OPO OPHTHALMIC & PHYSIOLOGICAL OPTICS
THE JOURNAL OF THE COLLEGE OF OPTOMETRISTS

Ophthalmic & Physiological Optics ISSN 0275-5408

REVIEW

Computer vision syndrome: a review of ocular causes and potential treatments

Mark Rosenfield

SUNY College of Optometry, New York, USA

Citation information: Rosenfield M. Computer vision syndrome: a review of ocular causes and potential treatments. *Ophthalmic Physiol Opt* 2011, **31**, 502–515. doi: 10.1111/j.1475-1313.2011.00834.x

Keywords: accommodation, computer vision, convergence, dry eye, near vision, reading

Correspondence: Mark Rosenfield
E-mail address: Mrosenfield@sunyopt.edu

Received: 1 December 2010; Accepted: 10 February 2011

Abstract

Computer vision syndrome (CVS) is the combination of eye and vision problems associated with the use of computers. In modern western society the use of computers for both vocational and avocational activities is almost universal. However, CVS may have a significant impact not only on visual comfort but also occupational productivity since between 64% and 90% of computer users experience visual symptoms which may include eyestrain, headaches, ocular discomfort, dry eye, diplopia and blurred vision either at near or when looking into the distance after prolonged computer use. This paper reviews the principal ocular causes for this condition, namely oculomotor anomalies and dry eye. Accommodation and vergence responses to electronic screens appear to be similar to those found when viewing printed materials, whereas the prevalence of dry eye symptoms is greater during computer operation. The latter is probably due to a decrease in blink rate and blink amplitude, as well as increased corneal exposure resulting from the monitor frequently being positioned in primary gaze. However, the efficacy of proposed treatments to reduce symptoms of CVS is unproven. A better understanding of the physiology underlying CVS is critical to allow more accurate diagnosis and treatment. This will enable practitioners to optimize visual comfort and efficiency during computer operation.

Introduction

The use of computers and digital electronic devices for both vocational and non-vocational activities including e-mail, internet access and entertainment is almost universal in modern Western society. A recent estimate of internet usage by continent ranged from 77.4% of the population of North America to 10.9% of Africa, with an estimated 1 966 514 816 users worldwide (or 28.7% of the world's population) (http://www.internetworldstats.com/stats.htm).

The viewing of digital electronic screens is no longer restricted to desktop computers located in the workplace. Today's visual requirements may include viewing laptop and tablet computers, electronic book readers, smartphones and other electronic devices either in the workplace, at home or in the case of portable equipment, in any location. Furthermore, computer use is not restricted to adults. A recent investigation of over 2000 American children between 8 and 18 years of age reported that in an average day they spend approximately 7.5 h using entertainment media, 4.5 h watching TV, 1.5 h on a computer and over an hour playing video games.[1] Some screen sizes may necessitate very small text which the observer frequently positions at a closer viewing distance than had previously been adopted for hard copy printed materials. These increased visual demands may give rise to a variety of symptoms which have been termed computer vision syndrome (CVS).

The American Optometric Association defines CVS as the combination of eye and vision problems associated with the use of computers. These symptoms result from the individual having insufficient visual capabilities to perform the computer task comfortably (http://www.aoa.org/x5374.xml). In a review of CVS, Thomson[2] indicated that up to 90% of computer users may experience visual symptoms including eyestrain, headaches, ocular discomfort, dry eye, diplopia and blurred vision either at near or when looking into the distance after prolonged computer use. It is unclear whether this number has increased, given the increased use of electronic displays today. Further, Rossignol *et al.*[3] reported that the prevalence of visual symptoms increased significantly in individuals who spent more than 4 h daily working on video display terminals (VDTs).

Asthenopia is a major complaint in subjects with CVS. The results of a 2008 questionnaire returned by over 400 computer operators in India revealed asthenopic symptoms in 46.3% of subjects.[4] Similarly, a survey of 212 bank workers in Italy found asthenopic symptoms in 31.9% of the subjects, though it is worthwhile noting that this percentage was calculated after 87 subjects were excluded due to uncorrected hyperopia, undercorrected astigmatism, or overcorrected myopia, because the investigators wanted to investigate only subjects 'without organic visual disturbances'.[5] A higher prevalence was found in a study of 35 Mexican computer terminal operators where 68.5% of the subjects experienced symptoms.[6] An Australian study of over 1000 computer workers found 63.4% reported symptoms with uncontrolled conditions; this number was reduced to 25.2% when an optimized, ergonomic desk and frequent work breaks were provided.[7] It is unclear whether asthenopia during computer use is associated with age,[4,7–9] although the prevalence does seem to be higher in females.[10–14]

In a review of asthenopia, Sheedy *et al.*[15] noted that symptoms commonly associated with this diagnostic term included eyestrain, eye fatigue, discomfort, burning, irritation, pain, ache, sore eyes, diplopia, photophobia, blur, itching, tearing, dryness and foreign-body sensation. While investigating the effect of several symptom-inducing conditions on asthenopia, the authors determined that two broad categories of symptoms existed. The first group, termed external symptoms, included burning, irritation, ocular dryness and tearing, and was related to dry eye. The second group, termed internal symptoms, included eyestrain, headache, eye ache, diplopia and blur, and is generally caused by refractive, accommodative or vergence anomalies. Accordingly, the authors proposed that the underlying problem could be identified by the location and/or description of symptoms.

It is important to identify whether symptoms (both internal and external, see above) are specific to computer operation, or are simply a manifestation of performing a sustained near-vision task for an extended period of time. If no physiological or subjective differences exist when patients view materials either on electronic screens or in printed form, then there would be little justification for special attention being paid to the visual demands encountered during computer operation. The electronic screen would simply represent another visual target. However, there is evidence that the two forms of target presentation are not equivalent. For example, Sheedy *et al.*[16] compared the performance of an editing task when the material was either presented on a VDT or in hard copy form. They observed that subjects made fewer errors and performed the task quicker with the hard copy presentation. Similar findings of fewer errors when viewing printed materials have also been reported in other studies.[17–19] More recently, Chu *et al.*[20] compared ocular symptoms immediately following a sustained near-task viewed either on a computer monitor or in hard copy format. Identical text was used in the two sessions, which was matched for size and contrast. In addition, target viewing angle and luminance were similar for the two conditions. Significant differences in median symptom scores were found with regard to blurred vision during the task and the mean symptom score. In both cases, symptoms were higher during computer use. Accordingly, it appears that the symptoms associated with CVS do not result from simply performing a near-vision task for a prolonged period of time. Even when viewing a modern flat panel monitor, subjects reported significantly greater blur during the computer task, when compared with a hard-copy printout of the same material.

