of a flat panel monitor arm for architecture employees has been found by the present study to have a positive effect for test subjects. Results supported the hypothesis that after the installation of the flat panel monitor arms (FPMA) reports of upper limb musculoskeletal discomfort would be significantly reduced for test subjects compared the control group.

Data from test subjects showed they were able to more easily position their computer monitor to a comfortable position with the use of the flat panel monitor arm. The test group responses to how often the monitor is at a comfortable viewing height were significantly greater than the control group in wave 3 ($p= 0.023$). Additionally, the change in responses for the test and control group was found to be significantly different between waves 1 and 2, but between waves 1 and 3.

A greater number of test subjects reported that their monitors were now at a more comfortable viewing distance and a better position for reading compared to the control subjects. The test group also reported that they were able to make adjustments to their screen more easily with the help of the monitor arm. The majority reported enjoying using the arm, that it helped to create more desk space and made it easier to adjust their monitor. A significant change in the distance measured from the subjects' torso to their desk over the course of the study was found. On average, all subjects moved closer to the edge of their desk at each wave of data collection. Additionally, test subjects reported that the FPMA gave more space on desks and that it eased adjustments of the monitor.

It was also predicted the test group would have less frequent eyestrain and individual CVS symptoms. However, there were no significant differences found for these variables. It was also predicted that posture would be improved for test subjects, but there was no significant change in the RULA scores.

Overall impressions of the flat panel monitor arm were extremely positive and all test subjects reported liking it in both the 2nd and 3rd waves.

4.1 FPMA and Symptoms of CVS

Surveys of computer workers from previous studies have found that about 70% of people who do daily work at a computer report CVS and 88% of all computer users are expected to develop some symptoms of CVS at some stage in their lives (Collins, 1991; NIOSH, 1995). Blehm et al. (2005) reviewed studies of CVS to better understand the symptoms, causes and treatments that have been investigated. They reported that treatment requires a multidirectional approach, combining ocular therapy with proper workstation adjustments. Using a flat panel articulating monitor arm is thought to improve workstation configuration and potentially reduce the symptoms of CVS due to adjustability of the monitor.

4.1.1 Monitor Position

Previous research have shown that there is not one recommended position of the monitor to decrease musculoskeletal and visual discomfort, but ranges for distance, height and angle of the monitor that depend on each viewers' visual acuity and preference (Blehm et al, 2005; Seghers et al., 2003). What has been proven in the research is that most computer viewers prefer lower monitor heights, between 8^{o} and 20^{o} below eye level, to prevent neck strain and eye strain (Sheedy, 1992; Seghers et al., 2003; Sommerich et al., 2001). Monitor height below horizontal eye level also allow the viewer to gaze downward, exposing less of the eye to the ambient environment and reducing potential tear evaporation (Psihogio et al., 2001).

Results confirmed the hypothesis that test subjects who were given a flat panel monitor arm would be able to more frequently find a comfortable viewing position for their computer monitor.

Although test subjects indicted that they could find proper heights and distances of their monitors for viewing, they also indicated infrequent movements of their monitors. Perhaps they did not frequently adjust their screens once it was at a comfortable position. Also, the question regarding monitor movements may have been ambiguous and test subjects could have interpreted it to concern gross screen movements instead of finer adjustments. Additionally, the height of the subjects' monitors was not measured in the field research, but only questioned in the survey. Future research on the effects of adjustable workstation equipment should include measuring change in monitor height. Future results can then be compared to the study by Seghers et al. (2003) that investigated effects of prolonged computer use at four different monitor heights on posture, muscle activity and the development of muscle fatigue. It was found in this study that for tasks up to 89 minutes, lowering the monitor resulted in increased viewing angles and increased muscle activity in the neck muscles.

Monitor distances closer than 20 inches and farther than 40 inches has been found to be less preferred by computer users and to be correlated with visual strain (Ankrum, 1996; Bergqvist et al., 1995; Jaschinski et al., 2000; Knave, 1994; Sommerich et al., 2001). The results from the current study show that all subjects' monitors were in location within this recommended range. These results may correspond to the fairly low reports of eyestrain by the study subjects.

Low responses for symptoms of eyestrain made it somewhat difficult to compare changes due to the use of a flat panel monitor arm. When investigated further, a dramatic decrease in eyestrain frequency and intensity was seen for 3 individual subjects in the test group. One subject reported in the first survey that they experienced eyestrain once a day and that it was moderately uncomfortable. By the second survey, the same subject reported that they never had eyestrain and indicted no discomfort. Two other subjects in the test group reported less frequent eyestrain and less discomfort by the third survey. Additionally, one control subject reported in the first survey that they never had eyestrain and then reported experiencing eyestrain 3-4 times per week in the third survey. Although this is not statistically significant data, this information provides some support that eyestrain was reduced as a result of using the flat panel monitor arm.

An index for Computer Vision Syndrome (CVS Index) was also created to see the effects of the FPMA on combined symptoms. The index combined the data collected for frequency of headache, eyestrain, and tired eyes. The mean index values for wave 1 was 4.2, wave 2 decreased to a mean of 2.5 and stayed the same for wave 3. The highest index value that could be obtained was 15, indicating a fairly low frequency of eyestrain symptoms throughout the study. Furthermore, no significant changes were found over time for the eyestrain index or between the test and control groups.

4.1.2 Glare

Minimizing the amount of glare on a computer monitor is important for proper monitor visibility, viewing and reading (Sheedy et al., 2005). Inefficient lighting conditions and glare can result in annoyance, visual discomfort and eye fatigue (Goodwin, 1987; Hedge, 1995; Sheedy et al., 2005). Glare on a computer monitor can be minimized with the use of indirect lighting systems (Hedge et al., 1995) and by following ergonomic guidelines for screen location and orientation. Other products, such as glare filters, can be purchased to minimize the negative effects of glare.

In the present study, natural lighting was available to employees through a large window wall at one end of the office and from overhead indirect luminaries. The desks in the office were mostly oriented at right angles to the window and partitions between desks also helped to block sunlight from causing glare. Fortunately, for the subjects in this study, glare generally was not a serious concern. Nevertheless, there were some subjects who initially reported having some trouble with their work as a result of glare on their computer monitor. In the test group, the number of subjects who reported always having a problem decreased from 15% to 0% and the subjects who reported never having a problem with glare increased from wave 1 (30.8%) to wave 2 (50%). This helps to support the hypothesis that using an articulating monitor arm decreases the amount of glare. This most likely occurred because the monitor arm allowed the user to position the monitor in a location with the least amount of glare problems.

4.1.3 Corrective Lenses

Fourteen subjects in the present study reported wearing some form of corrective lens. This included regular reading glasses, bifocals, trifocals, and contact lenses. Wearing the appropriate type of corrective lens is critical for conducting work at a computer, but the distance of the monitor is also important for proper reading and viewing (Butzon et al., 2002). The distance of the computer from the user should be within the range that the corrective lenses allow the user to see most effectively, which is different for each type of lens and prescription (AOA, 1997). Subjects wearing bifocal lenses in previous research have been found to experience much more neck, head and back pain and lower performance rates because of an inaccurate positioning of the monitor and awkward postures (Balci & Aghazadeh, 1998; Basrai & Aghazadeh, 2004). Only two subjects in the current study reported wearing bifocal lenses and both were in the test group. In the first wave they had low frequency ('never' or '1-2 times per week') of eyestrain and tired eyes. In the second and third waves, they both reported that they never had eyestrain or tired eyes and no visual discomfort. Throughout the study, both subjects who reported wearing bifocals also had very low frequency and little or no discomfort in their neck or head.

