2007

Effects Of Optical Blur On Visual Performance And Comfort Of Computer Users

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EFFECTS OF OPTICAL BLUR ON VISUAL PERFORMANCE AND COMFORT OF COMPUTER USERS

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A DISSERTATION

Submitted to the graduate faculty of the University of Alabama at Birmingham
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy/ Vision Science

BIRMINGHAM, ALABAMA

2007

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FERIAL M. ZERIED

ABSTRACT

Background. The study examined the effects of optical blur on the visual performance and comfort of computer workers. Since most workers have significant degrees of optical blur, the study may elucidate improved methodology for workplace comfort and function.

Methods. Since young and old workers experience blur from different sources, the study incorporated two different designs. The study examined the correction of optical blur using a randomized, double-blind, placebo-controlled, crossover design. The primary outcomes of the study were visual comfort and productivity. In study one, subjects were required to be 19-35 yrs of age, have at least 0.50D uncorrected refractive error (URE) in at least one eye, use a computer for at least1-hr/day and have at least 20/40 corrected visual acuity (VA) in each eye. During two one-month study periods, subjects wore either lenses fitted for their best or habitual correction and completed 4 hours of testing. In study two, subjects were required to be 40 years of age or older with corrected VA of at least 20/40 and to require a near plus lens addition. Subjects completed a total of 4 hours of testing in ten 15-minute periods with their near plus prescription and a test pair of lenses (plano, +/-0.50 or +/-1.00D) with head free or fixed on a chin rest.

Results. Analysis for the first study confirmed a relationship between the visual comfort index (VCI) and the number of eyes meeting the criteria of 0.50D URE and the task order (p = 0.0003, 0.0025) and suggested a trend for a similar relationship for correct comfortable work (CCW, p=0.0149). For the second study, the VCI declined by 15.4% (p = 0.0001) while total correct work (TCW) and CCW increased (36.4, 25.9%, respectively; p=0.0001, 0.0094) over the 2.5 hr work period. Analysis supported a hypothesis of a significant interaction of lens and head for VCI and CCW (p=0.0049, 0.0088, respectively) as well as a main effect for head position for TCW (p = 0.0069).

Conclusion. Subjects were most comfortable and productive while working with low or absent degrees of optical blur in at least one eye.

DEDICATION

This dissertation is dedicated to my parents. More than a few times in the course of doing the work of it, their prayers for my success inspired me to go on when I imagined I could not. It is sad for me that my mother passed away before seeing those of her prayers answered. But I am certain she still watches over me and, to her, I offer a special ‘thank you’ in mine. This dissertation is also dedicated to my husband. Without his support, I would not have been able to perform the tasks required of me. And to my children. For their patience with their mom ‘being away’ to pursue a career in vision science research.

ACKNOWLEDGEMENTS

My gratitude and admiration go to for Dr. Kent Daum for his steadfast support, flexibility, endless flow of ideas and consistent graciousness. My thanks, too, go to Dr. Kent Keyser for his support and advice; Maria Voce for her help in recruiting subjects for my project; and to Dr. Marcia O`Neal for the excellent statistical analysis she conducted on my project. I also extend special thanks to the Vision Council of America, PRIO Corporation and the Environmental/Occupational Vision Committee of the American Optometric Association for funding the study.

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LIST OF ABBREVIATIONS

B. Best

C. Condition

CCW. Comfortable correct work

D. Diopter

DS. Diopter sphere

E. Eye

H. Habitual

J45. 45/135 refractive vector

JO. 180/90 refractive vector

L. Lens

M. Spherical refractive vector

N, n. Number

O. Order

PAL. Progressive addition lenses

RE. Refractive error

TCW. Total correct work

URE. Uncorrected refractive error

VA. Visual acuity

VCI. Visual comfort index

VD. Vector diopter

VDD. Vector dioptric difference

CHAPTER 1

EFFECTS OF OPTICAL BLUR ON COMPUTER USERS

INTRODUCTION

The computer has been an essential feature of the workplace for many years and has become a common and visually demanding tool in the office and factory, as well as in homes, colleges, and universities. According to the US Census Bureau, in 2003, 70 million American households, or 62 percent, had one or more computers and 86.3 percent of all children 3 to 17 years old used a computer at home while 83.4 percent worked with computers in school (U.S. Census Bureau [UCB], 2003).

About one hundred million working adults in the United States spend their workday in front of a computer monitor (Sheedy & Shaw-McMinn, 2003). For the working population 18 years and older, the most common computer tasks at work involve e-mail and Internet access (75.4%), word processing (67.8%), spreadsheets (64.4%), and scheduling (57%) (UNCB, 2003).

Some jobs require short periods of work in front of a computer monitor; others require short but frequently repeated periods of work; and others, such as word processing, data entry, or programming demand sustained periods of such work.

Vision-related problems are the most frequently reported health-related problems of computer users, occurring in over 70% of computer workers (Collins, Brown, Bowman & Caird, 1991; Dain, McCarthy & Chan-Ling, 1988; Stammerjohn, Smith & Cohen, 1981). Frequent headaches, focusing difficulties, double or blurry vision, eye strain, fatigue and irritation, pain or burning in the eyes, and frequent blinking or squinting are the most commonly reported symptoms.

The more time workers spend using a computer, the more often vision problems such as these develop (Sheedy & Shaw-McMinn, 2003). The amount of time spent on the computer is commonly thought to be a major factor in the visual fatigue computer users experience. (Knave, Wibon, Voss, Hedstrom & Bergqvist, 1985; Rechichi, De Moja & Scullica, 1996). In addition to visual problems, neck and back aches, as well as other musculoskeletal conditions such as carpal tunnel syndrome, have also been reported in computer users (Bergqvist ,Wolgast, Nilsson, & Voss, 1995; Dain, McCarthy, & Chan-Ling, 1988; Fredriksson, Alfredsson, Ahlberg, Josephson, Kilbom, Wigaeus Hjelm, Wiktorin, & Vingard, 2002).

Although studies have suggested that a reduction in symptoms and substantial productivity gains are likely to occur when optimal vision care is provided, no double-masked study in the work place has been completed to confirm these suppositions (Daum et al, 2004a, b). An appropriately constructed study has the potential to determine how optimizing the visual correction of workers affects the accuracy and volume of their work. In addition, further analysis may allow an estimate of the cost-benefit advantages to employers providing employees optimal eyewear for the work in question (Daum et al, 2004a, b).

Optical blur is a common problem usually resulting from incorrect refractive correction (Foran et al., 2002; Taylor, Livingston, Stanislavsky & McCarty, 1997). This project examines the hypothesis that optical blur represents a drag on the efficiency of workers using computers, particularly if the workers are engaged in such work over extended periods of time. The extent that adaptation to blur ameliorates its potentially damaging effects on productivity is a central issue for this study since laboratory studies have previously demonstrated these effects in short-term examinations of the question. A complete discussion of the hypothesis and its significance is provided later in the manuscript.

COMPUTER VISION SYNDROME

Computer vision syndrome (CVS) is a conceptual framework describing the complex of vision-related symptoms among computer users (Sheedy & Shaw-McMinn, 2003). Accomplishing computer-related tasks requires frequent eye movements from the work document to the computer or from the computer to the keyboard and back again. If the objects being viewed are at two distances (computer and hard copy), the eye also must alter its focusing to maintain a clear image. These changes occur repeatedly during computer use.

Eye movements, accommodation, and eye alignment processes involve repetitious muscular activity. The movement of each of the eyes is controlled by six extra-ocular muscles, (Davison, 1990a) which are responsible for proper alignment of the eyes when viewing objects such as the computer. The ability of the eyes to change focus is controlled by the ciliary muscle, which exerts a force on the crystalline lens of the eye (Davison, 1990b). The flexibility of the lens within the eye and the contraction of the ciliary muscle gradually decrease with age and results in the onset of presbyopia, which affects most people after about age 40.

One survey estimated that about 10 million Americans per year seek eye examinations related to issues related to the use of computers (Sheedy, 1992a). There is a 25 to 39% prevalence of CVS among workers who use computers intensively for more than three to four hours per day without a break (Sheedy & Shaw-McMinn, 2003). The prevalence of CVS among African American computer workers could be higher than this estimate (Tielsch, Sommer, Witt, Katz & Royall, 1990).

Causes of Computer Vision Syndrome

CVS is often thought to be a result of a multi-factorial etiology. Contributing causes include convergence and accommodation and decreased blinking related to sustained viewing (Dain et al, 1988). Refractive error and ergonomic characteristics of the workstation environment also are potential etiological factors (Sheedy, 1992a; Dain et al, 1988; Grant, 1987; Daum et al., 1988; Thomson, 1998). The design of the computer video display, such as monitor resolution and contrast, and image refresh rates (flicker) also may cause CVS. Glare, inappropriate working distances and/or angles may also contribute to worker symptoms (Sheedy, 1994; Campbell & Durden, 1983). Finally, noise combined with high luminance also has been demonstrated to affect mental activity (i.e., concentration) among computer workers, at least in the short term (Takahshi et al., 2001).

Harrison (1983) found that eyestrain is more common among computer workers than among other clerical workers and that CVS could arise due to factors in the office environment. These factors included the design and position of the computer, duration of working period and type of work, the psychological stress related to the work demands and concentration required, as well as job security and remuneration (Harrison, 1983). CVS symptoms, e.g., asthenopia, may result from near work if the visual demand of the task exceeds the visual abilities of the individual to comfortably perform the task (Harrison, 1983).

SYMPTOMS RELATED TO THE USE OF COMPUTERS

Eye and Head Discomfort

Computer workers complain of vision problems more than other workers, and more than they complain of any other physical problem. Frequent headaches, focusing difficulties, double or blurry vision, eye strain, fatigue and irritation, pain or burning in the eyes, and frequent blinking or squinting are the most commonly reported symptoms (Council on Scientific Affairs, 1987; Rohovit, 2004; Sheedy, 1992a; Smith, 1979; Dain et al., 1988; Harrison, 1983; Ho, 1999).

Optical blur, caused by refractive error, is one source of these discomforts. However, using the computer for long periods of time also contributes to visual discomfort (Sheedy, 1992). Optical blur may affect both the visual comfort and the productivity of computer users (Daum et al., 1988; Wiggins, Daum & Snyder, 1992; Wiggins & Daum, 1991; Daum et al, 2004a, b).

Physiological Problems & Musculoskeletal Issues

One physiological problem that results from working at the computer for extended hours without moving is the relative immobility of the vertebral column and joints, leading to blood circulation problems and musculoskeletal injuries such as neck and back muscle spasms and joint stiffness (Campbell & Durden, 1983).

Musculoskeletal system problems, such as neck, shoulder and backaches may be due to improper posture resulting from the combination of the workstation set-up and the way that the eyes are required to look at the computer. The use of spectacles not designed for the computer task likely contributes in some cases.

Monofocal or single-vision glasses should provide the appropriate optical correction for the working distance between the monitor and the computer user's eyes and allow users to view the whole screen with a minimum up-and-down head movement. The disadvantage of single-vision lenses for many presbyopic subjects is that both distant objects and reading materials that are closer than the computer screen will appear blurry (Canadian Centre for Occupational Health and Safety [CCOHS], 2006).

Bifocal glasses can be prescribed so that the upper segment is set up for the screen distance and a lower segment for work that is closer than the screen. The disadvantage of this option is that objects farther away than the screen are blurry. The bifocal addition is generally arranged to provide clear, comfortable vision for materials held in the reading position. The reading position is typically closer than the computer monitor and is also set for viewing at a lower angle than the computer. Because of this most bifocal users viewing a computer monitor must move closer while tipping their head back to see. Unsurprisingly, this accommodation often causes discomfort if maintained for a significant period of time.

Bifocal lenses may also distort images of objects in the peripheral zone of vision. Bifocals and other segmented glasses like those mentioned below have a smaller area for viewing the monitor. This means more up-and-down head and/or neck movement is required to view all parts of the screen (CCOHS, 2006) and this movement has the potential to cause head, neck and shoulder discomfort (i.e., musculoskeletal disorders).

Trifocal glasses have lenses that combine a segment for far vision, an intermediate segment for vision at the screen distance and another segment for near vision. The disadvantage of using trifocal lenses is a limited continuity of vision and the small clear area available for viewing the computer monitor. Also, distortion in peripheral vision may be more pronounced than with bifocals (CCOHS, 2006).

Progressive addition lenses (PAL) offer better continuity of vision by eliminating lines between segments of different focal power. Wearers of PALs also report less distortion of peripheral vision than those wearing conventional multifocal glasses (CCOHS, 2006).

Spectacles for computer use should be individually designed to enable wearers to focus effortlessly on the screen with their normal head position, but also enable them to see the keyboard and to read printed copy without having to raise or lower their chin, or adopt unnatural postures that could lead to the musculoskeletal problems mentioned above. Visual ability, personal preferences of a computer user, the type of work, the distance between the computer user's eyes and the monitor, and the lighting design are all factors that should be taken into consideration (CCOHS, 2006).

Most recommendations suggest that workers should change positions frequently and note the importance of appropriate job and workstation design and office management, with suitable furniture and frequent movement and activities. This action can help to prevent symptoms as well as cramping or fatigue; as Campbell said, "sitting hurts your joints, staring your eyes" (Campbell & Durden, 1983).

Bergqvist, Wolgast, Nilsson and Voss (1995) found no general differences between computer and non-computer users as to the occurrence of muscle problems. However, they did find that certain combinations of work at a VDT, such as data entry, for more than 20 hours per week and the presence of other factors were associated with excess risks of muscle problems. These other factors included: the use of bifocal or progressive glasses during VDT work; stomach-related stress reactions; limited rest periods; repetitive movements; lack (or non-use) of lower arm support; and, possibly, the vertical position of the keyboard and specular glare. For example, they found that individuals doing data entry work with a keyboard placed low (below the elbow) had an increased odds ratio for arms/hands discomfort, and that individuals working more than 20 hours per week at a computer executing tasks which involved repetitive movement and who reported frequent stomach reactions had an excess odds ratio for neck/shoulder discomfort.

In a study designed to measure head flexion and postural loads on the trapezius and infraspinatus muscles, Horgen, Aaras, Kaiser and Thoresen (2002) found no significant musculoskeletal risk differences between computer workers who wore single-vision lenses and those who wore specially-designed computer lenses. Even so, a significant number of participants wearing single-vision lenses complained about tiredness after the full test period, and a time-dependent effect on EMG recordings was found for both the right and left trapezius muscles. The increase in EMG readings may support the importance of varying the work task or taking short breaks during extended work.

The combination of the type (data entry) and length of time of work on the computer (more than 20 hours per week) and the presence of some other factors has been associated with excess risks of certain muscle problems (Bergqvist et al., 1995). Choom-Nam Ong and his colleagues examined the possible causes of musculoskeletal disorder among computer workers. They noted that the relationship between musculoskeletal disorders and computer users was centered on occupational factors, work-related psychological factors, and psychosocial factors (Ong, Chia, Jeyaratnam & Tan, 1995).

Since many computer workers suffer pain and inconvenience when using a computer and the associated medical costs may be considerable, preventing and managing musculoskeletal disorders warrants urgent attention. Ong and colleagues suggested some preventive strategies such as, (1) improving the ergonomic design of computer work stations; (2) initiating occupational legislation; and, (3) improving occupational health services in order to reduce the incidence of this type of disorder in computer workers (Ong et al.,1995).

Symptom Resolution

One relatively simple solution for many problems and complaints when using a computer is to take rest periods away from computer work during working hours. These rest periods have the potential to affect productivity, either positively or negatively. To optimize workload performance and minimize the number of errors with visually intensive computer work, one recommendation is to take a five-minute break from the computer for every 30 minutes of work, and the duration of continuous computer work should be 60 minutes or less (Nishiyama, 1990). Horie (as cited by Nishiyama, 1990) concluded that 60 minutes of work with 10-minute breaks is optimal and recommended that those who work over two hours per day on a computer take at least a 15-minute break from the computer for every 60 minutes of work. Misawa (as cited by Nishiyama, 1990) found a significant correlation between a lengthened near point of convergence distance, increase of symptoms, an increased error rate and an increased working time without breaks.

Optical Blur

Optical blur may cause significant problems for computer users. Blurred vision at near may be a result of accommodative spasm, presbyopia, refractive error, improper refractive correction or other eye disorders (Sheedy, 1992a). Non-optical blurred vision can also result from factors in the working environment, such as a dirty monitor, poor viewing angle, reflected glare or poor monitor quality. Even if visual acuity is relatively unaffected, small amounts of uncorrected astigmatism may contribute to visual discomfort (Wiggins & Daum, 1991).

Accommodation is “a change in curvature of the lens of the eye [which] occurs when attention is shifted from an object at one distance to another object at a different distance from the eye” (Smith, 1979). At about the age of forty years, a gradual lessening of the power of accommodation becomes noticeable for most individuals due to changes in the lens and its associated apparatus. This condition is known as presbyopia. Collins and Kirvohlavy (as cited by Smith, 1979) explored the idea that accommodation and convergence changes were the most sensitive measure of visual fatigue. Kravkov (as cited by Smith, 1979) supported this finding by emphasizing that visual fatigue resulted in reducing the range of accommodation. Most people at the age of forty years and older require plus addition lenses in order to clearly see near objects, because the capacity for accommodation reduces with age (Ciuffreda, 1998).

For those presbyopic people who frequently use a computer in their work, visual problems may arise because a plus lens addition either is not being worn or is of an inappropriate power. Presbyopic subjects who are wearing a plus lens addition for near may still suffer a degree of optical blur when using their computer if the plus addition was prescribed to correct vision for the common, near-work distance of 40 cm (16 inches) rather than the intermediate distances used in computer work (50 to 60 cm, 20 to 30 inches) and the user does not adjust their posture.

Causes of Blur

Refractive error as major cause of blur. Optical blur lowers visibility in general and computer monitor visibility in particular. Workers with uncorrected refractive errors (hyperopes, myopes or astigmats) may experience optical blur. The resulting difficulty in seeing material on a computer exacerbates symptoms related to computer use and can extend the work time necessary to complete vision-related tasks, as well as increase the likelihood of errors during the execution of tasks (Daum et al., 1988).

Refractive error is very common. In the year 2000, roughly one-third of persons 40 years or older in the U.S. and Western Europe, and one-fifth of the population in this age group in Australia had significant myopia or hyperopia (Kempen, Mitchell, Lee , Tielsch, Broman, Taylor, Ikram, Congdon and O'Colmain, 2004). The estimated crude prevalence for hyperopia of +3D or greater was 9.9% (11.8 million persons), 11.6% (21.6 million persons), and 5.8% (0.47 million persons) in the U.S., Western Europe and Australia, respectively (Kempen et al., 2004). For myopia of -1D or more, the estimated crude prevalence was 25.4% (5.3 million persons), 26.6%, (8.5 million persons), and 16.4%, (0.23 million persons) in the U.S., Western Europe and Australia, respectively (Kempen et al., 2004).. These distributions are expected to remain similar through 2020 (Kempen et al., 2004). Thus, approximately 47.9 million persons in the presbyopic age groups in these areas (hyperopia and myopia) in 2000 were affected with either hyperopia or myopia, and in 1990, in the U.S. alone, an estimated $12.8 billion was spent to correct refractive errors (Kempen et al., 2004).

Refraction correction error. More important than overall refractive error is the adequacy of refractive correction. Several studies suggest that the risk for under-corrected refractive error increases dramatically with age, beginning at around 40 years, where 8% of subjects have been found to be poorly corrected (Liou, McCarty, Jin, Taylor & Fraco, 1999; Saw et al., 2004). The risk of poor refractive correction increases 1.8 times for every decade of life thereafter (Liou et al., 1999; Saw et al., 2004). In subjects older than 80 years, under-correction can be as high as 29% of total patients (Liou et al., 1999; Saw et al., 2004). In their study of subjects aged 49 to 87 years, Foran, Rose, Wang and Mitchell (2002) noted that correctable visual impairment accounted for two-thirds of visual impairment in that age range. Overall, estimates suggest that about half or more adults could improve their visual acuity with an updated refractive correction (Foran et al., 2002; Taylor et al, 1997).

In order to best perform accurate work with good visual comfort when viewing a computer, a person must have good visual acuity. Having good vision i.e., 20/20 visual acuity or there abouts, does not mean a subject will not experience blurred vision or dry eyes during work at a computer. Sometimes, low refractive errors, including astigmatism, can cause these symptoms. Some individuals, including contact lens wearers, also experience dry eyes and blurred vision. This is caused by a number of factors and may be associated with infrequent blinking thereby making the contact lenses dry and dirty.

Optical blur should be considered when any symptoms of computer users are being monitored or measured. An accurate correction of refractive error may remove blur that may be contributing to visual discomfort and musculoskeletal problems.

Grisham and Simons (1986) stated that hyperopia and anisometropia may be related to poor reading progress and that correcting it with prescription glasses may improve reading skills and performance. This also supports the correction of refractive errors causing a decrement in image quality to significantly improve comfort and reading performance.

These studies suggest that greater diagnostic scrutiny and more strenuous visual health outreach could be applied to patients in these age groups. To the extent that the average age of the working population approaches or enters the presbyopic age ranges, studies suggesting a connection between refractive correction and visual comfort and productivity as well as musculoskeletal disorders carry profound implications for employers. Taken together, present evidence suggests that an employer’s choices are limited to either providing appropriate vision care to employees or absorbing the productivity costs of not doing so.

Optical Blur in Presbyopia

Presbyopia is a significant issue for computer workers since the computer is located in the intermediate zone of vision, where accommodation is required. A presbyopic computer worker using a bifocal may often find it hard to focus on the monitor because bifocals are designed to correct either distance vision and normal reading vision, at a typical distance for reading material of 40 cm (16 inches). In addition, such corrective bifocal spectacles are designed assuming a downward gaze of 25° to 30º when reading (Sheedy & Shaw-McMinn, 2003).

A computer, however, is generally viewed from 50 to 60 cm (20 to 24 inches) from the eyes, and optimally is seen at a 10° to 20° downward angle. As a result of these differences of the computer in both the distance and location of near material, bifocal wearers have to constantly keep moving back and forth while changing their posture to focus material on a computer. This often results in the assumption of an improper or awkward posture and further results in neck and back strains (i.e., musculoskeletal disorders; Sheedy & Shaw-McMinn, 2003). Differences in worker behavior during computer work as opposed to behavior associated with reading near hard copy material presents a wide range of challenges to optometrists in order to maintain a person's comfort level during computer use.

Burns (1993) noted that a previous study by Yeow and Taylor (1990) found no correlation between age and computer-related symptoms on presbyopic and non-presbyopic subjects regarding symptoms when using computers. Yeow and Collins (as cited by Burns, 1993), supported this finding. Burns (1993) also stated "Makitie (1968) found eyestrain was not more frequent in computer work than in paperwork for presbyopes or non-presbyopes," while Dain (as cited by Burns, 1993), found that blurry vision was the only symptom that increased with age. This could be because subjects delayed managing their presbyopic symptoms (Grundy, as cited by Burns, 1993).

HOW VISION PROBLEMS AFFECT PRODUCTIVITY

We define productivity as the combined accuracy and magnitude of work as measured in a controlled environment. In laboratory settings, visual discomfort and optical blur has been shown to reduce productivity (Daum et al., 2004a). That reducing vision discomfort should increase productivity is an intuitive conclusion but precisely how and to what extent poor vision conditions decrease productivity and appropriate vision corrections increase it have not been precisely defined and are questions that need answering if practical responses to the expense and health issues of vision complaints of computer workers are to be undertaken.

At this writing, research into these questions has given no clear indication of exactly what magnitude of refractive error, under what working conditions, produces what type and level of discomfort sufficient to decrease productivity. For example, in their study comparing the effect of cylindrical errors on editing performance while using the computer and hard copy, Sheedy, Bailey and Fong (1989) and Sheedy et al. (1990) found that a 1.0D error or greater of defocus in the cylinder consistently resulted in a decrease in performance in computer use and, to a lesser extent, in work with hard copy as well. In the same study, Sheedy et al. (1990) found that low–power plus spherical lenses did not affect performance. Meanwhile, Daum et al. (1988) found that refractive errors as small as 0.5D or as large 1.0D, can – depending on the task type and the magnitude of blur – decreased productivity ranging from 9% to 40% in magnitude of work and 38% to over 100% in the number of errors. One estimate was that refraction mis-correction of as little as 0.5D can decrease productivity by approximately 2.3% (Daum et al., 2004a).

This is a very strong indication that an overarching conceptual framework uniting new research and existing literature is lacking and in need of development. Even so, some things can be said with high degrees of certainty:

- Lighting has the potential to affect productivity and comfort. A comparison study between lensed-indirect lighting and parabolic down lighting found an increase in self-reported productivity of 2 to 3% for the lensed-indirect lighting (Hedge et al., 1995).
- To the extent that the computer worker adjusts (or maintains) his or her physical position to compensate for visual discomfort or ergonomic shortcomings of the workstation, musculoskeletal and associated issues can come into play, further compromising worker health and well-being and, thus, productivity (Horgen et al., 2002).
- A current recommendation for managing or eliminating these and related symptoms is for the computer worker to take frequent breaks from computer work. If this is the only method of addressing such complaints, time-at-work on the computer is lost and productivity is further diminished by what is supposed to be a solution. This is a clear indication of the state of the technology and the state of research, and a strong argument for additional studies designed to more precisely target areas of investigation

toward isolating technological solutions that improve upon current procedural ones.

Precise research should include rigorous investigations of research methodologies themselves. For example, Homan and Armstrong (2003) note that worker self-reporting may not represent an accurate account of time spent performing tasks, in as much as "...worker self-reports overestimated actual keyboard usage by a factor of approximately 1.5 for workers using the keyboard an average of 4 hours per day to a factor of 4 for workers using the keyboard an average of 30 min per day." In self-reporting, subjects may 'load' or 'spin' their reporting to accomplish one or another outcome which casts them in a positive light. Studies relying on self-reported data should be designed to take such mis-reporting into account.

Meanwhile, Jorna and Snyder (1991) point out that proof reading may not be an appropriate measure of performance, in as much as inconsistencies in the types of word misspellings studies present can introduce perceptual and pyschological variables which can have an impact on performance outcomes, but having little or nothing to do with visual performance, per se, and are not always measurable or accounted for in study designs. On the other hand, others have found proof reading to be a satisfactory method of measuring performance (Daum et al., 2004b). Studies relying on proof reading data should be designed around one or another word recognition model (the word shape model, or serial or parallel models of letter recognition), and should, perhaps, contain uniform types of errors.

Real world effects of optical blur can be significant. If uncorrected (or improperly corrected) vision problems can lead to as much as a 5% decrease in overall productivity for computer workers, this could translate into large dollar amounts for an organization. For example, a $24,000 per year clerk with poorly corrected vision and a loss of 5% productivity represents a $1,200 annual loss of output. Multiply that number by the number of employees engaged in similar work and the dollar value of lost productivity can reach into the millions for mid-level organizations with 800 to 1,000 employees (Daum et al., 2004a).

Assume the average cost of an eye examination is $80.00, and the average cost of eyewear (including discounts) is $188.00 for a total of $268.00. If one assumes a 3% increase in productivity from an employee making $24,000.00 per year, this means that a $268 employer investment is capable of producing a $720 return. If employee productivity remains constant, this return can be repeated year after year (Daum et al., 2004a).

Looking at it from a task perspective, if the mean productivity of a worker earning $24,000 for a 2080-hour work year (260 working days) is 100 tasks per day, the worker earns approximately $11.54 per hour and each task costs approximately $0.92 to execute. A 3% increase in productivity with vision correction would be equal to $717.60 for the work year. For this result, the cost benefit ratio would be favorable, $717.60 in productivity resulted from an investment of $268. If the company provides health insurance that already provides for a portion of the vision examination or eyewear, the cost benefit ratio would be correspondingly and favorably altered.

BARRIERS TO VISUAL HEALTH ON THE JOB

Acceptance

Over the years, the advantages of making improvements in the visual environment of the workplace often have been either unknown, poorly understood, or not accepted by the general public and the industrial complex. It is therefore important to understand the relationship between work and vision and to emphasize the need for developing interdisciplinary teams of investigators and practitioners comprising ophthalmologists, optometrists, ergonomists, engineers, architects, occupational hygienists, et cetera who can holistically evaluate work-vision relationships and recommend individual psychological, psychosocial and physio-pathological improvements in both the visual and work environment (Piccoli, 2003). Continuous communication between experts in these diverse fields could develop a continuously improving system that could monitor the cycle of changing processes, measure levels of activity and productivity that contribute to decreased costs and improved quality, and provide recommendations that, ultimately, could increase productivity and income to employers and promote better visual health to the working population at large.

Because of the high prevalence of ocular or visual problems in the working population that uses computer, many recommendations have already emerged from clinical and technical arenas to the public at large. But the recommendations often have been poorly disseminated and may not provide as much information about work-vision paradigms as they could.

An accurate evaluation of possible links between vision complaints and computer work should encompass investigations of three major areas of exposure to underlying determinants: 1) objectively measured task duration; 2) average observation distance; and 3) environmental agents affecting the ocular surface (Picolli, 2003). In response to the exposure data obtained, health surveillance should also be implemented. The International Labor Office (1997) recommended the following guidelines: 1) eye examinations should be strictly relevant to the assessed risk; 2) appropriate tests should be selected in order to detect early signs and symptoms, and 3) job-fitness assessments should be provided (Picolli, 2003).

Cost

All computer operators who could benefit should wear appropriate visual correction to obtain maximum visual comfort and work productivity. Financial considerations sometimes present obstacles to accomplishing this. As suggested by the cost benefit examples given above, one way to overcome such obstacles would be for employers to provide all or part of the costs of eye examinations and, when needed, treatment for eye and vision problems. Another method would be for insurance companies and vision service providers to critically re-examine their respective policies and procedures with an eye toward conforming them to emerging realities.

“Computer Vision Syndrome” is not an International Classification of Diseases (ICD) term, and carriers distinguish “routine” services from services performed that are “directly concerned” with diagnosis and treatment of “pathological” conditions or symptoms. Current research is causing the line that divides “routine” from “pathological” to blur. Conditions that define these terms are changing as are specific services that are directly concerned with diagnosing and treating these conditions. “An eye health exam for patients with specific health disorders is no longer a routine examination.” (Soroka, 1986)

Third party coverage for optometric service has also changed in recent years. Legislative changes expanding the scope and responsibility of services rendered by optometrists allow today’s optometrists to use pharmacological agents for diagnostic and therapeutic purposes, and give them a legal responsibility to detect, diagnose, treat and manage patient health as well. Coupled with freedom of choice laws, these changes have set the stage for increased coverage of optometric care (Soroka, 1986).

Industry response to these and other changes has been uneven and has created a confusing array of complex options for consumers and providers alike. Beginning in the late 1960’s, prepaid vision care plans and subscribers increased dramatically. Medicaid and Medicare provide vision care services only to specific populations. Of the many plans provided by Blue Cross/Blue Shield, only a few contain vision care provisions. Other non-governmental plans (e.g., nonprofit and labor union plans) differ in terms of sponsorship, delivery mode, and method of reimbursement. Alternate delivery models such as health maintenance organizations (HMOs), individual practice associations (IPOs), preferred provider organizations (PPOs), and the more recent medical savings account (MSA) plans each apply their own formulas in determining what merits provider reimbursement and which patients qualify for care. In addition, some companies directly provide such benefits as eye exams and eyewear for their computer workers (Soroka, 1986). The sheer volume of choices can so overwhelm employers, consumers and practitioners that adoption of any vision care plan sometimes is abandoned because the burden of work involved in making the choice is too great.

Education

In addition to confusion resulting from the vast array of disparate coverages available, misunderstandings concerning the use of tests and procedures prevail. Insurance coverage determinations are often made on the basis of a patient's diagnosis without a careful evaluation of the tests and procedures performed. A refractive diagnosis may be disallowed because the eye examination may be viewed as a routine exam to determine the refractive state of the eyes rather than as a diagnostic tool to determine the presence or absence of a disease condition. Carrier clerical personnel may be unaware of the law or the type of procedures and tests that are available, or how they fit in Current Procedural Terminology (CPT) codes. Service providers, themselves, often err in applying CPT codes (Soroka, 1986).

There is also a gap in communication between vision care providers and the communities they serve. A computer vision specialist may require a marketing plan in order to make his or her practice successful. These plans should include an agenda for both internal marketing to staff and colleagues within the organization, and external marketing to patients. Internal plans would result in patients and staff becoming more knowledgeable of available techniques and technologies, and help meet the expectations of one's external plan.