In addition to the discomfort experienced during computer operation, symptoms of CVS may also have a significant economic impact. As noted above, symptoms can increase the number of errors made during a computer task as well as necessitating more frequent breaks. Musculoskeletal injuries associated with computer use may account for at least half of all reported work-related injuries in the USA.[21] Indeed, Speklé *et al.*[22] noted that conservative estimates of the cost of musculoskeletal disorders to the United States economy as reported in 2001, when measured by compensation costs, lost wages and reduced productivity were between 45 and 54 billion dollars annually or 0.8% of gross domestic product. Further, the prevalence of neck, shoulder and arm symptoms in computer workers may be as high as 62%.[23] In addition to productivity costs, it was estimated in 2002 that employers in the USA paid approximately $20 billion annually in workers compensation resulting from work-related musculoskeletal disorders.[24] When considering CVS specifically, Daum *et al.*[25] estimated that provision of an appropriate refractive correction alone could produce at least a 2.5% increase in productivity. This would result in a highly favourable cost-benefit ratio to an employer who provided computer-specific eyewear to their employees. Accordingly, it is clear that the economic impact of CVS is extremely high, and minimizing symptoms that reduce occupational efficiency will result in substantial financial benefit. It should also be noted that both national and international regulations have been issued with regard to health and safety requirements for workers using VDTs to minimize these disorders [e.g. European Council directive 90/270/EEC, the United Kingdom Health and Safety (Display Screen Equipment) (DSE) regulations and the Australian Occupational Health & Safety Act of 2000].

Effect of uncorrected refractive error

Given the need to achieve and maintain clear and single vision of relatively small targets throughout the computer task, it is important that the retinal image be focused appropriately. Thus, spherical hyperopia and high myopia should be corrected to reduce the ocular stimulus to accommodation and minimize blur. Additionally, the correction of small astigmatic errors may also be important to reduce symptoms of CVS. In two similar experiments, Wiggins and Daum[26] and Wiggins *et al.*[27] examined the effects of uncorrected astigmatism while reading material from a computer screen. In both studies the authors observed that the presence of 0.50–1.00 D of uncorrected astigmatism produced a significant increase in symptoms. Interestingly, Wiggins *et al.*[27] tested subjects with up to 1 D of residual astigmatism who were corrected with spherical soft contact lenses. This is a common clinical practice. The residual uncorrected astigmatism produced a significant increase in symptoms during the computer task. Accordingly, the authors suggested that symptoms could be reduced either by fitting these individuals with toric contact lenses, or alternatively by using a spectacle overcorrection to correct the residual astigmatism during computer operation.

A recent study in our laboratory (paper in preparation) recorded ocular symptoms (both internal and external) using a written questionnaire immediately after a sustained period of reading from a computer monitor either through the habitual distance refractive correction or with a supplementary −1.00 or −2.00 D oblique cylinder added over these lenses. Additionally, the distance correction condition was repeated on two occasions in 12 subjects to assess the repeatability of the symptom questionnaire. The results showed no significant difference between the habitual correction conditions, but the change from 1 to 2 D of induced astigmatism produced a significant increase in post-task symptoms. These results are shown in *Figure 1*. The presence of uncorrected oblique astigmatism will reduce visual acuity significantly. The increase in target blur will make performing the task more difficult, thereby leading to an increase in symptoms such as eyestrain and headache. Therefore, the correction of

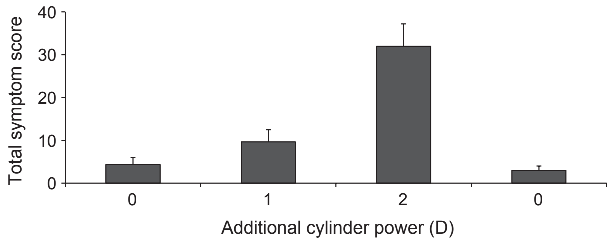

Figure 1. Total symptom score following a 20 min period of reading from a computer monitor either through the distance refractive correction or with a supplementary −1.00 or −2.00 D oblique cylinder added over these lenses. The distance correction condition was repeated on two occasions in 12 subjects to assess the repeatability of the symptom questionnaire. Error bars indicate 1 S.E.M.

astigmatic refractive errors may be important in minimizing symptoms associated with CVS.

Smartphone working distances and text sizes

As noted earlier, many of the portable devices used today for written communication (e.g. text messaging, e-mail and internet access) have relatively small screens that may necessitate close working distances and small text sizes. These can increase the demands placed upon ocular accommodation and vergence when compared with printed materials. Indeed, Bilton[28] proposed the term '1, 2, 10' to describe commonly adopted working distances, with mobile (cell) phones and e-books typically being held approximately one foot (≈30 cm) away, desktop computers being viewed at about 2 feet (≈60 cm), while televisions are often viewed at a distance of 10 feet (approximately 3 m). A study in our laboratory measured both font size and viewing distance in 129 individuals using hand-held electronic devices.[29] The mean font size of 1.12 M (S.D. = ±0.24), 6/19.2 (S.D. = ±5.25) or ∼N9 was comparable with newspaper print, which generally ranges between 0.8 and 1.2 M (N6–N10).[30] These results are shown in *Table 1*. However, Sheedy and Shaw-McMinn[31] suggested that a 3× acuity reserve should be adopted, indicating that prolonged viewing of a 6/19.2 letter would require visual acuity of at least 6/6.4. Further, as noted in *Table 1*, in some cases, the text size was as small as 6/8.25 equivalent, which based on the 3× reserve would require visual acuity of 6/2.75 for comfortable, sustained viewing.

Additionally, the mean working distance (36.2 cm) was closer than the typical near working distance of 40 cm for adults when viewing hardcopy text,[32] and was as close as 17.5 cm for one individual. Indeed, 75% of the subjects examined used viewing distances between 26 and 40 cm while 22.5% adopted viewing distances of <30 cm (see *Table 1*). These close distances will place increased

Table 1. Mean and range of values for font size and working distance while using a smartphone

	Mean ± 1 S.D.	Range
Font size (mm)	1.63 ± 0.35	1.0–3.0
Snellen fraction	6/19.2 ± 5.25	6/8.3–6/35.3
M acuity	1.12 ± 0.24	0.70–2.10
Working distance (cm)	36.2 ± 7.1	17.5–58.0

Font size is expressed either as the height of the letter, as a Snellen fraction or in terms of M acuity (i.e. the distance in meters at which the letter subtends 5 min of arc). Note that the standard deviation for the Snellen fraction refers only to the denominator of the fraction.

demands upon both ocular accommodation and vergence, especially if maintained for an extended period of time, which could exacerbate symptoms when compared with the longer viewing distances more commonly found when viewing printed materials. Practitioners need to consider the closer distances adopted while viewing material on smartphones when examining patients and prescribing refractive corrections for use at near, as well as when treating patients presenting with asthenopia associated with nearwork.