Five test subjects reported wearing contact lenses in the baseline survey. Research has shown that computer users wearing contact lenses have a higher severity of ocular discomfort due to drying of the eye (Shimmura, Shimazaki & Tsubota, 1999; Wiggins, Daum & Snyder, 1992). The results from the current study did not give sufficient evidence to support previous research. Two subjects who wore contact lenses in the test group reported to have less eyestrain frequency and intensity between waves 1 and 3. However, another contact lens wearing test subject continued to have frequent eyestrain over the course of the study.

In order to further reduce any eyestrain that is experience by computer users with corrective lenses, it is recommended by the American Optometric Association (AOA) that a professional eye examination be first obtained and occupational progressive lenses, or "computer glasses" be considered (Butzon et al., 2002). Wearing more appropriate corrective lenses may solve the issue of visual discomfort and fatigue, but "computer glasses," as defined by the AOA (date?), have been recently designed specifically for the computer workplace. They have been shown to be significantly more effective then typical ergonomic adjustments ($p<0.008$) and are predicted to decrease computer vision syndrome symptoms by 25-70% (Butzon, Sheedy, & Nilson, 2002).

4.1.4 Headaches

Headaches are a symptom of CVS and these have been found to be a severe problem among computer users. Results from the current study showed that 77% of the test subjects reported to have some frequency of headache and by the third wave of data collection 70% still reported having headaches ‘1-2 times per week’. Similarly, 80% of the control group reported having some frequency of headaches in the first wave and this was the same in the third wave. No significant change was seen during this study, but slight improvements were noticed between wave 1 and wave 2 for test subjects. In the first wave, 3 (23%) test subjects reported never having headaches. This increased to 5 (42%) test subjects in the second wave and decreased again to 3 (30%) test subjects in the third wave. However, there were no reports for ‘3-4 times per week’ of experiencing headaches in the third survey. Since no significant changes were seen and the reports were continuously high, further investigation of the cause of headaches for all subjects is recommended.

4.2 The FPMA and WMSDs

When computer users assume uncomfortable postures while viewing a computer monitor they put themselves at a greater risk for upper extremity discomfort and strain , including the head, neck, back, shoulders and arms, which over time can lead to more serious musculoskeletal disorders (Collins et al, 1990**;** Psihogios et al., 2001). The position of the monitor in relation to the computer user is especially crucial for neck and head postures. Kumar (1994) found that electromyograph (EMG) activity in neck and back muscles increased as neck extension increased, and computer users who had extended neck postures had greater discomfort.

Forward head positioning, with the head upright, and extended forwards from the trunk, is sometimes an attempt to relieve muscle tension caused by contracted neck muscles (Ankrum, 2001; Mackinnon and Novak, 1994). Additionally, forward head postures have been associated with cervical headaches (Watson & Trott, 1993) and increased overall fatigue (Urbanowicz, 1991).

The present study set out to investigate the differences in posture and subjective discomfort between the two groups of subjects. In the online surveys, questions regarding frequency of discomfort, intensity and interference with work were also asked about eleven specific upper extremities. It was found that the reports of upper limb musculoskeletal disorders symptoms significant reduced in the test group and was significantly different compared to the control group. RULA scores were also collected before and after the FPMA was installed in order to determine if using a flat panel monitor arm would reduce the risk of developing WMSDs. RULA scores were not found to be statistically different between groups, but there was an overall significant decrease in distance to the subjects' desks over the course of the study.

4.2.1 Self-Reported WMSD Symptoms and Discomfort

In the initial wave of data collection almost all (92.6%) subjects reported having had some back, neck or upper extremity discomfort in the first wave. The reports hardly changed with 90% (N=18) of all subjects reporting some type of WMSD symptom in the third and final wave. Symptoms on the right side of the body were more prevalent than on the left, but the symptoms in the left were reported by left-handed mouse users.

Discomfort in the neck was fairly high in the first survey at 85.2% (N=23) of all subjects. However, after the three waves of data were collected and responses of frequency and intensity were combined into an index, no significant differences in neck strain were found.

The ULMSD index for wave 1 showed an average or moderate level of discomfort for all subjects and then there was a significant decrease in ULMSD scores for the test group but not for the control group after the installation of the FPMAs.

In wave one the greatest ULMSD score was 35 and in wave 2 this decreased to 20. Between waves 1 and 2, the ULMSD index decreased for 11 test subjects and increased for only 1. Five (5) control subjects decreased their ULMSD index, 3 stayed the same and 3 increased their index value. From waves 1 to 3, 8 test subjects decreased their ULMSD index value and only 2 of the control group had a decreased ULMSD index.

The change in ULMSD scores from wave 1 to wave 2 in the test group was significantly different than the change in scores of the control group. The change in ULMSD scores from wave 1 to 3 was also significantly different between the groups. This indicates that the test group had less discomfort in the upper limbs compared to the control group after the installation of the FPMA.

The significant overall decrease in upper limb discomfort experienced for test subjects after the installation of the FPMA supports the hypothesis that it contributes to a reduction in upper limb symptoms. However, it was not possible to pin point the source of test effect in just one body region because there were no significant changes for individual upper body segments. Insignificant results for specific areas of the body may have been a result of few responses and the small sample size.

4.2.2 Distance between the Body and Workstation

The mean distance for all subjects that was measured between their torso and edge of their desk significantly changed over the course of the three waves of data collection. The mean distance from the torso to the desk was first measured as 34.7 ± 3.5 cm (13. 8in ± .9), in wave 2 as 32.4 ± 2.3 cm (12.76in ± .91) and in the third wave was 28.9 ± 3.4 cm (12.5in ± 1.5). This change in positioning of the subjects in relation to their workstation could indicate a greater awareness to working in a more neutral posture or within a neutral reach zone on the desk. Moving closer to the desk could also allow for the upper arms to be closer to the body and in a more neutral position when typing or working at the desk. However, the results from the current study did not show a change in the upper arm posture from the individual observations in the RULA method, or a significant difference in the overall RULA scores.

4.2.3 RULA

The subjects' RULA scores were consistent with the results from the literature, such as a study by Shuval and Dochin that found all subjects (n=84) to had improper working postures (RULA scores >= 3). The mean RULA score for both test and control subjects in all waves of data collection was a 3, indicating moderate levels of risk exposure to WMSDs. Gerr et al. (2002), who reviewed studies on the relationship of keyboard use (hours per day and hours per week) and upper extremity ratings, found high portions of computer users who worked in non-neutral positions. It was also reported by Gerr that people who worked 8 hour days, 5 days a week and spent at least half the time on the computer were had exceptionally high risk levels for developing upper extremity disorders.