One example of a goal for internal marketing is improving the compliance of one's patients with prescribed treatment relative to computer use (Sheedy & Shaw-McMinn, 2003; Picolli, 2003). Another might be to provide computer glasses and visual therapy to staff members to assist them in recognizing the value and worth of what one has to offer to computer workers (Sheedy and Shaw-McMinn, 2003; Picolli, 2003;

Council on Scientific Affairs, 1987). External plans might include the goal of educating the community at large and senior citizens in particular on how to keep their vision functioning at its best with age so their computer experience would be more comfortable (Picolli, 2003).

More generally, employers should also give serious attention to job design by consulting with experts who thoroughly understand the physiological and psychological issues that contribute to physical or ocular problems or other physical discomfort at computer workstations. This would help optimize employee satisfaction, minimize the negative effects of visual workloads, and obtain maximum performance and productivity.

Both workers and management should be aware of factors in the work area that affect vision conditions and work together to manage and develop the work area for maximum positive effect (Campbell & Durden, 1983). This would help in risk assessment and cost-effective optimization of the work environment (Piccoli, 2003).

Above all of these considerations, computer workers must have accurate optical correction designed to meet the unique demands of computer work and workstations. By examining the hypothesis that optical blur represents a drag on the efficiency of workers using computers, particularly if the worker is engaged in such work over an extended period of time, this project aims to contribute data to the field which can go toward accomplishing that for all computer workers.

GENERAL OBJECTIVES

The effect of optical blur on the visual performance and comfort of computer users on the job has not been exhaustively studied either for presbyopic or non-presbyopic subjects. This protocol was designed to test the practical effects of optical blur in a controlled work environment for both groups.

For the non-presbyopic individuals, the protocol tested the improvement of visual status of computer workers by using the best correction and determining how it affected productivity and visual comfort.

For presbyopic individuals, it tested whether the addition of a lens addition that is either greater or lesser than the most appropriate add affected the productivity and comfort of computer users.

SIGNIFICANCE OF THE PROTOCOL

The project is designed to test the practical effects of optical blur in a controlled work environment. It has significant practical importance because most subjects work with some degree of optical blur as a result of poorly corrected refractive error, which affects visual comfort leading to decrements in productivity and an increment in the number of errors. As a result, the project has the potential to determine whether optimizing the visual correction of workers affects the accuracy and volume of work.

STUDIES

This project included two studies. Study one was a cross-over study designed to examine the performance of subjects in two refractive conditions: corrected with their best refraction or corrected with their habitual lenses. This study examined how optical blur and adaptation to optical blur affect the productivity and efficiency of computer workers.

Study two was designed to examine the effect of altering the magnitude of near plus additions on both the visual performance and comfort of computer users. Keeping the head fixed should increase the effects of blur from the altered lens addition. Allowing the head to move provided the opportunity to reduce the effects of optical blur although possibly at the expense of discomfort from the newly adopted posture. To eliminate or reduce optical blur, some subjects may move their heads relative to the computer if the add was too weak (move back) or too strong (move in) in order to compensate for an incorrect near lens addition, thus altering the optical blur resulting from the addition. These head movements associated with errors in the near lens addition may not only affect the performance of work but may also significantly increase head and neck discomfort. Study 2 also had the potential to provide data confirming the significance of an accurate add power for computer users by way of eliminating head and neck pain, providing visual comfort, and improving the quality and quantity of work.

CHAPTER 2

EFFECTS OF OPTICAL BLUR ON PERFORMANCE AND COMFORT

STUDY ONE

Objectives

The aim of this study was to examine the relationship between optical blur from poor refractive corrections of computer workers to their productivity and comfort in the workplace.

Hypothesis

We hypothesized that improving the visual status of computer workers by decreasing optical blur would result in greater productivity and improved visual comfort.

Significance

The potential effect of optical blur on the visual performance and comfort of computer users at work has not been well studied. Some previous studies have examined this hypothesis in a laboratory situation (Daum et al., 2004a) and other studies have not addressed the effects on productivity. This study examines this question by creating a quasi-workplace where activities may be tightly controlled. If the hypothesis of this study is correct, then optimizing the visual correction of workers would significantly improve their visual comfort, performance, accuracy and productivity. Since visual performance and productivity are critical issues for most businesses, the results of this study may be a valuable contribution to the literature. In addition, this study examined the cost-benefit ratio between a principle aspect of visual welfare (optical blur) and productivity. If the cost-benefit ratio is favorable, then optimizing the visual correction of employees would improve worker satisfaction and result in substantial gains in productivity. Thus, if the hypothesis was confirmed, the outcome of this study should be highly welcomed and appreciated by both employers and employees.

Methods

Inclusion and Exclusion Criteria

Subjects were required to be 19 to 35 years of age and to wear a spectacle correction over the period of the study. Contact lens wearers were eligible to participate if they were willing to forego the use of contact lenses during the period of the study. Subjects who normally wear rigid gas-permeable contact lenses were required to discontinue lens wear two weeks prior to participating in the study. Subjects with self-reported dry eye syndrome and subjects taking medications with the potential to exacerbate or cause dry eye syndrome (e.g., antihistamines, anti-cholinergic and psychotropic medications) were required to adhere to a consistent treatment regimen during the period of the study. Subjects were required to have corrected visual acuity of 20/40 or better at distance and near. Subjects were required to have a habitual uncorrected refractive error (URE) of 0.5D or more in at least one eye as calculated using the vector dioptric difference (VDD) technique i.e., the URE must exist during their habitual status with or without glasses. Summed VDD errors of hyperopia, myopia, astigmatism or some combination between the eyes amounting to 0.50D or more qualified. Subjects were required to use the computer for a minimum of one hour per work day. Subjects were required to participate in the data collecting aspect of the experiment for a total of about eight hours over the eight-week duration of the total study.

Subjects were excluded from the study if they did not meet the age requirement or did not work at least one hour per day on a computer or did not have at least 0.50D URE or were unable to complete the data collecting experimental portion of the study by participating a total of eight hours with at least two hours per experimental session. No other factors were used to exclude subjects from the study. Subjects were paid an hourly rate to participate in the study.

Subject Recruitment

Subjects were recruited from posters in the community and via an ad in the *UAB Reporter*.

Informed Consent, IRB Approval

All potential subjects underwent informed consent prior to enrolling in the study. All subjects were free to withdraw at any point in the study without penalty. The study protocol and all aspects of the study were approved by the UAB Institutional Review Board (IRB) prior to the initiation of the study (APPENDIX A).

Subject Screening

After the informed consent process, potential subjects underwent testing by a licensed, experienced optometrist to ascertain their study eligibility. The qualification testing consisted of assessment of visual acuity at distance and near with habitual correction, manifest refraction and a measurement of their habitual correction. Appendix B presents the eligibility form used to collect these data. An Excel spreadsheet (Thibos, Wheeler & Horner, 1997) was used to calculate VDD error values and determine whether the qualification criterion for URE was met. The VDD established the difference between the habitual and best correction lenses which determined the URE of the subject's qualification for the study. At the time of qualification, subjects also completed additional survey questions specifying the number of hours that they typically used the computer on a work day and the type of tasks they normally encountered and were asked to report the presence of other visual conditions including ergonomic issues (Appendix B).

Vector Dioptric Difference Calculations

We assessed URE using previously described vector methodology (Harvey, Miller, Dobson, Tyszko & Davis, 2000; Thibos, Wheeler & Horner, 1997; Raasch, 1995). Briefly, this methodology (Daum et al., 2004a) provided a mathematical system to determine and compare orthogonal refractive components of the refractive state. Since these components were orthogonal, they could be added, subtracted or averaged. In addition, this methodology allowed different refractive states to be expressed as a single number (vector diopters or VD) thereby obviating difficulties that occur when comparing refractive states with cylinders at different axes. The vector system used in this paper expressed refractive errors equivalent to their spherical errors (Thibos et al., 1997). These UREs have been shown to have a predictable effect on visual acuity (Raasch, 1995).

The habitual spectacle correction for volunteer subjects was compared to their current refraction as assessed by an experienced optometrist. Subjects qualified for the study if the URE in one eye or the other was greater than or equal to 0.50D.

Eyewear

After qualifying, each subject selected a new frame from a variety available. About one week was required to fill the prescription. Each frame had two pairs of ophthalmic lenses (CR-39 or polycarbonate), one pair equal to the habitual prescription and another pair equal to the best correction. The lens pairs for each period were randomly assigned (with replacement in the second period) to subjects for the first period. Both the opticians and the subjects and the person administering the data-collecting protocol were masked to the identity of the lens prescriptions. Lenses and frames were individually fit to the subjects by licensed opticians.

Compensation

Subjects were paid an hourly rate for their time in the data-collecting experimental portion of the study. The subjects received the eye screening to determine qualification for the study at no charge. At the end of the study, the subjects were allowed to keep the new pair of glasses with their best correction

Computer and Workplace Set-up

Individual rooms in The UAB School of Optometry Clinical Eye Research facility were used for informed consent, patient eligibility determination, data entry and surveys associated with the study. These rooms were free from distraction with good lighting and no sources of glare.

Subjects used an Open S3 Graphics ProSavage DDR monitor with attached full-sized Logitech keyboards and a wireless Logitech mouse. The computer monitor was positioned on a desk 30" off of the floor at a distance 50 cm (20") away from the subject. This distance was indicated for each subject using a piece of cardboard suspended from the ceiling set the appropriate distance from the monitor. Standard settings for Microsoft Word and Excel were used throughout the experiment. The monitor resolution was set at 1280 by 1024 pixels, normal fonts (96 DPI) and 32-bit color.

Study Conditions

The study condition (C, best or habitual correction with task 1 and 2) was the primary independent, categorical variable in the study. All subjects completed the experiment with two different prescriptions, sequentially placed in a new frame. One prescription was designed to fully correct their RE, the best correction. Another pair was designed to be identical to their habitual correction, the URE condition. A secondary independent categorical variable was the number of eyes meeting the URE criterion in the habitual condition.

Study Periods

Subjects were randomly assigned to one of the two URE groups (either habitual or best correction lenses) for the first period. After completing the protocol for that period, their lenses were replaced with the other pair and the subject completed the identical protocol during the second period of the study. The only difference for the subjects in the two periods was the pair of lenses that the subject was wearing. The study protocol for each period lasted for one month. No data was collected during the first two weeks of wear in each period to allow for adaptation to the correction.

Timing

During the on-site data collecting portion of the experiment, a stopwatch was used by the examiner to time the performance of each patient on each task. Each task lasted 45 minutes with a break of approximately 5 minutes between the two tasks.

Variables and Analysis

The cross-over study was designed to examine the performance of subjects in two conditions: corrected (best) and uncorrected (habitual) lenses. The primary independent, categorical variable was the refractive error condition of the study (best or habitual). Other analyses were completed using the number of eyes meeting the qualification criterion of URE of 0.50VDD. In this analysis, subjects either had 0, 1 or 2 eyes meeting the criterion. Other secondary analyses were also completed using the VDD error as an independent, continuous variable.

The primary dependent variable for the study was productivity as measured by correct comfortable data processed per hour of work (comfortable correct work, CCW). The visual comfort index (VCI) was the result of a 10-question previously validated survey of visual comfort (Daum et al., 2004a). The data processed were either correct entries per hour (for the population data entry task) or correct words processed per hour (for the apostrophe editing task). CCW was determined by multiplying total correct work (TCW) by VCI/100. A similar analysis was completed for TCW.

Survey assessments of visual comfort and quality of life were assessed as secondary dependent measures. The study used the general linear models methodology to examine whether there was evidence of a difference in productivity between the two lens conditions over the two month length of the study.

The analyses for experiments 1a and b used a split plot design ANOVA. The analyses used dependent variables of visual comfort index (VCI), total correct work (TCW) and correct comfortable work (CCW). This resulted in six different analyses for each experiment. An appropriate correction for these multiple ANOVA was made, so that α was considered significant at $p < 0.008$ (Bonferroni correction, 0.05/6). We considered using age and estimated time of the subject at the computer as covariates. However, correlation analysis suggested a lack of correlation of either of these with any of the dependent variables and hence they were not included. The data (VCI, TCW, CCW, except accuracy) met appropriate criteria for normality (Shapiro-Wilk test) and homogeneity of variances.

Pilot Study, Significance Levels, Sample Size

The final protocol was established after the completion of an unmasked pilot phase. The sample size of the study was set to be able to reliably detect about 0.75 SD of the estimated difference (total correct words edited from the apostrophe editing task) between the two conditions (best vs. URE) with 80% power (β error) and α error of 0.05. There were five subjects in the pilot study.

The pilot phase data was used so that study 1 was designed to detect 73% of the pooled standard deviation of the two tasks. The pooled standard deviation for the population data entry task was 465. For a 1-way ANOVA using a β error of 0.80 and an α error of 0.05, a sample size of 30 in each of two groups allowed the reliable detection of a difference of 342 total words correct per hour between the two groups. This represented a value of about 33% of the mean value and 73% of one standard deviation. For the apostrophe editing task, a 1-way ANOVA using a β error of 0.80 and an α error of 0.05, a sample size of 30 in each of two groups would allow the reliable detection of a difference of 721 total words correct per hour between the two groups. This represented a value of about 12% of the mean value and 73% of one standard deviation. A complete description of the pilot study is contained in Appendix C.

Experimental Tasks

Population Data Entry. The population data entry task required the subject to enter the correct population into a corresponding, blank table from the U.S. Census 2000 (http://factfinder.census.gov/servlet/QTGeoSearchBy-ListServlet?_lang=en&_ts=124219317250). The task consisted of entering a column of numbers from one of the states of the U.S. into an identically constructed spreadsheet in Microsoft Excel. The spreadsheet included the distribution of people by age category (5-year bins), males and females by age and ethnic distribution. The subject was required to enter the data into appropriate cells in the matching Excel spreadsheet. The spreadsheet was viewed in Arial 10 point font with 100% zoom setting. Appendix D displays an example of the text to be entered into the computer spreadsheet and Appendix E displays an example of the blank form on the computer to be completed.

Prior to the task, the subject was taught how to use the keyboard number pad to enter data. A short practice session that was 5 minutes in length was completed prior to beginning the experiment. After the subject completed the population entry task, the file was saved indicating the date, subject and period.

The total magnitude of work, ‘total number of entries’, was calculated by counting the total number of cells into which data were entered. The total number of entries was a secondary dependent, continuous variable in the study.

The accuracy of the data entry task was determined by subtracting the total number of incorrect entries in the subject’s edited document from the total number of possible entries in a correct copy of the document, matched for the length of the entries made (percentage accuracy = ((‘total possible entries’- ‘total incorrect entries’)/(’total possible entries’)*100)). The percentage accuracy was a secondary dependent variable in the work.

The primary dependent variable in this aspect of the study was the total number of correct entries (TCW). The TCW was equal to the total number of entries times the percentage accuracy and represented the total number of correct entries made during the work period. Other secondary analyses examined the relationship of the magnitude and type of the VDD to the total number of correct entries. These analyses were carried out using correlation analysis and regression techniques.

Apostrophe Editing. The apostrophe editing task required the subject to edit a document by searching for and deleting all of the apostrophes (‘) in a long document displayed in 10 point Times New Roman font in Print Layout View and 100% zoom setting in Microsoft Word. The documents were approximately 24-page manuscripts about various states of the U.S. (e.g., Ohio) drawn from MSN Encarta Encyclopedia Article Center (http://encarta.msn.com/artcenter_0/Encyclopedia_Articles.html). A sample of the apostrophe task is shown in Appendix F. The subject’s task was to search through the manuscript; find all words (correct or not) that had an apostrophe symbol (‘); and, delete the apostrophe. Subjects were coached on scanning the document, inserting the cursor just in front of the apostrophe and using the ‘delete’ key to delete the mark from the document. Prior to beginning the data taking, all subjects completed a 5-minute long practice session. The editing activity continued during the 45-minute time-period allotted to the task. After the time was completed, a technician marked the endpoint of each subject’s editing and the edited document was saved for each subject for each task. The data were reduced by deleting the portion of the document that the subject did not edit. The saved document therefore contained all of the material that was searched and edited for apostrophes.

The total magnitude of work, ‘total words edited’, was determined by using the ‘Word Count’ option (‘Tools’ menu, ‘Word Count’) to provide the number of words in the edited document. The total magnitude of work was a secondary dependent variable in the study.

The accuracy of the editing task was determined by subtracting the total remaining apostrophes in the subject's edited document from the total number of apostrophes in an original copy of the document, matched for length (percentage accuracy = ((‘total apostrophes’- ‘total remaining apostrophes’)/(’total apostrophes’)*100)). The percentage accuracy was a secondary dependent variable in the work.

The primary dependent variable in this aspect of the study was the total correct words edited (TCW). The total correct words edited was equal to the total words edited times the percentage accuracy and represented the total number of words correctly scanned while editing during the work period. Other secondary analyses examined the relationship of the magnitude and type of the VDD to total correct entries. These analyses were carried out using correlation analysis and regression techniques.

Surveys

Survey of Visual Comfort. Survey measures of visual comfort and quality of life were secondary, dependent variables in the study. A previously validated, nine-question modified visual function questionnaire was used to assess the patient visual comfort index (VCI) after each work session on the computer (Modified Vision Quality of Life Questionnaire, VCI; Daum et al., 2004a; Appendix G). This survey was designed primarily to assess symptoms during the work session and was reported as the visual comfort index (VCI) with a scale ranging from 100 (most comfortable) to 0 (extremely uncomfortable).

Survey of Quality of Life (NEI Refractive Error Quality of Life). A modified, 17-question National Eye Institute Refractive Error Quality of Life survey (NEI RE-QL; Hays et al., 2003; Nichols, Mitchell, Saracino & Zadnik, 2003; Appendix H) was used at the end of each month-long period of the experiment. This was designed to ascertain the patient's overall impression of their visual quality of life using the lens pair worn in each period. Limitations of the NEI RE-QL survey instrument (due to expected maximum ratings by many subjects) may hamper discrimination of visual comfort between the two periods in this study (Walline, Bailey & Zadnik, 2000).

Symptom Assessment During Work

The on-the-job experimental portion of the protocol was designed to document the current symptoms of subjects using computers with each type of optical correction. After dispensing the glasses, the subjects were allowed to adapt over a two-week period. Following the adaptation period, an investigator completed a phone survey assessment of the subject's symptoms while using their computer. A phone VCI assessment was completed before the initiation of a computer activity and immediately after a computer activity of at least 1-hr duration. Because the VCI contained only 9 questions, the survey was completed in less than 5 minutes. The number of hours of work prior to the survey was determined for each at-work survey. This provided an index of the level of symptoms in the subject associated with computer activity and the changes related to the use of the computer. A similar symptom assessment was completed during the second period for the other optical design.

Symptom Assessment 3-months After Completion of the Study

The symptom assessments 3-months after completion of the experimental portion of the protocol were designed to document the current symptoms of the subjects with the best refractive optical designs using computers. After the completion of the study, the subjects were provided the pair of glasses with their best correction. Following a 3-month period, an investigator completed a phone survey assessment of the subject's symptoms while using their computer.

Masking

The subjects were informed of the overall purpose of the study but they were intentionally not informed about the specific lenses to be worn in either period. Any subject who did not wear glasses used plano glasses as their habitual RE lenses. The investigator responsible for the completion of the work session and the opticians who fitted the glasses and switched lens pairs also were masked regarding the pair of lenses the subject used in each trial. All the data collected during each period were later decoded for each subject.

Cross-over Design

Subjects in the study served as their own controls since the lens pairs were switched after one month of wear. All subjects started their lens wear on a Monday and ended their four weeks of lens wear on a Friday.

Cost-Benefit Ratio

The cost benefit ratio was derived using two portions of data. The cost was determined by calculating the average cost of a vision examination and the eyewear (with the best correction) provided to the subjects. The benefit was determined by calculating the worth of the net change in productivity for the average of the workers over a one-year period. We assumed that the productivity as determined during the study would remain constant over that year. The cost-benefit ratio was determined by dividing the cost by the benefits likely to accrue over a one-year period.

For example, assume a given worker was provided a vision examination and a pair of glasses with a total cost of $268 ($80 vision examination; $88 pair of lenses; $100 frame). If the mean productivity of the worker was 100 claims per day (100 claims per 8 hrs equals 12.5 claims per hour or 0.21 claims per minute or 1 claim about every 5 minutes) and the worker earns $50 per day ($6.25/ hr), then each claim processed costs $0.50. If one further assumes that the change in productivity was 3 claims per day for a year's period (250 days), then a cost benefit can be calculated. Three claims per day equals a $1.50 increase in productivity per day for a 250-day period, the productivity would be equal to $375. For this result, the cost benefit ratio would be favorable, $375 in productivity resulted from an investment of $268, a ratio of 1.40 to 1. For every $1 invested in workers in this manner, the employer receives $1.40. If the company provided health insurance that already provided for a portion of the vision examination or eyewear, the cost benefit ratio would be favorably and correspondingly altered.

For study 1b, we determined the percentage changes in mean CCW. Assuming that the mean differences were sustained over a one year period, we were able to determine the return on investment (ROI) for a clerk making $30,000 per year.

Results

Conditions for the Experiment, Temperature, Humidity and Illumination

Table 1 describes the temperature, humidity and illumination conditions under which the experiment was conducted. Student's t-test (2-sample, 2-tailed) did not provide evidence to support a hypothesis of differences in temperature, humidity or illumination from period 1 to period 2 (t=0.01, 0.02, 0.00; df=148, 146, 149; NS, NS, NS, respectively).

Table 1. *Temperature, humidity and illumination conditions for experiment 1*

	Temperature (ºF)	Humidity (%)	Illumination (lux)
N	150	148	151
Mean	73.4	47.1	305.0
Median	73.8	45.0	322.0
Std Dev	2.5	14.9	52.0
Range	65.7 to 79.7	23.0 to 78.0	96.3 to 339.0

Potential Subjects Excluded

A total of 13 potential subjects (5 male, 8 female; mean age 28.0 yrs, std dev 3.7, range 21 to 34 yrs) were excluded from the protocol. All were excluded because the vector dioptric difference of the refractive error (best correction vs. habitual correction) of each eye was less than 0.50VD. A 2-sample t-test did not provide evidence to support a difference in age distribution for the subjects excluded vs. those subjects included in the study ($t = 0.27$, $df = 23$, $p = NS$). Chi-square analysis also did not provide evidence to support a hypothesis of a difference in the gender distribution between the subjects excluded vs. those subjects included in the study (chi-square = 1.868, $df = 1$, $p = NS$).

The refractive error of the 13 excluded subjects tended to be significantly less than those subjects included in the study (Table 2). The excluded subjects had a significantly smaller M (spherical equivalent), J0 (180/90 cylindrical component) and VD (vector dioptric value) than the included subjects. The two groups had similar J45 values (45/135 cylindrical component). The VDD between the two groups was significantly different as a result of the study protocol.

Table 2. *Refractive status (M, J0, J45 and VD) of both eyes of excluded and included subjects with 2-sample t-test (VDD calculated from comparing habitual vs. best corrections)*

Subjects	M	J0	J45	VD	VDD
Excluded					
Mean	0.76D	-0.03	0.02	1.11	0.15
Std Dev	1.24	0.17	0.05	0.95	0.13
Range	-3.00 to 2.38	-0.50 to 0.24	-0.12 to 0.19	0.00 to 3.01	0.00 to 0.40
Included					
Mean	-3.12	0.28	0.04	3.20	0.80
Std Dev	2.88	0.48	0.29	2.85	0.57
Range	-10.00 to 0.13	-0.45 to 1.71	-0.93 to 1.30	0.00 to 10.01	0.00 to 3.03

Table 2. (continued)

Subjects	M	J0	J45	VD	VDD
2-sample T-test (with Bonferroni correction)					
T	5.64	-4.70	0.69	-5.45	-9.18
DF	93	95	82	95	87
P	0.002	0.002	NS	0.002	0.002

Subjects Included

A total of 36 subjects were included in the study (7 male, 29 female; mean age 27.7 yrs, std dev 4.1, range 21 to 35 yrs). Table 2 describes the refractive characteristics of these subjects.

Prior to beginning the study the subjects completed a survey regarding their estimated daily hrs of computer use and the tasks they typically completed on the computer. The subjects estimated that they spent a mean of 5.1 hrs/day on the computer (std dev 2.2, range 1.5 to 10 hrs). The subjects estimated that 'Internet Use' was the most common task (median rank 2.0) followed by 'Word Processing', 'E-mail' and 'Spreadsheet' (median ranks 3.0), 'Data Entry' (median rank 3.5), 'Proofreading' (median rank 5.0) and 'Other' (median rank 6.5). Table 3 provides details by subject.

Subjects also completed a questionnaire regarding any self-reported visual conditions (Table 4). Six subjects reported dry eye syndrome (16.7%); ten reported focusing problems (27.8%); one reported a binocular problem (2.8%); and, fourteen reported glare problems (38.9%). Reports of dry eye syndrome were significantly correlated with reports of focusing problems ($r = 0.39$, $p = 0.019$) and binocular problems ($r = 0.38$, $p = 0.023$). Reports of focusing problems were significantly correlated with reports of glare ($r = 0.40$, $p = 0.017$).

Nine subjects (25.0%) self-reported a total of 15 ergonomic problem areas when using their computers (Table 5). These included issues regarding the desk (n = 2, 5.6%), chair (n = 1, 2.8%), monitor (n = 2, 5.6%), keyboard (n = 2, 5.6%), mouse (n = 2, 5.6%) and lighting (n = 6, 16.7%). Correlation analysis suggested that reports of ergonomic problems were interrelated. Significant relationships between reports of these ergonomic problems included desk with keyboard and also with mouse (both, r = 0.47, p = 0.004); desk with lighting (r = 0.54, p = 0.001); monitor with keyboard and also with mouse (both, r =0.47, p = 0.004); and, monitor with lighting (r = 0.54, p = 0.001).

Table 3. *Details of computer use by subject*

N	Sex	Age (yr)	Hrs Use	Computer Use*						
				Data entry	Word processing	Email	Internet	Spreadsheet	Proof reading	Other
1	F	21	10	6	3	2	1	4	5	7
2	F	26	6	1			2			
3	F	28	5	6	1	4	3	2	5	7
4	F	33	3.5	5	1	3	4	2	6	7
5	F	34	6	6	3	4	5	1	7	2
6	F	23	2		4	3	2			1
7	F	31	2			2	1			
8	F	27	5	4	3	1	6	5	7	2
9	F	28	6	4	1	3	5	2		6
10	M	31	1.5	5	6	4	1	3	2	7
11	F	30	5	1	3	7	2	6	5	4
12	M	23	3	4	3	2	1	7	5	6
13	F	22	4		1	4	2		3	
14	F	21	2.5	5	3	2	1	4	6	
15	M	25	5.5	5	2	3	4	1	6	7
16	M	26	3.5	4	3	1	2	5	6	
17	F	25	1.5			2	1			
18	F	33	6	4	3	1	2			
19	M	35	2.5	1	4	3	2	5	7	6
20	F	25	2.5	5	3	2	1	6	4	

Table 3. (Continued)

N	Sex	Age (yr)	Hrs Use	Computer Use*						
				Data entry	Word processing	Email	Internet	Spreadsheet	Proof reading	Other
21	F	22	5	2	3	5	6	1	4	7
22	F	29	7	1	2	4	5	3	6	
23	F	32	9	3	5	6	2	4	1	
24	F	23	6	1	3	2	3	1	1	
25	F	28	5	2	1	3	4	5	1	
26	F	26	5		1					
27	F	26	3.5	2	3	1	1	3		
28	F	26	7.5			3	1	2		
29	F	27	8	1	5	4	3	6	7	2
30	F	23	6		2	5	4	1		3
31	M	35	7		3	2	1			
32	F	29	6	2	1	4	3	6	5	
33	F	27	7	2	3	4	5	1	6	7
34	M	31	3.5	1	2	3	4			
35	F	34	5	1	4	2	6	3	5	7
36	F	31	9	5	4	1	2	3	6	7

*Rank 1 (most common) to 7 (least common)

Table 4. *Self-reported visual conditions by subject*

N	Self Reported Visual Condition*			
	Dry eye syndrome	Focusing problems	Binocular problems	Glare
1	0	0	0	1
2	0	0	0	1
3	0	1	0	1
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	1
9	0	0	0	0
10	1	1	0	1
11	0	0	0	0

Table 4. (Continued)

N	Self Reported Visual Condition*			
	Dry eye syndrome	Focusing problems	Binocular problems	Glare
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	1	0	1
16	0	1	0	0
17	0	0	0	0
18	0	0	0	1
19	0	0	0	0
20	0	1	0	1
21	0	0	0	0
22	0	0	0	1
23	1	1	0	0
24	0	0	0	0
25	0	0	0	0
26	1	0	0	0
27	0	1	0	1
28	1	1	1	1
29	0	0	0	0
30	0	0	0	1
31	0	0	0	0
32	0	0	0	0
33	0	1	0	0
34	0	0	0	1
35	1	0	0	0
36	1	1	0	1

*1, present; 0, not present

Table 5. *Self-reported ergonomic problems by subjects with detail*

N	Ergonomic Problem*	Ergonomic Problem Detail*						
		Desk	Chair	Monitor	Keyboard	Mouse	Lighting	Other
1	1	0	0	0	0	0	1	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	1	0	0	0	1	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	1	1	0	1	0	1	1	0
11	1	0	0	0	0	0	1	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	1	0	0	0	0	0	1	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	1	0	1	0	0	0	0	0
21	1	0	0	0	0	1	0	0
22	1	0	0	0	0	0	1	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0

*1, present; 0, not present

Loss to Follow-up

A total of five subjects (13.9%) were lost to follow-up over the course of the study (Table 6). Four of the five subjects withdrew after informed consent and the initial qualification examination but before initiating the remainder of the protocol. A single subject withdrew after completing the first period of the protocol.

Table 6. *Losses to follow-up for the study*

Subject	Withdrawal time	Reason
2	Before initiating study	Time not available to complete protocol
19	Before initiating study	Time not available to complete protocol
22	Before initiating study	Time not available to complete protocol
33	Before initiating study	Time not available to complete protocol
37	After period 1	Time not available to complete protocol

Experiment 1a. Visual comfort and productivity a function of refractive correction worn by subjects

Experiment 1a considered the original hypothesis that visual comfort and productivity were a function of the correction that the subjects wore (i.e., best or habitual). Experiment 1a used a split plot design that accounted for repeated measures (Table 7). Table 8 summarizes the results of analyses concerning the experiment for tasks, data entry and editing. The interactions between order (O; habitual correction first or best correction first) and condition (C; habitual condition or best condition) in both tasks (apostrophe editing and data entry tasks) for three results (VCI, TCW, CCW) were not significant (Table 8). The main effect for condition (C; habitual condition or best condition) was significant for the VCI for the data entry task ($p = 0.004$) and likewise suggested a trend for VCI for the editing task (Tables 8 and 9). (The trend was indicated by a p value of 0.02, slightly greater than the significance level for α of 0.008 considered significant). The effect was that the visual comfort reported by the subjects was greater when wearing their best correction compared to that reported with their habitual correction and its associated URE. As with the VCI in the data entry task, the trend in the editing task was that subjects reported higher levels of visual comfort when wearing their best correction compared to their habitual correction.

There was also a trend for TCW for the data entry task to be related to the order ($p = 0.05$; habitual or best correction first; Tables 8 and 10). Individuals who started their work wearing their best correction first tended to complete more TCW than those who started their work wearing their habitual correction. No other order or condition main effect reached significance for either the editing or the data entry task. The results of the individual ANOVAs using the split plot design for VCI, TCW and CCW are displayed in Tables 9 and 11 for the editing task and Tables 12 and 14 for the data entry task, respectively.