Correction of presbyopia

The correction of presbyopia can be problematic for patients who spend extended periods of time viewing digital screens. These difficulties may be most severe when viewing desktop monitors placed at fixed viewing distances and gaze angles. These screens are generally placed at or just slightly below primary gaze. Accordingly, the use of a standard bifocal spectacle lens, with the segment placed for a target positioned in downward gaze and providing clear vision for a viewing distance around 40 cm may be inappropriate. Wearers of many progressive addition lenses experience similar difficulties. In providing an appropriate form of spectacle correction, practitioners must consider both the viewing distance and gaze angle (both horizontal and vertical). In terms of viewing distance, the United States Occupational Safety and Health Administration (OSHA) state that the preferred viewing distance for a desktop monitor is between 50 and 100 cm (representing an accommodative stimulus in a corrected individual of between 1 and 2 D). Additionally, they recommend that the centre of the computer monitor should normally be located 15–20° below the horizontal eye level and the entire visual area of the display screen should be located so the downward viewing angle is never >60° (http://63.234.227.130/SLTC/etools/computerworkstations/components_monitors.html). Other national agencies such as the United Kingdom Health and Safety Executive (http://www.direct.gov.uk/en/Employment/HealthAndSafetyAtWork/DG_10026668) and Australian Standards (http://www.gamc.nsw.gov.au/workplace-guidelines/1_GuidelineContent/guidelines_1_07.htm) also include guidelines for computer set-up and operation. Further, the actual viewing distance and gaze angle may depend on the organization of the workstation, the height of the material being viewed and the physical size of the observer.

The use of non-spectacle methods of correcting presbyopia, such as contact lenses and intra-ocular lenses may also be problematic. For example, alternating or translating lens designs where the near portion of the lens moves in front of the pupil during downward gaze[33] are unlikely to be successful when viewing a desktop computer screen positioned in primary gaze. A monovision correction, where one eye is corrected for distance vision while the fellow eye is corrected for near may be successful in early presbyopes (although the loss of stereopsis may provide difficulties). However, as the near addition power increases, the loss of clear intermediate vision may become an issue. 'Simultaneous vision' type lenses, whereby multiple powers are positioned before the pupil at the same time, are becoming increasingly common. These lenses require the wearer to suppress the blurred images.[34] There appears to be little research at the present time as to whether the quality of intermediate vision provided by these lenses is sufficient to avoid CVS symptoms, given that small residual refractive errors (or the presence of significant amounts of retinal blur) may be challenging to the patient. Other new forms of presbyopic correction, such as multifocal and 'accommodating' intraocular lenses[35] may raise the same issues as multifocal contact lenses, and further studies are required to determine whether they provide sufficiently clear vision for prolonged viewing of electronic screens at a variety of distances and gaze angles.

Laptop computers are typically placed at different distances and gaze angles to desktop models. The fact that the keyboard is attached to the monitor means there is less flexibility in adjusting the workstation while the keyboard remains in comfortable reach.[36] The smaller screen size (and text height) may also impact upon the viewing distance depending on the observer's visual resolution. Harris and Straker[37] noted that laptop computers may be used in a variety of positions, ranging from sitting at a desk, sitting with the computer on one's lap or even lying prone. Accordingly, a form of presbyopic spectacle correction prescribed for a desktop computer is often inappropriate for a laptop. A laptop computer is often viewed in downward gaze at a distance which may approximate the position at which a presbyopic individual would read hand-held printed materials. This may actually make providing a spectacle correction easier for these types of devices. As noted earlier, smartphones are often held at closer viewing distances than those adopted when viewing printed materials.[19,29,38] Practitioners must consider the viewing distance and gaze angle adopted when providing a refractive correction for use when viewing electronic screens. They should ask about the type and number of devices being used. It is not uncommon for an individual to be using both a laptop and desktop computer as well as one or more handheld devices. In addition, the user may need to read printed materials, view multiple screens simultaneously or desire clear distance vision at the same time they are observing the electronic screens. Multiple pairs of glasses may be required and in some cases single vision spectacles may be the only solution to allow clear vision at the particular gaze angle and working distance in use.

Ocular causes of CVS

In considering ocular factors that may lead to CVS, two primary areas have been identified namely: (1) inappropriate oculomotor responses and (2) dry eye. It should be noted that non-ocular causes of CVS such as poor design or organization of the workstation, which may also be a significant cause of symptoms such as back, neck, shoulder and wrist pain as well as inappropriate lighting and excess glare are beyond the scope of this paper and will not be discussed here. However, they were reviewed extensively by Sheedy and Shaw-McMinn.[31] Furthermore, it seems reasonable to assume that a combination of symptom-inducing factors, such as uncorrected refractive errors and poor illumination could be additive, thereby increasing the magnitude of symptoms.

Oculomotor responses

Viewing any form of near target requires appropriate accommodative and vergence responses to provide clear and single vision of the object of regard. While both of these oculomotor functions have been cited as contributing to the symptoms associated with computer use, there is relatively little objective data detailing how these parameters change during computer work.

Accommodation

Blurred vision, either at near or when looking into the distance after prolonged computer use is a symptom commonly associated with CVS. This could result from an inaccurate accommodative response (AR) during the computer task or a failure to relax the AR fully following the near-vision demands. Patients' symptoms frequently relate to near-visual activities, and inappropriate responses, whether under or over-accommodation relative to the object of regard are a common cause of asthenopia.[39] Indeed, amongst a group of symptomatic computer users, accommodative infacility was the most common oculomotor anomaly found.[40]

However, the evidence for a difference in the AR between computer and hard-copy tasks is not compelling. For example, Wick and Morse[41] used an objective infrared optometer to measure the accommodative response (AR) in five emmetropic subjects when viewing either a VDT or printed copy of the same text displayed on the monitor. They reported that four subjects showed an increased lag of accommodation to the VDT (mean increase = 0.33 D) when compared with the hard copy condition. Later, Penisten *et al.*[42] used dynamic retinoscopy to assess the AR when subjects viewed a printed card, a VDT or a simulated computer display. The examiners do not appear to have been masked during this study, i.e. they were aware of the findings for each test condition. Results were presented for two examiners, and the observed differences were relatively small although a significantly reduced lag of accommodation was observed with the simulated computer display when compared with the printed target. For examiner 1, the mean lag of accommodation for the printed card and VDT was 0.63 and 0.72 D, respectively, while for the second observer the mean lags were 0.92 and 0.75 D, respectively. These differences were smaller than the observed levels of inter- and intra-examiner repeatability. Results from our laboratory found no significant difference in the AR as a function of symptom score during the course of a 30 min computer task performed at a distance of 50 cm.[43] The mean AR for the most and least symptomatic subject groups was 1.04 D (S.D. = ±0.12) and 1.10 D (S.D. = ±0.14), respectively. The mean ARs during the trial are shown in *Figure 2*.