In this study, a majority of subjects had some degree of musculoskeletal discomfort, as reported in the self-assessments and RULA scores. However, there was no significant correlation between the differences in the mean RULA scores between or within groups over the course of the three waves of data collection. Subjects in the current study were equipped with some ergonomically designed furniture, including keyboard trays and chairs, which may have decreased their exposure of WMSD risk factors, but most subjects still were not using their equipment in an optimal manner.

Although most subjects had a moderate RULA score, some attention should still be given to their workstation postures.

Self assessments can be assumed to be a reliable source for discomfort and research has suggested that the RULA method is also a valid tool for assessing improper posture and potential injury risk (McAtamney & Corlett, 1993). Similarly to the study by McAtamney and Corlett (1993), the relationship between RULA scores and the subjective data from the surveys were compared. The results of this study show that there were no relationship between the self-assessments of discomfort of the upper extremities (ULMSD) and the RULA scores. This does not conclude that the RULA method is invalid, but causes debate for reliability. Further studies should be done to enhance the validity of this assessment method.

4.3 Workstation Considerations

Results from subjective data support the hypothesis that using the flat panel monitor arm creates more usable work surface area. The amount of work surface space was a definite issue as 14 (51.9%) subjects reported inadequate work surface area in wave 1. Seven of these respondents who had insufficient work surface area were project architects and may have used more work area for larger paper documents. Although there was not a significant difference between groups in the responses for amount of work surface area at the workstation, 100% of test subjects in wave 2 and 3 (N=12; N=9) reported that the FPMA gave them a little or much more work surface area.. The reason for this contradiction in responses may be that the FPMA gave the test group more workspace, but then they immediately utilized that area. It could also be that the FPMA gave the test group more work surface area, but subjects would still prefer to have more. It was also noted by the researcher that the arm allowed for a better configuration of documents and workstation components and provided more desk area for positioning items within a neutral reach zone.

4.4 Additional Findings

4.4.1 Collaborative Work

Comments and observations by the researcher also revealed a high frequency of collaborative work at the architecture firm office. The results of this study show that use of a flat panel monitor arm helps to foster collaborative work and communication among users. In fact, it was found that 87.5% of the test subjects met with colleagues at their workstation to look at the computer monitor and those same respondents reported that the arm made it easier to do so.

4.4.2 Ergonomics Training

The effects of ergonomic interventions on musculoskeletal discomfort for office workers have been shown in some cases to be extremely positive when implemented with ergonomic training. Menendez, Robertson, Amick, Harrist, Bazzani, Derango, and Moore (2006) conducted a longitudinal study looking at the effects of ergonomic training and adjustable workstation components on visual symptoms and WMSD. Subjects were placed into one of three study groups: one group receiving a highly adjustable chair with office ergonomics training ($n = 69$), one group receiving only the office ergonomics training ($n = 61$), and a control group receiving the office ergonomics training at the end of the study ($n = 78$). Symptoms were recorded three times a day. After one year, the group that received the chair and training experienced a significant reduction in upper limb musculoskeletal disorder symptoms ($p<0.05$) while the training only group did not ($p>0.10$). It was also found from the same study that individual visual symptoms were reduced in both groups that received the ergonomic training. The study replicated a previous study, of which the results were similar. It was concluded that an office ergonomics intervention of a highly adjustable chair with office ergonomics training can improve worker health.

Results from the current study revealed that subjects in the test group reported the ergonomic training to be ‘somewhat more useful’ than those in the control group. It is also suggested that since the subjects in the current study were provided with a highly adjustable chair and office ergonomics training they were given opportunities to adopt improved postures and behaviors and provide the worker with the skills to identify and make needed ergonomic workstation changes (Amick et al., 2003). This may have been the cause to why all subjects moved closer to their desks over the course of the study. Also, increased knowledge and behavioral change should in turn lead to visual health improvements and affect productivity. Although the results of the control group were not significantly different between waves, there was a slight reduction in the index values for ULMSD (wave 1: 15.4 $\pm$ 4.5; wave 2: 14.3 $\pm$ 3.3) and CVS (wave 1: 6.1 $\pm$ .56; wave 2: 5.3 $\pm$ .3) between waves 1 and 2. However, both index means increased again from wave 2 to wave 3 in the control group.

For future research, it may be helpful to ask the test subjects if they made adjustments to their monitors after receiving the ergonomic training. Further research could also compare the effect of a flat panel monitor arm with or without ergonomic training to see the influence it has on making adjustments to the arm.

4.4.3 Storage

Observations, comments and low satisfaction responses regarding the amount of storage in the workstation indicated insufficient work surface area and storage space. Results from the study showed that the use of the flat panel monitor arm was only beneficial for accessing storage space and work surface area. Although no specific measures were taken of the amount of storage area, it is likely that the FPMA allowed the monitor to be moved away revealing more desk space that could be more easily accessed and utilized for storage. It is recommended that more be done to increase the amount of storage area for subjects who did not see a change in amount of storage during the study.

4.4.4 Vibration

Post installation, comments and observations revealed unpredicted issues concerning the use of the monitor arm. First of all, some test subjects reported that the monitor shook when people walked past their desk. This caused annoyance and discomfort, and could potentially result in reduction of productivity.

4.5 Limits to Validity

4.5.1 Representative Sample

One limitation to this study was the sample size and subject variability. Some subjects had moved to a new workstation just prior to data collection conducted in wave 1. Additionally, a few subjects moved workstations during the course of the study as part of office reconfiguration. This change in workstation area may have influenced factors such as workstation configuration, lighting angles, comfort and satisfaction.

Another limit to validity of the present study was sample attrition. Of the employees who were initially asked to participate, 28 fitted the criteria and participated in the baseline phase of the study. One set of data was removed due to incompletion of the online survey. For the second wave, 5 subjects were removed from the study and in the third wave, 2 additional subjects were removed. These subjects either indicated that they no longer desired to be in the study, were relocated to a desk that did not have an ergonomic keyboard tray, or were no longer employees of the firm. Time constraints and availability of subjects could not prevent this limited sample.

As a result of the small sample size, it was difficult to get an accurate representation of work station configurations to compare with subjective measurements. For instance, only four of the twenty-seven subjects were in closed offices with larger desks. Subjects in offices, compared to those in cubicles, had different job status and responsibilities. Therefore, comparing subjects with different types of desks may not be considered completely valid. Additionally, only one architecture firm that was examined in the study allowing the possibility that other office would have different workstation equipment, configurations and injury risk. The limited size sample also influenced the statistical analysis of data. It was often seen that some answers did not receive any responses resulting in non normal distributions.

4.5.2 Self Selection

Since employees of the architecture firm were asked to volunteer to be subjects in this study, it is possible that they had an interest in ergonomics or reducing the risk of WMSDs because they were experiencing symptoms or discomfort. Some employees may have felt they did not have time to fully participate in the study because of the time commitment. However, these individuals may also be at risk for developing disorders especially if they are not conscientious of their posture or do not make the time for workstation adjustments. Additionally, hours spent at the computer outside the office were not asked, which could have influenced the effect on the risks of disorders and symptoms.