Table 7. *Split plot design for repeated measures; dependent Variables VCI, TCW, CCW for editing and data entry tasks*

Order	Subject	Condition			
		Habitual Task 1	Habitual Task 2	Best Task 1	Best Task 2
Habitual First	1-17				
Best First	18-32				

Table 8. *Summary of results of split plot ANOVAs for experiment 1a for the editing and data entry tasks for order (O) and condition (C)*

Task	Variable	Interactions	Main Effects		Comment
Editing	VCI	OxC=ns	C=ns	O=ns	C=0.02[t]
	TCW	OxC=ns	C=ns	O=ns	
	CCW	OxC=ns	C=ns	O=ns	
Data Entry	VCI	OxC=ns	C=0.004*	O=ns	
	TCW	OxC=ns	C=ns	O=ns	O=0.05[t]
	CCW	OxC=ns	C=ns	O=ns	

*Significant at p=0.008 or less; [t]trend to significance

Table 9. *Results of split plot ANOVAs for experiment 1a for VCI for the editing tasks for order and condition*

Source	DF	Type III SS	Mean Square	F Value	Pr>F
Order	1	2639.47	2639.47	1.86	0.18
Subject(Order)	29	41035.18	1415.01	35.81	0.13
Condition	5	1593.73	318.75	2.84	0.02[t]
Order*Condition	5	474.07	94.81	0.84	0.52
Condition*Subject(Order)	142	15952.69	112.34	2.84	0.44
Error	1	39.51605	39.51605		
Corrected Total	183	61718.98			

*Significant at p=0.008 or less; [t]trend to significance

Table 10. *Results of split plot ANOVAs for experiment 1a for TCW for the editing tasks for order and condition*

Source	DF	Type III SS	Mean Square	F Value	Pr>F
Order	1	1330754.5	1330754.5	0.27	0.61
Subject(Order)	29	144824584.4	4993951.2	109.73	0.08
Condition	3	4341908.7	1447302.9	1.21	0.31
Order*Condition	3	877677.6	292559.2	0.24	0.87
Condition*Subject(Order)	83	99325748.4	1196695.8	26.29	0.15
Error	1	45511.4	45511.4		
Corrected Total	120	250175701.4			

Table 11. *Results of split plot ANOVAs for experiment 1a for CCW for the editing tasks for order and condition*

Source	DF	Type III SS	Mean Square	F Value	Pr>F
Order	1	316718.8	316718.8	0.06	0.81
Subject(Order)	29	151389174.2	5220316.4	1519.21	0.02
Condition	3	3676922.6	1225640.9	1.71	0.17
Order*Condition	3	3118717.6	1039572.5	1.45	0.23
Condition*Subject(Order)	80	57318749.3	716484.4	208.51	0.06
Error	1	3436.2	3436.2		
Corrected Total	117	212545754.6			

Table 12. *Results of split plot ANOVAs for experiment 1a for VCI for the data entry tasks for order and condition*

Source	DF	Type III SS	Mean Square	F Value	Pr>F
Order	1	1528.4	1528.4	1.31	0.26
Subject(Order)	29	33904.4	1169.1		
Condition	5	2081.4	416.3	3.58	0.004*
Order*Condition	5	271.3	54.3	0.47	0.80
Condition*Subject(Order)	144	16747.5	116.3		
Corrected Total	184	54557.9			

*Significant at p=0.008 or less

Table 13. *Results of split plot ANOVAs for experiment 1a for TCW for the data entry tasks for order and condition*

Source	DF	Type III SS	Mean Square	F Value	Pr>F
Order	1	1625762.36	1625762.36	4.24	0.049[t]
Subject(Order)	29	11126420.88	383669.69		
Condition	3	22406.70	7468.90	0.24	0.87
Order*Condition	3	179523.33	59841.11	1.95	0.13
Condition*Subject(Order)	85	2603749.91	30632.35		
Corrected Total	121	15493870.76			

*Significant at p=0.008 or less; [t]trend to significance

Table 14. *Summary of results of split plot ANOVAs for experiment 1a for CCW for the data entry tasks for order and condition*

Source	DF	Type III SS	Mean Square	F Value	Pr>F
Order	1	535521.09	535521.09	1.87	0.1818
Subject(Order)	29	8297189.73	286109.99		
Condition	3	136696.78	45565.59	1.50	0.2216
Order*Condition	3	135162.46	45054.15	1.48	0.2261
Condition*Subject(Order)	85	2589862.16	30468.97		
Corrected Total	121	11616573.76			

Experiment 1b. Number of eyes meeting the criteria of 0.50D or more URE in the habitual state related to the subject's visual comfort and/or visual productivity

A review of the URE presented in the habitual state revealed that one portion of subjects had 0.50D or more URE in both eyes and another portion had 0.50D or more URE in only one eye. Accordingly, we designed analyses to consider a hypothesis that the number of eyes meeting the criteria of 0.50D or more URE in the habitual state was related to the subject's visual comfort and/or visual productivity. With this hypothesis, subjects wearing their best correction would have neither eye meeting this criterion and when wearing their habitual correction all subjects would have either one (n=15) or both eyes (n=17) meeting this criterion. Dependent variables were VCI, TCW and CCW for both the editing and data entry tasks.

These analyses were carried out using a split plot design ANOVA that accounted for repeated measures with the number of miss-corrected eyes (E; 0, 1 or 2) and the order (O; habitual first or best first) and condition (C; habitual task 1 and 2 or best task 1 and 2); Table 15) as independent variables. Six ANOVAs were completed for VCI, TCW and CCW for each of the tasks, data entry and editing. To compensate for multiple

ANOVAs, we considered p = 0.008 or less as significant for α errors (Bonferroni correction, 0.05/6).

Table 15. Split plot design for repeated measures; dependent variables VCI, TCW, CCW for editing and data entry tasks

Eyes	Order	Subject	Condition			
			Habitual Task 1	Habitual Task 2	Best Task 1	Best Task 2
1 Eye	Habitual First	1-7				
	Best First	8-15				
2 Eyes	Habitual First	16-25				
	Best First	26-32				

The data (VCI, TCW, CCW, except accuracy) met appropriate criteria for normality (Shapiro-Wilk test) and homogeneity of variances. The split plot ANOVA did not suggest any significant interactions between eyes (E), order (O), and condition (C) for either task for any of the dependent variables (VCI, TCW, CCW; Table 16) This analysis also did not suggest any significant interactions between eyes and order, or order and condition for either of the tasks, editing or data entry (Table 16). A significant interaction was suggested for eyes and condition for VCI for both the editing and the data entry tasks, (p = 0.0003, 0.0025, respectively). No other interactions between eyes and condition were significant. In addition, no main effects of E, O or C were statistically significant. A trend was identified for CCW for eyes and condition interaction for the editing task, (p = 0.0149).

Table 16. *Summary of results of split plot ANOVAs for experiment 1b for the editing and data entry tasks for eyes (E), order (O), and condition (C)*

Dependent Variables	Interactions		Main Effects
VCI-Editing	ExOxC=ns ExO=ns ExC=0.0003*	OxC=ns	O=ns (E and C, NA)
TCW-Editing	ExOxC=ns ExO=ns ExC=ns	OxC=ns	E=ns O=ns C=ns
CCW-Editing	ExOxC=ns ExO=ns ExC=0.0149[t]	OxC=ns	E=ns O=ns C=ns
VCI-Data Entry	ExOxC=ns ExO=ns ExC=0.0025*	OxC=ns	O=ns (E and C, NA)
TCW-Data Entry	ExOxC=ns ExO=ns ExC=ns	OxC=ns	E=ns O=ns C=ns
CCW-Data Entry	ExOxC=ns ExO=ns ExC=ns	OxC=ns	E=ns O=ns C=ns

*Significant at p=0.008 or less; [t]trend to significance

Subjects working on the editing task with two eyes having an URE of 0.50D or more with their habitual lenses were less comfortable when completing the editing task with their habitual correction than the comfort reported before completing the same task with their best correction (and therefore with neither eye miss-corrected). Table 17 provides the detail of the split plot ANOVA for VCI for the editing task demonstrating a significant interaction between eyes (number of eyes with 0.50D URE with habitual lenses) and condition (habitual task 1 and 2 or best task 1 and 2). Tables 18 through 20 show means, number of subjects and sum of squares and Tables 21 and 22 display the results for the simple main effects ANOVA and the Tukey HSD test for VCI for the editing task for the significant 2-way interaction between eyes and condition. Figure 1 displays the VCI for four eye-order groups across time within condition for the editing task.

Table 17. *Results of split plot ANOVAs for experiment 1b for VCI the editing tasks for eyes (E), order (O) and condition (C)*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Eyes	1	917.65	1917.65	1.34	0.26
Order	1	3014.72	3014.72	2.10	0.16
Eyes*Order	1	283.58	283.58	0.20	0.66
Subjects(Eyes*Order)	27	38745.85	1435.03	36.32	0.13
Condition	5	1437.68	287.54	2.86	0.02
Eyes*Condition	5	2500.81	500.16	4.97	0.0003*
Order*Condition	5	339.97	67.99	0.68	0.64
Eyes*Order*Condition	5	162.34	32.47	0.32	0.90
Condition*Subjects(Eyes*Order)	132	13272.63	100.55	2.54	0.47
Error	1	39.52	39.52		
Corrected Total	183	61718.98			

*Significant at p=0.008 or less

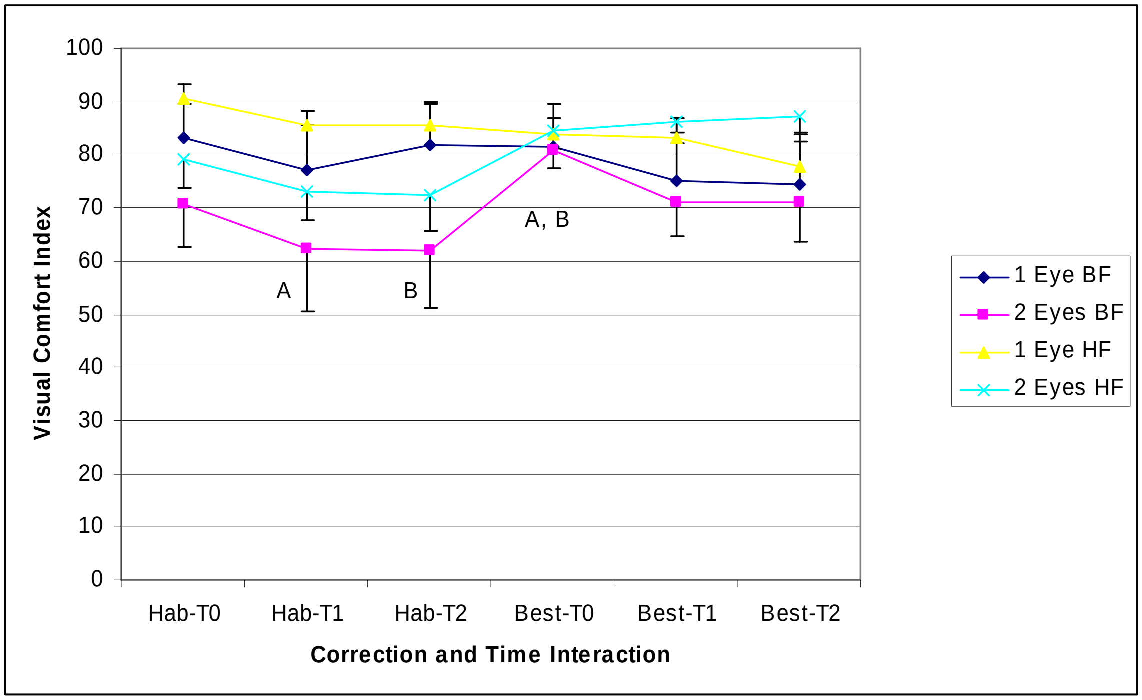

Figure 1. Visual comfort for four eye-order groups (1 or 2 Eyes, number of eyes miss-corrected with habitual lenses) across time within condition for the editing task. Error bars indicate standard error of mean. Points A and B differ significantly from A, B (Tukey HSD test, $p<0.01$). BF, best first; HF, habitual first; T0, T1, T2, time before task, after task 1 or 2, respectively.

Table 18. *VCI means for number of eyes with 0.50D or more uncorrected in habitual state and condition for experiment 1b for the editing task.*

Eyes	Condition					
	H Pre-task*	*H* Task 1*	*H* Task 2*	*B* Pre-task*	*B* Task 1*	*B* Task 2*
1 Eye	86.35	80.79	83.33	82.38	78.81	75.73
2 Eyes	75.69	68.63	67.56	83.01	80.00	80.56

*Habitual (H) or best (B) correction

Table 19. *VCI number of subjects for number of eyes with 0.50D or more uncorrected in habitual state and condition for experiment 1b for the editing task.*

Eyes	Condition						Sum
	H* Pre-task	H* Task 1	H* Task 2	B* Pre-task	B* Task 1	B* Task 2	H* Pre-task
1 Eye	14	14	14	14	15	13	84
2 Eyes	17	17	15	17	17	17	100
Sum	31	31	29	31	32	30	

*Habitual (H) or best (B) correction

Table 20. *VCI sum of squares for number of eyes with 0.50D or more uncorrected in habitual state and condition for experiment 1b for the editing task.*

Eyes	*Condition*						*Sum*
	H* Pre-task	H* Task 1	H* Task 2	B* Pre-task	B* Task 1	B* Task 2	
1 Eye	1208.90	1131.06	1166.62	1153.32	1182.15	984.49	6826.54
2 Eyes	1286.73	1166.71	1013.40	1411.17	1360.00	1369.52	7607.53
Sum	2495.63	2297.77	2180.02	2564.49	2542.15	2354.01	

*Habitual (H) or best (B) correction

Table 21. *Results of split plot ANOVA for VCI for 2-way interaction between number of eyes (E) miss-corrected with 0.50D or more in the habitual state and condition (C) for the editing task.*

Source	SS	Df	MS	ET	F	Critical F Value 0.05	0.01	
E @ C H0	872.43	1	872.43	327.16	2.67	3.92	6.85	(df 1,159)
E @ C B0	3.05	1	3.05	327.16	0.01	3.92	6.85	(df 1,159)
E @ C H1	1135.23	1	1135.23	327.16	3.47	3.92	6.85	(df 1,159)
E @ C H2	1800.88	1	1800.88	327.16	5.50[t]	3.92	6.85	(df 1,159)
E @ C B1	11.28	1	11.28	327.16	0.03	3.92	6.85	(df 1,159)
E @ C B2	171.86	1	171.86	327.16	0.53	3.92	6.85	(df 1,159)
C @ 1 E	930.94	3	310.31	100.55	3.09[t]	2.29	3.17	(df 5,132)
C @ 2 E	3453.83	3	1151.28	100.55	11.45*	2.29	3.17	(df 5,132)

*Significant at p=0.01 or less; [t]trend to significance; H0, B0, H1, B1, H2, B2: habitual (H) or best (B) pre-task, after task 1 and 2, respectively.

Table 22. Results of Tukey Honest Significant Difference (HSD) test for condition(C) for subjects with two eyes miss-corrected (0.50D or more) with habitual lenses for the editing task.

	B* Pre-task	B* Task 2	B* Task 1	H* Pre-task	H* Task 1	H* Task 2
B pre-task		2.45	3.01	7.32	14.38**	15.45**
B task 2			0.56	4.87	11.93*	13.00*
B task 1				4.31	11.37*	12.44*
H Pre-task					7.06	8.13
H task 1						1.07

*Critical HSD (0.05, k = 6, df = 16) = 11.21 (any difference exceeding this value is significant at 0.05).
**Critical HSD (0.01, k = 6, df = 16) = 14.07 (any difference exceeding this value is significant at 0.01); Differences between pairs (arranged by size of means) for condition with two eyes miss-corrected; habitual (H) or best (B) correction.

The Tukey HSD test (Table 22) demonstrated that for those individuals with both eyes having a significant URE during the habitual state that the visual comfort was significantly better before testing with their best correction (mean = 83.0; Table 18) than during either of the tasks completed with their habitual correction (means = 68.6, 67.6; Table 18). Although it did not reach significance, there was a trend for those same individuals to have better visual comfort with their best correction for tasks 1 and 2 (means = 80.0, 80.1; Table 18) compared to those with their habitual correction (means = 68.6, 67.6; Tables 18 and 21).

A trend was identified in this analysis for an interaction between the individuals with one eye miss-corrected in the habitual state and their visual comfort level with their best versus their habitual correction. The trend, although not significant, suggested a trend toward differences among visual comfort indices. Interestingly, the means did not conform to the hypothesis of improved visual comfort with less refractive error (Tables 18 and 21).

A trend toward an interaction between the number of eyes miss-corrected and the visual comfort for the second habitual editing task was also identified (Table 21). The mean VCI reported for those with one eye miss-corrected during the second task was 83.3 versus 67.6 reported by those with two eyes miss-corrected (table 18).

Table 23 provides the details of the split plot ANOVA for TCW for the editing task where no significant effects or trends were identified for any of the independent variables. Table 24 provides details for the same analysis for CCW. A trend for an eyes*condition interaction was identified. The trend for CCW for the editing task suggested that individuals with one eye miss-corrected tended to produce more comfortable correct work than those with two eyes miss-corrected when in the habitual state.

Table 23. *Results of split plot ANOVAs for experiment 1b for TCW the editing tasks for eyes (E), order (O) and condition (C)*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Eyes	1	6083898.6	6083898.6	1.20	0.28
Order	1	2245900.3	2245900.3	0.44	0.51
Eyes*Order	1	191902.0	191902.0	0.04	0.83
Subjects (Eyes*Order)	27	137139894.4	5079255.3	111.60	0.07
Condition	3	5696490.2	1898830.1	1.56	0.20
Eyes*Condition	3	327733.0	109244.3	0.09	0.96
Order*Condition	3	1026299.7	342099.9	0.28	0.84
Eyes*Order*Condition	3	6173274.0	2057758.0	1.70	0.18
Condition*Subjects (Eyes*Order)	77	93470998.1	1213909.1	26.67	0.15
Error	1	45511.4	45511.4		
Corrected Total	120	250175701.4			

Table 24. *Results of split plot ANOVAs for experiment 1b for CCW the editing tasks for eyes (E), order (O) and condition (C)*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Eyes	1	406.0	406.0	0.00	0.99
Order	1	231643.1	231643.1	0.04	0.84
Eyes*Order	1	925175.4	925175.4	0.16	0.69
Subjects (Eyes*Order)	27	152716218.2	5656156.2	1646.05	0.02
Condition	3	2607915.3	869305.1	1.37	0.26
Eyes*Condition	3	7107658.4	2369219.5	3.72	0.02[t]
Order*Condition	3	2608235.6	869411.9	1.37	0.26
Eyes*Order*Condition	3	3080620.1	1026873.4	1.61	0.19
Condition*Subjects (Eyes*Order)	74	47083022.3	636257.1	185.16	0.06
Error	1	3436.2	3436.2		
Corrected Total	117	212545754.6			

*Significant at p=0.008 or less; [t]trend to significance

Table 16 presents a summary of the results of the split plot ANOVAs for the data entry task with a significant interaction for the dependent variable visual comfort determined between eyes and condition (p=0.0025). Table 25 presents the details for the split plot ANOVA for VCI for the data entry task. Tables 26 through 30 present the details of the interaction of the VCI as a function of the number of eyes with URE in the habitual state and the condition for the data entry task.

Table 25. *Results of split plot ANOVAs for experiment 1b for VCI the data entry tasks for eyes(E), order (O) and condition (C)*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Eyes	1	2269.41	2269.41	1.93	0.18
Order	1	2079.11	2079.11	1.77	0.19
Eyes*Order	1	8.47	8.47	0.01	0.93
Subjects (Eyes*Order)	27	31703.39	1174.19		
Condition	5	1885.61	377.12	3.52	0.005
Eyes*Condition	5	2083.94	416.79	3.89	0.003*
Order*Condition	5	279.50	55.90	0.52	0.76
Eyes*Order*Condition	5	310.88	62.18	0.58	0.71
Condition*Subjects (Eyes*Order)	134	14350.82	107.09		
Corrected Total	184	54557.89			

*Significant at p=0.008 or less

Table 26. *VCI means for eyes (E, one or two eyes miss-corrected) and condition (C) for experiment 1b for the data entry task*

Eyes	*Condition*					
	H Pre-task*	*H* Task 1*	*H* Task 2*	*B* Pre-task*	*B* Task 1*	*B* Task 2*
1 Eye	86.35	81.11	83.18	82.38	79.84	81.59
2 Eyes	75.69	66.99	70.00	83.01	80.20	82.52

*Habitual (H) or best (B) correction

Table 27. *VCI number of subjects for eyes (E) and condition (C) for experiment 1b for the data entry task*

Eyes	Condition						Sum
	H* Pre-task	H* Task 1	H* Task 2	B* Pre-task	B* Task 1	B* Task 2	
1 Eye	14	14	14	14	14	14	84
2 Eyes	17	17	17	16	17	17	101
Total	31	31	31	30	31	31	

*Habitual, H or best, B, correction; E, one or two eyes miss-corrected

Table 28. *VCI sum of squares for eyes (E) and condition (C) for experiment 1b for the data entry task*

Eyes	Condition						Sum
	H* Pre-task	H* Task 1	H* Task 2	B* Pre-task	B* Task 1	B* Task 2	
1 Eye	1208.90	1153.32	1135.54	1164.52	1117.76	1142.26	6922.30
2 Eyes	1286.73	1411.17	1138.83	1120.00	1363.40	1402.84	7722.97
Sum	2495.63	2564.49	2274.37	2284.52	2481.16	2545.10	

*Habitual, H or best, B, correction; E, one or two eyes miss-corrected

Table 29. *Results of split plot ANOVA for VCI for 2-way interaction between number of eyes (E) miss-corrected with 0.50D or more in the habitual state and condition (C) for the data entry task*

Source	SS	Df	MS	ET	F	Critical F value		
						0.05	0.01	
E @ C H0	872.43	1	872.43	286.05	3.05	3.92	6.85	(df 1,161)
E @ C B0	3.05	1	3.05	286.05	0.01	3.92	6.85	(df 1,161)
E @ C H1	1530.68	1	1530.68	286.05	5.35[t]	3.92	6.85	(df 1,161)
E @ C H2	1297.05	1	1297.05	286.05	4.53[t]	3.92	6.85	(df 1,161)
E @ C B1	0.99	1	0.99	286.05	0.00	3.92	6.85	(df 1,161)
E @ C B2	6.64	1	6.64	286.05	0.02	3.92	6.85	(df 1,161)
C @ 1 E	351.19	3	117.06	107.10	1.09	2.29	3.17	(df 5,134)
C @ 2 E	3793.79	3	1264.60	107.10	11.81*	2.29	3.17	(df 5,134)

*Significant at p=0.01 or less; [t]Trend to significance; H0, B0, H1, B1, H2, B2: habitual (H) or best (B) pre-task, after task 1 and 2, respectively.

Table 30. Results of Tukey HSD test for condition (best or habitual within task) for subjects with two eyes miss-corrected (0.50D or more) with habitual lenses for the data entry task

	B* pre-task	B* task 2	B* task 1	H* pre-task	H* task 2	H* task 1
B pre-task		0.49	2.81	7.32	13.01*	16.02**
B task 2			2.32	6.83	12.52*	15.53**
B task1				4.51	10.20	13.21*
H pre-task					5.69	8.70
H task 2						3.01

*Critical HSD (0.05, k=6, df=16) = 11.50 (any difference exceeding this value is significant at 0.05).
**Critical HSD (0.01, k=6, df=16) = 14.43 (any difference exceeding this value is significant at 0.01); Differences between pairs (arranged by size of means) for condition with two eyes miss-corrected habitual (H) or best (B).

The Tukey HSD test (Table 30) demonstrated that for those individuals with both eyes with an URE of 0.50D or more in the habitual state, the VCI was significantly better before testing with their best correction and after the second task with their best correction (means = 83.0, 82.5; Table 26) than during the first task completed with their habitual correction (means = 67.0; Table 26). Figure 2 displays the VCI for four eye-order groups (1 or 2 Eyes, number of eyes miss-corrected with habitual lenses; BF, best first; HF, habitual first; T0, T1, T2, time before task, after task 1 or 2, respectively) for the data entry task.

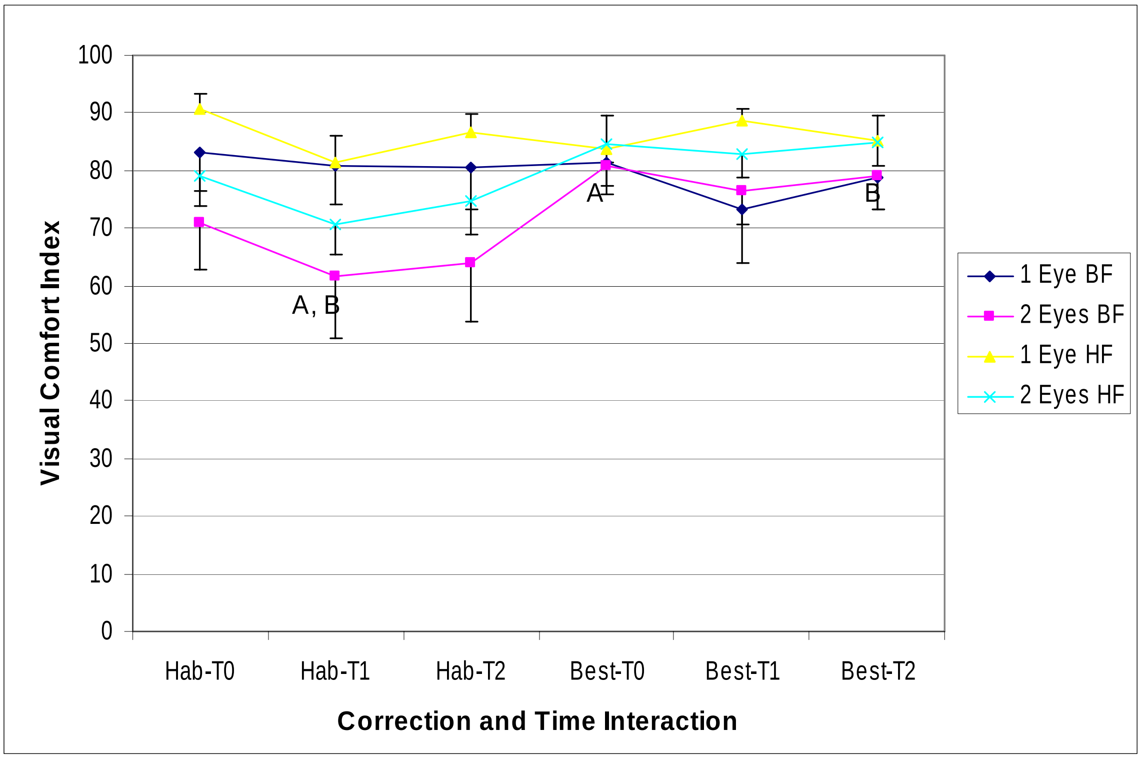

Figure 2. Visual comfort index for four eye-order groups (1 or 2 Eyes, number of eyes miss-corrected with habitual lenses across time within condition for the data entry task. Error bars indicate standard error of mean. Points A and B differ significantly from A, B (Tukey HSD test, $p<0.01$). BF, best first; HF, habitual first; T0, T1, T2, time before task, after task 1 or 2, respectively.

Although differences in VCI did not reach significance, there was a trend for those same individuals (2 Eyes, BF) to have better visual comfort with their best correction before testing and after task 2 (means = 83.0, 82.5, respectively; Tables 26 and 30) compared to those with their habitual correction after task 2 (mean = 70.0; Tables 26 and 30). Also for those with both eyes (and BF) with URE of 0.50D or more in the habitual state, analysis suggested a trend for a difference between the VCI reported after completion of task 1 with the best correction vs. that for the habitual correction (means = 80.2 vs. 67.0, Tables 26 and 30).

Table 29 demonstrated a trend for a difference in VCI after the completion of the data entry tasks in the habitual state between those with one eye vs. those with both eyes having an URE with their habitual lenses. The trend suggested greater visual comfort for those with only one eye miss-corrected (means = 81.1, 83.2, Table 26) vs. those with two eyes miss-corrected (means = 67.0, 70.0, Table 26).

Tables 31 and 32 provide the detailed results of split-plot ANOVAs for TCW and CCW for the data entry task for experiment 1b. No evidence confirmed a hypothesis of a relationship for significant interactions or main effects on these dependent variables by any of the independent variables in the experiment (eyes, one or two eyes miss-corrected; order, task 1 and 2, or condition; habitual or best correction).

Table 31. *Results of split-plot ANOVAs for TCW for the data entry task for experiment 1b*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Eyes	1	98353.08	98353.08	0.25	0.62
Order	1	1556951.92	1556951.92	4.01	0.06
Eyes*Order	1	571275.82	571275.82	1.47	0.24
Subject (Eyes*Order)	27	10459369.73	387384.06		

Table 31. (continued)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Condition	3	30547.58	10182.53	0.32	0.81
Eyes*Condition	3	27579.09	9193.03	0.29	0.83
Order*Condition	3	176697.73	58899.24	1.85	0.14
Eyes*Order*Condition	3	67061.45	22353.82	0.70	0.55
Condition*Subjects (Eyes*Order)	79	2508686.59	31755.53		
Corrected total	121	15493870.76			

Table 32. *Results of split-plot ANOVAs for CCW for the data entry task for experiment 1b*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Eyes	1	21942.97	21942.97	0.07	0.78
Order	1	426207.38	426207.38	1.43	0.24
Eyes*Order	1	266591.83	66591.83	20.90	0.35
Subject(Eyes*Order)	27	8040605.88	297800.22		
Condition	3	118377.85	39459.28	1.26	0.30
Eyes*Condition	3	100952.78	33650.93	1.08	0.36
Order*Condition	3	109562.73	36520.91	1.17	0.33
Eyes*Order*Condition	3	17838.42	5946.14	0.19	0.90
Condition*Subject(Eyes*Order)	79	2472691.79	31299.89		
Corrected total	121	11616573.76			

The difference in mean CCW for the editing task during experiment 1b suggested a difference of about 24% productivity for individuals with URE in two eyes in the habitual state versus that achieved when completely corrected. The mean CCW for URE in two eyes was 2762.0 and 3042.4 words edited in the first and second editing task. The corresponding means when fully corrected were 3465.3 and 3732.3, respectively. The mean standard error for CCW for the four tasks was 361.9 (11.1% of the mean). Although not significant, the mean difference in CCW for the data entry task between subjects with 2 eyes URE vs. completely corrected was 10.4% (643.1 vs. 582.7 CCW).

Assuming a cost of $268 per employee for a comprehensive vision examination and a pair of spectacles, a cost benefit can be calculated for CCW. An employee earning $30,000 per year whose productivity could be altered by 24% would represent an increase of $7200 in productivity for a cost of only $268. This would represent a return on investment (ROI) of 26.9 and suggests a strong benefit of vision care. If the potential 10.4% difference was significant for the data entry task, the increase in productivity for the same worker would be $3107 for the same cost of $268 and an ROI of 11.6. We note that these effects demonstrated only a trend toward significance and that further work is required to assess the likelihood of such effects and ROI.

Discussion

The conditions under which the experiment was conducted approximated those found in many office environments and were stable from period 1 to period 2. None of the subjects remarked adversely about the conditions and, accordingly, the conditions seemed appropriate for the experiment.

The analysis of data from the excluded subjects concerned the ability to generalize the results of the study. The excluded subjects were similar in terms of age and gender and were different in refractive error from subjects included in the study. Evidence suggested that the excluded subjects had smaller spherical (M) and 180/90 astigmatic components (J0) and overall refractive errors (VD). Although the 45/135 component (J45) was similar, these data suggested that overall the excluded subjects had lesser degrees of refractive error. The VDD of the included subjects also was higher than those excluded. The higher VDD was to be expected since this was the principal basis for inclusion or exclusion from the study. We are unaware of any bias for this type of study that may have distorted the results on the basis of the degree of refractive error. Never-the-less, these data should be applied to populations of emmetropes with caution.

As in many office environments, there was a substantially greater representation of females than males (81% female) in the subjects. Otherwise, the group of subjects appeared to represent a relatively typical group of young office workers. The subjects estimated that they spent an average of 5.1 hrs/day using the computer suggesting that they were heavy users of computers. An examination of their self-reported computer tasks suggested that they were primarily involved in general office work since they ranked 'Internet Use' as the most common task (median rank 2.0) followed by 'Word Processing', 'E-mail' and 'Spreadsheet' (median ranks 3.0). Specialized uses such as 'Data Entry' (median rank 3.5), 'Proofreading' (median rank 5.0) and 'Other' (median rank 6.5) were ranked lower.

The self-reported visual conditions of the subjects suggested that glare problems (38.9%) were the most common visual complaint. A number of subjects noted focusing problems (27.8%) that may have been related to their uncorrected refractive error although other etiologies (i.e., accommodative dysfunction) may also have explained the results. A significant proportion of the subjects reported dry eye syndrome (16.7%). Extended work on a computer likely exacerbated this problem. A substantial proportion of the subjects (25%) also reported ergonomic problems with the computer they most commonly use. In contrast to a prevalence of 38.8% that reported glare problems, only 16.7% noted glare or poor lighting in the ergonomic survey portion. The remainders of the ergonomic issues were spread between desk (5.6%), chair (2.8%), monitor (5.6%), keyboard (5.6%) and mouse (5.6%).