In a recent paper, Tosha *et al.*[44] examined the relationship between visual discomfort and the AR. They observed an increased lag of accommodation in subjects reporting higher discomfort, which became manifest with extended viewing (typically after at least 30 s of sustained fixation). This was attributed to accommodative fatigue. However, these differences were apparent for the 4 and 5 D accommodative stimulus conditions, but were not significant for the 2 or 3 D stimulus levels. Accordingly, for the lower stimulus demands typically found with desktop and laptop computers, these differences may not be relevant. Given the closer viewing distances commonly adopted with hand held smartphone-type instruments as noted earlier, accommodative fatigue may become significant, and future studies should examine whether any change in ARs result when viewing these devices for sustained periods of time.

Accommodative facility is a standard clinical test that stimulates rapid changes in the accommodative stimulus.

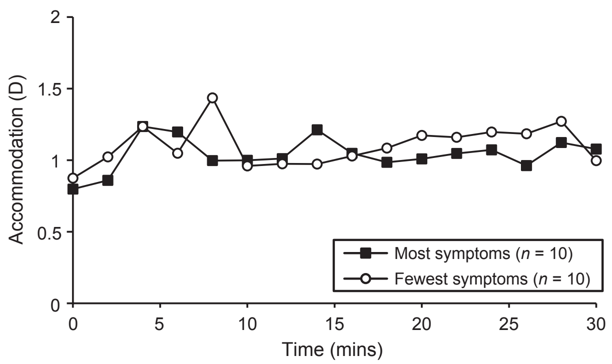

Figure 2. Mean values of accommodative response during the course of a 30 min computer task performed at a viewing distance of 50 cm for the 10 subjects reporting the most and fewest symptoms, respectively. No significant difference in responses was observed between these two subgroups. Error bars have been removed for clarity. Data from Collier and Rosenfield.[43]

Indeed, Sheedy and Parsons[40] reported that in a retrospective review of clinical records from CVS patients, accommodative infacility, i.e. an inability to complete 20 cycles in 90 s using a ± 1.50 D flipper was the most common diagnosis. One might predict that computer use would produce a decline in the ability to make dynamic oculomotor changes, possibly due to fatigue. In addition, a reduced facility finding could be predictive of subjects with CVS. Accordingly, Rosenfield *et al.*[45] measured monocular and binocular accommodative facility with ±2.00 D flippers before and immediately after a 25 min computer task performed at a viewing distance of 50 cm. No significant change in either monocular or binocular accommodative facility was observed following the task. These results are shown in *Table 2*. Furthermore, no significant correlation was found between the mean symptom score during the task and any of the pre- or post-task accommodative facility findings. These results are consistent with the findings of Tosha *et al.*[44] who also reported no significant difference in either monocular or binocular accommodative facility in groups of subjects reporting high or low visual discomfort during nearwork.

Table 2. Mean values of monocular (RE and LE) and binocular (BE) accommodative facility (cycles per minute) measured before and immediately after a 25 min computer reading task performed at a viewing distance of 50 cm

	Accommodative facility (RE or OD)	Accommodative facility (LE or OS)	Accommodative facility (BE or OU)
Pre-task	11.00 (0.81)	10.54 (0.90)	8.25 (0.86)
Post-task	11.54 (0.73)	10.50 (0.80)	9.04 (0.97)
Change	0.54 (0.79)	−0.04 (0.67)	1.22 (0.56)
p	0.51	0.95	0.16

Figures in parentheses indicate 1 S.E.M.

The accommodative facility test is a standard clinical procedure which produces rapid changes in the accommodative stimulus. While different results might have been found had more rapid shifts in the accommodative stimulus been created in the laboratory, and more reliable results might have been obtained if these changes in AR were measured objectively, the facility test has the advantage of being a simple and inexpensive test that can easily be performed in the clinical environment.

There is little experimental evidence to support the notion that CVS is associated specifically with accommodative abnormalities in young healthy patients, since no significant relationship was found between symptoms, and either the AR or accommodative facility findings. However, it is of interest that several recent investigations have reported an association between contraction of the ciliary muscle and either musculoskeletal symptoms[10,12] or specifically trapezius muscle activity.[46] Accordingly, the discomfort reported by VDT operators in the shoulder-neck region could be related to oculomotor function. For example, Lie and Watten[47] noted that altering the accommodative and vergence demands produced changes in electromyographic responses from muscles in the head, neck and shoulder region. Similarly, Richter *et al.*[46] used plus and minus lenses and changes in target position to vary the accommodative stimulus, and observed that an increase in the accommodative response was coupled with a positive shift in trapezius muscle activity in a dose-response manner. Further, in an investigation of symptoms in 1183 call-centre operators, Wiholm *et al.*[10] found a significant positive association between eyestrain and neck-shoulder symptoms. The authors conjectured that either these complaints are physiologically inter-related, or alternatively, the visual demands of the workstation may result in a change in posture leading to musculoskeletal difficulties. Alternatively, oculomotor fatigue may lead to a secondary change in innervation to the postural muscles in the neck, shoulder and upper back, resulting in discomfort in these areas. However, these findings do not explain why differences in symptoms are reported when viewing materials on either electronic screens or printed hardcopy.

An alternative hypothesis was proposed by Wilkins and co-workers,[48,49] who suggested that visual discomfort could result from certain patterns of striped lines giving rise to symptoms of eyestrain and headaches. They also proposed that 'visual hypersensitivity' could be ameliorated by the use of coloured lenses and/or overlays. However, the mechanism whereby these coloured filters could reduce symptoms is unclear. Both Ciuffreda *et al.*[50] and Simmers *et al.*[51] reported that the filters did not produce a significant change in the accommodative stimulus-response function (although Simmers *et al.*[51] observed a reduction in low frequency accommodative microfluctuations with the tinted lenses). Nevertheless, an increase in reading performance has been reported with the coloured filters,[52] and changes in the colour of the text and/or background of the computer display may reduce symptoms of CVS. The latter is worthy of further investigation.

In addition, patients with accommodative anomalies (especially accommodative insufficiency and infacility[53]) would be expected to exhibit similar symptoms to those experienced when viewing hard copy materials, and practitioners examining patients presenting with CVS should perform a full assessment of the accommodative system. The clinical parameters which should be examined are listed in the later section on treatment.