4.5.3 The RULA Method

The RULA method is used to assess potential risks of work-related musculoskeletal disorders in the upper extremities. Since it is used as a quick prognosis, it may not give enough detail about the postural risks and may have angle ranges that are too broad. (Fountain, 2001). There have been studies (McAtamney & Corlett; 1993; Fountain, 2001; Drinkaus et al., 2003) that have specifically examined the validity of this method as an assessment tool based on comparison with other assessment methods. In their first experiment, the reports of discomfort in the neck and lower arm and the individual RULA scores were found to be statistically significant ($p<0.01$). However, the upper arm, wrist, trunk and legs were not found to be statistically significant with the self reports of discomfort. These researchers also compared the RULA scores of multiple subjects on images of seated postures. However, the number of images and results were not given in the study. In the study by Fountain (2001) that examined the relationship between RULA scores and self-reports of discomfort, results showed a statistically significant difference between perceived discomfort and the RULA scores for 'high' risk postures. This indicates that RULA might not be as effective for identifying moderate risks of disorders.

Additionally, because of the arrangement of the work station, it was difficult for the researcher to see all angles of each subject. This may have affected the reliability of the observations and, in turn, the assessment scores. Error in assessment by the researcher could have been reduced if multiple observations and assessments were made or if more than one researcher conducted the assessment. The observations and assessment scores could then be compared. Multiple assessments and observations would also help to see if different postures were taken by the subjects' at different times.

The RULA method is used for assessing seated operation postures, such as at a computer workstation. An improved RULA or more specified risk assessment may better predict the potential for computer related disorders. Questions about the distance of the user to the computer components may be helpful for finding these risks. Finding the risks of visual symptoms may improve the assessment score for computer related tasks. Additionally, combining postures scores at different times of the day and for multiple tasks on the computer (precision tasks versus reading) may also add to the reliability of assessing WMSD risks.

4.5.4 Field Research

Interaction of the researcher may have been another limitation to validity in this study. Taking direct measures of subjects and asking them to act naturally may have caused evaluation apprehension. This occurs when the subjects want to sit with what they believe to be correct postures when they are observed or measured. This may have caused subjects to be more sensitive to testing. Therefore, observation and assessment results could have influenced measurements or RULA scores. Future studies may consider ways to have indirect, non-obtrusive measures taken.

4.6 Market Research on Flat Panel Monitor Arms

From research that was obtainable on the internet of flat panel monitor arms, it was found that there is a fairly small selection of products that have similar qualities and functions of the flat panel monitor arm (Humanscale Model M7) used in this experiment. The Market Survey chart shown in Appendix M compares the functions, materials, costs and unique company information for flat panel monitor arm models researched.

In making the decision to purchase furniture, office equipment or general products like a flat panel monitor arm, it is important to consider the sustainability of the product and its impact on the environment. Some qualities to consider when determining the impact of a product include: the manufacturing processes, the material of the product, its durability and life span, the ease of maintenance, and how easy it is to disassemble and recycle the parts at the end of the product's life.

Metal and plastic are both potentially recyclable, and can therefore be considered for reuse in future products. More furniture on the market now is being made from recycled plastics and metals. In fact, there are claims that 85% of all material used in Humanscale products are recycled or recyclable (Humanscale, 2004). According to their website, Humanscale's monitor arm, as well as other office equipment made from aluminum is 100% recycled and recyclable. Also, because this metal never degrades, it can be reused multiple times, making it a more sustainable material. The market survey revealed that the use of recycled material was only used for one other flat panel monitor arm (Astra).

Durability and ease of maintenance is something that is not usually considered when thinking about what furniture or office equipment to purchase. However, the longer the product can last and function properly for the user, the less frequent it will need to be replaced. For this reason, it is important to consider the design of the product and how well it will function for its intended use. If the product is able to adjust and adapt to a variety of user requirements, it will last longer, save money and be better for the environment.

Ergonomic products that are adjustable are more likely to be usable for a wider variety of users, which makes them more sustainable. The Ergonomic Excellence Award by the Furniture Industry Research Association (FIRA) was actually given to the Humanscale Model M7 monitor arm in 2000, along with two other ergonomic products by Humanscale for meeting and exceeded the British and European ergonomic standards (Furniture Industry Research Association [FIRA], 2007). Consequently, the Model M7 monitor arm can be considered a certified ergonomic product.

One aspect that is common throughout the design of the monitor arms researched for the market survey is that they all are Video Electronics Standards Association (VESA) compliant, meaning the arms can be attached to most existing flat panel monitor screens. This is important to consider because it reduces the amount of products needed to attach the screen to the arm, makes the product more flexible and therefore, a smaller environmental impact.

The ease of disassembly and recyclability is also a product quality to consider. If the product has minimal parts that hold it together there is more opportunity for it to be reused. Additionally, if it can be taken apart easily then the components can be reused with less effort, minimizing the processes and energy needed to create future products.

Another important aspect of the design to consider is its mass and weight. By creating a product that weighs less, less material is used. Also, light weight products could also mean that there are fewer parts and less energy needed in the manufacturing processes. Humanscale was the only company of those researched that outwardly commits to creating lighter products. However, two other products, one by Workrite Ergonomics and IdeaMax, weighed less than the Humanscale model at 8-9lbs each.

The downfall of a product that is too light weight is that it would not be able to support a greater weight. As it was shown in previous research, larger monitors are better for productivity and reduced error in computer tasks. Therefore a monitor arm must be capable of support larger sized monitors and sometimes more than one at a time. Luckily, technology is increasing rapidly and products are becoming more advanced and with lighter weight materials. Hopefully this will transfer to the design and production of computer monitors and office equipment.

4.7 Further Research

Some suggestions for additional research have been integrated in to the chapter of this report. These suggestions include conducting a study where the depth and height of the monitor was measured. A more in-depth measurement of the postural angles, specifically in the neck, may be helpful to find the effects of using flat panel monitor arms. Measurements that were taken of the neck angles in the present study were assessed through the RULA method, but it is suggested that more precise angle of the neck be found, possible with the use of a goniometer.

Additional research should also be conducted on other adjustable workstation components to determine whether people actually adjust them to the correct positions and if they are more satisfied after adjustments have been made. It would be interesting to determine the effects of different types of corrective lenses and the use of a flat panel monitor arm on the symptoms of CVS and other WMSDs. Finding the effects of an ergonomic training with the implementation of an ergonomic intervention would also be interesting and beneficial for possible methods of reducing WMSDs.

Future studies may include a larger sample size from more than one architecture firm. Locating subjects that have more risk of work-related injuries in the initial phase of the study may help to show greater significant differences from the interventions implemented. Subjects should be surveyed more in depth about musculoskeletal discomfort and computer use, including computer use outside the work environment. Additional factors that would help in determining the effects of ergonomic interventions are occupational factors, physical health, frequency and duration of rest breaks, and previous ergonomic training. Future studies may consider ways to have indirect, non-obtrusive measures taken, such as video recording.

4.8 Conclusion

The purpose of this study was to see the effects of using a flat panel monitor arm on the risk of developing work related upper extremity musculoskeletal disorders and CVS, and the impact on workstation comfort and satisfaction based on objective and subjective data. Currently, there is a lack of research on the effects of adjustable workstation equipment and its actual benefits in reducing the risk of injury. Additionally, research on the positioning of workstation components and its effects on discomfort is somewhat contradicting.