A total of five subjects (13.9%) were lost to follow-up over the course of the study. This proportion, although unfortunate, appeared to be a reasonable consequence of the protocol and the approximate 6 month overall course of the study. Most of the loss to follow-up related to the demands of the protocol on the subject's time. The impact of losses to follow-up appeared to have a minimal effect on the study since analysis suggested that there were no significant effects between the groups on the basis of gender, age and VDD comparing those lost vs. those remaining in the study.

The completion rate for the phone surveys for the subjects was 87.5% (including those lost to follow-up). If the subjects lost to follow-up were removed, only a single phone survey was not completed (1 of 124 surveys). The overall phone visual symptom survey with identical 9-question surveys with a separation of 1-hr was approximately stable with nearly identical mean completion rates of 83.0% and 83.4% before and after the hour of working in their offices or homes. The phone survey completion rate appeared to be adequate to fulfill the protocol.

Overall, the subjects appeared to be relatively comfortable while working in their own office setting in that the mean visual symptom index was 83.2 (median, 86.7; 100 is most comfortable and 0 is least comfortable). In addition, the identical median visual symptom index in the two periods suggested a relatively stable work environment. This conclusion was supported by statistical examination of a difference in medians (i.e., no significant difference). The subjects did not show a difference in the visual symptoms before or after one hour of working in their offices during each period. This suggested that over the hour of working, no difference in visual comfort occurred. This consequence may be related to the nature of the work being completed. The protocol did not provide for monitoring interruptions or other activities to allow confirmation of this hypothesis.

Substantial evidence suggested that the subjects were most comfortable while working with low or absent degrees of optical blur in at least one eye. Although the median phone visual symptom index (86.7) was identical for both corrections (best and habitual), the mean phone visual symptom for the best correction (85.1), as hypothesized, was higher than the mean for the habitual correction (81.1) but the two levels were not statistically distinguishable.

For the entire protocol, 86.1% (i.e., 31 of 36 subjects) provided complete data for the in-office visual comfort surveys. An additional two subjects provided surveys only for the first period so that overall the in-office completion rate for both periods for all subjects was 88.9% (64 of 72 possible). The completion rate appeared to be adequate to examine the hypotheses.

The in-office, monitored-work data support a similar conclusion to the phone visual symptom index regarding the elimination of optical blur and increased visual comfort. The mean visual symptom index of in-office work was lower than that in the subject's own offices (78.3 vs. 83.2). During the in-office working hours the subjects reported less visual complaints in period two than one (median visual symptom index 84.4 vs. 82.2, respectively) although the difference was not statistically significant. We speculate that this small difference may have been related to the adaptation time over the course of the protocol.

For work completed in the laboratory, over the course of working a one-hour period, the subjects reported a decrease in visual comfort (about a 7.3% decrease). Visual comfort decreased over a full hour of working on the computer without a break. The contrast with the findings regarding visual comfort for an hour of work in the subject's own offices (i.e., no difference in comfort over an hour) may be related to the greater and more concentrated demands of the in-office sessions. The small number of subjects who completed all four hours in a single session per period did not show a significant change in their visual symptoms. This may be related to an inability to recognize the differences in view of the variability of the index and the small sample size. Future work aimed at elucidating relationships of visual comfort and work should monitor the type and degree of work being completed.

Experiment 1a examined the visual comfort and productivity as a function of the correction (best or habitual) that the subjects wore in both tasks (apostrophe editing and data entry tasks). The data analysis suggested a significant effect of condition (habitual or best condition) for the VCI for the data entry task and a trend for the editing task. Overall, the subjects reported a higher degree of visual comfort working with their best correction than working with their habitual correction. These findings supported the hypothesis of the study and also suggested that the elimination of optical blur by correcting refractive error is associated with less visual complaints.

Thirty subjects (83.3%) completed the entire apostrophe editing task; two subjects (5.6%) completed work for one period or the other; and, four subjects (11.1%) did not complete any of the task. Overall, 62 of 72 data sessions (86.1%) were completed which appeared sufficient for data analysis.

Thirty-one subjects (86.1%) completed the entire population data entry task; two subjects (5.6%) completed work for one period or the other; and, three subjects (8.3%) did not complete any of the task. Overall, 64 of 72 data sessions (88.9%) were completed and this also appeared sufficient for data analysis.

The analysis of experiment 1a suggested a trend for an effect of order (habitual or best correction first) on the TCW of the subjects. Those subjects who started their work on the data entry task and wearing their best correction produced more accurate work (TCW) than those who started their work wearing their habitual correction. We speculate that the improved clarity of the best correction may have allowed earlier and better learning of the task. The order or condition effect did not reach significance for TCW and CCW for either of the tasks (editing or the data entry task).

Experiment 1b was designed to analyze the hypothesis that the number of eyes with URE of 0.50D or more in the habitual condition was related to the subject's visual comfort and/or visual productivity. During the in-office working hours, those subjects with both eyes having URE of at least 0.50D reported more visual symptoms when they worked on the editing task with their habitual correction than before working on the same task with their best correction. This may be related to the amount of optical blur they were working with in their habitual correction.

Subjects with both eyes having URE of 0.50D or more reported a higher degree of visual comfort with their best correction before starting work (mean = 83.0, Table 18) than the visual comfort reported during their work with their habitual correction on either of the tasks (means = 68.6, 67.6, Table 18). Likewise, those subjects who wore their best correction showed somewhat better visual comfort when they worked on both tasks (means = 80.0, 80.6, Table 18) than those wearing their habitual correction (means = 68.6, 67.6, Table 18). This suggested that optimizing the URE of subjects working on the computer may optimize visual comfort and maximize the magnitude of correct comfortable work.

Subjects who had URE of at least 0.50D in one eye demonstrated somewhat better visual comfort during the second editing task with their habitual correction compared to those who completed the same task with two eyes miss-corrected (means = 83.3, 67.6, Table 18). In addition, the improved visual comfort may lead to improved productivity since subjects with one eye miss-corrected tended to produce more comfortable correct work (CCW) on the editing task than those with two eyes miss-corrected when they wore their habitual correction. These data suggest that URE of at least 0.50D in one eye can significantly affect visual comfort and work performance.

For the editing task, the subjects demonstrated a substantial decrease in productivity (mean CCW 24% less) for subjects with two eyes miss-corrected with their habitual condition compared to those with best correction. The analysis confirmed a relationship between CCW and number of eyes with URE 0.50D or more.

Substantial evidence demonstrated the significant effect of eyes and condition interaction (eyes*condition) on the VCI for the data entry task. For this task, the split plot ANOVA demonstrated a significantly greater VCI for the subjects who had URE of at least 0.50D in both eyes and wore their best correction before testing and after the second task (means = 83.0, 82.5 respectively) than their work on the first task with their habitual correction (mean = 67.0).

The data also suggested a trend of better visual comfort before testing and after working on tasks 1 and 2 for those individuals with both eyes miss-corrected who wore their best correction (means = 83.0, 80.2, 82.5, respectively) than individuals who worked with their habitual correction on the second task (mean = 70.0). Another trend suggested that subjects reported better visual comfort working on task 1 with their best correction than with their habitual correction and both eyes miss-corrected (means = 80.2 vs. 67.0). This trend suggested a relationship between visual comfort and the number of eyes miss-corrected. In this task, the data tended to confirm the hypothesis of a relationship between VCI and optical blur.

The analysis also demonstrated a trend of a relationship between the number of eyes with a URE of 0.50D or more and the VCI. The data demonstrated significantly better visual comfort between subjects completing tasks 1 and 2 with their habitual corrections with one eye miss-corrected (means = 81.1, 83.2) versus those for subjects completing the same tasks with both eyes miss-corrected (means = 67.0, 70.0).

The split-plot ANOVAs did not provide evidence for a significant effect of eyes, order, or condition interactions for the TCW and CCW for the data entry task and therefore did not support evidence for a significant relationship between performance and optical blur. The TCW and CCW of the population data entry task may have been affected by sequence errors in entering the data. Some errors occurred because printouts of the task sheets containing data source material did not include a row number column. As a result, some participants entered correct data into incorrect cells, i.e., order errors. Correcting these data order errors in future studies would involve re-printing the task sheets with row number columns.

The subjects demonstrated substantial variability in the performance of the data entry task. This was so even though the task was limited to using a number key pad and hitting ‘enter.’ Future work should consider including checks on order errors. These checks may include numbering lines and mandatory periodic checks.

At the end of each month–long period of the experiment, the subjects completed a 17-question modified National Eye Institute Refractive Error Quality of Life survey (NEI RE-QL) with the lens pair worn in each period. The subjects reported greater comfort (less visual symptoms) during their working time with the best correction than with the habitual correction (mean, 87.2 vs. 78.6, respectively) although there was not a statistically significant difference. The data also did not show significant differences in the NEI RE-QL index with other potentially related variables and was not significantly related to the number of eyes meeting the criteria of VDD error >=0.50D. Although parametric analysis suggested a significant difference in the visual comfort index between the three groups of eyes meeting the criteria, the sample size may have inhibited recognition of the significance of the data. The relationship between the number of eyes meeting the criteria of VDD error >=0.50D and the NEI RE-QL index was similar to that in the phone and in-office surveys.

Three months after the completion of the initial study protocol, the subjects reported significantly improved visual comfort with their best refractive corrections (mean=92.6) compared to that reported for visual symptoms with the best or habitual corrections as assessed during the 1-month experimental periods. These results suggested that the visual comfort with the best correction was improved after three months of wear from that experienced during the study. This also may suggest that adaptation to the eyewear continued for extended periods (to at least 3 months). Improvements in visual comfort over at least 3 months should be considered in future work of this type.

Considering the mean difference of the CCW for the first and second editing task during experiment 1b in the habitual state versus best correction suggested the presence of an effect on productivity as a function of optical blur for the editing task. Although the trend suggested that optimizing the visual correction of employee may improve the annual performance and productivity of employee by about 24%, the lack of significance suggests that caution be used in interpreting the data. Consistent with the hypotheses, however, these analyses demonstrate a substantial benefit of vision care in the improvement of the visual comfort and productivity of workers using computers. These data also suggest substantial benefits of future study concerning the effects of such issues.

Summary

In general, the data supported the hypothesis of the study. The subjects estimated they spent a mean of 5.1 hrs/day on the computer. The internet was the most common task (median rank 2.0) followed by 'Word Processing', 'E-mail' and 'Spreadsheet' (median ranks 3.0), 'Data Entry' (median rank 3.5), 'Proofreading' (median rank 5.0) and 'Other' (median rank 6.5). The data demonstrated that the glare problem (38.9%) was the most common visual problem reported between the subjects. There was a correlation between dry eye syndrome and focusing problems ($p = 0.019$) and binocular problems ($p = 0.023$). Also, focusing problems were significantly correlated with glare problems ($p = 0.017$).

In addition, there were a total of 15 ergonomic problem areas when using their computers. These ergonomic problems are related to the desk, keyboard, monitor and mouse (5.6%), chair (2.8%). Lighting was the most common ergonomic problem between subjects (16.7%). The data demonstrated significant relationships between reports of these ergonomic problems included desk with keyboard and also with mouse (both, p =0.004); desk with lighting (p = 0.001); monitor with keyboard and also with mouse (both, p = 0.004); and, monitor with lighting (p = 0.001).

There was evidence suggesting that the subjects were more comfortable while working with low or absent degrees of optical blur in at least one eye. Overall, these data suggested that subjects with two eyes significantly miss-corrected (0.50D or more) were relatively less comfortable working on either the editing or the data entry tasks with their habitual lenses than subjects with their best correction. These data demonstrated that the subjects with both eyes miss-corrected habitually reported significantly better visual comfort before performing the tasks with their best correction (mean = 83.0) than during either of the editing tasks (1 & 2) completed with their habitual correction (means = 68.6, 67.6). Also the subjects with one eye miss-corrected habitually reported greater VCI than those with two eyes miss-corrected (means =83.3, 67.6) when they completed the second editing task. For the data entry task, subjects with both eyes miss-corrected habitually had significantly better VCI before testing and after completing the second task with their best correction (means = 83.0, 82.5) than during the first task completed with their habitual correction (means = 67.0). These data suggested that both refractive error and work time effect visual comfort. Relatively little data supported the hypothesis that uncorrected refractive error affected either the TCW or the CCW. However, a trend was identified that those with less uncorrected refractive error tended to produce more than those with more uncorrected refractive error when wearing their habitual lenses. The trend for CCW for the editing task suggested that individuals with no eye miss-corrected (i.e., both completely corrected) tended to produce more comfortable correct work (means = 3465.3 and 3732.3) than those with two eyes miss-corrected when in the habitual state (means = 2762.0 and 3042.4) with a mean difference of 24% for the first and second editing task. Consequently, the data suggested a significant relationship between performance and optical blur.

CHAPTER 3

EFFECTS OF DIFFERENT ADD POWERS WITH FIXED OR FREE HEAD MOVEMENT

STUDY TWO

Objective

The purpose of this study was to examine the effect of different add powers on the comfort and productivity of computer users with the head fixed or free to move, considering that the magnitude of an add and head movement were the most likely factors related to visual comfort and performance.

Hypothesis

We hypothesized that near lens additions that were greater or lesser than the most appropriate add would result in decreased productivity and comfort of computer users.

Significance

This study is significant because no previous study has described the effects of such errors in prescribing plus lens additions consequently; this leaves optometrists without reference in their prescriptive tasks. This study also had the potential to document a widely known problem with individuals using adds designed for near work on their computers. If the near plus addition of a typical bifocal correction was too strong, then an individual may be forced to move forward and tilt their head back to see the computer clearly, thereby causing head and neck pain. Selecting the magnitude of an add for a computer user is not always straightforward, even setting aside all other factors (angle, position, lens design, etc.) besides distance that may be potentially involved. There are several different methods used to determine adds, such as the plus build-up, NRA/PRA, binocular crossed-cylinder as well as age-related algorithms (Carlson & Kurtz, 2004). In practical situations, these methods do not always suggest identical plus lens additions. Although certain methods (e.g., plus build-up and age) are often preferred clinically because of their ease of use, little attention has been given to the effect of different adds on visual comfort and productivity. Since there is essentially no work that documents either visual comfort or productivity decrements with altered adds, the clinical significance of different adds is presently unclear. If a technique is used to prescribe lenses for presbyopic computer users that produces an add that differs from the usual and customary add value, the community presently is unable to determine the significance of the difference since the difference threshold is unknown.

Methods

Inclusion/Exclusion Criteria

Subjects were required to be 40 years of age or older. Volunteers were required to undergo refractive assessment by a licensed optometrist. Subjects must have had corrected visual acuity of 20/40 or better at distance and near. Subjects with self-reported dry eye syndrome and/or subjects taking medications with potential to exacerbate or cause dry eye syndrome (e.g., antihistamines, anticholinergic, and psychotropic medications) were required to adhere to a consistent treatment regimen during the brief period of the study. At the time of screening, potential subjects must have required a near plus lens addition to comfortably perform near tasks and also were required to be able to perform rudimentary tasks on a computer. There were no restrictions on subjects on the basis of sex or any other criteria (e.g., binocularity, refractive error). Contact lens wearers were included if they were willing to forgo contact lens wear during the brief period of the experimental session. Subjects who normally wore rigid gas-permeable contact lenses were required to discontinue lens wear two weeks prior to participating in the study.

Subjects were excluded from the study if they did not meet the age requirement or did not require a plus lens addition or were unable to complete the experimental portion of the study by participating a total of about four hours in one session. No other factors were used to exclude subjects from the study. Subjects were paid an hourly rate to participate in the study.

Subject Recruitment

Subjects were recruited using posters in the community and via an ad in the *UAB Reporter*.

Subject Screening

After the informed consent process, potential subjects underwent non-cycloplegic refractive assessment (visual acuity, auto-refractor, manifest subjective refraction) that included the determination of an add for a computer by an experienced optometrist to ascertain their study eligibility. The add was determined using a plus build-up technique using a standard Reichart Rotochart. At the time of qualification, subjects also completed additional survey questions specifying the number of hours that they typically used the computer on a work day and the type of tasks they normally encountered and were asked to report the presence of other visual conditions including ergonomic issues (Appendix B).

Eyewear & Lenses

The lenses used in the study to correct the refractive error of subjects were trial lenses placed in a trial frame (Oculus UB-4) adjusted to be as comfortable as possible. The spherical and cylindrical portions of the best correction were placed in the sphere and anterior-most wells of the trial frame and were not masked to the technician. For the additional correction, a set of specially-cut, round CR-39 lenses was manufactured. These lenses included five pairs of trial lenses (plano, +/- 0.50DS, +/-1.00DS) to be used in the masked, lens addition portion of the study. These lenses were coded with labels on the lenses after their order was randomized so that the investigator and the subject completing the trial were intentionally unaware of which additional lens pair was being used.

Head Position

During the head-free portion, subjects began with the horizontal aspect of the head positioned 50.8 cm (20 inches) from the computer monitor and were free to adjust their position during the experimental trial. A digital video camera (Panasonic PV-

GS150) stationed directly lateral to the subject's head at the workstation was used to record the head position of subjects during the study. Tracking the anterior superior aspect of the trial frame against a grid on the wall positioned directly past the subject was used to determine vertical and horizontal head position at times 0, 0.5, 1.0, 2.0, 5.0, 7.5, 10, 12.5 and 15 minutes for each trial.

For the head restrained portion, subjects viewed a computer stationed 50.8 cm (20 inches) from a chin rest. The height of the chin rest was adjusted to a comfortable, normal height for each subject.

Add Magnitude

The magnitude of the difference of the add from that determined using the plus build up technique for the computer was the primary independent, categorical variable in the study. All subjects completed the experiment with ten different lens pair additions-head position combinations, randomly presented in a trial frame.

Computer and Workplace Set-up

Individual rooms in The UAB School of Optometry Clinical Research area were used for informed consent, patient eligibility determination, data entry and surveys associated with the study. These rooms were free from distraction with good lighting and no source of glare. Subjects used A Open S3 Graphics ProSavage DDR with attached full-sized keyboards Logitech and mouse Logitech. The computer was positioned on a desk 30" off of the floor at a distance of 20" away from the subject. This distance was indicated for each subject using a piece of cardboard suspended from the ceiling immediately above the subject to indicate the appropriate initial distance from the monitor. Standard settings for Word and Excel were used throughout the experiment. The monitor resolution was set at 1280 by 1024 pixel with small 12 point fonts and 32-bit color.

Study Periods and Protocol

Before a trial, an investigator used a computerized process to randomly assign the lens additions and head position for each subject for each condition and also provided data protocol sheets to the technician who conducted the experimental protocol. As a result, neither the subject nor the technician was aware of the lens addition condition being investigated during any of the trials. Both the subject and the technician were aware of whether the head was assigned to use the head rest or was free to move.

Subjects completed ten matched protocols for all aspects except the lens addition and whether the head was fixed or free to move. Subjects completed the protocol with their head fixed or with their head free and were corrected with each of five different pairs of additional lenses over the best add: best add (plano), +/-0.50D and +/-1.00D. The order of these protocols was randomly determined and assigned prior to the experimental session.

The subjects were randomly assigned to a randomized sequence of the ten different lens additions-head position combinations for the study periods. After a subject completed the protocol for a given period, their lenses were replaced with the next pair, the head was positioned appropriately (fixed or free) and the subject completed the identical protocol during the next period of the study. This process was completed until the entire list of ten trials was finished. The only difference for the subjects in the periods was the pair of additional lenses that the subject was wearing and whether or not their head was fixed. The study protocol for each trial lasted for 15 minutes. Since the subjects completed 10 trials, a total of 150 minutes of work were recorded for each subject. Counting breaks of about five minutes between each trial, each subject spent about four hours completing the experimental protocol.

Timing

A stopwatch was used by the examiner to time the performance of each patient on each trial. Each trial lasted 15 minutes with a short break of approximately 5 minutes between tasks.

Variables and Analysis

The study was designed to examine the performance of subjects in two conditions; head-free or head-fixed with five different combinations of additional lenses. One primary independent, categorical variable was the head condition of the study (free or fixed). The other independent, categorical variable was the additional lens combination used. The primary dependent variable for the study was productivity as measured by comfortable correct words processed per hour for the apostrophe editing task. Survey assessments of visual comfort were assessed as secondary dependent measures. The study used analysis of variance testing to examine whether there was evidence supporting a hypothesis of a difference in productivity between the two head conditions or the lens addition combinations. The ANOVA used a block factorial design analysis (Table 32) with the independent variables, subject, lens (+/-0.50,+/-1.00, plano) and head (on chin rest or free to move) and a lens*head interaction.

Pilot Study, Significance Levels, Sample Size

The protocol was modified after the completion of a pilot phase to establish an estimate of the necessary sample size. The anticipated sample size was a total of 30 subjects in the experiment. The pilot study suggested that the designated sample size would allow an assessment of slightly less than one standard deviation between the five optical blur groups. For a 1-way ANOVA using a β error of 0.80 and an α error of 0.05, a sample size of 30 in each of five groups would allow the reliable detection of a difference of 1185 total words correct per hour between the five groups. This represented a value of about 24% of the mean value and 91% of one standard deviation. A complete description of the pilot study is contained in Appendix I.

Experimental Task

Apostrophe Editing. The apostrophe editing task required the subject to edit a document by searching for and deleting all of the apostrophes (‘) in a long document displayed in 10 point Times New Roman font in Print Layout View and 100% zoom setting in Microsoft Word. The document to be edited was two consecutive, approximately 24-page manuscripts about two states of the U.S. (Ohio and California). These documents were drawn from MSN Encarta Encyclopedia Article Center (http://encarta.msn.com/artcenter_0/Encyclopedia_Articles.html). A sample of the apostrophe task is shown in (Appendix F). The subject’s task was to search through the manuscript; find all words that had an apostrophe symbol (‘); and, delete the apostrophe. Before the experiment, subjects were coached on scanning the document, inserting the cursor just in front of the apostrophe and using the ‘delete’ key to delete the mark from the document. Subjects deleted all apostrophes (correct or not) from the document. All subjects completed a five minute trial period to familiarize themselves with the task. The editing activity continued during each 15-minute time-period allotted to the task. Before and after the time was completed, a technician marked the beginning and endpoint of each subject’s editing by inserting highlighted numbers for each portion into the document. The edited document was saved for each subject for each task. The data were reduced by measuring the portion of the document that the subject edited in each head-lens combination. The final saved document contained all of the material that was searched and edited for apostrophes.

The total magnitude of work, ‘total words edited’, was determined by using the ‘Word Count’ option (‘Tools’ menu, ‘Word Count’) to provide the number of words in the edited document. The total magnitude of work was a secondary dependent variable in the study.

The accuracy of the editing task was determined by subtracting the total remaining apostrophes (total remaining apostrophes) in the subject’s edited document from the total number of apostrophes (total apostrophes) in an original copy of the document matched for length (percentage accuracy = ((‘total apostrophes’- ‘total remaining apostrophes’)/(’total apostrophes’)*100)). The percentage accuracy was a secondary dependent variable in the work. The primary dependent variable in this aspect of the study was the total correct words edited. The total correct words edited was equal to the total words edited times the percentage accuracy and represented the total number of words correctly scanned for editing during the work period. Analysis of this portion of the study was completed using analysis of variance to test the hypotheses that the total correct words edited were a function of the viewing condition of the subjects.

Surveys of Visual Comfort

Survey measures of visual comfort were a secondary dependent variable in the study. A ten-question modified visual quality of life questionnaire (MVQLQ) that was previously validated was used to assess visual comfort before the beginning of the study and at the end of each 15-minute period with the masked lens pairs (McKeon, Wick, Aday & Begley, 1997; Daum et al., 2004a; Appendix G). This questionnaire included questions addressing the following potential issues while using the computer: visual problems, clarity, episodes of blurred or double vision, limitations, losing place, lighting, hurting, headaches, frustration with vision and ergonomic status. The scale for each question allowed an assessment of the significance of each item for that refractive condition and resulted in a score ranging from 100 (very comfortable without limitations or other problems) to 0 (extremely uncomfortable with many problems).

Masking

Although the subjects were informed of the overall purpose of the study, they were intentionally not informed about the specific lenses worn in either period. All subjects wore their best correction plus their best plus lens addition and one of the five test pairs of lenses. The investigator responsible for the completion of the work session was masked regarding the pair of test lenses the subject used in each trial. The best correction was not masked to the investigator. All the data collected during each period were later decoded for each subject and all subjects were referred to only by number in the subsequent analysis. The technician who arranged the lenses in the trial frame and the subject were unaware of which pair of additional test lenses was being used by the subject in each trial. A different individual (who did not otherwise participate in the collection of data) marked the pairs of lenses and provided a random assignment of the lens conditions and the order of testing. To protect the identity of the additional lenses, the individual placing the lenses in the trial frame was instructed not to look through the lenses. All participants in the study were masked as to the additional lens condition during the phases of the study.

Randomized Design

Subjects in the study served as their own controls since the lens pairs were switched for each period of the study. The lens pair and head position (fixed or free) was randomly assigned to each of the 10 15-minute periods. Each lens pair-head position combination was used only once for each subject.

Cost-Benefit Ratio

The cost benefit ratio was derived using two portions of data. The cost was determined by calculating an average cost of a vision examination and eyewear (with the best correction). The benefit was determined by calculating the worth of the net change in productivity for the average of the workers over a one-year period. We assumed that the productivity as determined during the study remained constant over a year. The cost-benefit ratio was determined by dividing the cost by the benefits likely to accrue over a one-year period into the assumed productivity over the same period.

For example, assume a given worker was provided a vision examination and a pair of glasses with a total cost of $268 ($80 vision examination; $88 pair of lenses; $100 frame). If the mean productivity of the worker was 100 claims per day (100 claims per 8 hrs equals 12.5 claims per hour or 0.21 claims per minute or 1 claim about every 5 minutes) and the worker earns $50 per day ($6.25/ hr), then each claim processed costs $0.50. If one further assumes that the change in productivity was 3 claims per day for a year's period (250 days), then a cost benefit can be calculated. Three claims per day equals a $1.50 increase in productivity per day for a 250-day period and the productivity would be equal to $375. For this result, the cost benefit ratio would be favorable, $375 in productivity resulted from an investment of $268, a ratio of 1.40 to 1. For every $1 invested in workers in this manner, the employer receives $1.40. If the company provides health insurance that already provides for a portion of the vision examination or eyewear, the cost benefit ratio would be favorably and correspondingly altered.

Practice

To minimize learning effects, all subjects completed a short practice period of 5 minutes prior to beginning the experiment. During this trial, subjects wore either their best correction (in the trial frame) or their habitual correction.

IRB Approval

This protocol received IRB approval prior to its initiation (APPENDIX A). All potential subjects underwent informed consent prior to enrolling in the study. All subjects were free to withdraw at any point in the study without penalty. The research followed the tenets of the Declaration of Helsinki.

Results

Conditions for the Experiment, Temperature, Humidity and Illumination

Table 33 describes the temperature, humidity and illumination conditions under which the experiment was conducted. These were likely representative of a typical office environment and did not appear to have affected the experiment.

Table 33. *Temperature, humidity and illumination conditions during the experiment*

	Temperature (ºF)	Humidity (%)	Illumination (lux)
N	36	36	36
Mean	75.3	39.0	312.4
Median	75.9	40.5	312.5
Std Dev	2.4	10.1	10.7
Range	69.3 to 78.6	22.0 to 55.0	262.0 to 324.0

Potential Subjects Excluded

A total of 32 potential subjects (14 male, 18 female) were not used in the protocol. Of the 32, 17 were not available and were not considered for the protocol and 15 were excluded because they were did not meet the entrance criteria (Table 34). Overall, 70.6% (36 of 51) of available subjects were entered in the protocol.

Chi-square analysis did not provide evidence to support a hypothesis of a difference in gender distribution for the subjects excluded (9 females, 6 males, 15 total) vs. those subjects included (30 females, 6 males, 36 total) in the study (Pearson chi-square=3.204, df=1, p=NS). This suggested that the distribution of gender of the subjects in the study represented the population from which they were derived.

Table 34. *Reasons for subjects being excluded*

Exclusion Class	Reason	Males	Females
Not available	Unable to reach to make appointment	7	3
	Not interested	1	6
Excluded	Unable to give time for experiment	2	7
	Doesn’t use a computer at least 1 hr per day	1	2
	Not at least 40 yrs of age	2	0
	Reduced visual acuity and strabismus	1	0
	Total	14	18

The refractive error of the 15 excluded subjects was not assessed. The refractive data for the study subjects for M (spherical equivalent), J0 (180/90 cylindrical component) and VD (vector dioptric value) is shown in Table 35. The mean M (spherical) component of the subjects’ distance correction was 0.21D less minus than their best corrected status and the J0 and J45 (cylindrical components) were approximately correct. The overall VD status indicated a mean distance refractive error of 0.55D. When considering only the near addition, the subjects' habitual correction was, on average, 0.89D too low for reading at 40 cm. and 0.38D too low for a task at 50 cm. If the additions were considered in the overall context of vector dioptric analysis, the mean errors at the near point were higher, 1.00D and 0.83D for 40 cm and 50 cm tasks, respectively. Alterations of additions in the range of 0.50 to 1.00D, as encountered in this study, appeared to be well-aligned with errors encountered by these subjects during daily living.

Table 35. *Vector dioptric assessment of refractive status of subjects (n=36 subjects, 72 eyes, paired t test)*

Type		M	J0	J45	VD	Add 40 cm	Add 50 cm	VD 40 cm	VD 50 cm
Habitual									
	Mean	-0.61	-0.02	0.06	1.37	0.85	Same as 40 cm	1.61	Same as 40 cm
	Median	0.00	0.00	0.00	0.72	0.00		0.93	
	Std Dev	2.09	0.36	0.27	1.74	1.01		1.81	
	Range	-8.75 to 3.00	-1.14 to 1.17	-0.54 to 1.49	0.00 to 8.81	0.00 to 2.75		0.00 to 6.58	
Best Correction									
	Mean	-0.82	-0.06	0.06	1.63	1.74	1.24	1.94	1.77
	Median	-0.25	0.00	0.03	1.22	2.00	1.50	1.51	1.35
	Std Dev	2.12	0.43	0.29	1.66	0.53	0.53	1.49	1.48
	Range	-9.25 to 3.13	-1.50 to 1.08	-0.62 to 1.37	0.00 to 9.25	0.75 to 2.50	0.25 to 2.00	0.35 to 7.00	0.00 to 7.50
Difference									
	Mean	-0.21	-0.04	-0.00	0.55	0.89	0.38	1.00	0.83
	Std Dev	0.54	0.26	0.22	0.39	0.87	0.87	0.74	0.66
	95% Conf Interval	-0.33 to -0.08	-0.10 to 0.02	-0.05 to 0.05	0.46 to 0.64	0.68 to 1.09	0.18 to 0.59	0.83 to 1.18	0.68 to 0.98

Subjects Included

A total of 36 subjects were included in the study (6 male, 30 female; mean age 50.3 yrs, std dev 9.0, range 40 to 81 yrs). Prior to beginning the study, the subjects completed a survey regarding their estimated daily hours of computer use and the tasks they typically completed on the computer. The subjects estimated that they spent a mean of 4.5 hrs/day on the computer (Std dev 2.6, range 1 to 11 hrs). The subjects estimated that 'E-mail' was the most common task (median rank 1.0) followed by 'Data Entry,' 'Word Processing,' 'Internet Use' and 'Spreadsheet' (median ranks 3.0), 'Proofreading' (median rank 4.0) and 'Other' (median rank 7.0). Table 36 provides details of computer use by subject.