Vergence

While few studies have examined the vergence response during the course of VDT work, several investigators have measured vergence parameters before and after periods of computer usage. For example, Watten *et al.*[54] measured positive and negative relative vergence (or vergence ranges)[55] at near both at the beginning and end of an 8-h workday. They observed significant decreases in both parameters, implying that computer use decreased one's ability to converge and diverge appropriately. In contrast, Nyman *et al.*[56] found no significant change in positive or negative relative vergence at near after 5 h of VDT work. They also reported no significant change in either distance and near heterophoria or the near point of convergence (NPC) following the work period. Similarly, Yeow and Taylor[57] also observed no significant change in NPC after short term VDT use (up to 2.35 h of continuous use or an average of 4 h intermittent use in a normal working situation). In a subsequent longitudinal study, Yeow and Taylor[58] monitored NPC, near horizontal heterophoria and associated phoria (AP), i.e. the prism to eliminate fixation disparity, over a 2-year period in both VDT and non-VDT workers in the same office environment. While both the VDT and control groups exhibited a decline in NPC with age, no significant difference was observed between these groups. Similarly, no significant change in either near heterophoria or AP was found.

Jaschinski-Kruza[59] measured both accommodation and fixation disparity during the course of a 30 min computer task at viewing distances ranging from 25 to 85 cm. No significant change in either of these parameters was observed over time. However, no assessment of visual symptoms was made during the task, and he noted that 'subtle oculomotor effects' could contribute to difficulties in performance or visual fatigue in the workplace. Subsequently, Jaschinski[60] used fixation disparity as a measurement of near vision fatigue following work at a computer workstation. Near vision fatigue was associated with greater exo (or less eso) fixation disparity as the target was brought closer to the observer. In order to examine the within-task vergence response and its relationship to CVS symptoms, Collier and Rosenfield[43] measured AP during a period of sustained VDT fixation. The mean AP for the subjects who reported the least and greatest discomfort during the task was 1.55Δ exo and ortho, respectively ($p = 0.02$). These findings are illustrated in *Figure 3*. CVS was significantly worse in subjects exhibiting zero fixation disparity when compared with those subjects having exo AP.

The increased vergence response in those subjects who converged accurately on the monitor (as shown by zero AP) may be responsible for the greater symptoms when compared with those individuals who had a lower symptom score and small amounts of exo AP. The notion that having exo fixation disparity at near may be more comfortable than accurate vergence differs from earlier work indicating a positive relationship between AP and symptoms.[39,61–63] It should be noted that the range of exo AP found in the low symptom group was relatively small (mean = 1.55Δ; range = 0.78–2.33Δ). Interestingly, the Optometric Extension Program (OEP) system of case analysis regards exophoria at near as desirable, since it provides a 'buffer' to overconvergence.[64] The minimum vergence response necessary to place the retinal images within Panum's fusional area (thereby allowing binocular single vision) may provide a more comfortable oculomotor posture than precise ocular alignment.

CVS and dry eye

Dry eye has previously been cited as a major contributor to CVS. For example, Uchino *et al.*[65] observed symptoms

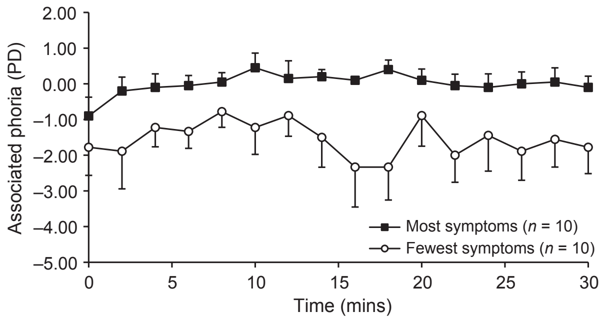

Figure 3. Mean values of associated phoria in prism dioptres (PD) during the course of the 30 min computer task performed at a viewing distance of 50 cm for the 10 subjects reporting the most and fewest symptoms, respectively. A significant difference in vergence response between the two groups was observed. Error bars indicate 1 S.E.M. Data from Collier and Rosenfield.[43]

of dry eye in 10.1% of male and 21.5% of female Japanese office workers using VDTs. Furthermore, longer periods of computer work were also associated with a higher prevalence of dry eye.[3] In an extensive review, Blehm *et al.*[66] noted that computer users often report eye dryness, burning and grittiness after an extended period of work. They suggested that these ocular surface related symptoms may result from one or more of the following factors:

(1) Environmental factors producing corneal drying. These could include low ambient humidity, high forced-air heating or air conditioning settings or the use of ventilation fans, excess static electricity or air-borne contaminants.

(2) Reduced blink rate. Several investigations have shown that blink rate is reduced during computer operation. For example, Tsubota and Nakamori[67] compared the rate of blinking in 104 office workers either when they were relaxed, reading a book or viewing text on a VDT. Mean blink rates were 22 per min while relaxed, but only 10 and 7 per min when viewing the book or VDT, respectively. Additionally, Patel *et al.*[68] observed mean blink rates prior to and during VDT operation of 18.4 and 3.6 per min, respectively. In addition, they noted a significant relationship between the stability of the precorneal tear film and the interval between blinks. Schlote *et al.*[69] found that the reduced blink rate associated with VDT use was also accompanied by distinct patterns of blinking. For example, some patients (all of whom had symptoms of dry eye) exhibited alternating inter-blink periods of longer and shorter duration. These authors hypothesized that the change in inter-blink duration during the course of VDT operation represented cognitive adaptation to the computer task. Further, no significant correlation was observed between clinical measurements of the ocular tear film (tear breakup time, Schirmer I or Jones tests) and the observed blink rate during computer operation.

It has also been reported that blink rate decreases as font size and contrast are reduced,[70] or the cognitive demand of the task increases.[71,72] Additionally, Sheedy *et al.*[73] noted that voluntary eyelid squinting reduced the blink rate significantly. Therefore, the poorer image quality of the electronic text (as evidenced by increased reports of blurred vision during the course of a computer task when compared with printed materials[20]) may adversely affect the blink rate. Interestingly, the application of topical elastoviscous solutions to the cornea does not modify the reduced blink rate associated with VDT use.[74] Reduced blinking may also exaggerate the symptoms of pre-existing dry eye, which could be exacerbated by other aspects of the work environment as noted above, as well as factors such as contact lens wear and increasing age (particularly in females).