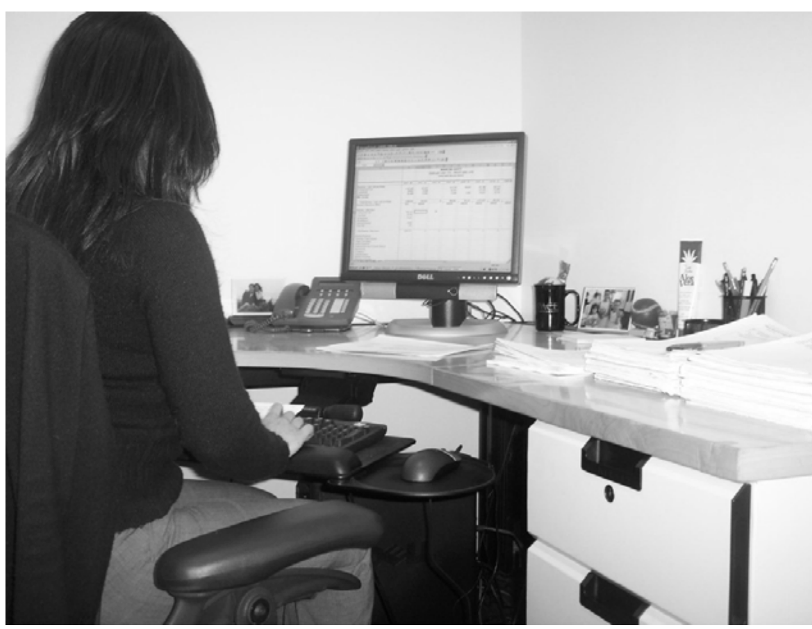
The significant change in reported ULMSD index between test and control groups provided some evidence for the reduced risk of WMSDs. Observations and subjective data also revealed an overall favorable opinion of subjects who received the FPMA at their workstation. Test subjects reported high satisfaction and comfort for their monitor screen because the FPMA allowed them to position their screen at a comfortable viewing height and distance. Test subjects also reported that they could more easily share the information on their screen with colleagues with the use of the monitor arm.

Subjects who received the monitor arm also reported a greater satisfaction for the amount of storage at their workstation as compared to subjects in the control group. With the addition of the articulating monitor arm, subjects were able to utilize the space underneath the monitor for additional storage. The monitor arm allowed users to more easily access items that were located behind the monitor by simply pushing it to the side.

With the use of the monitor arm, subjects in the test group were able to position the monitor at a comfortable viewing distance more frequently than those in the control group. Furthermore, repositioning the monitor to a comfortable viewing distance and height was also easier to achieve with the use of an articulating monitor arm.

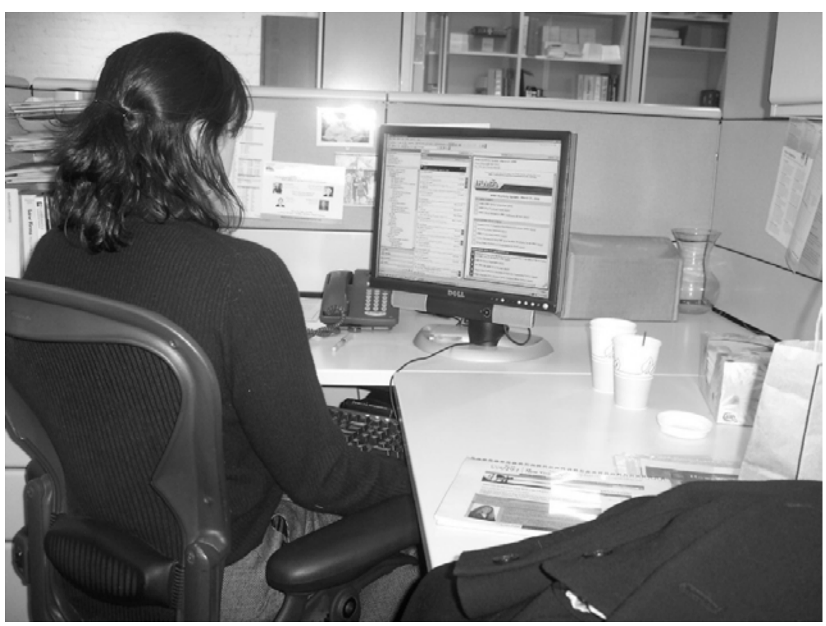
Appendix A: Office Desk with 90^{o} Corner

Appendix B: Office Desk with Curved Corner



Appendix C: Typical Office Work (Architect)

Appendix D: Typical Office Work (Administration)



Appendix E: Workstation with FPMA installed

Appendix F: Online Survey Wave 1

Cornell University Office Environment Survey

Thank you for volunteering to participate in this study. Please answer all of the following questions about your office workstation. This is the first of two brief surveys that your will receive. The second survey will be sent in around 1 month's time. Your answers are **Confidential** and individual answers will only be seen by researchers at Cornell. When a report of this study is completed it will only contain anonymous summary statistics.

1. How long have you worked at your present desk? [Select one...]
2. How many days each week do you work in the office? [Select one...]
3. About how many hours each day do you work at your desk in the office? [Select one...]
4. What corrective lenses do you wear to work on your office computer? (indicate all that apply)

☐ None	☐ Regular glasses	☐ Trifocals
☐ Reading glasses	☐ Bifocals	☐ Contact Lenses

5. How old are you? [Select one...]
6. What is your gender?

○ Man ○ Woman

7. On a typical workday, about how long do you spend:

a. working with paper documents/ plans at your desk	Select one...
b. using your work surface for work related tasks	Select one...

c. using your computer at your desk	Select one...

8. How comfortable are the following workstation items?

	Very comfortable	Fairly comfortable	Fairly uncomfortable	Very uncomfortable	Not applicable
a. computer keyboard	○	○	○	○	○
b. computer mouse	○	○	○	○	○
c. computer screen	○	○	○	○	○
d. computer chair	○	○	○	○	○

9. How often do you move your computer screen to create space for paperwork on your desk?

Several times a day	Once or twice a day	3-4 times a week	Hardly ever	Never
○	○	○	○	○

10. How do the following statements describe your use of the computer screen at your desk?

	Always	Most of the time	Some of the time	Hardly ever	Never
a. My screen is at a comfortable viewing distance	○	○	○	○	○
b. My screen is at a comfortable viewing height	○	○	○	○	○

c. My screen is comfortable to read	○	○	○	○	○
d. There is bothersome glare on my screen	○	○	○	○	○

11. Do you feel the amount of work surface area is sufficient for necessary tasks that you perform?

○ Yes, very ample space	○ Yes, just enough space	○ No, insufficient space

12. How satisfied are you with each of the following components of your current computer workstation furniture configuration?