Table 36. *Details of computer use by subject*

N	Sex	Age (yr)	Hrs Use	Computer Use*						
				Data entry	Word processing	Email	Internet	Spreadsheet	Proof reading	Other
1	F	56	4.5	2		4	3	1	1	
2	F	57	11	6		3	2	5	4	7
3	F	67	1.5	6	2	1	3	5	4	
4	F	40	4	4	3	1	2	5	6	
5	F	56	6	2	3	1	6	5	4	
6	F	45	2	1		2	3		1	
7	F	47	6.5	1	6	4	5	2	3	7
8	F	45	8	1		2			3	4
9	F	42	2.5			2	3			1
10	M	50	1	3		1	2			
11	F	59	8		3	4	1		2	
12	M	41	3.5		2	1	3	4	5	
13	F	52	5							1
14	F	41	2.5				1			
15	M	41	8	1						
16	M	56	7	4	5	1	2	3	6	7

Table 36. (Continued)

N	Sex	Age (yr)	Hrs Use	Computer Use*						
				Data entry	Word processing	Email	Internet	Spreadsheet	Proof reading	Other
17	F	49	6	4	5	1	2	3	6	7
18	F	55	5.5	1						
19	M	47	6	3		1	4	2		
20	F	51	6	1	2	3	6	4	5	7
21	F	40	1			1	2			3
22	F	50	6	6	1	2	4	5	3	7
23	F	43	3	1		4	3	2		
24	F	40	3	7	3	2	1	6	4	5
25	F	54	1			1	2			3
26	F	51	2			1	2			
27	F	63	11	4	3	1		2	5	
28	F	81	2	4	5	1	3	2		
29	F	40	2			1	2	3		
30	F	49	3		2	1	3			
31	M	40	4	3	5	2	4	6	1	7
32	F	53	1.5		2		1			3
33	F	41	6.5	1		2	4	3		
34	M	56	4		3	1	2			4
35	F	55	5	4	1	2	3	5	6	7
36	F	56	3.5	1	2	4	5	3	6	7

*Rank 1 (most common) to 7 (least common)

Subjects also completed a questionnaire regarding any self-reported visual conditions (Table 37). Seven subjects reported dry eye syndrome (19.4%); fourteen reported focusing problems (38.9%); five reported a binocular problem (13.9%); and, eight reported glare problems (22.2%). Reports of focusing problems were significantly correlated with reports of binocular problems (r=0.50, p=0.002). Reports of binocular problems were significantly correlated with reports of glare (r=0.36, p=0.029).

Table 37. Self-reported visual conditions by subject

N	Self-reported Visual Conditions*			
	Dry eye syndrome	Focusing problems	Binocular problem	Glare
1	1	0	0	0
2	0	0	0	0
3	1	1	0	0
4	0	1	0	0
5	0	0	0	1
6	0	1	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	1
10	0	1	0	0
11	0	0	0	1
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	1
16	0	0	0	0
17	0	1	0	0
18	0	0	0	0
19	1	0	0	0
20	0	0	0	0
21	0	1	1	0
22	0	0	0	0
23	1	0	0	0
24	0	1	0	0
25	1	1	1	1
26	0	1	0	0
27	0	0	0	1
28	0	0	0	0
29	0	0	0	0
30	0	1	1	0
31	0	0	0	0
32	0	1	1	1
33	1	1	0	0
34	0	1	0	0
35	0	0	0	0

Table 37. (Continued)

N	Self-reported Visual Conditions*			
	Dry eye syndrome	Focusing problems	Binocular problem	Glare
36	1	1	1	1

*1, present; 0, not present

Using a questionnaire, nine subjects (25.0%) self-reported a total of 23 ergonomic problem areas when using their computers (Table 38). These were reported with respect to the desk (n=3, 8.3%), chair (n=6, 16.7%), monitor (n=3, 8.3%), keyboard (n=3, 8.3%), mouse (n=2, 5.6%), lighting (n=5, 13.9%) and 'other' (n=1, 2.8%). Correlation analysis suggested that reports of ergonomic problems were frequently related to one another. Significant relationships between reports of ergonomic problems included desk with chair, keyboard, mouse and lighting (r=0.67, p=0.0001; r=0.64, p=0.0001; r=0.80, p=0.0001; r=0.46, p=0.007; respectively), chair with monitor, keyboard, mouse and other (r=0.41, p=0.014; r=0.67, p=0.0001; r=0.54, p=0.001; r=0.38, p=0.026; respectively) and monitor with keyboard, mouse and lighting (r=0.64, p=0.0001; r=0.37, p=0.028; r=0.46, p=0.006, respectively) and keyboard with mouse (r=0.80, p=0.0001). Six of 36, or 16.6% of subjects reporting ergonomic issues reported more than one ergonomic issue.

Table 38. *Self-reported ergonomic problems by subjects with detail*

N	Ergonomic Problem*	Ergonomic Problem Detail*						
		Desk	Chair	Monitor	Keyboard	Mouse	Lighting	Other
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	1	0	1	1	1	0	0	0
4	0	0	0	0	0	0	0	0
5	1	0	0	0	0	0	1	0
6	0	0	0	0	0	0	0	0

Table 38. (Continued)

N	Ergonomic Problem*	Ergonomic Problem Detail*						
		Desk	Chair	Monitor	Keyboard	Mouse	Lighting	Other
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	1	1	1	0	0	0	1	0
10	1	0	1	0	0	0	0	1
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	1	1	1	0	1	1	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	1	0
24	0	0	0	0	0	0	0	0
25	0	0	0	1	0	0	1	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	1	0	1	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	1	1	1	1	1	1	1	0

*1, present; 0, not present

Loss to Follow-up

All subjects accepted into the study completed the protocol. No loss to follow-up occurred.

Experiment 2

The analysis for experiments 2 a and b used randomized block or block factorial design ANOVAs, respectively. Experiment 2a used order i.e., time on task as the independent variable. Experiment 2b used head (head free to move or on fixed on the chin rest) and lens addition (masked additional lens, +-1.00D, +-0.50D or plano) as independent variables. The dependent variables for both analyses were visual comfort index (VCI), total correct work (TCW) and correct comfortable work (CCW). This resulted in three different analyses for each part. An appropriate correction for these multiple ANOVA was made, so that α was considered significant at $p < 0.01$. This correction was slightly more conservative than the Bonferroni correction (0.05/3) of 0.017. We considered using age and estimated time at the computer as covariates. However, correlation analysis suggested a lack of correlation of either of these with any of the dependent variables and hence they were not included**.** The data (VCI, TCW, and CCW) except accuracy met appropriate criteria for normality (Shapiro-Wilk test) and homogeneity of variances.

Experiment 2a. Effects of Order for VCI, TCW and CCW

Experiment 2a investigated the effect of order i.e., time at task, on the VCI, TCW and CCW. Table 39 displays the randomized block design used in the analysis with order as the effect. Order described the 15-minute work sessions completed with different additional lenses for the editing task. There were 10 trials using each of five different additional lenses (+/-1.00, +/-0.50 and plano) with the head on a chin rest or free to move. An additional assessment of VCI was completed before beginning so a total of 11 assessments were made for VCI and 10 for TCW and CCW.

Table 39. The randomized block design with order effect; dependent variables were VCI, TCW, and CCW

Subject	Order									
	1	2	3	4	5	6	7	8	9	10
1-36										

Table 40 provides a summary of the randomized block ANOVAs for the effect of order on VCI, TCW and CCW. Order had a significant effect on the VCI and TCW of subjects working on the editing task with the variety of different adds and head positions ($p= 0.0001$, 0.0001, respectively) and suggested a trend for CCW ($p=0.0094$). Details of the analyses for the three independent variables are provided in Tables 41 through 43. The model used in the ANOVAs determined r^2 values of 0.43, 0.70, 0.62 for VCI, TCW and CCW, respectively.

Table 40. Summary of results of ANOVA using randomized block design for independent variable order (O) on VCI, TCW and CCW

Variable	Main Effects
VCI	O = 0.0001*
TCW	O = 0.0001*
CCW	O = 0.0094^t

*Significant at p=0.008 or less; t trend

Table 41. Results of ANOVA using randomized block design for VCI for effect of order for experiment 2a

Source	DF	Sum of Square	Mean Square	F Value	Pr>F
Subject	35	51970.34	1484.87	6.30	<.0001
Order	10	9347.97	934.80	3.97	<.0001*
Error	350	82505.26	235.73		
Corrected Total	395	143823.58			

*Significant at p=0.008 or less

Table 42. *Results of ANOVA using randomized block design for TCW per hour for effect of order for experiment 2a*

Source	DF	Sum of square	Mean Square	F Value	Pr > F
Subject	35	364450162.7	10412861.8	19.61	<.0001
Order	9	33511216.7	3723468.5	7.01	<.0001*
Error	315	167239882.9	530920.3		
Corrected Total	359	565201262.4			

*Significant at p=0.008 or less

Table 43. Results of ANOVA using randomized block design for CCW for effect of order for experiment 2a

Source	DF	Sum of square	Mean Square	F Value	Pr > F
Subject	35	335215260.7	9577578.9	14.15	<.0001
Order	9	15129818.9	1681091.0	2.48	0.0094*
Error	315	213284024.6	677092.1		
Corrected Total	359	563629104.2			

*Significant at p=0.008 or less

Figures 3 and 4 show the relationship of order i.e., time on task, to VCI, TCW and CCW for experiment 2a. Over the course of the 11 assessments, lasting about 2 hrs and 45 minutes, mean visual comfort decreased by 15.4% (means, 84.8 to 71.7). During the same assessment period, TCW and CCW increased by 36.4% (means, 2849 to 3834) and 25.9% (2349 to 2957), respectively.

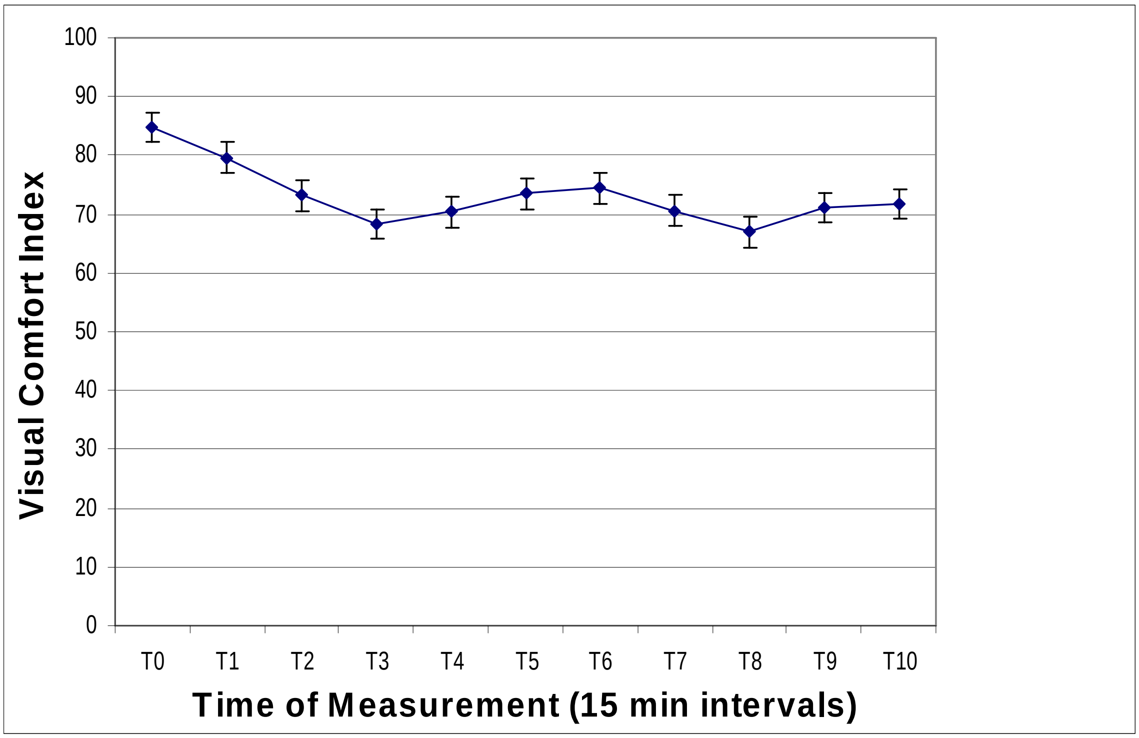

Figure 3. Mean visual comfort index (VCI) as a function of time worked (n=396 total, 36 in each point). Error bars indicate standard error of the mean.

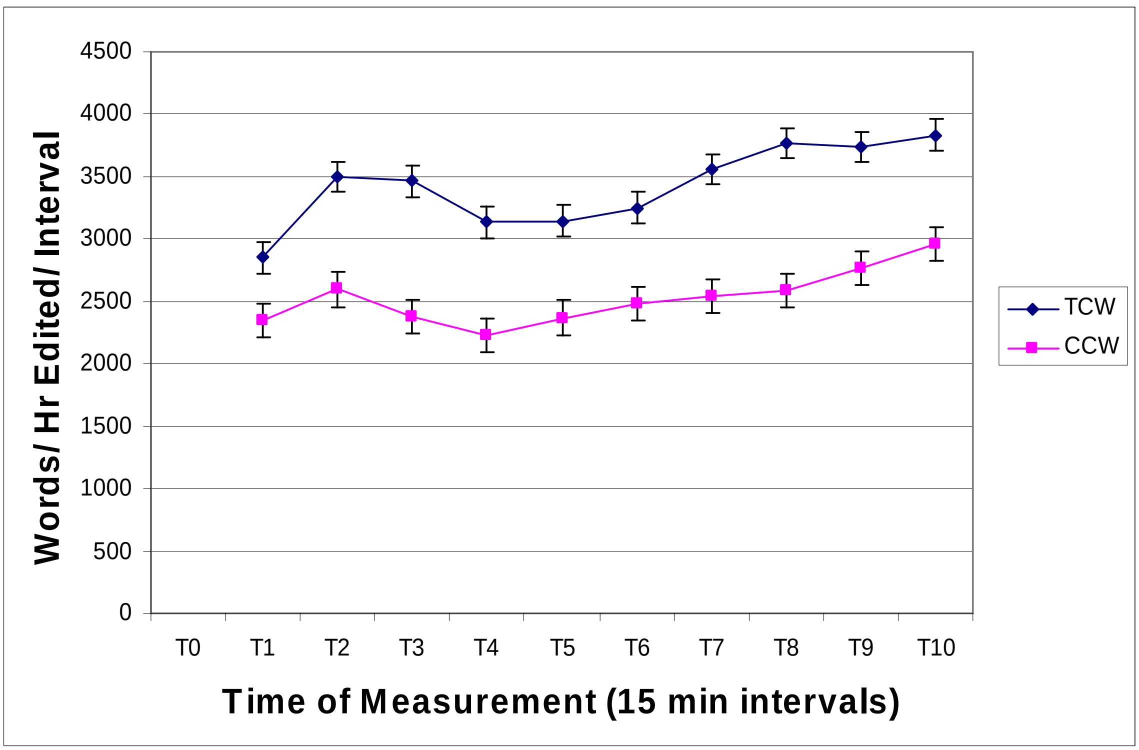

Figure 4. Mean total correct work (TCW) and mean correct comfortable work (CCW) as a function of time worked (n=36 in each point). Error bars indicate standard error of the mean.

*Experiment 2b. Effects of Lens, Head and Lens*Head for VCI, TCW and CCW*

The ANOVA used a block factorial design analysis (Table 44) with the independent variables, subject, lens (+/-0.50,+/-1.00, plano) and head (on chin rest or free to move) and a lens*head interaction. The results of the ANOVAs suggested that there was a significant effect of the lens*head interaction on the dependent variables, VCI and CCW but not for TCW (p=0.0049, 0.0088, respectively; Table 45). These analyses also identified a main effect for head position for TCW (p=0.0069, Table 45).

Table 44. Randomized block factorial design for experiments 2b and 2c with dependent variables*, distance* assessed during each of the ten 15-min trials and independent variables (subject, lens* and head*)

Subject	Lens and Head									
	Head on Chin Rest					Head Free to Move				
	Lens A	Lens B	Lens C	Lens D	Lens E	Lens A	Lens B	Lens C	Lens D	Lens E
1-36										

*VCI, TCW, CCW; Time 0 (start), distance Time 9 (end), average distance across 9 times; additional lenses, +-1.00, +-0.50 and plano; on chin rest or free to move

Table 45. Summary of ANOVAs using block factorial design for subject, lens (L), head (H) and lens-head interaction (L x H) for experiment 2b

Independent Variable	Interactions	Main Effects
VCI	LxH = 0.0049*	NA
TCW	LxH = ns	L= ns H = 0.0069*
CCW	LxH = 0.0088*	NA

*Significant at p=0.008 or less

Tables 46 through 48 provide the details for the block factorial design ANOVAs for the three dependent variables, VCI, TCW and CCW. The model in Table 46 demonstrated that the lens*head interaction was significant (p = 0.0049) for VCI and explained a substantial portion of the variance (r^2= 0.54). Subjects who worked on the editing task with adds of +1.00D and their head in the chin rest position were less comfortable than when they worked with other adds on the chin rest (-1.00, 0.00,+/-0.50; mean=55.14; p=<0.0001; Table 49). Subjects who worked on the editing task with adds of +1.00D and their head free to move were also less comfortable than when they worked with other adds and their head was free to move (0.00, +/-0.50; mean = 63.24; p = <0.0001; Table 49). Tables 50 through 54 provide details for the analysis leading to the Tukey HSD test for differences in VCI as a function of lens addition and head position. Figure 5 shows these effects graphically.

Table 46. *Results of ANOVA using block factorial design for lens and head interaction for VCI for experiment 2b*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Subject	35	51262.54	1464.64	7.64	<.0001
Lens	4	17069.70	4267.43	22.26	<.0001
Head	1	59.52	59.52	0.31	0.5778
Lens*Head	4	2914.45	728.61	3.80	0.0049*
Error	315	60400.77	191.75		
Corrected Total	359	131677.09			

*Significant at p=0.008 or less

Table 47. Results of ANOVA using block factorial design for TCW for lens adds and head for experiment 2b

Source	*DF*	*Type III SS*	*Mean Square*	*F Value*	*Pr > F*
Subject	35	364716906.2	10420483.0	17.49	<.0001
Lens	4	3625109.3	906277.3	1.52	0.1957
Head	1	4404717.0	4404717.0	7.39	0.0069*
Lens*Head	4	5172082.2	1293020.6	2.17	0.0721
Error	315	187635339.5	595667.7		
Corrected Total	359	565201262.4			

*Significant at p=0.008 or less, (+/-0.50, +/-1.00, plano); (free to move or on chin rest)

Table 48. Results of ANOVA using block factorial design for the lens and head effect on CCW for experiment 2b

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Subject	35	334574479.3	9559270.8	15.68	<.0001
Lens	4	26249096.8	6562274.2	10.76	<.0001
Head	1	2287560.6	2287560.6	3.75	0.0536
Lens*Head	4	8435289.7	2108822.4	3.46	0.0088*
Error	315	192063202.7	609724.5		
Corrected Total	359	563629104.2			

*Significant at p=0.008 or less

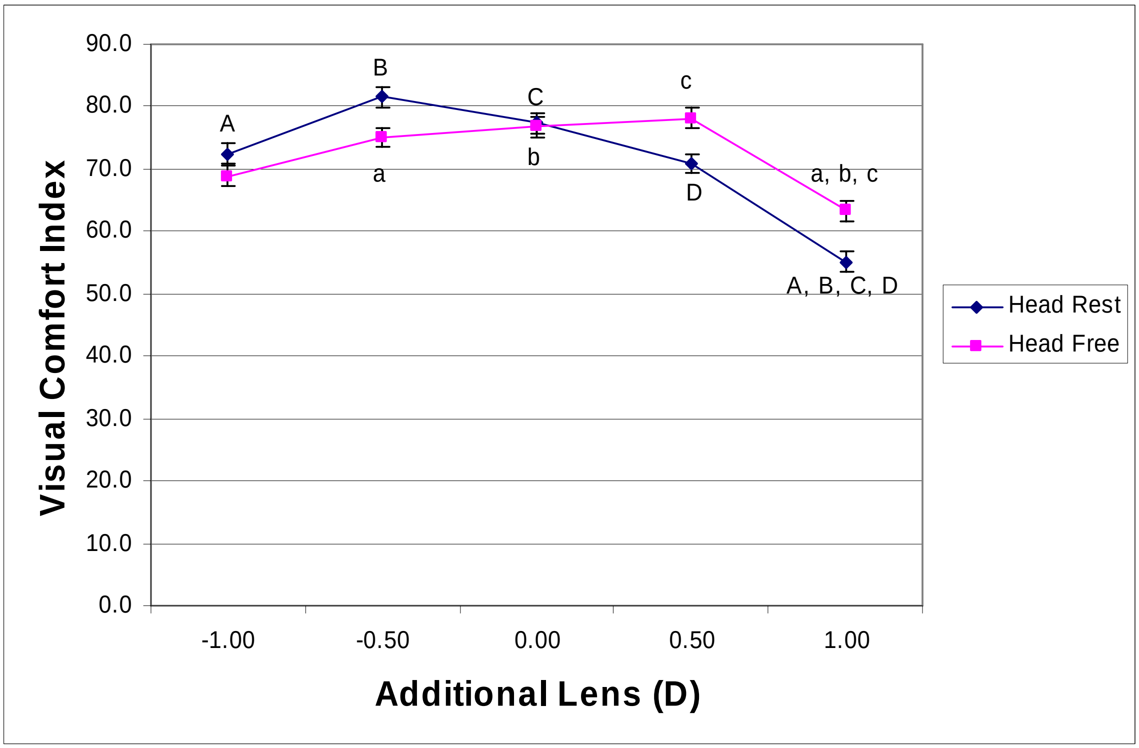

Figure 5. VCI as a function of additional lens addition on the editing task. Error bars indicate standard error of the mean. Tukey HSD test confirmed differences between points marked with letters ($p<0.01$).

Table 49. VCI means for independent variables lens and head for the editing task for experiment 2b

Lens (D)	Head	
	Rest	Free
-1.00	72.50	68.83
-0.50	81.48	75.06
0.00	77.41	76.79
+0.50	70.86	78.15
+1.00	55.14	63.24

Table 50. *VCI number of subjects for independent variables lens and head for the editing task for experiment 2b*

Lens (D)	Head		Total
	Rest	Free	
-1.00	36	36	72
-0.50	36	36	72
0.00	36	36	72
+0.50	36	36	72
+1.00	35	37	72
Sum	179	181	

Table 51. *VCI sum of squares for independent variables lens and head for the editing task for experiment 2b*

Lens (D)	Head		Total
	Rest	Free	
-1.00	2610.00	2477.88	5087.88
-0.50	2933.28	2702.16	5635.44
0.00	2786.76	2764.44	5551.20
+0.50	2550.96	2813.40	5364.36
+1.00	1929.90	2339.88	4269.78
Total	12810.90	13097.76	

Table 52. *Details of block factorial design ANOVA for two way interaction between lens additions with the best correction when the head is on the chin rest or free to move for VCI for experiment 2b*

Source	*SS*	*DF*	*MS*	*ET*	*F*	*0.05*	*0.01*	
Lens @ Head R	14260.65	4	3565.16	191.75	18.59*	2.37	3.32	(df 4,inf)
Lens @ Head F	5701.85	4	1425.46	191.75	7.43*	2.37	3.32	(df 4,inf)
Head @ Lens -0.50	741.90	1	741.90	191.75	3.87^{t}	3.84	6.63	(df 1,inf)
Head @ Lens +0.50	956.59	1	956.59	191.75	4.99^{t}	3.84	6.63	(df 1,inf)
Head @ Lens 0.00	6.92	1	6.92	191.75	0.04	3.84	6.63	(df 1,inf)
Head @ Lens -1.00	242.44	1	242.44	191.75	1.26	3.84	6.63	(df 1,inf)
Head @ Lens +1.00	1180.07	1	1180.07	191.75	6.15^{t}	3.84	6.63	(df 1,inf)

*Significant at p=0.01 or less; ^{t}Trend to significance

Table 53. Tukey HSD follow-up for VCI differences between pairs (arranged by size of means) for lens additions to the best correction when the head was on chin rest for Experiment 2b

Lens (D; mean VCI)	-0.50D	0.00	-1.00D	+0.50D	+1.00D
-0.50 (81.48)		4.07	8.98	10.62*	26.34**
0.00 (77.41)			4.91	6.55	22.27**
-1.00 (72.50)				1.64	17.36**
+0.50 (70.86)					15.72**
+1.00 (55.14)					

*Critical HSD (0.05, k=5, df=35) = 9.39 (any difference exceeding this value is significant at 0.05)
**Critical HSD (0.01, k=5, df=35) = 11.52 (any difference exceeding this value is significant at 0.01)

Table 54. Tukey HSD follow-up for VCI differences between pairs (arranged by size of means) for lens additions to the best correction when the head was free to move for Experiment 2b

Lens (D; mean VCI)	+0.50D	0.00	-0.50D	-1.00D	+1.00D
+0.50 (78.15)		1.36	3.09	9.32	14.91**
0.00 (76.79)			1.73	7.96	13.55**
-0.50 (75.06)				6.23	11.82**
-1.00 (68.83)					5.59
+1.00 (63.24)					

*Critical HSD (0.05, k=5, df=35) = 9.39 (any difference exceeding this value is significant at 0.05)
**Critical HSD (0.01, k=5, df=35) = 11.52 (any difference exceeding this value is significant at 0.01)

ANOVA analysis using a block factorial design identified a main effect for head position for TCW (Tables 45 through 47). The subjects were significantly more productive when they worked on the editing task with their head in the free position compared to when their head was in the chin rest position (p=<0.0069; mean TCW = 3532.7, 3311.0, respectively) and the model explained a substantial portion of the variance (r^2= 0.67). There was no trend of an effect of the lens*head interaction on the TCW of subjects working on the editing task with different adds nor was a significant main effect for the lens addition identified for TCW.

Analysis using the block factorial design ANOVA identified a significant interaction between lens and head on CCW (p=0.0088; Tables 45 and 48) and the model explained a substantial portion of the variance (r^2= 0.66). Tables 55-57 show details including means, number of subjects, sum of squares and the results of the analysis leading to the Tukey HSD test.

The +1.00D additional lenses had a significant effect on the subjects' work and productivity. Subjects were significantly less comfortable and less productive when they worked on the editing task with a +1.00D lens addition to their best computer distance correction than when they worked with other adds (-1.00, 0.00, +/-0.50) and their head was in the chin rest position (mean CCW = 1692.28, $p<0.01$; Table 43). There also was a trend for subjects to be significantly less comfortable and less productive when they worked on the editing task with a +1.00D additional lens to their best computer distance correction than when they worked with other adds (-1.00, 0.00, +/-0.50) and their head was free to move (mean CCW = 2345.33; Table 43).

With the +1D additional lens over their best computer distance correction, these demonstrated that the subjects were significantly more productive when they worked on the editing task with their head free to move than when their head was positioned on the chin rest (Table 43, $p<0.01$). Figure 6 displays these effects for CCW for lens and head.

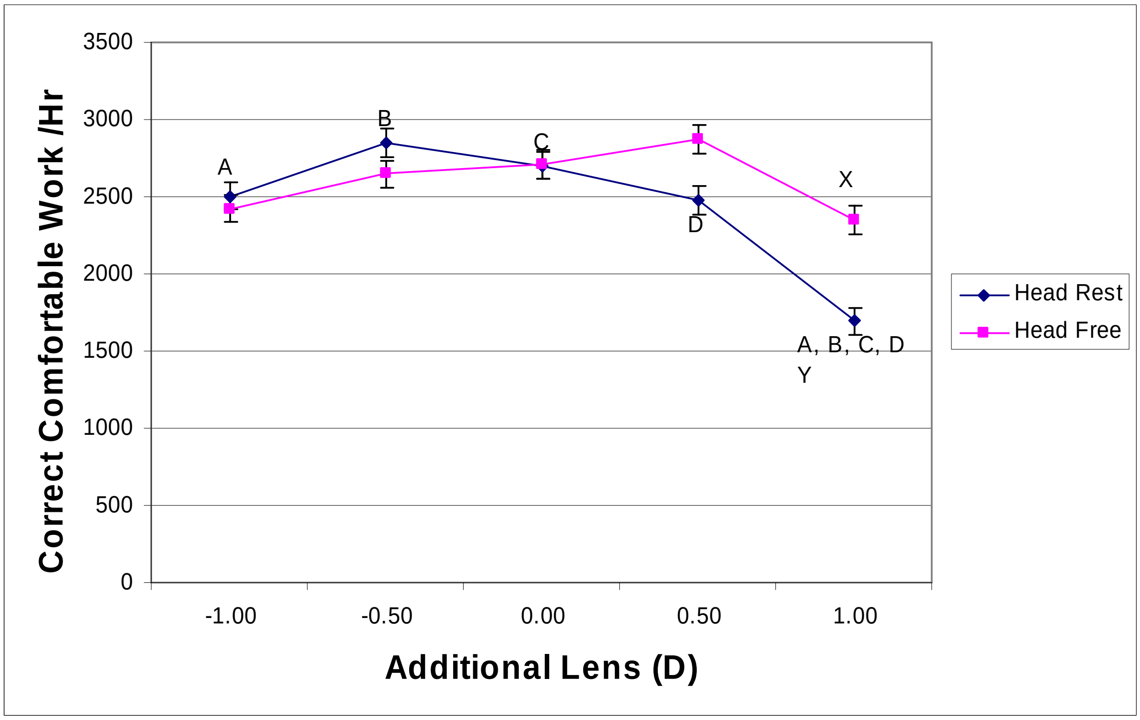

Figure 6. CCW per hour as a function of masked lens addition. Error bars indicate standard error of the mean. Tukey HSD test confirmed differences for points marked with letters.

Table 55. *CCW means for lens additions to the best correction and head is free to move or head is on the chin rest for the editing task for experiment 2b*

Lens (D)	Head	
	Rest	Free
-1.00	2505.27	2423.69
-0.50	2848.86	2646.05
0.00	2702.78	2711.99
+0.50	2476.69	2873.01
+1.00	1692.28	2345.33

Table 56. *CCW number of subjects for lens additions to the best correction and head is free to move or head is on the chin rest for the editing task for experiment 2b*

Lens (D)	Head		Total
	Rest	Free	
-1.00	36	36	72
-0.50	36	36	72
0.00	36	36	72
+0.50	36	36	72
+1.00	35	37	72
Total	179	181	

Table 57. *CCW sum of squares for lens additions to the best correction and head is free to move or head is on the chin rest for the editing task for experiment 2b*

Lens (D)	Head		Sum
	Rest	Free	
-1.00	90189.72	87252.84	177442.56
-0.50	102558.96	95257.80	197816.76
0.00	97300.08	97631.64	194931.72
+0.50	89160.84	103428.36	192589.20
+1.00	59229.80	86777.21	146007.01
Sum	438439.40	470347.85	

Table 58. *Details of block factorial design ANOVA for two way interaction between lens additions with the best correction when the head is on the chin rest (R) or free to move (F) for CCW for experiment 2b*

Source	SS	df	MS	ET	F	0.05	0.01	
Lens @ Head R	28257967.26	4	7064491.81	609724.50	11.59*	2.37	3.32	(df 4,inf)
Lens @ Head F	6729504.06	4	1682376.01	609724.50	2.76[t]	2.37	3.32	(df 4,inf)
Head @ Lens -1.00	119795.34	1	119795.34	609724.50	0.20	3.84	6.63	(df 1,inf)
Head @ Lens -0.50	740374.13	1	740374.13	609724.50	1.21	3.84	6.63	(df 1,inf)
Head @ Lens 0.00	1526.83	1	1526.83	609724.50	0.00	3.84	6.63	(df 1,inf)
Head @ Lens +0.50	2827251.76	1	2827251.76	609724.50	4.64[t]	3.84	6.63	(df 1,inf)
Head @ Lens +1.00	7670614.19	1	7670614.19	609724.50	12.58*	3.84	6.63	(df 1,inf)

*Significant at p=0.01 or less; [t]Trend to significance

Table 59. *Tukey HSD follow-up for CCW differences between pairs (arranged by size of means) for lens additions to the best correction when the head was on chin rest for Experiment 2b*

Lens (D; mean CCW)	-0.50	0.00	-1.00	+0.50	+1.00
-0.50 (2848.86)		146.08	343.59	372.17	1156.58**
0.00 (2702.78)			197.51	226.09	1010.50**
-1.00 (2505.27)				28.58	812.99**
+0.50 (2476.69)					784.41**
+1.00 (1692.28)					

*Critical HSD (0.05, k=5, df=35) = 529.68 (any difference exceeding this value is significant at 0.05).
**Critical HSD (0.01, k=5, df=35) = 649.41 (any difference exceeding this value is significant at 0.01)

Table 60. *Tukey HSD follow-up for CCW differences between pairs (arranged by size of means) for lens additions to the best correction when the head was free to move for Experiment 2b*

Lens (D; mean CCW)	+0.50	0.00	-0.50	-1.00	+1.00
+0.50 (2873.01)		161.02	226.96	449.32	527.68
0.00 (2711.99)			65.94	288.30	366.66
-0.50 (2646.05)				222.36	300.72
-1.00 (2423.69)					78.36
+1.00 (2345.33)					

*Critical HSD (0.05, k=5, df=35) = 529.68 (any difference exceeding this value is significant at 0.05).
**Critical HSD (0.01, k=5, df=35) = 649.41 (any difference exceeding this value is significant at 0.01)

Experiment 2c. Effects of lens and head on distance of the head to the computer monitor

Experiment 2c used block factorial design ANOVAs to examine the potential effects of additional masked lens (+-1.00, +-0.50, plano) and head position (fixed on chin rest or free to move) on distance as the dependent variable (Table 44). Distance was considered as the beginning, ending or the mean distance of the head from the computer monitor over the 15-min trial period for each of the ten trials. Table 61 provides a summary of the analyses. The analysis identified a main effect for head position on the distance of the head from the computer monitor at the beginning of the trials ($p<0.0001$). The analysis demonstrated significant effects of a lens*head interaction on the distance of the head from the computer monitor at the end of the trials ($p=0.0021$). Also, the analysis demonstrated a similar interaction of lens*head for the mean distance of the head from the computer monitor ($p<0.0001$). Tables 62 through 69 provide the details of the block factorial ANOVA for the effects of additional masked lens (L; +-1.00, +-0.50, plano) and head position (H; fixed on chin rest or free to move) on the start, end and average distance of the head from the computer monitor as the dependent variable, respectively.