(3) Incomplete blinking. While blink rate has been shown to decrease significantly with computer use,[68,69,74] an additional factor to consider is the completeness of the blink, i.e. does the upper lid cover the exposed cornea completely during the blink process. Himebaugh *et al.*[71] analyzed the blink amplitude during a number of tasks including computer operation and observed that incomplete blinking was common, task dependent and present in all subjects. These included both individuals with symptoms of dry eye and aged-matched normals. It is unclear whether incomplete blinking is undesirable. Harrison *et al.*[75] noted that partial blinking is associated with staining of (and presumably damage to) the inferior cornea.[76,77] Yet incomplete blinking is commonly found in asymptomatic patients[77] and provided that portion of the cornea covering the pupil is covered by the upper eyelid, one would expect to find uninterrupted clear vision. A recent study by Portello *et al.*[78] examined both the completeness of the blink during computer operation and post-task symptoms. A significant positive correlation was observed between the percentage of blinks deemed incomplete and the total symptom score. This is illustrated in *Figure 4*. These findings suggest that incomplete blinking leading to ocular dryness may be a significant cause of CVS. Additionally, Chu *et al.*[79] noted both a higher prevalence of incomplete blinking and higher symptom score in subjects following a reading task performed on a VDT, when compared with subjects undertaking the same task from hard copy material. These findings also imply that incomplete blinking may be a

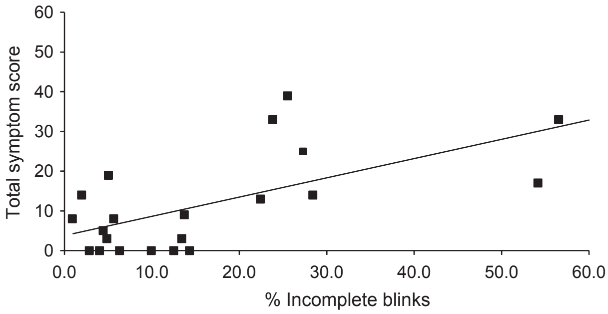

Figure 4. Total symptom score plotted as a function of the percentage of blinks that were deemed incomplete during the course of a 15 min computer task performed at a viewing distance of 50 cm in 21 subjects. A significant positive correlation was observed ($r = 0.63$; $p = 0.002$). Even if the two outlying subjects with more than 50% of their blinks being incomplete are removed from the analysis, the correlation is still statistically significant ($r = 0.63$; $p = 0.004$). Data from Portello *et al.*[78]

partial cause of CVS symptoms. Interestingly, Harrison *et al.*[75] observed that partial blinking may be advantageous since it does not interrupt concentration on a visual task as much as complete blinks. This is consistent with the findings of Portello and Rosenfield[80] who reported that increased conscious blinking during computer operation interfered with the subjects' ability to perform the task satisfactorily.

(4) Increased corneal exposure. Desktop computers are commonly used with the eyes in the primary position, whereas hardcopy text is more commonly read with the eyes depressed. The increased corneal exposure associated with the higher gaze angle could also result in an increased rate of tear evaporation. It should also be noted that laptop computers are more typically used in downward gaze while smartphone type devices can be held in primary or downward gaze. Variations in the angle of gaze may also alter either the accommodative and/or vergence response,[81–83] and therefore the level of symptoms experienced.

(5) Age and gender. The prevalence of dry eye increases with age and is higher in women than men.[13,84–90] The estimated prevalence of dry eye in women and men over 50 years of age in the USA is 7.8% and 4.3%, respectively.[89,90]

(6) Systemic diseases and medications. While a review of this topic is beyond the scope of this paper, Moss *et al.*[91,92] reported that the incidence of dry eye was greater in subjects with arthritis, allergy or thyroid disease not treated with hormones. Additionally, the incidence was higher in individuals taking antihistamines, anti-anxiety medications, antidepressants, oral steroids or vitamins, as well as those with poorer self-rated health. A lower incidence of dry eye was found with higher alcohol consumption levels.

(7) Contact lens wear. The presence of a contact lens on the anterior surface of the cornea has been shown to alter the blink rate significantly. This may result from irritation by the lens or a more unstable tear film.[69] York *et al.*[93] examined the effect of contact lenses on blink rate during conditions of varying levels of difficulty. Subjects were required to view either an audio-visual film strip, read graded material or read material while determining how many times the letter 'a' appeared in the text. The authors observed that while the mean blink rate decreased with increasing task difficulty for all conditions, wearing contact lenses increased the blink rate. However, the subjects in this study were all new contact lens wearers, and the authors speculated that over time, increasing adaptation to the lenses could lessen the effect of contact lenses on blink rate. Indeed, an investigation by Pointer[94] on new hydrophilic contact lens wearers observed that over a 1 month lens adaptation period, task difficulty became the predominant stimulus for blink rate.

A recent report by Jansen *et al.*[72] examined the effect of task difficulty in adapted contact lens wearers. In comparing the inter-blink interval when either listening to music or playing a video game, a significantly longer inter-blink interval was noted for the video game when contact lenses were not worn. However, when subjects wore their habitual contact lenses, no significant difference in blink rate was observed as a function of task difficulty. These results suggest that soft contact lenses, even in a fully adapted wearer provide sufficient ocular surface or lid stimulation to increase the rate of blinking. Based on these results, one might speculate that if CVS is produced by a decreased blink rate, symptoms should be less severe in adapted contact lens wearers. However, this proposal contradicts the finding that contact lens wearers are 12 times more likely than emmetropes and five times more likely than spectacle wearers to report dry eye symptoms.[95] For a much fuller discussion on the topic of dry eye and contact lens wear, see the report of the definition and classification subcommittee of the International Dry eye workshop.[96]

As noted previously, the presence of relatively small amounts of uncorrected astigmatism (<1.0 D) may produce a significant increase in symptoms of CVS.[26,27] Common clinical practice is to provide patients seeking contact lenses who have astigmatism of this magnitude with spherical lenses. Accordingly, increased symptoms might occur in these individuals, not as a result of the contact lens inducing or enhancing problems associated with dry eye, but rather as a result of the uncorrected refractive error. The use of toric contact lenses or a spectacle overcorrection to eliminate the uncorrected astigmatism may be appropriate here.

(8) Ocular conditions. An extensive review of dry eye disease[96] noted that this condition could either be caused by decreased lacrimal tear secretion or excessive evaporation. Either of these causes could lead to symptoms of CVS. Decreased secretion could be due to Sjogren's syndrome, an autoimmune condition which affects both the lacrimal and salivary glands.[97] Alternatively, reduced tear output could result from either primary or secondary deficiencies or obstruction of the lacrimal glands, reflex hyposecretion resulting from reduced sensory input from the trigeminal nerve or damage to the facial nerve. Evaporative dry eye could be extrinsic, resulting from Meibomian gland dysfunction, an increase in exposed ocular surface area or a low blink rate or extrinsic, being due to ocular surface disorders (including

vitamin A deficiency) or diseases including allergic conjunctivitis.