	Very unsatisfied	Fairly unsatisfied	Fairly satisfied	Very satisfied	No opinion
a. computer keyboard arrangement	○	○	○	○	○
b. computer mouse arrangement	○	○	○	○	○
c. computer screen arrangement	○	○	○	○	○
d. computer chair	○	○	○	○	○
e. workstation workspace	○	○	○	○	○
f. storage at workstation	○	○	○	○	○
g. keyboard tray	○	○	○	○	○

13. Please answer the following questions about your upper body aches, pain, or discomfort.

	During a typical work <u>week</u> about how often do you experience aches, pain, or discomfort in the following upper body regions:	If you experienced aches, pain, or discomfort, how uncomfortable was this?	If you experienced aches, pain, or discomfort, did this interfere with your ability to work?

	Never	1-2 times last week	3-4 times last week	Once every day	Several times every day	Slightly uncomfortable	Moderately uncomfortable	Very uncomfortable	Not at all	Slightly interfered	Substantially interfered
Neck	○	○	○	○	○	○	○	○	○	○	○
Left Shoulder	○	○	○	○	○	○	○	○	○	○	○
Right Shoulder	○	○	○	○	○	○	○	○	○	○	○
Left Upper Arm	○	○	○	○	○	○	○	○	○	○	○
Right Upper Arm	○	○	○	○	○	○	○	○	○	○	○
Left Forearm	○	○	○	○	○	○	○	○	○	○	○
Right Forearm	○	○	○	○	○	○	○	○	○	○	○
Left Wrist	○	○	○	○	○	○	○	○	○	○	○
Right Wrist	○	○	○	○	○	○	○	○	○	○	○
Left Hand	○	○	○	○	○	○	○	○	○	○	○
Right Hand	○	○	○	○	○	○	○	○	○	○	○

14. Please answer the following questions about headache or eye discomfort.

	During a typical work week about how often do you experience:					Did this interfere with your ability to work?		
	Never	1-2 times last week	3-4 times last week	Once every day	Several times every day	Not at all	Slightly interfered	Substantially interfered
Headache	○	○	○	○	○	○	○	○
Tired eyes	○	○	○	○	○	○	○	○
Irritated eyes	○	○	○	○	○	○	○	○
Eyestrain	○	○	○	○	○	○	○	○

15. Please write any comments that you have about the survey.

Appendix G: Online Survey Wave 2

Cornell University Office Environment Survey 2

Only complete this survey if you had a new LCD arm installed at your workstation last month. If you did <u>not</u> have a new LCD arm installed at your workstation complete the <u>control survey</u>

Thank you for volunteering to participate in this study. Please answer all of the following questions about your office workstation. This is the follow-up survey to the one you previously completed. You only be seen by researchers at Cornell. When a report of this study is completed it will only contain anonymous summary statistics.

1. How comfortable are the following workstation items?

	Very comfortable	Fairly comfortable	Fairly uncomfortable	Very uncomfortable	Not applicable
a. computer keyboard	○	○	○	○	○
b. computer mouse	○	○	○	○	○
c. computer screen	○	○	○	○	○
d. computer chair	○	○	○	○	○

2. How often do you move your computer screen to create space for paperwork on your desk?

Several times a day	Once or twice a day	3-4 times a week	Hardly ever	Never
○	○	○	○	○

3. How do the following statements describe your use of the computer screen at your desk?

	Always	Most of the time	Some of the time	Hardly ever	Never
a. My screen is at a comfortable viewing distance	○	○	○	○	○
b. My screen is at a comfortable viewing height	○	○	○	○	○
c. My screen is comfortable to read	○	○	○	○	○
d. There is bothersome glare on my screen	○	○	○	○	○

4. Do you feel the amount of work surface area is sufficient for necessary tasks that you perform?

○ Yes, very ample space ○ Yes, just enough space ○ No, insufficient space

○ Yes, very ample space	○ Yes, just enough space	○ No, insufficient space

5. How satisfied are you with each of the following components of your current computer workstation furniture configuration?

	Very unsatisfied	Fairly unsatisfied	Fairly satisfied	Very satisfied	No opinion
a. computer keyboard arrangement	○	○	○	○	○
b. computer mouse arrangement	○	○	○	○	○
c. computer screen arrangement	○	○	○	○	○
d. computer chair	○	○	○	○	○
e. workstation workspace	○	○	○	○	○
f. storage at workstation	○	○	○	○	○
g. keyboard tray	○	○	○	○	○

6. Please answer the following questions about your upper body aches, pain, or discomfort.

	During a typical work week about how often do you experience aches, pain, or discomfort in the following upper body regions:					If you experienced aches, pain, or discomfort, how uncomfortable was this?			If you experienced aches, pain, or discomfort, did this interfere with your ability to work?		
	Never	1-2 times last week	3-4 times last week	Once every day	Several times every day	Slightly uncomfortable	Moderately uncomfortable	Very uncomfortable	Not at all	Slightly interfered	Substantially interfered
Neck	○	○	○	○	○	○	○	○	○	○	○
Left Shoulder	○	○	○	○	○	○	○	○	○	○	○
Right Shoulder	○	○	○	○	○	○	○	○	○	○	○
Left Upper Arm	○	○	○	○	○	○	○	○	○	○	○
Right Upper Arm	○	○	○	○	○	○	○	○	○	○	○
Left Forearm	○	○	○	○	○	○	○	○	○	○	○
Right Forearm	○	○	○	○	○	○	○	○	○	○	○
Left Wrist	○	○	○	○	○	○	○	○	○	○	○
Right Wrist	○	○	○	○	○	○	○	○	○	○	○
Left Hand	○	○	○	○	○	○	○	○	○	○	○
Right Hand	○	○	○	○	○	○	○	○	○	○	○

7. Please answer the following questions about headache or eye discomfort

	During a typical work week about how often do you experience:					Did this interfere with your ability to work?		
	Never	1-2 times last week	3-4 times last week	Once every day	Several times every day	Not at all	Slightly interfered	Substantially interfered
Headache	○	○	○	○	○	○	○	○
Tired eyes	○	○	○	○	○	○	○	○
Irritated eyes	○	○	○	○	○	○	○	○
Eyestrain	○	○	○	○	○	○	○	○

.8. What is your opinion of the LCD arm that has been fitted to your desk?

Really dislike	Somewhat dislike	Somewhat like	Really like	No opinion
○	○	○	○	○

9. How has the LCD arm affected the workspace at your desk?

Created much less space	Created a little less space	Created a little more space	Created much more space	No effect
○	○	○	○	○

11. How has the LCD arm affected how often you adjust your screen position?

Adjust LCD position much less often	Adjust LCD position a little less often	Adjust LCD position a little more often	Adjust LCD position much more often	No effect
○	○	○	○	○

12. How easy is it to adjust the position of your LCD with the LCD arm?

Very difficult	Difficult	Easy	Very Easy	No opinion
○	○	○	○	○

13. How useful was the ergonomic training that you received in helping you to improve your workstation and how you work?

Not at all useful	Not very useful	Fairly useful	Very useful	No opinion
○	○	○	○	○

14. Have you made changes or adjustments to any of the following as a result of the ergonomics training (check all that apply)?