Table 61. *Summary of block factorial design ANOVAs for the effects of additional masked lens* and head position* on distance as the dependent variable*

Distance	Interactions	Main Effects
Beginning	L x H = ns	L = ns H < 0.0001*
End	L x H = 0.0021*	NA
Mean	L x H < 0.0001*	NA

*Significant at p=0.008 or less; (L; +-1.00, +-0.50, plano); (H; fixed on chin rest or free to move).

The main effect identified by the analysis of head position (fixed on the chin rest or free to move) suggested that the starting position for the trials was 58.5 cm (SE 0.19) when the head was on the chin rest and 57.2 cm (SE 0.19) when the head was free to move, a mean difference of 1.3 cm (2.3% closer when the head free to move). The model (Table 62) calculated an r^2 of 0.32.

Table 62. *Results of ANOVA analysis of effect of additional masked lens and head position on distance of the head from the computer monitor at the starting time of the trial (time 0) as the dependent variable*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Subject	35	715.36	20.44	3.11	<.0001
Lens	4	74.48	18.62	2.83	0.0249
Head	1	151.13	151.13	22.96	<.0001*
Lens*Head	4	20.65	5.16	0.78	0.5359
Error	315	2073.14	6.58		
Corrected Total	359	3034.69			

*Significant at p=0.01 or less; lenses, +-1.00, +-0.50, plano; head position, fixed on chin rest or free to move

Table 63 displayed the detail of the significant interaction between the additional masked lens and head position on the distance of the head from the computer monitor at the end of each of the ten trials in the ANOVA analysis (Time 15 min model $r^2 = 0.37$).

Tables 64 through 69 show details including means, number of subjects, sum of squares and the results of the analysis leading to the Tukey HSD test. The distance of the head from the computer monitor when free to move was within a cm of the same distance when on the chin rest for the -1.0, -0.5 and plano lenses. When free to move, the head moved 5.9 and 10.3 cm closer to the computer with the +0.5 and +1.0D additional lenses. Figure 7 shows a graph of distance of the head from the computer monitor (cm) at the end (Time 15 min) of each of the ten trials as a function of the masked additional lens. The Tukey HSD test confirmed significant differences between the points marked with letters.

Table 63. *Results of ANOVA analysis of effect of additional masked lens and head position on distance of the head from the computer monitor at the end (Time 15 min) of each of the ten trials as the dependent variable*

Source	DF	Sum of Square	Mean Square	F Value	Pr > F
Subject	35	11385.45	325.01	3.80	<.0001
Lens	4	1724.78	431.02	5.04	0.0006
Head	1	1066.88	1066.88	12.47	0.0005
Lens*Head	4	1477.49	369.37	4.32	0.0021*
Error	315	26952.52	85.56		
Corrected Total	359	42704.93			

*Significant at p=0.008 or less; lenses, +-1.00, +-0.50, plano; head position, fixed on chin rest or free to move

Table 64. *Mean distance (cm) for the effect of additional masked lens and head position on distance of the head from the computer monitor at the end (Time 15 min) of each of the ten trials as the dependent variable for experiment 2c*

Lens (D)	Head	
	Rest	Free
-1.00	58.01	58.32
-0.50	58.32	57.46
0.00	57.95	57.33
+0.50	57.89	52.02
+1.00	57.68	47.34

Table 65. *Number of subjects for the effect of additional masked lenses and head position on distance of the head from the computer monitor at the end (Time 15 min) of each of the ten trials as the dependent variable for experiment 2c*

Lens D	Head		Total
	Rest	Free	
-1.00	36	36	72
-0.50	36	36	72
0.00	36	36	72
+0.50	36	36	72
+1.00	35	37	72

Table 66. *Sums of squares for the effect of additional masked lens and head position on distance of the head from the computer monitor at the end (Time 15 min) of each of the ten trials as the dependent variable for experiment 2c*

Lens D	Head		Sum
	Rest	Free	
-1.00	2088.36	2099.52	4187.88
-0.50	2099.52	2068.56	4168.08
0.00	2086.20	2063.88	4150.08
+0.50	2084.04	1872.72	3956.76
+1.00	2018.80	1751.58	3770.38
Sum	10376.92	9856.26	

Table 67. *Details of block factorial design ANOVA of the effect of additional masked lens and head position on distance of the head from the computer monitor at the end (Time 15 min) of each of the ten trials as the dependent variable for experiment 2c*

Source	SS	Df	MS	ET	F	0.05	0.01	
Lens @ Head R	7.66	4	1.91	85.56	0.02	2.37	3.32	(df 4,inf)
Lens @ Head F	3246.93	4	811.73	85.56	9.49*	2.37	3.32	(df 4,inf)
Head @ Lens -1.00	1.73	1	1.73	85.56	0.02	3.84	6.63	(df 1,inf)
Head @ Lens -0.50	13.31	1	13.31	85.56	0.16	3.84	6.63	(df 1,inf)
Head @ Lens 0.00	6.92	1	6.92	85.56	0.08	3.84	6.63	(df 1,inf)
Head @ Lens +0.50	620.22	1	620.22	85.56	7.25*	3.84	6.63	(df 1,inf)
Head @ Lens +1.00	1923.00	1	1923.00	85.56	22.48*	3.84	6.63	(df 1,inf)

*Significant at p=0.01 or less; R, fixed on chin rest; or F, free to move

Table 68. *Tukey HSD follow-up for the effect of additional masked lens (arranged by size of means) when the head was on chin rest on distance of the head from the computer monitor at the end (Time 15 min) of each of the ten trials as the dependent variable for experiment 2c*

Lens (D; mean distance)	*-0.50*	*-1.00*	*0.00*	*+0.50*	*+1.00*
-0.50 (58.32)		0.31	0.37	0.43	0.64
-1.00 (58.01)			0.06	0.12	0.33
0.00 (57.95)				0.06	0.27
+0.50 (57.89)					0.21
+1.00 (57.68)					

*Critical HSD (0.05, k=5, df=35) = 6.27 (any difference exceeding this value is significant at 0.05)
**Critical HSD (0.01, k=5, df=35) = 7.69 (any difference exceeding this value is significant at 0.01)

Table 69. *Tukey HSD follow-up for the effect of additional masked lens (arranged by size of means) when the head was free to move on distance of the head from the computer monitor at the end (Time 15 min) of each of the ten trials as the dependent variable for experiment 2c*

Lens (D; mean distance)	-1.00	-0.50	0.00	+0.50	+1.00
-1.00 (58.32)		0.86	0.99	6.30*	10.98**
-0.50 (57.46)			0.13	5.44	10.12**
0.00 (57.33)				5.31	9.99**
+0.50 (52.02)					4.68
+1.00 (47.34)					

*Critical HSD (0.05, k=5, df=35) = 6.27 (any difference exceeding this value is significant at 0.05)
**Critical HSD (0.01, k=5, df=35) = 7.69 (any difference exceeding this value is significant at 0.01)

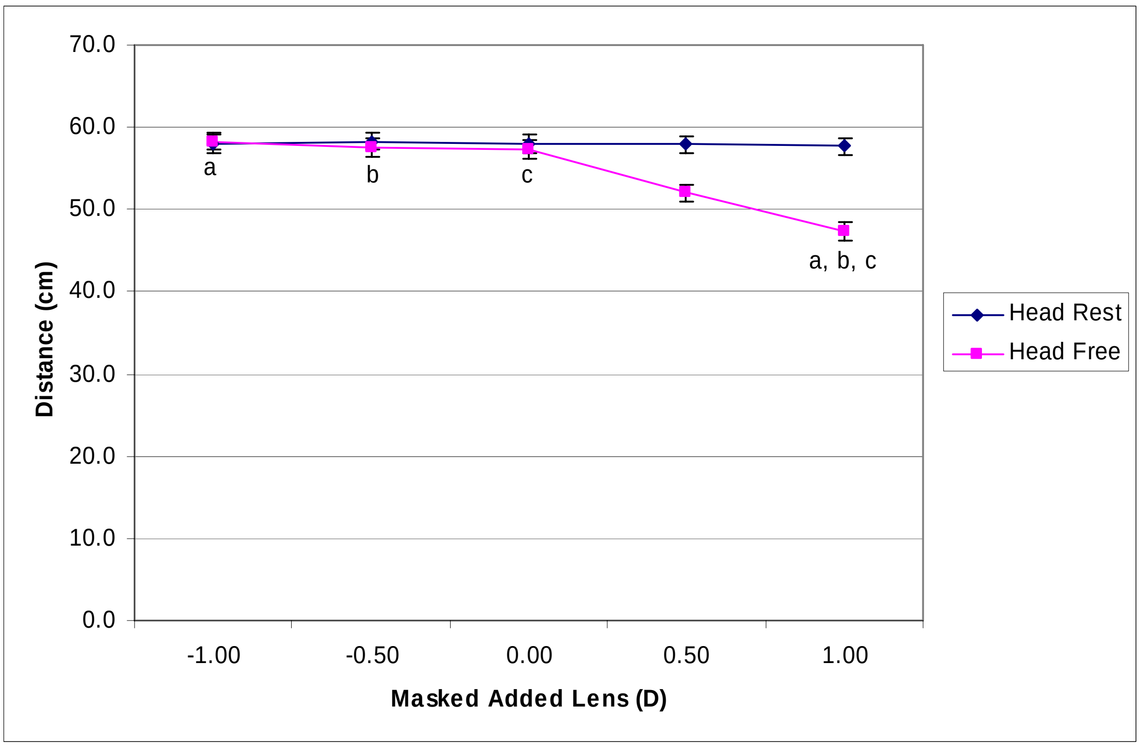

Figure 7. Graph of distance of head from computer monitor (cm) at the end of the ten trials as a function of the masked additional lens. Error bars indicate standard error of the mean. Tukey HSD test confirmed significant differences for points marked with letters

Table 70 provided the details of ANOVA analysis for the significant effect of the lens and head (lens*head) interaction on the mean distance of the head from the computer monitor for the ten trials (model $r^2 = 0.49$). Tables 71 through 76 show details including means, number of subjects, sum of squares and the results of the analysis leading to the Tukey HSD test. Similar to the effects noted for the distance of the head from the computer monitor at the end of the ten trials, the mean distance of the head moved significantly closer to the monitor for both the +0.5 (4.9 cm; vs. -1.0) and +1.0D (9.2 cm; vs. -1.0, -0.5 and plano) additional lenses. A trend for difference in mean distance was identified between the +0.5 and the -0.5D additional lenses as well as the +1.0 and the +0.5D additional lenses. Figure 8 shows a graph of the mean distance of the head from the computer monitor (cm) for the ten trials as a function of the masked additional lens.

Table 70. *Results of ANOVA analysis of effect of additional masked lens and head position on the average distance of the head from the computer monitor across the ten trials as the dependent variable*

Source	DF	Sum of Square	Mean Square	F Value	Pr > F
Subject	35	8064.53	230.42	6.10	<.0001
Lens	4	1251.64	312.91	8.28	<.0001
Head	1	1113.59	1113.59	29.47	<.0001
Lens*Head	4	984.41	246.10	6.51	<.0001*
Error	315	11904.24	37.79		
Corrected Total	359	23388.69			

*Significant at p=0.008 or less; lenses, +-1.00, +-0.50, plano; head position, fixed on chin rest or free to move

Table 71. *Mean effect of additional masked lens and head position on the average distance (cm) of the head from the computer monitor across the ten trials as the dependent variable for experiment 2c*

Lens (D)	Head	
	Rest	*Free*
-1.00	58.42	58.84
-0.50	58.61	57.38
0.00	58.45	55.67
+0.50	58.05	53.16
+1.00	58.00	48.84

Table 72. *Number of subjects for the effect of additional masked lens and head position on the average distance of the head from the computer monitor across the ten trials as the dependent variable for experiment 2c*

Lens	Head		Total
	Rest	Free	
-1.00	36	36	72
-0.50	36	36	72
0.00	36	36	72
+0.50	36	36	72
+1.00	35	37	72
Total	179	181	

Table 73. *Sums of squares for the effect of additional masked lens and head position on the average distance of the head from the computer monitor across the ten trials as the dependent variable for experiment 2c*

Lens (D)	Head		Sum
	Rest	Free	
-1.00	2103.12	2118.24	4221.36
-0.50	2109.96	2065.68	4175.64
0.00	2104.20	2004.12	4108.32
+0.50	2089.80	1913.76	4003.56
+1.00	2030.00	1807.08	3837.08
Sum	10437.08	9908.88	

Table 74. *Details of block factorial design ANOVA of the effect of additional masked lens and head position on the average distance of the head from the computer monitor across the ten trials as the dependent variable for experiment 2c*

Source	SS	df	MS	ET	F	0.05	0.01	
Lens @ Head R	10.18	4	2.54	37.79	0.07	2.37	3.32	(df 4,inf)
Lens @ Head F	2265.04	4	566.26	37.79	14.98*	2.37	3.32	(df 4,inf)
Head @ Lens -0.50	27.23	1	27.23	37.79	0.72	3.84	6.63	(df 1,inf)
Head @ Lens +0.50	430.42	1	430.42	37.79	11.39*	3.84	6.63	(df 1,inf)
Head @ Lens 0.00	139.11	1	139.11	37.79	3.68	3.84	6.63	(df 1,inf)
Head @ Lens -1.00	3.18	1	3.18	37.79	0.08	3.84	6.63	(df 1,inf)
Head @ Lens +1.00	1509.14	1	1509.14	37.79	39.93*	3.84	6.63	(df 1,inf)

*Significant at p=0.01 or less; R, fixed on chin rest; or F, free to move

Table 75. *Tukey HSD follow-up for the effect of additional masked lens (arranged by size of means) when the head was on chin rest on the average distance of the head from the computer monitor across the ten trials as the dependent variable for experiment 2c*

Lens (D; mean of average distance)	-0.50	0.00	-1.00	+0.50	+1.00
-0.50 (58.61)		0.16	0.19	0.56	0.61
0.00 (58.45)			0.03	0.40	0.45
-1.00 (58.42)				0.37	0.42
+0.50 (58.05)					0.05
+1.00 (58.00)					

*Critical HSD (0.05, k=5, df=35) = 4.17 (any difference exceeding this value is significant at 0.05)

**Critical HSD (0.01, k=5, df=35) = 5.11 (any difference exceeding this value is significant at 0.01)

Table 76. *Tukey HSD follow-up for the effect of additional masked lens (arranged by size of means) when the head was free to move on the average distance of the head from the computer monitor across the ten trials as the dependent variable for experiment 2c*

Lens (D; mean of average distance)	-1.00	-0.50	0.00	+0.50	+1.00
-1.00 (58.84)		1.46	3.17	5.68**	10.00**
-0.50 (57.38)			1.71	4.22*	8.54**
0.00 (55.67)				2.51	6.83**
+0.50 (53.16)					4.32*
+1.00 (48.84)					

*Critical HSD (0.05, k=5, df=35) = 4.17 (any difference exceeding this value is significant at 0.05)
**Critical HSD (0.01, k=5, df=35) = 5.11 (any difference exceeding this value is significant at 0.01)

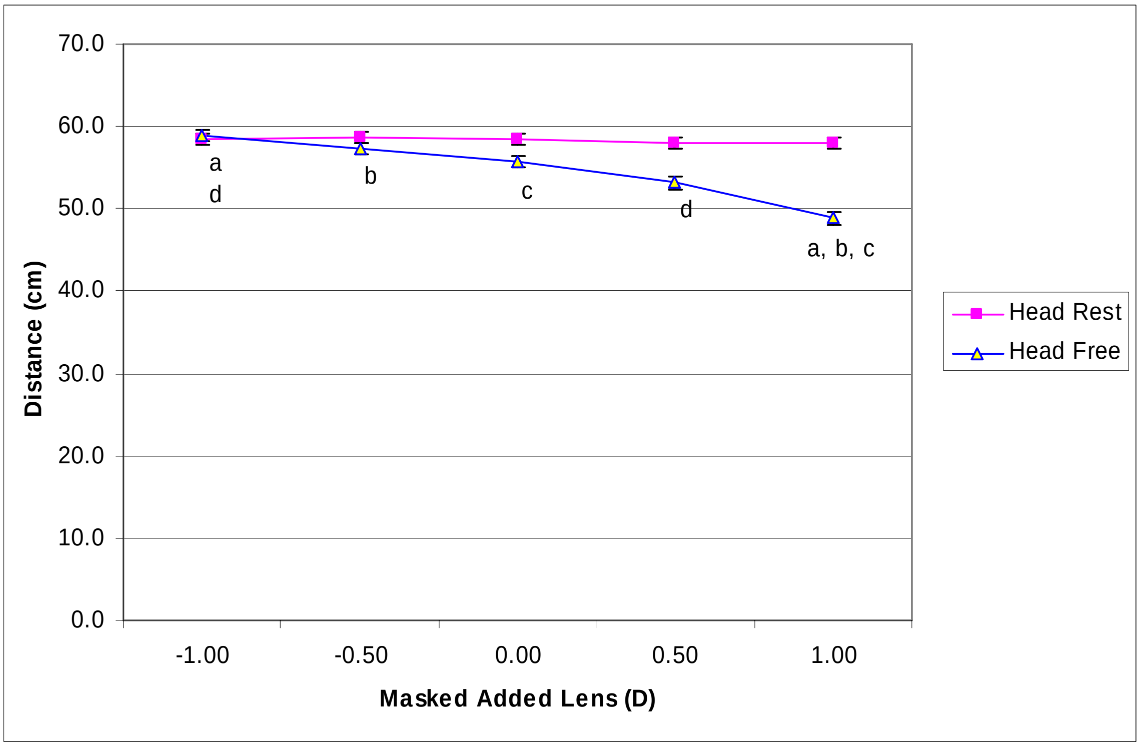

Figure 8. Graph of mean distance of head from computer monitor (cm) over the ten trials as a function of the masked additional lens. Error bars indicate standard error of the mean. Tukey HSD test confirmed differences for points marked with letters.

Musculoskeletal Symptom Index

During the experimental protocol, 396 surveys of musculoskeletal comfort while working in-office were completed on the 36 subjects. The mean musculoskeletal symptom index (100, Most Comfortable; 0, Least Comfortable) for the entire group was 3.51 (median, 4.00; Quartile 1, 3.00; Quartile 3, 4.00; Minimum, 1.0; Maximum 5.0). There was evidence to support a hypothesis that the symptom index distribution was not normally distributed (Anderson-Darling value, 17.972, p value <0.005, n=396). Non-parametric analysis was subsequently used to assess the musculoskeletal symptom index in view of the non-normal distribution of the data. Figure 9 displays the in-office musculoskeletal symptom index distribution.

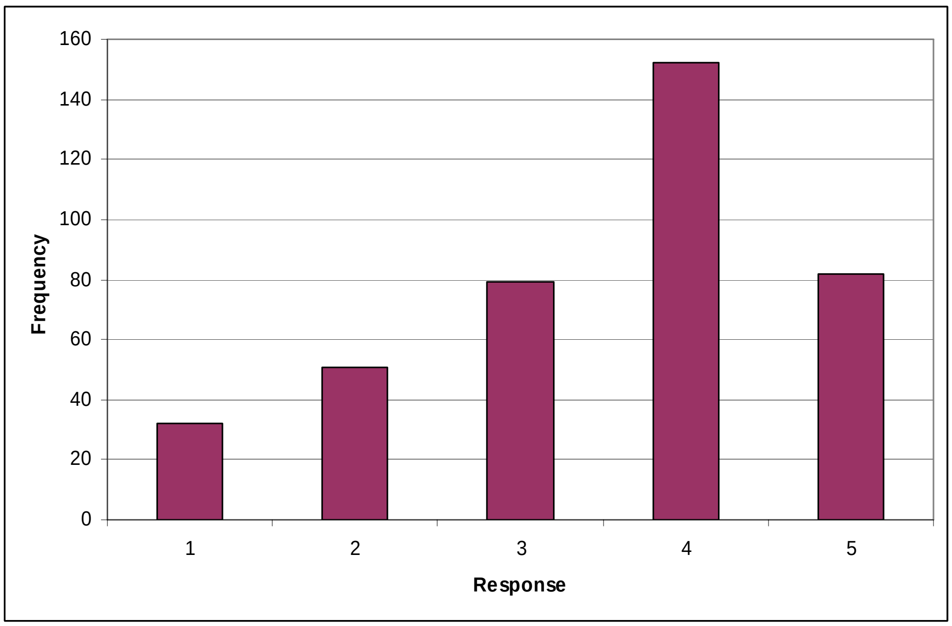

Figure 9. Frequency histogram of in-office musculoskeletal symptom index (Response, 1, least comfortable; 5, most comfortable; n=396)

The median musculoskeletal symptom index before any activity was 4.0 (mean 3.97). Kruskal-Wallis non-parametric analysis did not support a hypothesis of a difference in symptom score as a function of amount of time worked (H=14.18, df=10, n=396, p=NS). Figure 10 displays a plot of the mean musculoskeletal symptom index as a function of the experimental trial (i.e., time worked). The consistent decline in the musculoskeletal symptom index suggested that the lack of statistical relationship with work duration may be a result of an inadequate sample size. Over the work period of 2.5 hrs, the mean musculoskeletal symptom index declined by 14.0% (3.97 to 3.42).

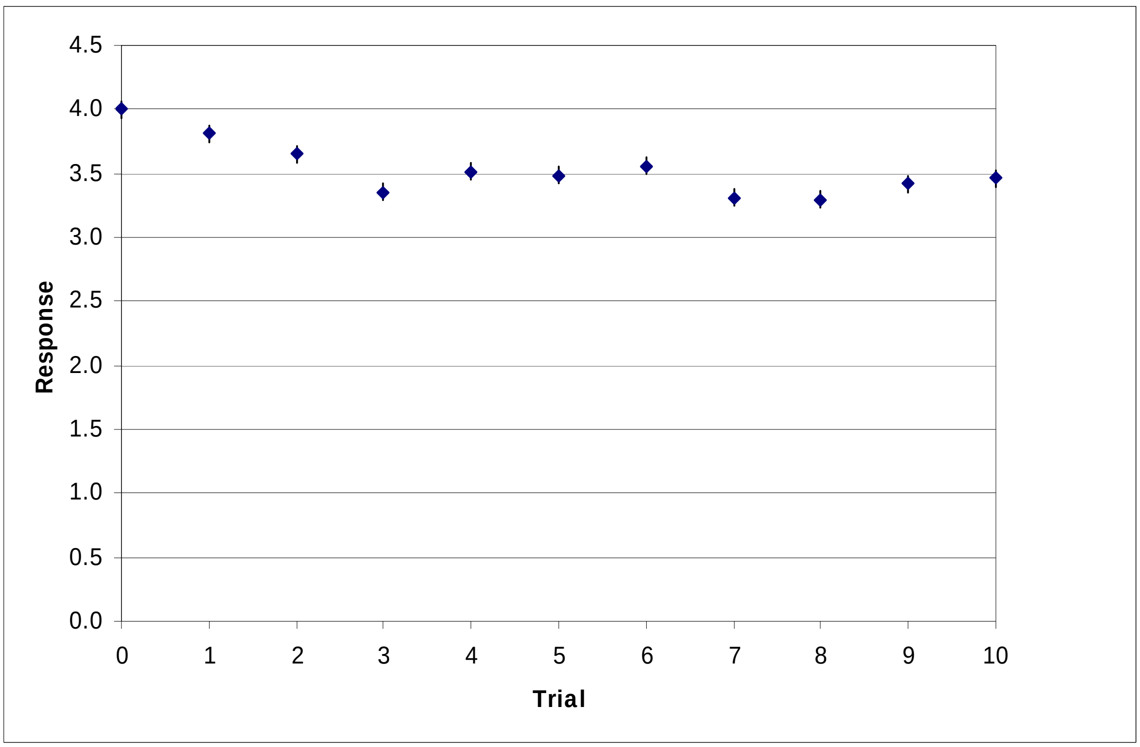

Figure 10. Plot of mean musculoskeletal symptom index as a function of trial i.e., time worked (n=396 total, 36 in each box). Error bars indicate standard error of the mean.

A plot of the musculoskeletal index demonstrated that the mean musculoskeletal index was lower (mean index = 2.9) for the case when the subjects completed the editing task with the +1.0D additional lens and the head free to move (Figure 11). The mean index for other lenses and head positions was within 0.2 from the average of 3.5. This change was in the hypothesized direction.

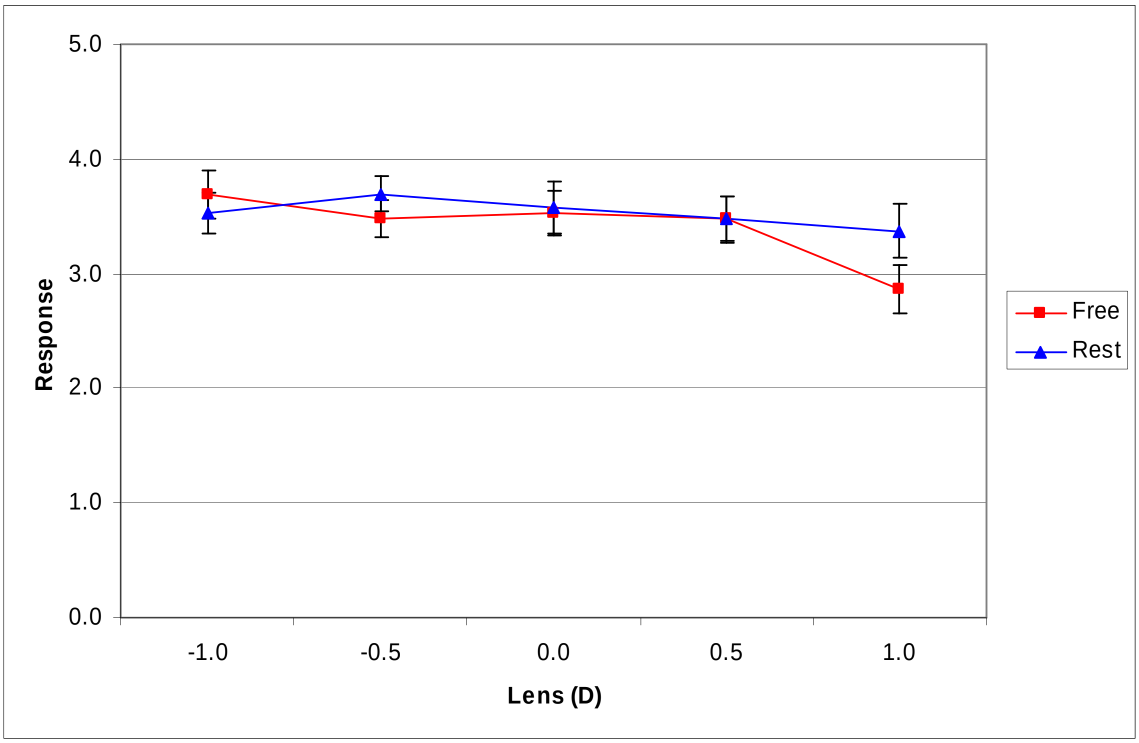

Figure 11. Mean musculoskeletal index (response) as a function of head position and change in lens addition. Error bars indicate standard error of the mean.

Discussion

The conditions under which the experiment was conducted approximate those found in many office environments. None of the subjects remarked about the conditions and, accordingly, the conditions seemed appropriate for the experiment.

The comparison of the excluded subjects versus the included subjects suggested the extent that the results may be generalized. The excluded subjects were similar in terms of age and gender to the subjects included into the study. The protocol design prevented any assessment of potential refractive error differences between included vs. excluded subjects. Overall, this evidence suggested that the subjects included in the study likely represented the population from which they were selected. The results should be applied to other populations with an appropriate degree of caution.

Table 35 provided data regarding the adequacy of the subjects' habitual refractive corrections. A comparison of the habitual vs. the best correction of the subjects demonstrated that the habitual correction spherical component (M) was 0.21D less minus than that of their best correction spherical component. The habitual astigmatic components, 180/90 (J0) and 45/135 (J45) were similar in the habitual vs. the best correction. The overall refractive errors (Best vs. habitual; VD) indicated a mean error of about 0.55D for their distance refractive corrections.

This suggested only a slight deficit in distance visual acuity of about 1 to 2 lines (Raasch, 1995). The subjects' habitual refractive condition for near indicated that their habitual add was about 0.89D too low for reading at 40 cm and 0.38D too low for reading at a distance of 50 cm. The design of the lenses in this protocol utilized full field trial lenses and therefore provided a single vision lens similar to reading corrections.

Accordingly, the design of these lenses did not require any movements for the subjects except fore and aft to achieve clarity of vision for the monitor. When the overall combination of correction and add was considered, the subjects were habitually, on average, about 1.00D out of focus for a distance of 40 cm. and were 0.83D out of focus for the 50 cm. distance of the computer in this protocol.

The range of refractive errors in the protocol therefore appeared to represent those errors demonstrated in the subjects' habitual corrections. The protocol did not take into account potential issues with the design of the eyewear that could require the alteration of head position and angle to clearly see the monitor. These factors should be considered in future work.

As in many office environments, there was a substantially greater representation of females than males (83.3% female) in the group of subjects. Otherwise, the group appeared to represent a relatively older group of self-employed and office workers. The subjects estimated that they spent an average of 4.5 hrs/day using the computer. This suggested that they were heavy users of computers. An examination of their self-reported computer tasks suggested that they were primarily involved in general office work since they ranked 'E-mail Use' as the most common task (median rank 1.0), followed by 'Word Processing', 'Internet Use' 'Spreadsheet' and Data Entry' (median ranks 3.0). Relatively specialized uses such as 'Proofreading' (median rank 4.0), and 'Other' (median rank 7.0) were ranked lower.

The self-reported visual conditions of the subjects suggested that focusing problems (38.9%) were the most common visual complaint that may have related to the uncorrected refractive error although other etiologies may also have explained the results.

A substantial proportion of subjects noted glare problems (22.2%) and dry eye syndrome (19.4%). Extended work on a computer likely exacerbated these problems and the subjects' mean age of 50 yrs may also have contributed to the issue of dry eye. A number of the subjects (13.9%) reported ergonomic problems with the computer they most commonly used. Glare or poor lighting was reported by 13.9% and the remainders of the ergonomic issues were well-spread between desk (8.3%), chair (16.7%), monitor (8.3%), keyboard (8.3%), mouse (5.6%), and other (2.8). The report of glare in the ergonomic survey was less than glare reported in the self-reported visual conditions survey. Taken together, these self-reported problems confirmed the relatively poor habitual refractive status of these subjects. Overall, the subjects appeared to be functioning in a relatively appropriate ergonomic environment as self perceived. Since a comparison group was not assessed, the relative significance of this prevalence's remains unclear.

All subjects accepted into the study completed the protocol in all aspects. All of the thirty-six subjects completed the apostrophe editing task under ten different conditions. There was no loss to follow-up since the entire experiment was completed in a single session. The subjects worked a total of 2.5 hours on the apostrophe editing task. This was divided into ten trials with each trial a 15-minute session per lens addition.