Potential treatments for CVS

Potential therapeutic interventions for patients with symptoms of CVS can be divided into three main areas namely:

(1) Refractive and accommodative disorders
(2) Vergence anomalies
(3) Dry eye

Refractive and accommodative anomalies

As noted earlier, the presence of uncorrected ametropia may lead to an increase in symptoms. Given that individuals may spend many hours (often continuously) viewing electronic screens, it is important that they are able to maintain a clear image of the target over time. There is little evidence to support the proposal that the accommodative demands of the VDT differ from viewing printed materials at the same distance and gaze angle. However, the presence of any refractive or accommodative anomaly (e.g. accommodative infacility or insufficiency[53]) could impact upon the patient's level of visual comfort during the task. In examining patients with CVS, the following clinical parameters should be assessed [with all near testing being performed at the distance(s) at which the electronic screen(s) are positioned]:

(1) Best corrected visual acuity
(2) Refractive error (including binocular balancing)
(3) Accommodative error (lag) at the appropriate working distance
(4) Monocular and binocular amplitude of accommodation
(5) Monocular and binocular accommodative facility
(6) Negative and positive relative accommodation

Patients with accommodative anomalies may benefit from measures to improve the accuracy and dynamics of their accommodative response, including vision therapy and/or the provision of lenses to provide a clear image of the target at the required viewing distance and gaze angle. If adjustments can be made to optimize the design of the workstation, these should also be discussed with the patient.

In addition, patients should be advised regarding their working times. Fixation on any near object for a sustained period of time, whether a computer screen or printed material may lead to asthenopia. Indeed, Henning *et al.*[98] compared computer workers typing performance at baseline, when they were allowed three 30 s breaks plus a 3 min break each hour, and a rest break plus exercise condition where stretching exercises were introduced during the breaks. A 5% and 15% improvement in productivity was observed for the breaks and breaks plus exercise conditions, respectively. Accordingly, it seems reasonable that any patient should be advised to take breaks and to look into the distance periodically in order to reduce the accommodation and vergence responses.

Vergence anomalies

It has been demonstrated that subjects reading text on a computer were most symptomatic when they converged accurately on the screen, i.e. having ortho associated phoria (AP), when compared with individuals having exo AP who were less symptomatic (see *Figure 3*).[43] Given this finding, one might conjecture whether intentional correction of a subject's AP to an exo posture would reduce asthenopic symptoms after a computer task. Accordingly, our laboratory compared post-task symptoms immediately following a continuous 20 min reading task from a desktop computer monitor at a viewing distance of 50 cm. Each subject ($n = 40$) attended for two trials. In the first session, subjects wore the amount of prism corresponding to their AP at the computer test distance over their refractive correction. In the second trial, subjects were given 3Δ more base-out prism than their measured AP in order to induce an AP of 3Δ exo. No significant difference in total ocular symptom score between the two groups was observed following these two conditions. However, five individuals showed a significant preference for the ortho condition, whereas nine subjects showed a marked preference for the 3Δ exo condition. Further analysis indicated differences in binocular accommodative parameters between these two subgroups. The group whose symptoms were reduced with exo AP had significantly lower negative relative accommodation (NRA) and a higher accommodative response (i.e. smaller lag) when compared with the ortho AP preferred group. No significant difference in either distance or near heterophoria was observed between the two groups. Thus a subgroup of patients may exist whose symptoms of CVS can be alleviated by creating exo AP. This proposal should be examined further in a larger population.

Any vergence anomaly which would cause difficulty with maintaining clear and single vision of printed text at near (e.g. uncompensated heterophoria, convergence excess or insufficiency or vergence infacility) is likely to give rise to symptoms during sustained viewing of an electronic screen at near. Accordingly, when examining patients with CVS, the following clinical vergence parameters should be assessed [with all near testing being performed at the distance(s) at which the electronic screen(s) are positioned]:

(1) Near point of convergence

(2) Near heterophoria
(3) Horizontal and vertical fixation disparity and/or associated phoria.
(4) Vergence facility
(5) Vergence ranges (negative and positive relative vergence)
(6) Stereopsis
(7) AC/A and CA/C ratios.

Dry eye

As noted previously, the presence of dry eye may play a significant role in the aetiology of CVS. Computer use has been associated with both a reduced rate of blinking and a high number of incomplete blinks when compared with viewing hard copy materials. Additionally, the environments where computers are located often have low ambient humidity and forced-air heating or air conditioning which may exacerbate symptoms of dry eye. Accordingly, practitioners should consider both patient education and a range of therapies available to attenuate this condition.

Dry eye therapies which have been proposed to minimize symptoms of CVS include the use of lubricating drops, ointments and topical medications for blepharitis or allergic conditions. Additionally, blink training to increase the blink rate during computer use,[99] as well as changes in ambient humidity, hydration (drinking more water) and redirection of heating and air conditioning vents have all been proposed.

The benefit of many of these therapies for minimizing CVS symptoms is unproven. For example, Acosta *et al.*[74] observed that topical instillation of an elastoviscous solution did not produce a significant change in the computer-induced reduction in blink rate. Mean blink rates for the computer condition with and without instillation of the elastoviscous solution were 6.4 and 6.1 blinks min^{-1}, respectively. Accordingly, it is uncertain whether the use of lubricating or rewetting drops will indeed reduced CVS symptoms. With regard to increasing the blink rate, Portello and Rosenfield[80] compared post-task symptoms when subjects were either allowed to blink voluntarily or when the blink rate was consciously increased using a metronome during computer use. Although a significantly increased blink rate was recorded in the metronome condition (23.5 vs 11.3 blinks min^{-1} in the control session), no significant difference in post-task CVS symptoms was found either in the entire population tested ($n = 23$) or in those subjects reporting the highest symptom scores in the control condition. Furthermore, several subjects stated that increased conscious blinking interfered with their ability to perform the task satisfactorily, which may limit the practicality of this advice.

Furthermore, Acosta *et al.*[74] noted that blowing an air stream onto the face while subjects were playing a computer game did not produce a significant change in blink rate. Accordingly, to date there appears to be little experimental evidence to support many of the therapeutic interventions that have been proposed. Further work is required to determine what aspects of dry eye treatments will indeed reduce CVS symptoms.

Conclusions

As noted above, the use of electronic devices to view small type for many hours, frequently at close working distances, has become commonplace in modern society in patients of all ages. Many individuals use multiple devices such as a desktop and laptop computer as well as one or more handheld devices. These present a variety of visual demands that are significantly different from those of printed materials in terms of working distances, gaze angles and text sizes. It is no longer reasonable to assume that a patient will read text at a viewing distance of approximately 40 cm with their eyes depressed. Accordingly, a significant change in both optometric testing methods and the design of ophthalmic lenses (particularly for the correction of presbyopia) will probably be required.

Given that the prevalence of symptoms (including eyestrain, headaches, ocular discomfort, dry eye, diplopia and blurred vision) may be as high as 90%, it is likely that an increasing number of patients will present for eye examinations due to symptoms associated with CVS. Practitioners need to consider what are appropriate examination procedures and treatment regimens for these individuals. Near testing at a single distance and gaze angle such as is commonly employed when a nearpoint card is positioned in the primary position at a viewing distance of 40 cm is not adequate. The assessment of oculomotor functions at multiple viewing distances and gaze angles may be required. One should note that this cannot be achieved when the patient is viewing through a phoropter, and nearpoint testing in free space, with the patient wearing a correction mounted in a trial frame is required.