☐ Keyboard	☐ Keyboard tray	☐ Mouse	☐ Mouse position	☐ Chair
☐ Screen height	☐ Screen position	☐ Workspace layout	☐ Phone	☐ Documents

15. Please write any comments that you have about the LCD arm and how this has affected your workspace.

Appendix H: Online Survey Wave 3

Cornell University Office Environment Survey 3

Only complete this survey if you have an LCD arm installed at your workstation. If you do not have a new LCD arm installed at your workstation complete the control survey.

Thank you for volunteering to participate in this study. Please answer all of the following questions about your office workstation. This is the FINAL follow-up survey to the one you previously answers will only be seen by researchers at Cornell. When a report of this study is completed it will only contain anonymous summary statistics.

1. How comfortable are the following workstation items?

	Very comfortable	Fairly comfortable	Fairly uncomfortable	Very uncomfortable	Not applicable
a. computer keyboard	○	○	○	○	○
b. computer mouse	○	○	○	○	○
c. computer screen	○	○	○	○	○
d. computer chair	○	○	○	○	○

2. How often do you move your computer screen to create space for paperwork on your desk?

Several times a day	Once or twice a day	3-4 times a week	Hardly ever	Never
○	○	○	○	○

3. How do the following statements describe your use of the computer screen at your desk?

	Always	Most of the time	Some of the time	Hardly ever	Never
a. My screen is at a comfortable viewing distance	○	○	○	○	○
b. My screen is at a comfortable viewing height	○	○	○	○	○
c. My screen is comfortable to read	○	○	○	○	○
d. There is bothersome glare on my screen	○	○	○	○	○

4. Do you feel the amount of work surface area is sufficient for necessary tasks that you perform?

○ Yes, very ample space ○ Yes, just enough space ○ No, insufficient space

5. How satisfied are you with each of the following components of your current computer workstation furniture configuration?

	Very unsatisfied	Fairly unsatisfied	Fairly satisfied	Very satisfied	No opinion
a. computer keyboard arrangement	○	○	○	○	○

a. computer keyboard arrangement	○	○	○	○	○
b. computer mouse arrangement	○	○	○	○	○
c. computer screen arrangement	○	○	○	○	○
d. computer chair	○	○	○	○	○
e. workstation workspace	○	○	○	○	○
f. storage at workstation	○	○	○	○	○
g. keyboard tray	○	○	○	○	○

6. Please answer the following questions about your upper body aches, pain, or discomfort.

	During a typical work week about how often do you experience aches, pain, or discomfort in the following upper body regions:					If you experienced aches, pain, or discomfort, how uncomfortable was this?			If you experienced aches, pain, or discomfort, did this interfere with your ability to work?		
	Never	1-2 times last week	3-4 times last week	Once every day	Several times every day	Slightly uncomfortable	Moderately uncomfortable	Very uncomfortable	Not at all	Slightly interfered	Substantially interfered
Neck	○	○	○	○	○	○	○	○	○	○	○
Left Shoulder	○	○	○	○	○	○	○	○	○	○	○
Right Shoulder	○	○	○	○	○	○	○	○	○	○	○
Left Upper Arm	○	○	○	○	○	○	○	○	○	○	○
Right Upper Arm	○	○	○	○	○	○	○	○	○	○	○
Left Forearm	○	○	○	○	○	○	○	○	○	○	○
Right Forearm	○	○	○	○	○	○	○	○	○	○	○
Left Wrist	○	○	○	○	○	○	○	○	○	○	○
Right Wrist	○	○	○	○	○	○	○	○	○	○	○
Left Hand	○	○	○	○	○	○	○	○	○	○	○
Right Hand	○	○	○	○	○	○	○	○	○	○	○

7. Please answer the following questions about headache or eye discomfort.

	During a typical work week about how often do you experience:					Did this interfere with your ability to work?		
	Never	1-2 times last week	3-4 times last week	Once every day	Several times every day	Not at all	Slightly interfered	Substantially interfered
Headache	○	○	○	○	○	○	○	○
Tired eyes	○	○	○	○	○	○	○	○
Irritated eyes	○	○	○	○	○	○	○	○
Eyestrain	○	○	○	○	○	○	○	○

.8. What is your opinion of the LCD arm that has been fitted to your desk?

Really dislike	Somewhat dislike	Somewhat like	Really like	No opinion
○	○	○	○	○

9. How has the LCD arm affected the workspace at your desk?

Created much less space	Created a little less space	Created a little more space	Created much more space	No effect
○	○	○	○	○

11. How has the LCD arm affected how often you adjust your screen position?

Adjust LCD position much less often	Adjust LCD position a little less often	Adjust LCD position a little more often	Adjust LCD position much more often	No effect
○	○	○	○	○

12. How easy is it to adjust the position of your LCD with the LCD arm?

Very difficult	Difficult	Easy	Very Easy	No opinion
○	○	○	○	○

13. Has the LCD arm allowed you to find an optimal position for your screen?

○ Yes ○ No

14. How often do you meet with colleagues at your workstation to look at information on your screen?

Several times a day	Once or twice a day	3-4 times a week	Hardly ever	Never
○	○	○	○	○

15. How has the LCD arm affected how you meet with colleagues to look at information on your screen?

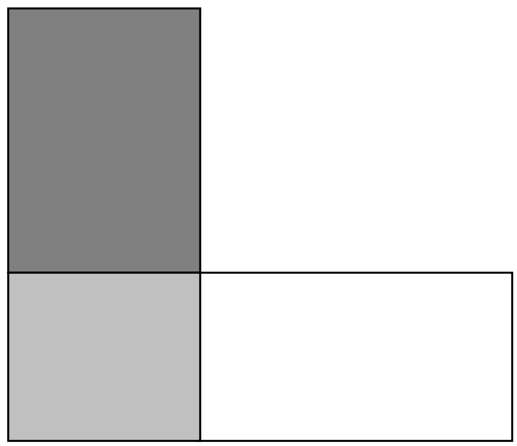
Much easier to show screen to others	Somewhat easier to show screen to others	Somewhat harder to show screen to others	Much harder to show screen to others	No opinion
○	○	○	○	○