Overall, the subjects appeared to be only relatively comfortable while working in the experiment with different lens adds, since the mean symptom index was 73.1 (median, 77.8). For example, the mean phone visual comfort index for the group in experiment 1 was 83.2. The in-office, monitored mean visual symptom index appeared to be similar to that in experiment 1, 78.3, although the task may have been somewhat more challenging (possibly primarily due to a longer experimental time, generally 2.5 hrs vs. 1.5 to 2 hrs) leading to the somewhat lower symptom index (6.6% lower).

Before the initiation of the 2.5 hr study protocol, the subjects reported themselves to be very comfortable (median symptom index, 87.8). Over the work period of 2.5 hours, the subjects reported increased visual symptoms and became less comfortable. The median value of the symptom index declined by 19.0% over the 2.5 hr work period (from 87.8 to 71.1, p=0.001). Visual comfort appeared to undergo a relatively steady decline as a function of working time. This decline in visual comfort probably was related to the use of the randomized, incorrect lens additions (most of the time) being worn for short periods such that adaptation to the poor correction was minimized or absent. Slight or no movement of the head and the resulting failure to obtain the clearest image was evidence that suggested minimal adaptation for many of the subjects. Future work may examine the time course of such adaptations to lens additions.

An assessment of individual symptoms vs. time worked suggested that ‘clearness’ was the most strongly related symptom (p=0.0001), followed by ‘blur/double vision’ and ‘limitations’ (p=0.001). Symptoms such as ‘problems with eyes’ (p=0.01), and ‘losing place’ (p=0.003) were also related to time worked. Symptoms such as ‘headache’, ‘lighting’, ‘hurts’/water/burns /itching’ and ‘frustration’ did not differ as a function of work time. The symptoms subjectively related to vision appeared to change as a function of the time spent working. Those symptoms less directly related to vision did not appear to change as a function of work time.

Overall, visual comfort decreased from 87.8 to 73.1 during the work time. The specificity of the visual symptoms related to work time suggested the possibility of a more focused survey instrument for visual symptoms and work of this nature. For this to be appropriate, similar data concerning the relationship of individual symptoms to optical blur should occur. The lack of relation of some symptoms to work time could be due to the short time of working (15 minutes) on the computer task with each correction.

Overall, the subjects reported a significant difference in the visual comfort index during the 2.5 hrs total working time on the computer as a function of head position (head free or fixed). The modest overall head movement during the study may been a result of subjects not having been aware of the potential benefits of altering their head position to obtain clear imagery, particularly given the short 15-minute time of each trial.

Experiment 2b used the ANOVA block factorial design analysis to determine the effect of lens, head, and lens and head interaction (independent variables) for the VCI, TCW, and CCW (dependent variables). The data suggested that there was a significant effect of lens and head interaction for VCI ($p = 0.0049$).

An examination of the VCI during the work period using different additions suggested that the subjects who completed the editing task with +1.00D were less comfortable than when they worked with other adds (-1.00, 0.00,+/-0.50) whether their head was on the chin rest (mean = 55.14; $p = < 0.0001$) or the head was free to move (mean = 63.24; $p = < 0.0001$). Subjects with excessive plus lens additions using the chin rest saw blurred imagery and were without recourse to alter it. This likely resulted in decreased visual comfort. On the other hand, subjects who worked with excessive plus lens additions when their head was free to move did not generally prefer to move closer to the monitor than the starting position used in the experiment (50 cm). Under these conditions with only 15 minutes of work subjects may not have recognized that moving closer would have provided increased clarity and presumed greater comfort.

For the editing task, the TCW was relatively high when the subject worked with their head free to move with a mean of 3532.7 correct words edited per 15 minutes of work compared to when their head was positioned on the chin rest with a mean of 3311.0 correct words edited per 15 minutes of work. Evidence suggested that the subjects were able to alter their head position to clear the image on the computer monitor and also were adapted to the task with different adds.

The data did confirm our hypothesis of a significant relationship between the CCW (i.e., productivity) and the lens and head interaction either with all of the data together or with the head free or head fixed conditions analyzed separately. Substantial evidence identified the effect of lens and head interaction on the CCW. The data displayed a significant effect toward reduced comfort and productivity with a +1.00D lens addition compared to the other adds (-1.00, 0.00, +/-0.50) when the head was on the chin rest (mean = 1692.3). This may be a result of the increased optical blur associated with the +1D lens addition at an inappropriate viewing distance for that lens addition.

An effect of the head position (head free to move) on CCW showed a trend toward lesser comfort and productivity with the +1.00D lens than with other adds (-1.00, 0.00, +/-0.50; mean = 2345.3). This may be a result of the greater viewing distance from the material on the computer monitor with strong adds. Subjects apparently did not realize that moving closer to the computer monitor may have improved clarity and produced greater comfort.

The subjects produced more work with +1.00D at the computer distance of 50 cm when their head was free to move than when their head was on the chin rest. This may be due to their adaptation to the computer task over the 15-min work period and the short experience of moving closer to the monitor to create greater clarity of the image. We speculate that if the subjects realized the effect of moving closer to the monitor, the magnitude of work would increase and the visual comfort would improve but the physical comfort would reduce.

The musculoskeletal symptom survey question suggested a relatively sharp decrease in comfort for the +1.0D additional test lens in the head free condition. This was probably a function of the head forward position necessarily adopted to see the monitor clearly for this lens. For all other differences in test lens addition, little change in the musculoskeletal symptom index appeared to occur. The musculoskeletal symptom index did not significantly change as a function of time worked although a plot of the mean musculoskeletal symptom index as a function of time demonstrated a consistent reduction in musculoskeletal comfort. The lack of significance of the change may have related to the relatively small sample size and the relatively short work time.

When the subjects used a chin rest, head position was stable. Differences in the overall distance of the head from the monitor occurred because of differences in the height of the subject independent of the position of the trial frame. These changes in distance were relatively small but did affect the baseline for each subject. No evidence suggested a change in head position with time for subjects using the chin rest i.e., subjects using the chin rest maintained a stable position.

Evidence supported a change in head position as a function of the test lens addition when the head was free. The changes in head position, however, were modest with only a difference of 4.9 cm in position in going from the -1.0D additional test lens to the +0.50D additional test lens and 9.2 cm in going from the -1.0, -0.5 and plano lenses to the +1.0D additional test lens. The change in head position represented a dioptric change of about 0.33D for the 2D change in the additional lenses and represented a change in head position of only 16.5% of the total dioptric change.

In experiment 2c, ANOVA used the block factorial design to examine the effects of lens adds and head position on the distance (the beginning, ending or the mean distance) of the head from the computer monitor across the ten trials with 15-min per trial. The data provided a significant effect of the head position (on chin rest or free to move) on the distance of the head from the computer at the beginning of the trials ($p<0.0001$). Likewise, the head and lens interaction had a significant effect on the distance of the head from the computer at the end of the ten trials ($p = 0.0021$) as well as on the average distance across the ten trials ($p < 0.0001$).

The analysis identified a mean difference in the distance of the head position from the computer monitor at the starting point as 1.3 cm (2.3% closer when the head was free to move). This small difference in the start distance could be due to the inability of the subjects of keeping their head still at the starting point and also due to the differences in the height of the subject.

The analysis demonstrated that with the minus and plano lens adds when the head was free to move the subjects' head distance at the end of the 15-min trial period was within a cm of the same distance from the computer monitor when the head was fixed on the chin rest. On the other hand, with the plus lens adds and the head free to move, the subjects moved their head by a distance of 5.9 and 10.3 cm closer to the computer. This closer distance may be related to clarifying the image. Due to the excessive strength of the adds this change caused greater distance magnification of the material with the closer viewing distance.

The analysis demonstrated also that the average distance of the head from the computer across the ten trials was significantly closer to the monitor for both the +0.5 (4.9 cm) compare to -1.0 add and +1.0D (9.2 cm) compare to -1.0, -0.5 and plano adds. This suggested a relationship between the RE and the distance of the monitor.
The data identified a trend for the difference in the average distance between the adds +0.50D and -0.50D as well as the +1.00D and +0.50D. This may be a result of the increased optical blur associated with the lens addition at an inappropriate viewing distance for that lens addition.

Summary

Under the conditions of this experiment, the subjects estimated that they spent a mean of 4.5 hrs/day on the computer. The data demonstrated that ‘E-mail’ was the most common task (median rank 1.0) followed by ‘Data Entry,’ ‘Word Processing,’ ‘Internet Use’ and ‘Spreadsheet’ (median ranks 3.0), ‘Proofreading’ (median rank 4.0) and ‘Other’ (median rank 7.0). Focusing problem was the most common visual problem reported by the subjects(38.9%); followed by glare problems (22.2%); dry eye syndrome (19.4%) and binocular problem (13.9%). There was a significant correlation between focusing problems and binocular problems (p=0.002) as well as a correlation between binocular problems and glare (p=0.029). 25% of subjects reported a total of 23 ergonomic problem areas. The analysis suggested that these ergonomic problems were significantly correlated with each other. We conclude that the lens adds and the text editing task in this experiment was sufficient to decrease visual comfort by 19.0% over 2.5 hrs of work. This decrease was probably a function of the poor refractive conditions combined with the demands of the task. Also there was a significant effect of order as a function of time on the TCW and was trend for the CCW. During the period of working time, TCW and CCW increased by 36.4% (means, 2849 to 3834) and 25.9% (2349 to 2957), respectively. For the effect of lens and head (lens*head) interaction, the analysis suggested a significant effect of the lens*head interaction on the VCI and CCW (p=0.0049, 0.0088). There was also a main effect of head position on TCW (p=0.0069). Under the condition of head on the chin rest, subjects reported less VCI when they worked with the add of +1.0D compared to other adds of (-1.00, 0.00,+/-0.50; mean=55.14; p=<0.0001). Under the condition of head free to move subjects were less comfortable when they worked with the add of +1.0D than when they worked with other adds of (0.00, +/-0.50 (mean = 63.24; p = <0.0001).

For the productivity, the data identified a main effect of head position on the magnitude of work (TCW). The subjects produced more work when they worked and their head was free to move than when their head was on the chin rest (p=<0.0069; mean TCW = 3532.7, 3311.0, respectively). The data also demonstrated a significant effect of lens and head (lens* head) interaction on the CCW. With the +1D additional lens over their best computer distance correction, these demonstrated that the subjects were significantly more comfortable and more productive when they worked on the editing task with their head free to move than when their head was positioned on the chin rest($p<0.01$),(mean CCW =2345.33,1692.28)

These data also indicated that many patients were at their workstations with significantly less than optimal refractive correction and that they were, on average, almost 0.83D different from what the best correction indicated for the monitor distance of 50 cm used in this protocol. These data suggested that a more focused survey instrument for symptoms on a computer monitor may be possible to develop since a portion of the symptoms did not correlate with the outcome.

An examination of lens and head interaction on the distance from the computer monitor at the beginning, ending and the average distance across the ten trials. The analysis identified a main effect for head position on the distance of the head from the computer monitor at the beginning of the trials ($p<0.0001$). Also, there was a significant effects of a lens*head interaction on the distance of the head from the computer monitor at the end of the trials ($p=0.0021$). Similar effect was identified for the mean distance of the head from the computer monitor ($p<0.0001$). At the end of each of the ten trials when head was free to move, the head moved 5.9 and 10.3 cm closer to the computer with the +0.5 and +1.0D additional lenses. The analysis demonstrated a significant effect of the lens*head interaction on the mean distance of the head from the computer monitor for the ten trials. The mean distance of the head moved significantly closer to the monitor for both the +0.5 (4.9 cm; vs. -1.0) and +1.0D (9.2 cm; vs. -1.0, -0.5 and plano) additional lenses

An examination of the musculoskeletal index suggested a trend toward lens additions affecting this index when the +1.0D lens was used in the head free position (decreased comfort). Over the work period of 2.5 hrs, the mean musculoskeletal symptom index declined by 14.0%. The occurred even though analysis of changes in viewing distance as a function of the lens addition amounted to only about a 10 cm change. Small differences in head posture may have made a larger than expected difference in musculoskeletal comfort. And, the symptoms may be in opposite directions e.g., improved visual comfort but decreased musculoskeletal comfort.

Over all, the study provided clear evidence that alterations in the lens addition affected the productivity and visual comfort of the subjects. Also, evidence confirmed that the lens addition affected head position. Over extended periods of work, both suggested that productivity may decline as a function of decreased comfort. Inappropriate correction of refractive power necessary for viewing a computer monitor at 50 cm. by a minimum of +/- 0.50 D may significantly increase visual symptoms while decreasing performance and productivity.

CHAPTER 4

CONCLUSION

CURRENT STATE OF THE FIELD

Overview

The research presented herein demonstrates that the best refractive correction increased visual comfort during computer work, and may have an effect on the productivity. It does not show conclusively that visual comfort increases productivity, nor does it give a clear indication of what type of intervention (visual or ergonomic) results in what specific musculoskeletal benefits for computer workers. More and tightly-focused studies are needed to more comprehensively answer these questions.

Computer workers may not be aware that the best refractive correction is more comfortable than an incorrect habitual correction. Unfortunately, optometrists may not inquire into how much their patients use computers before prescribing them a correction that, though suitable for habitual viewing, may be inappropriate for viewing while doing computer work, especially if prolonged and detailed.

Strengths and Weaknesses of the Studies

Study 1

Strengths. This study was significant because the potential effect of optical blur on the visual performance and comfort of computer workers has not been well examined in quasi- and actual workplace settings. The results of this study indicated that optimizing the visual correction of computer workers for computer work significantly improved their performance in terms of accuracy and volume of work. This suggests that the best refractive correction for computer workers could produce gains that would be greater than any investments an employer might make to provide its computer workers with such correction.

The results of this study and subsequent studies of its kind may change the ways in which optometrists prescribe corrections, encouraging them to collect information about the nature of their patients' work and work environments in order to ascertain whether, instead of having a single habitual correction, they might not get more benefit from having a set of corrections; one for habitual viewing and another for best viewing during computer work.

Weaknesses. The study's sample size was small, sufficient to suggest directions for additional investigation, but not sufficient to reveal undisclosed conditions a larger subject population would, likely, yield. The funding necessary to complete such a study would be a challenge to obtain.

Although the two week period for adaptation used in this experiment was standard for adaptation, it may not have been long enough. A period of adaptation of longer than two weeks is recommended before subjects begin study tasks with either best or habitual correction, and at the end of the study (with best correction). This would allow adaptation to the correction and might minimize the chance that changes in symptoms or performance were due to correction variables. Additionally, the study tasks should be as long as possible in duration so they resemble real-world working conditions as closely as possible.

In addition, a technical oversight in this study resulted in sequencing errors. Table row numbers were omitted from the printout of the task sheet subjects were given to refer to, and some subjects entered correct data from the printout to the wrong row on the computer monitor.

After completing the apostrophe editing task, many subjects expressed a desire for the task to be more interesting, or more related to their own daily work. Their lack of interest in the content of the task could have had an impact on results and merits considering altering the design of future studies to include parameters which permit analysis to differentiate between symptoms or performance variables that are a result of visual correction, versus any that may be a result of inattention or boredom.

Study 2

Strengths. This study was significant because no study has described the effects on visual performance of altering the magnitude of near plus additions *combined* with the head being in a fixed or mobile. The absence in the field of such description has left optometrists without reference in their prescriptive tasks.

This study also suggested that a common strategy of employing prescribed corrective lenses for most purposes, but employing off-the-shelf “readers” when working at their computer is likely inappropriate since the refractive error may be substantial in such situations.

Weaknesses. As with Study 1, this study’s subject population was small and a larger sample may have provided more conclusive results. Also, in order for the study task to more resemble real-world working conditions, the duration of the task should be longer than 15 minutes.

Summary

Study 1 Results Summary

The most commonly reported visual problems related to glare and focusing issues. The most commonly reported ergonomic problem related to poor lighting. The data support the hypothesis that visual comfort with best correction increases productivity.

In the apostrophe editing task, there was a relationship between total correct work and number of eyes with VDD of 0.50D or more. Even though the subjects were not interested in the task, the accuracy and magnitude of work was generally high. On the other hand, as described above, the accuracy and magnitude of the population data entry task was affected by sequencing errors.

There was a significant relationship between performance and optical blur. There was a correlation between the number of eyes with refractive error of 0.50 VD or greater and the phone visual comfort index after each period.

Subjects were more comfortable in their quality of life during their working time with best correction than with habitual correction, and their visual comfort was significantly improved after three months of wearing the best correction.

Study 2 Results Summary

On the apostrophe editing task, visual comfort decreased by 19.0% over 2.5 hrs of work. This could be a result of poor refractive correction alone, or *that* combined with the subject's disinterest in the content of the task. Future study designs may be able to differentiate between which factor is causing such outcomes.

When the +1.0D lens was used in working on the AE task with the head free position, visual and musculoskeletal comfort decreased. However, this should not to be construed to mean the lens addition, by itself, caused discomfort. Small differences in head position may have improved visual comfort, but only at the expense of larger than expected musculoskeletal comfort.

The foregoing suggests that, over extended periods of time doing computer work, productivity may decline as a function of decreased comfort the computer worker is not aware he or she is experiencing.

Overall, this study suggested that viewing a computer monitor over extended periods of time at a distance of 50 cm. using inappropriate refractive correction as small as +/- 0.50D significantly increased visual symptoms and decreased performance and productivity.

Challenges of Future Studies

The primary challenge of future investigations into the effects appropriate vision correction has on the comfort and productivity of computer workers is to acquire a large and varied enough subject base with which to conduct studies.

The secondary challenge is to design studies in a way that permits analysis to provide cost-benefit metrics to employers.

The tertiary challenge is to design studies in a way which interests subjects to a degree commensurate with their real-world work.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL OF STUDY ONE AND TWO

THE UNIVERSITY OF
ALABAMA AT BIRMINGHAM

Institutional Review Board for Human Use

Form 4: IRB Approval Form
Identification and Certification of Research
Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office for Human Research Protections (OHRP). The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56 and ICH GCP Guidelines. The Assurance became effective on November 24, 2003 and expires on February 14, 2009. The Assurance number is FWA00005960.

Principal Investigator:	DAUM, KENT M
Co-Investigator(s):	
Protocol Number:	**X050208014**
Protocol Title:	*Effects of Optical Blur on Visual Performance and Comfort of Computer Users*

The IRB reviewed and approved the above named project on 04-21-06. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received EXPEDITED review.

IRB Approval Date: 4-21-06

Date IRB Approval Issued: 04-21-06

HIPAA Waiver Approved?: No

Marilyn Doss

Marilyn Doss, M.A.
Vice Chair of the Institutional Review
Board for Human Use (IRB)

Investigators please note:

The IRB approved consent form used in the study must contain the IRB approval date and expiration date.

IRB approval is given for one year unless otherwise noted. For projects subject to annual review research activities may not continue past the one year anniversary of the IRB approval date.

Any modifications in the study methodology, protocol and/or consent form must be submitted for review and approval to the IRB prior to implementation.

Adverse Events and/or unanticipated risks to subjects or others at UAB or other participating institutions must be reported promptly to the IRB.

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THE UNIVERSITY OF
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Institutional Review Board for Human Use

Form 4: IRB Approval Form
Identification and Certification of Research
Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office of Human Research Protections (OHRP). The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56 and ICH GCP Guidelines. The Assurance became effective on November 24, 2003 and the approval period is for three years. The Assurance number is FWA00005960.

Principal Investigator:	DAUM, KENT M
Co-Investigator(s):	
Protocol Number:	**X050314015**
Protocol Title:	*Effects of Different Add Powers on the Comfort and Productivity of Computer Users with Fixed or Free Head Movement*

The IRB reviewed and approved the above named project on 05-24-05. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received EXPEDITED review.

IRB Approval Date: 5/24/05

Date IRB Approval Issued: 05-24-05

HIPAA Waiver Approved?: N/A

Marilyn Doss

Marilyn Doss, M.A.
Vice Chair of the Institutional Review Board for Human Use (IRB)

Investigators please note:

The IRB approved consent form used in the study must contain the IRB approval date and expiration date.

IRB approval is given for one year unless otherwise noted. For projects subject to annual review research activities may not continue past the one year anniversary of the IRB approval date.

Any modifications in the study methodology, protocol and/or consent form must be submitted for review and approval to the IRB prior to implementation.

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APPENDIX B

STUDY ELIGIBILITY EXAMINATION FORM

EFFECTS OF OPTICAL BLUR ON VISUAL PERFORMANCE AND COMFORT OF COMPUTER USERS
Study Eligibility Examination

Ferial M. Zeried, B.S., M..S.
Kent M. Daum, O.D., Ph.D.

Revised August 24, 2005

Instructions

The purpose of this form is to determine the eligibility of volunteers for the study. Questions 1-8 can be completed as a telephone screening before completing informed consent. Before completing the remainder of this exam (#9 and following), the volunteer should complete the informed consent process. After that process is completed, complete the following data for your patient by circling the correct response or filling in the blanks.

If any of the responses to items 1-8 below are 'No', the volunteer does not qualify and should be dismissed immediately. Items 16 and 17 should only be completed for individuals qualifying for the study.

Name___________________ **Birth date** _____/_____/_____ **Sex** M F

Date____________________ **Race** _________

1. Age. Is the volunteer 19 to 35 yrs of age? **Yes** **No**

2. Computer Use. Does the volunteer use a computer at least one hour per day on a typical day? **Yes** **No**

    a. Estimated number of hours of use of a computer on a typical work day? ____ hrs

3. Time for the Experiment. Is the volunteer willing and able to spend a total of 8-hrs (4-hrs during the last 2 weeks of each month period) completing the experiment for the 8-week period of the study? (Volunteers will be paid for their time.) **Yes** **No**

4. Brief telephone survey at work while using computer. Is the subject willing to allow two brief (5 minutes or less) telephone surveys of their visual comfort while at home or at work during the 8-week intervention period of the study? (Volunteers will be paid for their time.) **Yes** **No**

5. Brief telephone survey after the experimental period. Is the subject willing to allow three brief telephone surveys of their visual comfort while at home or at

work three months after the study intervention? (Volunteers will be paid for their time.) **Yes** **No**

6. Contact Lens Wear. If the volunteer is a contact lens wearer, is the volunteer willing to wear spectacles while at work during the 8 week period of the study? **Yes** **No**

7. Contact Lens Wear. If the volunteer wears RGP lenses, is the volunteer willing to discontinue wear for 2 weeks prior to refractive assessment and forego their use during the study? **Yes** **No**

8. Stable dosing regimen. If the volunteer is taking medication for any chronic condition (e.g., dry eye, antihistamines, anticholinergics, psychotropics), do they expect the dosing regimen to be stable over the period of the study? **Yes** **No**

9. Visual acuity, habitual (20/40 or better at distance and near to qualify)

   a. Snellen, 6M Right 20/_____ Left 20/_____
   b. M type, 40 cm Right ___/____ Left ___/____

10. Auto-refractor (attach tape to form)

11. PD (Distance/near) ___/___

12. Refraction, manifest, non-cycloplegic

Eye	Sphere	Cylinder	Axis
Right			
Left			

13. Lensometry, habitual correction.

Eye	Sphere	Cylinder	Axis
Right			
Left			

14. Enter data from #7 and 8 into Excel spread sheet (VDD, 0.50D or more in at least one eye to qualify). VDD? _____VDD

15. Qualification? Yes No

16. Computer Use. Check the type of computer use of the subject. Rank them in order of importance if more than one (1=most frequent).

    a. Data entry
    b. Word processing
    c. Email
    d. Internet
    e. Spreadsheet
    f. Proofreading
    g. Other

17. Other conditions. Is the volunteer aware of any of the following conditions?

    a. Dry eye syndrome or symptoms? Yes No
    b. Focusing problems? Yes No
    c. Binocular vision problems? Yes No
    d. Glare when using their computer? Yes No
    e. Ergonomic problems? (chair, desk, monitor, keyboard, mouse, lighting, etc.) Yes No

       If so, check those that apply:
       1. Desk
       2. Chair
       3. Monitor
       4. Keyboard
       5. Mouse
       6. Lighting (glare)
       7. Other

APPENDIX C

DESCRIPTION OF THE PILOT STUDY RESULTS FOR STUDY ONE

Study 1: Effect of Optical Blur on Productivity and Comfort of Computer Users

Pilot Study

Overview

The pilot study included five subjects meeting the criteria of the protocol and was designed to allow the modification of the protocol of the study to examine the performance of subjects in two conditions; corrected (best) and uncorrected (habitual) lenses.

All subjects completed the experiment with two different prescriptions, sequentially placed in a new frame. One prescription was designed to fully correct their RE (the best correction). Another pair was designed to be identical with their habitual correction, (the RE condition). The examiners were not masked as to the identity of the correction being worn by the subjects.

After adaptation for one week, subjects were randomly assigned to one of the two RE groups (either habitual or best correction lenses) for the first period. After completing the pilot study for that period, their lenses were replaced with the other pair and the subject completed the identical pilot study during the second period of the study. The only difference for the subjects in the two periods was the pair of lenses they were wearing.

The tasks used in the study were the population data entry task and the apostrophe editing task. The pilot study for each period lasted for two weeks. At the beginning of the study and after each work session, subjects completed visual comfort surveys. These were in addition to phone visual comfort surveys taken during their work in their office.

At the end of each two week long period of the experiment, subjects completed the Survey of Quality of Life (NEI Refractive Error Quality of Life).

Results

Five volunteer subjects (2 male, 3 female; mean age 26.8 yrs, std dev 4.4, range 23 to 33 yrs) participated in the pilot study. Their habitual corrections, best corrections and vector dioptric difference are presented in Table 77. The mean vector dioptric difference for the ten eyes was 0.36D (std dev, 0.10; range 0.25 to 0.50D). The mean vector dioptric errors were small and only one subject (#3) would have qualified for the study.

Table 77. *Characteristics of subjects in the pilot study for experiment one*

Subject	Sex	Age	Habitual Correction	Best Correction)	Vector Dioptric Difference
			(Right, Left, sphere, cylinder and axis)	(Right, Left, sphere, cylinder and axis)	(Right, Left, Mean, VD)
1	M	33	-1.50 -0.75 x 090	-1.25 -1.00 x 085	0.19
			-0.50 -1.25 x 094	-0.75 -1.25 x 075	0.48
					0.33
2	F	24	-0.25 -0.50 x 092	-0.50DS	0.25
			pl -0.50 x 102	-0.50 -0.25 x 088	0.40
					0.33
3	F	23	+4.25 -1.00 x 141	+3.75 -1.00 x 140	0.50
			+6.00 -1.25 x 035	+5.50 -0.75 x 040	0.36
					0.43
4	F	30	-4.00 -0.50 x 175	-4.25 -0.50 x 165	0.26
			-2.50 -0.50 x 161	-2.75 -0.75 x 155	0.40
					0.33
5	M	24	-2.75 -0.50 x 180	-3.25DS	0.35
			-3.00 -0.50 x 180	-3.50DS	0.35
					0.35

Symptoms

The Modified Visual Function Questionnaire (MVFQ, McKeon et al., 1997) was used to assess the level of symptoms before and after each in-office computer task. The MVFQ has been previously validated and provided an index of visual comfort ranging from 100 (extremely comfortable with few symptoms) to 0 (extremely uncomfortable with many symptoms). The tasks were ‘Population Data Entry’ and ‘Apostrophe Editing’. Each task lasted 45 minutes. Subjects completed four 45-minute sessions after wearing either the habitual lens correction or the best lens correction for at least one week.

The symptom index was significantly more comfortable for assessments wearing the best correction (Kruskal-Wallis test, $H=3.94$, d.f.$=1$, $p=0.047$; Figure 12).

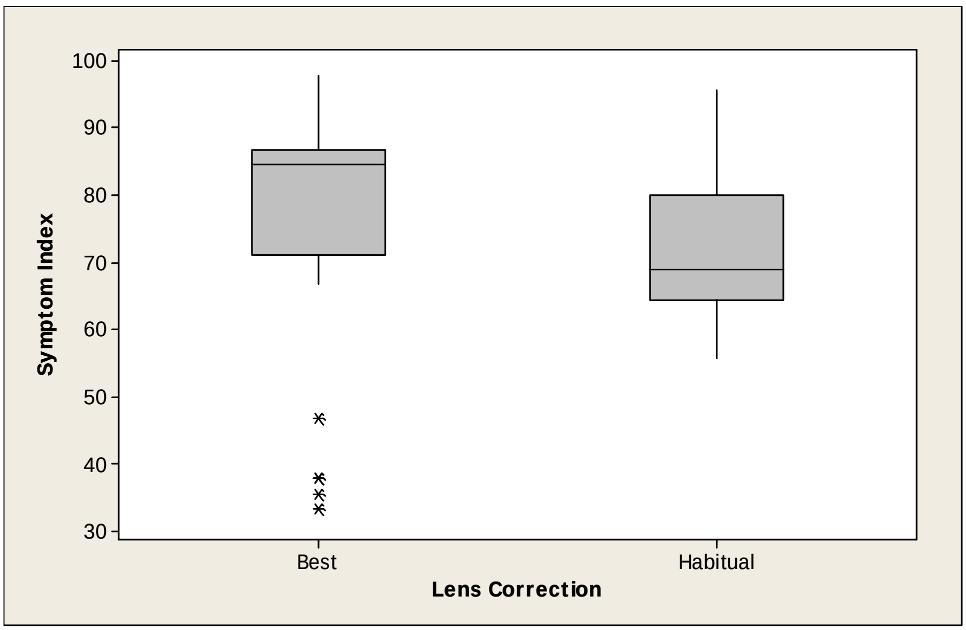

Figure 12. Symptom index as a function of type of correction Modified Visual Function Questionnaire. Higher index indicates greater comfort (McKeon et al., 1997)

The median symptom index for best correction was 84.4 and that for the habitual correction was 68.9 (higher index indicates greater comfort). The symptom index data were not normally distributed (n=54, Anderson-Darling test, AD=1.215, p<0.005).

The National Eye Institute Refractive Error Quality of Life survey suggested that the subjects may have experienced greater comfort wearing the best correction than they did wearing their habitual correction (Figure 13). The Kruskal-Wallis test was not significant but sample size calculations using the 1-sample t-test suggested that the mean difference between the symptoms scores was likely to be significant for a sample size of 17. Expanding the sample size to 30 suggested that the study would likely able to detect a difference between the mean visual symptom scores for the two lens correction conditions (best and habitual) of about 51.2% of a standard deviation.

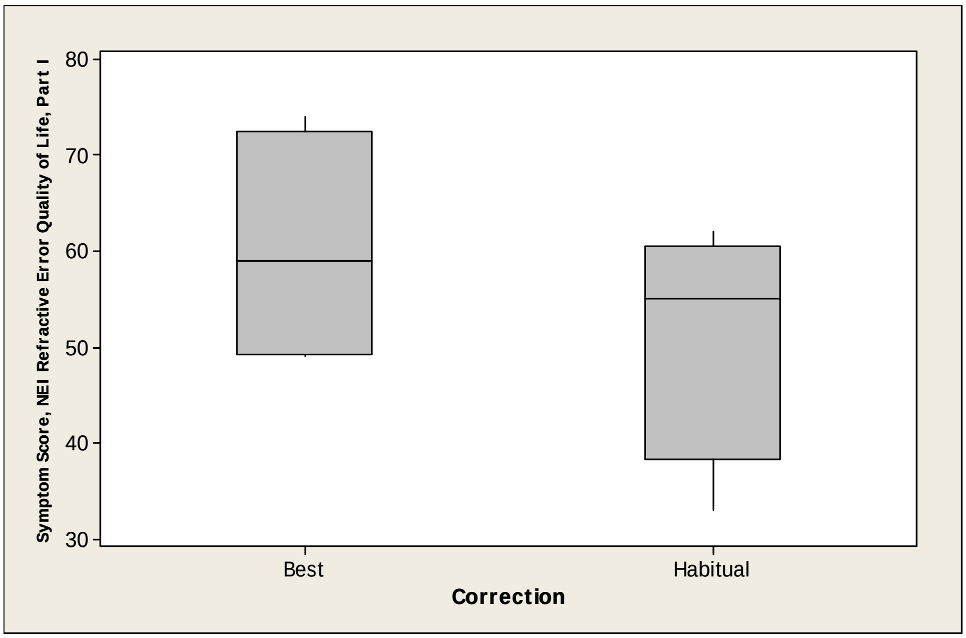

Figure 13. Symptom index as a function of type of correction, NEI Refractive Error Quality of Life, Higher index indicates greater comfort (Hays et al. 2003; Nichols, Mitchell, Saracino & Zadnik, 2003).