16. Are there any design changes to the LCD arm that would be useful to you?

Appendix I: Observation Checklist

Phone number ____________________________

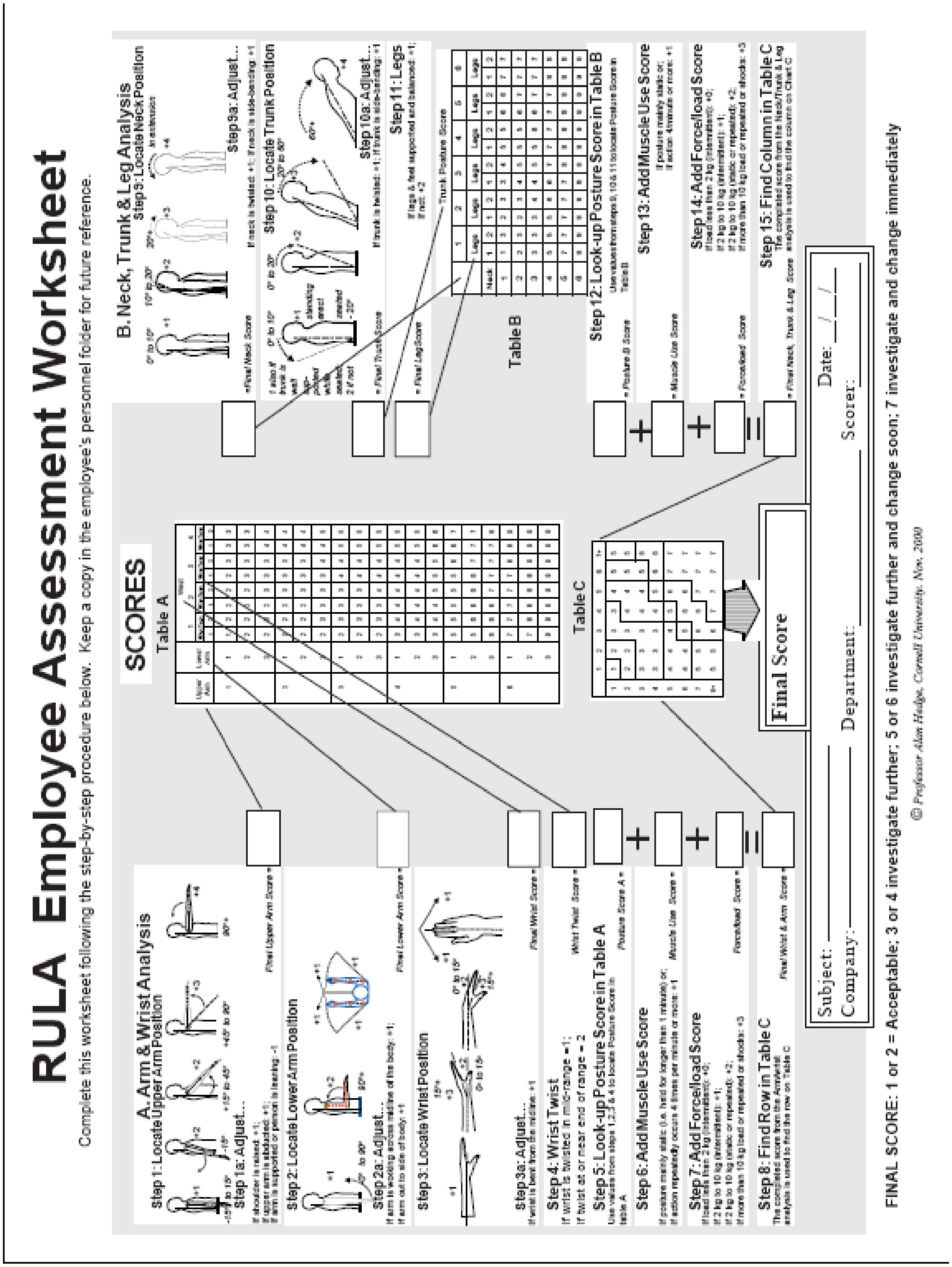
Computer/Desk configuration (sketch workstation layout)



Measurements	Distance	Notes
Eye to monitor		
Torso to monitor		
Torso to desk		
Wrist using mouse to center Torso		
Wrist to Shoulder		
Tilt of monitor		
Screen size		
Monitor to edge of desk		
Used Work Surface area		

Do you adjust based on pain?

Appendix J: Rapid Upper Limb Assessment Worksheet



Appendix K: Responses for Glare Problems

Responses for Frequency of Glare Problems						
	Test 1	**Test 2**	**Test 3**	**Control 1**	**Control 2**	**Control 3**
Never	30.8 %	50.0%	50.0%	16.7%	9.1%	30.0%
Hardly Ever	38.5 %	41.7%	40.0%	58.3%	54.5%	50.0%
Some of the Time	15.4%	8.3%	10.0%	25.0%	36.4%	10.0%
Always	15.4%	0%	0%	0%	0%	10.0%

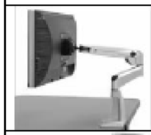
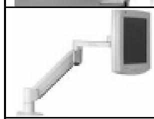
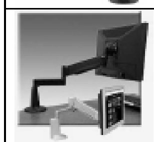
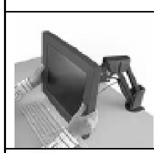
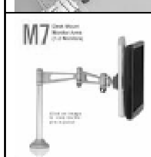
Appendix L: Descriptive Statistics of Torso to Desk Measurement for all subjects

Torso to Desk	N	Mean	Std. Error
Wave 1	28	35.02	2.32
Wave 2	23	34.29	2.34
Wave 3	18	31.90	3.73

Appendix M: Market Research

The Market Survey chart below compares these functions, materials, costs and unique company information for flat panel monitor arm models researched.

Product Features of the current market

Model Image	Model Name	Model Make	Model Rotation/Tilting Features	VESA compliant	Cost	Arm Weight	Weight Support	Model Material	Additional Company Information
	Workrite Ergonomics	SA1000-G Swing Arm	Ball swivel allows set viewing angle and monitor rotation Smooth tilting action helps eliminate glare on the screen	Yes	$249	9 lbs.	25lbs	Sheet Metal	• Do not have used product available for sale. • Recycle at the plant • Company offers product Quality Rating Economical — Premium
	ErgoMart	SAA2718	Vertical range of motion of almost 18" 200° tilt	Yes	$230	15 pounds	up to 33 lbs.	Die cast aluminum alloy	• LCD monitor arm reaches out 27" and folds up into 3.75". • More than 17.5" vertical travel when wall mounted.
	Innovative	9112-S-FM -	Rotates 360 degrees at three joints over 200°	Yes	$223	Not Known	up to 40 lbs.	Cast aluminum	• No recycled material • No recycling program • Own internal recycling program at company office.
	Astra	25-KCG-110S	Pivot (desk/display/arm) 360°/180°/360° Portrait and landscape rotation and side-to-side pivot	Yes	$285	Not Known	up to 24" or 25 lbs.	Die cast aluminum alloy	• It's available in three models with extensions of 13.5", 20" or 26.5". • It takes less than 5 lbs of force to raise or lower flat panel Green Products: Made with 100% recyclable materials.
	Idea@Work Mantis	MA-1000	360° horizontal rotation from base; 180° horizontal rotation from arm; 180° degree horizontal rotation/75° spherical tilt from socket clamp Height adjustable arm - the range is 19"; 11" above the hinge, and 8" below the hinge.	Yes	$199	8lbs	up to 25 lbs.	Die-cast aluminum alloy frame	• Bearing swivel base - Allows for adjustment of arm in a full 360 degree arc • 16.72-23.32 inches of horizontal arm range.
	Kensington Premium Gas Monitor Arm with SmartFit System	60106	Arm extends up to 20.5" in any direction. Tilts up to 90° in all directions. Three height levels.	Yes	$145	Not Known	up to 20lbs.	Die-cast aluminum alloy frame	• No recycling program • Gas Monitor Arm with Smartfit System
	Humanscale	M7	360° monitor rotation for portrait or landscape viewing 60° range of lateral and vertical monitor tilt	Yes	$297	9 lbs - 20 lbs	7 lbs to 35 lbs	Die-cast aluminum frame	• Made of 90% recycled aluminum • Products are 100% recyclable • Packaged in recycled paper products

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