Productivity Assessment

For the population data entry task, the evidence did not support a hypothesis of greater total correct work with the best correction (Kruskal-Wallis test, $H=0.28$, d.f.=1, p=NS; Figure 14). Since the sample size was small, this may not represent the final outcome with additional subjects included. The total correct work per hour for the population data entry task were normally distributed ($n=20$, Anderson-Darling test, $AD=0.268$, p<NS). The pooled standard deviation for this task was 465. For a 1-way ANOVA using a β error of 0.80 and an α error of 0.05, a sample size of 30 in each of two groups would allow the reliable detection of a difference of 342 total words correct per hour between the two groups. This represents value of about 33% of the mean value and 73% of one standard deviation.

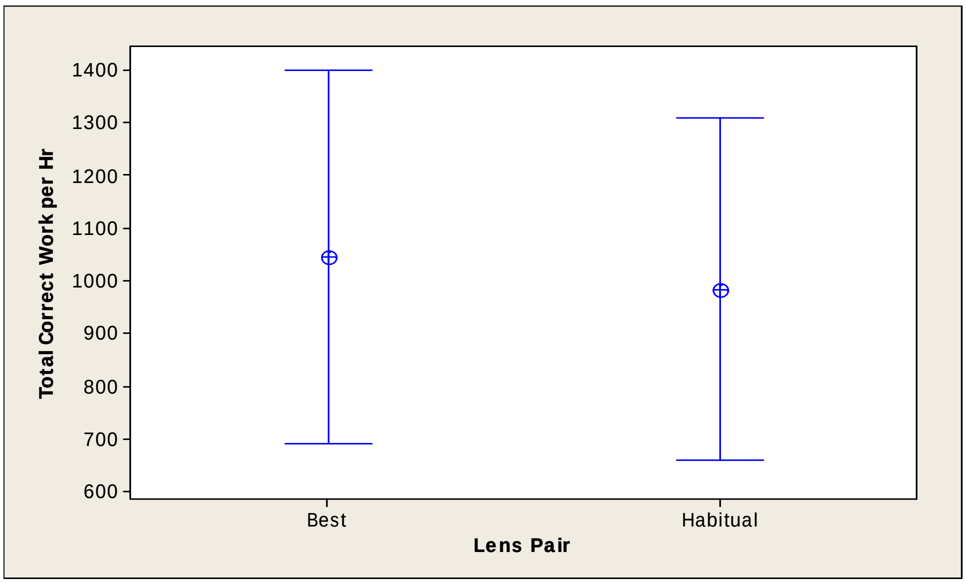

Figure 14. Plot of the total correct work per hour as a function of lens correction in the population data entry task (mean and 95% confidence interval)

On the apostrophe editing task, the evidence did not support a hypothesis of greater total correct work with the best correction (Kruskal-Wallis test, H=0.05, d.f.=1, p=NS; Figure 15). The total correct work per hour for the population data entry task was normally distributed (n=20, Anderson-Darling test, AD=0.294, p<NS). The pooled standard deviation for this task was 981. For a 1-way ANOVA using a β error of 0.80 and an α error of 0.05, a sample size of 30 in each of two groups would allow the reliable detection of a difference of 721 total correct words per hour between the two groups. This represents value of about 12% of the mean value and 73% of one standard deviation.

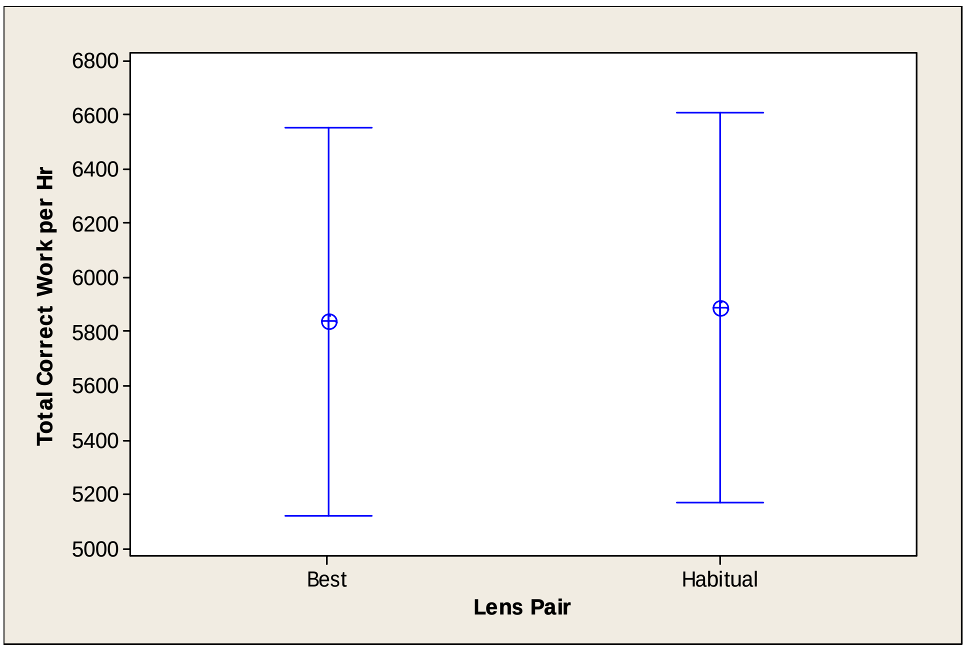

Figure 15. Plot of total correct work per hour as a function of lens correction in the apostrophe editing task (mean and 95% confidence intervals)

Discussion

In this pilot study, the sample size was very small; the mean vector dioptric errors were small and only one subject (#3) would have qualified for the study. The visual symptom index was significantly lower for assessments wearing the best correction. The median symptom index was 84.4 for best correction compared to 68.9 for the habitual correction. This suggested that subjects were more comfortable wearing their best correction. Also, the National Eye Institute Refractive Error Quality of Life survey suggested that the subjects experienced greater comfort wearing and working with their best correction than they did with their habitual correction.

For the population data entry task, the evidence did not support a hypothesis of greater total correct work with the best correction. This may have been due to the small sample size, which did not represent the final outcome of the official protocol when additional subjects were included. Also, on the apostrophe editing task, the evidence did not support a hypothesis of greater total correct work with the best correction due to the small sample size.

Conclusion

We conclude that a study with an appropriate sample size has the potential to confirm the hypothesis that subjects were more comfortable wearing and working with their best correction and their visual comfort index was significantly reduced.

APPENDIX D

EXAMPLE OF SHORTENED POPULATION ENTRY TASK FORM

Printed Text to be Entered into the Computer

Total Population, Georgia	8,186,453
Hispanic or Latino	435,227
Not Hispanic or Latino:	7,751,226
Population of one race:	7,663,862
White alone	5,128,661
Black or African American alone	2,331,465
American Indian and Alaska Native alone	17,670
Asian alone	171,513
Native Hawaiian and Other Pacific Islander alone	3,278
Some other race alone	11,275
Population of two or more races:	87,364
Population of two races:	80,963
White; Black or African American	17,161
White; American Indian and Alaska Native	18,255
White; Asian	13,156
White; Native Hawaiian and Other Pacific Islander	936
White; Some other race	9,754
Black or African American; American Indian and Alaska Native	5,289
Black or African American; Asian	3,386
Black or African American; Native Hawaiian and Other Pacific Islander	872
Black or African American; Some other race	6,468
American Indian and Alaska Native; Asian	809
Am. Indian & Alaska Native; Native Hawaiian & Oth. Pac. Islander	59
American Indian and Alaska Native; Some other race	352
Asian; Native Hawaiian and Other Pacific Islander	946

APPENDIX E

EXAMPLE OF SHORTENED BLANK FORM FOR SUBJECT TO COMPLETE MANUALLY

Blank Form on the Computer for Subject to Enter Data from Appendix D

1	Total Population, Georgia	
2	Hispanic or Latino	
3	Not Hispanic or Latino:	
4	Population of one race:	
5	White alone	
6	Black or African American alone	
7	American Indian and Alaska Native alone	
8	Asian alone	
9	Native Hawaiian and Other Pacific Islander alone	
10	Some other race alone	
11	Population of two or more races:	
12	Population of two races:	
13	White; Black or African American	
14	White; American Indian and Alaska Native	
15	White; Asian	
16	White; Native Hawaiian and Other Pacific Islander	
17	White; Some other race	
18	Black or African American; American Indian and Alaska Native	
19	Black or African American; Asian	
20	Black or African American; Native Hawaiian and Other Pacific Islander	
21	Black or African American; Some other race	
22	American Indian and Alaska Native; Asian	
23	Am. Indian & Alaska Native; Native Hawaiian & Oth. Pac. Islander	
24	American Indian and Alaska Native; Some other race	
25	Asian; Native Hawaiian and Other Pacific Islander	

APPENDIX F

EXAMPLE OF SHORTENED APOSTROPHE EDITING TASK FORM

Example of Shortened Text of Apostrophe Editing Task

Michigan

I. Introduction

Michigan, state I'n the East North Central Unite'd States. I't I's unique among the states because I't consists of' two peninsulas completel'y separated by water and bord'ering on four of' the f'ive Great Lakes. Between Lakes Michigan and Huron l'ie the Straits of Mackinac, which separ'ate Michigan's two peninsulas. The L'ower Peninsula is bo'unded on the east' by Lak'es Huron, Saint Clair, and Erie and by the Detr'oit and Saint Clair rivers,' al'l of which separat'e the state f'rom the Canadian province' of Ontario. This penin'sula is bounded on the sou'th by Ohio and Indiana, on the wes't by Lake Michigan', and on the north by Lakes Mic'higan and Huron and by the Str'aits of Mackinac. The Upper' Peninsula I's bordered' on the east by the Saint Marys River, on the sout'h by the Straits of Mack'inac and Lakes Huron and Mich'igan, on the west by Wiscon'sin, and on the north by Lake Super'ior. Lansing I's the capital of Michigan. Detroit' is the largest cit'y.

When Michig'an was admitte'd to the Union on January' 26, 1'837, as the 26th stat'e, I't was primarily' a f'ur-trading territory. It's rich agricultural resource's were not developed until l'ater in' the century. I't's industrial promi''nence dates f'rom the beginning's of automobile manu'f''acturing in the early 20'th century.

The way of' lif'e I'n Michigan's Lower Peninsula, with I'ts vast industrial develop'ment, has come to symboli'ze the 20th-cen'tury United States. The Upper Pen'insula I's a less populate'd region of great natur'al beauty that I's known as a recreati'on and wilderness area. It is' also noted f'or its mineral wealth.

APPENDIX G

MODIFIED VISION QUALITY OF LIFE QUESTIONNAIRE

Name ________________________ Date __________

Lens design code __________ (Technician completes)

Modified Vision Quality of Life Questionnaire
University of Texas School of Public Health/University of Houston Optometry Clinic
Modified March 26, 2002
Kent M. Daum, O.D., Ph.D.
School of Optometry/ University of Alabama at Birmingham

Instructions

For each of these questions, please respond with the number that best represents your answer. Your answer should be made in reference to the lens design and tasks you've just completed on the computer.

1. In general, would you say that with this lens combination you have problems with your eyes:
   a. All of the time
   b. Most of the time
   c. A good bit of the time
   d. Some of the time
   e. A little of the time
   f. None of the time

2. How would you rate the clearness of your vision with this lens combination?
   a. Excellent
   b. Very good
   c. Good
   d. Fair
   e. Poor

3. How often have you had episodes of blurred vision and/or double vision with this lens combination?
   a. All of the time
   b. Most of the time
   c. A good bit of the time
   d. Some of the time
   e. A little of the time
   f. None of the time

4. To what extent did problems with this lens combination limit your ability to do tasks on the computer or the amount of time that you needed to do them (for example, because you became tired, lost concentration or were not able to see well enough to complete the task)?
    a. Extremely
    b. Quite a bit
    c. Moderately
    d. Slightly
    e. Not at all

5. How often did you lose your place, reread the same line or skip lines when you were completing the tasks on the computer with this lens combination?

    a. All of the time
    b. Most of the time
    c. A good bit of the time
    d. Some of the time
    e. A little of the time
    f. None of the time

6. To what extent did the lighting affect your ability to complete the tasks on the computer with this lens combination?
    a. Extremely
    b. Quite a bit
    c. Moderately
    d. Slightly
    e. Not at all

7. How much did your eyes hurt, watered, burned, itched or become red or swollen in completing the tasks on the computer with this lens combination?
    a. All of the time
    b. Most of the time
    c. A good bit of the time
    d. Some of the time
    e. A little of the time
    f. None of the time

8. How much did you have headaches when completing the tasks on the computer with this lens combination?
    a. All of the time
    b. Most of the time
    c. A good bit of the time
    d. Some of the time
    e. A little of the time
    f. None of the time

9. To what extent were you embarrassed or frustrated when you were unable to complete the tasks on the computer because of this lens combination?
    a. Extremely
    b. Quite a bit
    c. Moderately
    d. Slightly
    e. Not at all

10*. To what extent did your neck, shoulder or back become uncomfortable or painful in completing the tasks on the computer with this lens combination?

a. Extremely (1)
b. Quite a bit (2)
c. Moderately (3)
d. Slightly (4)
e. Not at all (5)

*Note: Question 10 was used only for study two.

APPENDIX H

REFRACTIVE ERROR QUALITY OF LIFE SURVEY

Name ____________________ Date ____________________

Lens combination ___________ (Technician completes)

Modified National Eye Institute Refractive Error Quality of Life Survey
Modified December 6, 2004
Kent M. Daum, O.D., Ph.D.
School of Optometry/University of Alabama at Birmingham

Instructions

For each of these questions, please circle the number that best represents your answer. Your answer should be made in reference to the glasses you've been wearing over the past month and tasks you've just completed on the computer and other wise.

1. How much does pain or discomfort in or around your eyes keep you from doing what you'd like to be doing on the computer because of this lens combination?
   a. Severe
   b. Moderate
   c. Mild
   d. Not at all

2. How much difficulty do you have reading the task on the computer because of this lens combination?
   a. All of the time
   b. Most of the time
   c. A good bit of the time
   d. Some of the time
   e. A little of the time
   f. None of the time

3. How much difficulty do you have doing work or hobbies on the computer that require you to see well up close with this lens combination?
   a. All of the time
   b. Most of the time
   c. A good bit of the time
   d. Some of the time
   e. A little of the time
   f. None of the time

4. How much difficulty do you have finding something on a small print of task on the computer with using this lens combination?
   a. All of the time
   b. Most of the time
   c. A good bit of the time
   d. Some of the time
   e. A little of the time
   f. None of the time

5. How much difficulties do you have reading the task on the computer at a distance greater than 20” with using this lens combination?
   a. All of the time
   b. Most of the time
   c. A good bit of the time
   d. Some of the time
   e. A little of the time
   f. None of the time

6. How much of the time does your vision using this lens combination limit you in recognizing people or objects across from you in the workplace?
   a. All of the time
   b. Most of the time
   c. A good bit of the time
   d. Some of the time
   e. A little of the time
   f. None of the time

7. How much difficulty do you have seeing how people react to things you say by using this lens combination?
   a. All of the time
   b. Most of the time
   c. A good bit of the time
   d. Some of the time
   e. A little of the time
   f. None of the time

8. How much of the time do you worry about your eyesight during working on the computer?
   a. All of the time
   b. Most of the time
   c. A good bit of the time
   d. Some of the time
   e. A little of the time
   f. None of the time

9. Do you feel frustrated a lot of time during working on the computer because of your eyesight?
   a. All of the time
   b. Most of the time
   c. A good bit of the time
   d. Some of the time
   e. A little of the time
   f. None of the time

10. Do you have much less control over what you do on the computer because of your eyesight?
    a. All of the time
    b. Most of the time
    c. A good bit of the time
    d. Some of the time
    e. A little of the time
    f. None of the time

11. Do you worry about doing things on the computer that will embarrass others or yourself because of your eyesight?
    a. All of the time
    b. Most of the time
    c. A good bit of the time
    d. Some of the time
    e. A little of the time
    f. None of the time

12. Do you accomplish your work on the computer less than you would like because of your vision?
    a. All of the time
    b. Most of the time
    c. A good bit of the time
    d. Some of the time
    e. A little of the time
    f. None of the time

13. Do you accomplish your work on the computer better than should be with using this lens combination?
    a. All of the time
    b. Most of the time
    c. A good bit of the time
    d. Some of the time
    e. A little of the time
    f. None of the time

14. Are you limited in how long you can work on the computer or do other activities because of your vision?
    a. All of the time
    b. Most of the time
    c. A good bit of the time
    d. Some of the time
    e. A little of the time
    f. None of the time

15. Are you limited in how long you can work on the computer or do other activities with using this lens combination?
    a. All of the time
    b. Most of the time
    c. A good bit of the time
    d. Some of the time
    e. A little of the time
    f. None of the time

16. How satisfied are you with the glasses you have?
    a. Completely satisfied
    b. Very satisfied
    c. Somewhat satisfied
    d. Somewhat dissatisfied
    e. Very dissatisfied
    f. Completely dissatisfied

17. How many hours per day did you wear these glasses?
    a. ____ hour/s

APPENDIX I

DESCRIPTION OF THE PILOT STUDY RESULTS FOR STUDY TWO

Study 2: Effect of Different Adds on Productivity and Comfort of Computer Users

Pilot Study

Overview

The purpose of this study was to provide pilot data for a study designed to examine the effect of different add powers on the comfort and productivity of computer users with the head fixed or free to move, considering that the magnitude of an add and head movement are the most likely factors to cause visual discomfort and decreased performance. We hypothesized that near plus lens additions that were greater or lesser than the most appropriate add would result in decreased productivity and comfort of computer users.

Methods

The pilot study involved three subjects meeting the criteria of the protocol and was designed to allow the modification of the protocol of the study to examine the performance of subjects using different adds with the head in a fixed (using chin rest) or free to move (not using chin rest) position. All subjects underwent vision screening and potential subjects were required to need a near plus addition to comfortably perform near tasks, and were also were required to be able to perform rudimentary tasks on a computer.

The eyewear and lenses used in the pilot study are detailed in the protocol. Lenses were coded with labels after their order was randomized so that the investigator and the subject completing the trial were unaware of which additional lens pair was being used.

The subjects were randomly assigned to a randomized sequence of ten different lens additions and head position combinations for the study periods. The subjects completed ten different but matched protocols. After the subjects completed the protocol for a given period, their lenses were replaced with the next pair and they completed the identical protocol during the next period of the study. The only difference for the subjects in the periods was the pair of additional lenses that the subject was wearing and whether or not their head was fixed.

For the pilot study each period /trial lasted 10 minutes. Since the subjects completed 10 periods, a total of 150 minutes of work were recorded for each subject. Counting breaks of about five minutes between each trial, a subject spent about four hours completing the experimental protocol. At the beginning of the study and after each 10 minutes trial, subjects completed the visual comfort survey to asses the visual comfort of each subject with different lenses.

The apostrophe editing task was used in the pilot study as well as in the protocol, and the total magnitude of work and the accuracy of the editing task were determined by identical methods, which are described in the protocol.

Results

Three volunteer subjects (1 male, 2 female; mean age 48.7 yrs, std dev 6.7, range 41 to 53 yrs) the pilot study. Their habitual, best corrections and vector dioptric difference are presented in Table 78 .

Table 78. *Characteristics of the subjects in the pilot study for experiment two*

Subject	Sex	Age	Best Correction (Right, Left, sphere, cylinder and axis, corrected visual acuity)	Plus lens addition for 50 cm computer monitor
1	M	53	-1.75 -0.25 x 168 20/30 -1.50 -0.50 x 068 20/15	+1.75
2	F	52	-0.25 -1.00 x 080 20/15 -0.25 -0.50 x 090 20/15	+1.50
3	F	41	-3.50 -0.25 x 037 20/15 -3.75 -0.25 x 073 20/15	+0.50

Symptoms

The Modified Visual Function Questionnaire (MVFQ, McKeon et al., 1997) was used to assess the level of symptoms before and after each in-office lens addition, head position (fixed or free) computer task. The MVFQ has been previously validated and provides an index of visual comfort ranging from 100 (extremely comfortable with few symptoms) to 0 (extremely uncomfortable with many symptoms). The task was Apostrophe Editing. Each task lasted 10 minutes. Subjects completed ten 10-minute sessions with a randomized combination of lens addition difference from their best addition for the 50 cm (20 inch) distance (-1.0, -0.50, plano, +0.50, +1.0D) and head position (fixed or free).

The symptom index was significantly related to the lens addition difference (Kruskal-Wallis test, H=11.86, d.f.=5, p=0.037; Figure 16). The median symptom index before the test session was 93.3 and that after the best lens addition difference (plano) was 75.6 (higher index indicates greater comfort). The symptom index did not appear to be related to the head position (fixed or free; Kruskal-Wallis test, NS; Figure 17).

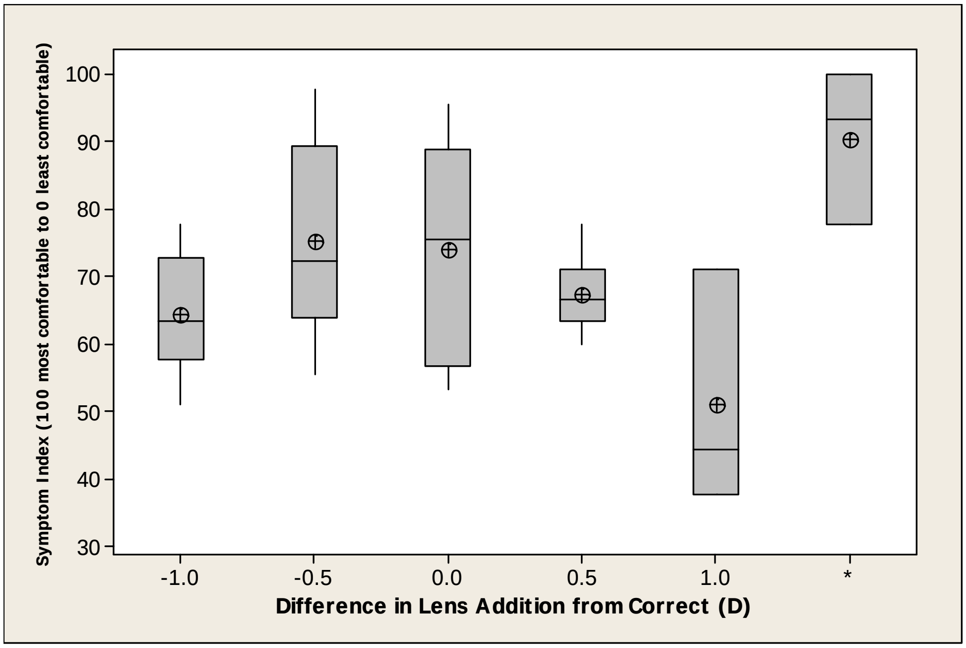

Figure 16. Boxplot of symptom index vs. lens addition difference for pilot study (n=3 subjects) Boxes indicate the interquartile range; median values are shown with horizontal line in the box and mean values with the circle with a plus sign. The box on the right marked with an "*" is the symptom value before the trials began.

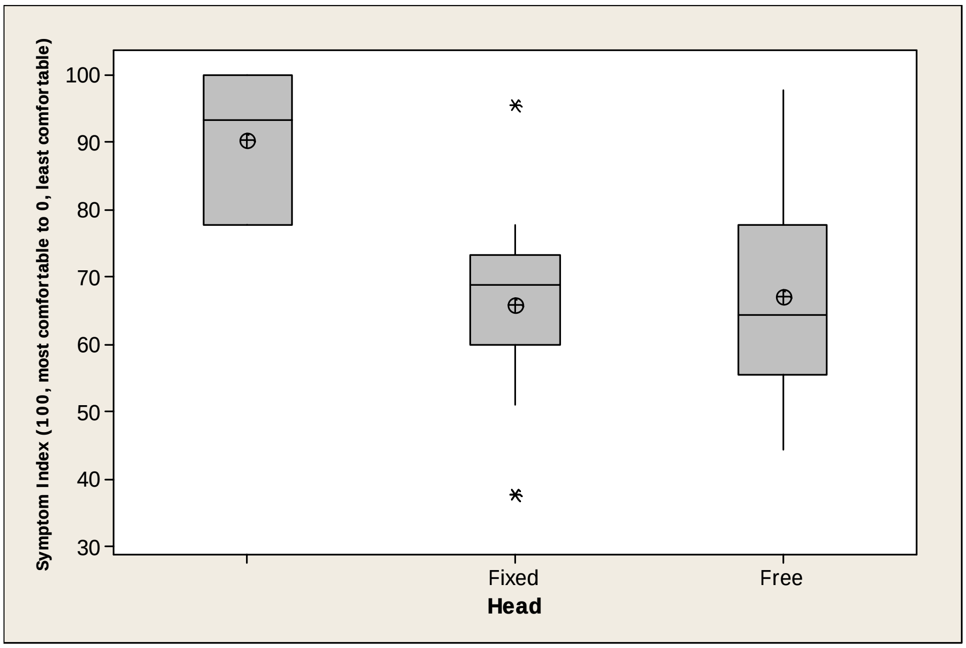

Figure 17. Boxplot of symptom index vs. head position. Boxes indicate interquartile range; horizontal lines represent the median and symbols indicate the mean). The box on the left indicates symptom index before the trials.

Head Position

Although the difference did not reach significance with the small sample size, head position appeared to be related to the lens addition when the head was free to move (Kruskal-Wallis, H=4.63, d.f., 4, p=0.32); Figure 18).

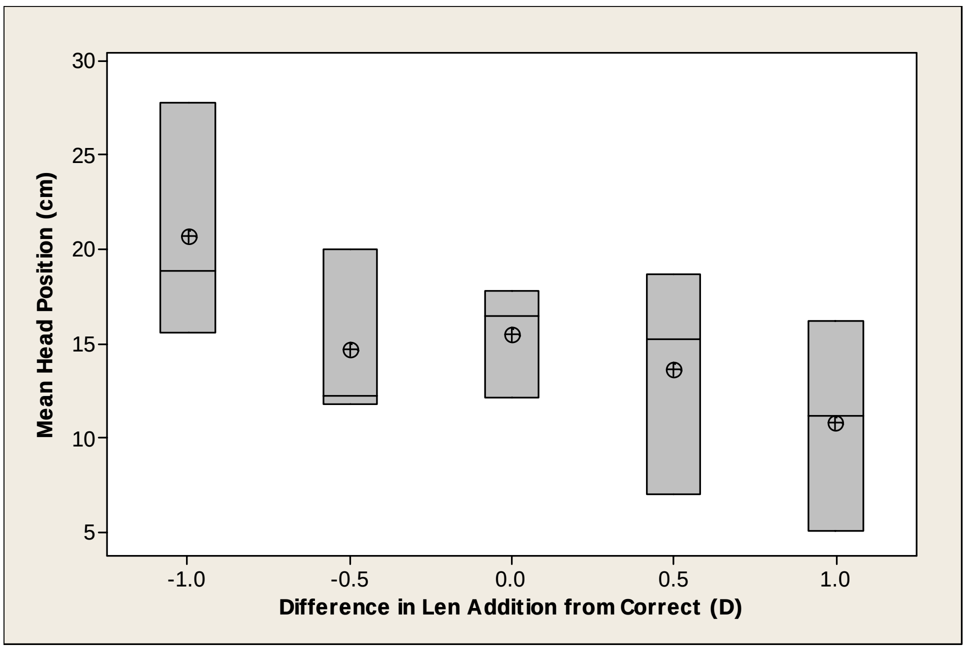

Figure 18. Boxplot of head position vs. lens addition when the head was free to move. Boxes indicate interquartile range; horizontal lines represent the median and symbols indicate the mean.

Productivity Assessment

The hypothesized changes in productivity did not reach statistical significance with the small sample size (Figure 19). An examination of the data for total correct work per hour as a function of the head (fixed or free) and lens addition over the best addition (-1.0, -0.5, 0, +0.5 and +1.0) suggested: (1) In four of the five lens additions states, the free head mean total correct work per hour was higher than the fixed head position; (2) In four of the five addition states, the range of total correct work per hour is greater in the free head state; and, (3) Although substantial variability allowed other interpretations, the data suggested that the total correct work per hour is somewhat better with plano and +0.50D adds over the best addition. For a 1-way ANOVA using a β error of 0.80 and an α error of 0.05, a sample size of 30 in each of five groups would allow the reliable detection of a difference of 1185 total words correct per hour between the five groups. This represents value of about 24% of the mean value and 91% of one standard deviation.

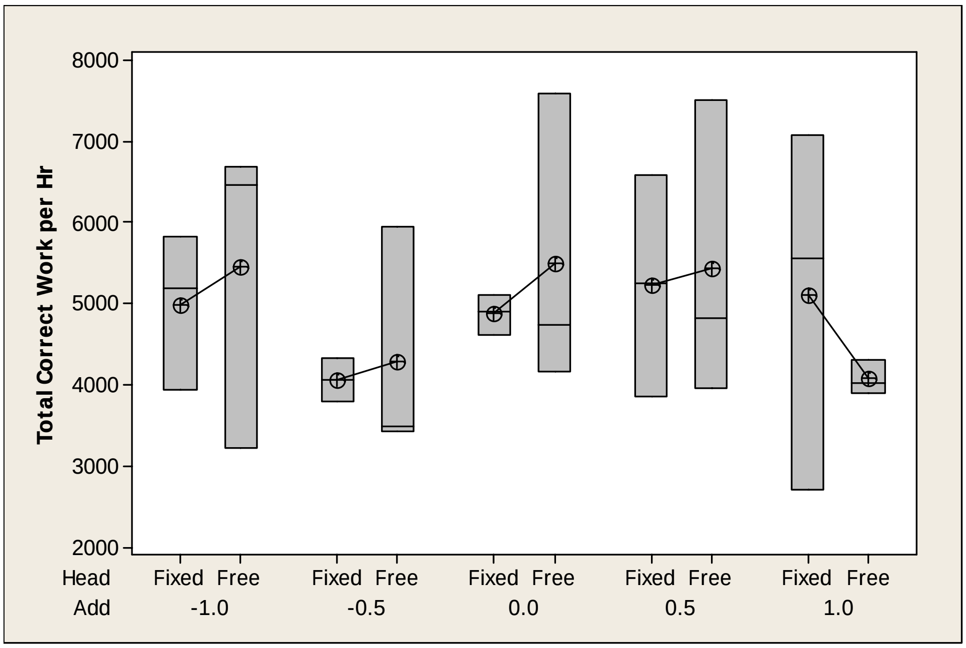

Figure 19. Plot of total correct work per hour as a function of head position (fixed or free). Median indicated by horizontal line; mean by symbol. Boxes indicate interquartile range.

Regression analysis of the total correct work per hour versus the symptom index and the difference of the additional correction from the best addition suggested that productivity may be related to the symptom index (Table 79). This did not reach statistical significance (p=0.059) although the small sample size may be responsible.

Table 79. *Regression Analysis: Total Correct Work per Hr versus Symptom Index, Rx. The regression equation is: Total Correct Work per Hr = 2735 + 32.5 Symptom Index + 204 Rx. 30 cases used, 3 cases contain missing values.*

Predictor	Coef	SE Coef	T	P
Constant	2735	1121	2.44	0.022
Symptom Index	32.54	16.51	1.97	0.059
Rx	203.8	346.2	0.59	0.561

Discussion

The symptom index was significantly related to the lens addition difference. The subjects were more comfortable before the test session than after the best lens addition difference (Plano). The symptom index did not appear to be related to the head position. Head position appeared to be related to the lens addition when the head was free to move. Even so, the sample size was small and the difference did not reach significance.

On the other hand, the productivity of the subjects as a function of lens addition was not statistically significant due to the small sample size. Calculating the total correct work per hour was somewhat better with Plano and +0.50D adds over the best addition. The total correct work per hour versus the symptom index and the difference of the additional correction from the best addition also was not significant possibly due to the small sample size.

Conclusion

We concluded that a study with an appropriate design and sample size has the potential to demonstrate that alterations in the lens addition affect the visual comfort and the productivity of the subjects. Also, alterations in the lens addition may affect head position. Thus over extended periods of work, performance and productivity may decline as a function of decreased in visual comfort and increased in musculoskeletal symptoms.

Inappropriate correction of the refractive power needed for working on a computer monitor at 50 cm. by a minimum of +/- 0.50 D may significantly increase visual symptoms while decreasing performance and productivity.