In addition, prescribing routines may need to be reconsidered. For example, small refractive errors (such as astigmatism between 0.50 and 1.00 D), which might have been left uncorrected in the past (particularly in contact lens wearers), should be corrected in a patient who is viewing an electronic screen for an extensive period of time. Similarly, instances of low to moderate oculomotor anomalies or cases of dry eye, which might previously have been left uncorrected may be of sufficient magnitude to cause significant symptoms when combined with prolonged computer use.

It is worth noting that the symptoms of CVS associated with accommodation and vergence disorders do seem, in most cases, to be a result of viewing a visually demanding near target for an extended period of time and not specific to the electronic monitor. In contrast, symptoms of dry eye do appear to be directly related to computer use due to the position of the monitor (producing increased corneal exposure), reduced blink rate, increased partial blinking and other environmental factors. Further research is required to determine the efficacy of dry eye treatments in reducing symptoms of CVS.

Given the remarkably high number of hours per day that many (or perhaps most) individuals now spend viewing small text on electronic screens at close working distances and varying gaze angles, it is incumbent upon all eye care practitioners to have a good understanding of the symptoms associated with, and the physiology underlying CVS. As modern society continues to move towards greater use of electronic devices for both work and leisure activities, it seems likely that the visual demands that these place upon our patients will only continue to increase. An inability to satisfy these visual requirements could present significant lifestyle difficulties for patients.

Acknowledgement

I would like to acknowledge the assistance of the following colleagues in this research: Yuliya Bababekova, Jaclyn Benzoni, Christina Chu, Juanita Collier, Rae Huang, Jennifer Hue, Marc Lay, Joan Portello, Daniel Recko, Elizabeth Wickware and Abraham Zuckerbrod.

References

1. Rideout VJ, Foehr UG & Roberts DF. Generation M^2. Media in the Lives of 8- to 18-Year Olds. A Kaiser Family Foundation Study. The Henry J. Kaiser Family Foundation: Menlo Park, CA, 2010.
2. Thomson DW. Eye problems and visual display terminals-the facts and the fallacies. *Ophthal Physiol Opt* 1998; 18: 111–119.
3. Rossignol AM, Morse EP, Summers VM & Pagnotto LD. Visual display terminal use and reported health symptoms among Massachusetts clerical workers. *J Occup Med* 1987; 29: 112–118.
4. Bhanderi DJ, Choudharg S & Doshi VG. A community-based study of asthenopia in computer operators. *Indian J Ophthalmol* 2008; 56: 51–55.
5. Mocci F, Serra A & Corrias GA. Psychological factors and visual fatigue in working with video display terminals. *Occup Environ Med* 2001; 58: 267–271.
6. Sanchez-Roman FR, Pererz-Lucio C, Juarez-Ruiz C, Velez-Zamora NM & Jimenez-Villarruel M. Risk factors for asthenopia among computer terminal operators. *Salud Publica Mex* 1996; 38: 189–196.
7. Dain SJ, McCarthy AK & Chan-Ling T. Symptoms in VDU operators. *Am J Optom Physiol Opt* 1988; 65: 162–167.
8. Hayes JR, Sheedy JE, Stelmack JA & Heaney CA. Computer use, symptoms, and quality of life. *Optom Vis Sci* 2007; 84: 738–744.
9. Rocha LE & Debert-Ribeiro M. Working conditions, visual fatigue and mental health among systems analysts in Sao Paulo, Brazil. *Occup Environ Med* 2004; 61: 24–32.
10. Wiholm C, Richter H, Mathiassen SE & Toomingas A. Associations between eyestrain and neck-shoulder symptoms among call-center operators. *SJWEH Suppl* 2007; 3: 54–59.
11. Taino G, Ferrari M, Mestad IJ, Fabris F & Imbriani M. Asthenopia and work at video display terminals: study of 191 workers exposed to the risk by administration of a standardized questionnaire and ophthalmologic evaluation. *G Ital med Lav Ergon* 2006; 28: 487–497.
12. Iwakiri K, Mori I, Sotoyama M *et al.* Survey on visual and musculoskeletal symptoms in VDT workers. *Sangyo Eiseigaku Zasshi* 2004; 46: 21–212.
13. Salibello C & Nilsen E. Is there a typical VDT patient? A demographic analysis. *J Am Optom Assoc* 1995; 66: 479–483.
14. Shima M, Nitta Y, Iwasaki A & Adachi M. Investigation of subjective symptoms among visual display terminal users and their affecting factors – analysis using log-linear models. *Nippon Eiseigaku Zasshi* 1993; 47: 1032–1040.
15. Sheedy JE, Hayes J & Engle J. Is all asthenopia the same? *Optom Vis Sci* 2003; 80: 732–739.
16. Sheedy JE, Bailey IL & Fong D. Editing performance-VDT vs. hard copy, black on white vs. white on black. *Optom Vis Sci* 1989; 66 (Suppl): 118.
17. Wilkinson RT & Robinshaw HM. Proof reading: VDU and paper text compared for speed, accuracy and fatigue. *Behav Inf Technol* 1987; 6: 125–133.
18. Wright P & Lickorish A. Proofreading texts on screen and paper. *Behav Inf Technol* 1983; 2: 227–235.
19. Yang SN, Tai YC, Hayes JR, Doherty R, Corriveau P & Sheedy JE. Effects of font size and display quality on reading performance and visual discomfort of developmental readers. *Optom Vis Sci* 2010; 87: E-abstract 105244.
20. Chu C, Rosenfield M, Portello JK, Benzoni JA & Collier JD. A comparison of symptoms after viewing text on a computer screen and paper. *Ophthal Physiol Opt* 2011; 31: 29–32.
21. Bohr PC. Efficacy of office ergonomics education. *J Occup Rehabil* 2000; 10: 243–255.
22. Speklé EM, Heinrich J, Hoozemans MJM *et al.* The cost-effectiveness of the RSI QuickScan intervention programme for computer workers: results of an economic evaluation alongside a randomized controlled trial. *BMC Musculoskelet Disord* 2010; 11: 259–270.
23. Wahlstrom J. Ergonomics, musculoskeletal disorders and computer work. *Occup Med* 2005; 55: 168–176.
24. Chindlea GG. About a healthy workstation. Annals of the Oradea University. Fascicle of Management and Technological Engineering, Vol VII (XVII), 2008:1998–2005.

25. Daum KM, Clore KA, Simms SS *et al.* Productivity associated with visual status of computer users. *Optometry* 2004; 75: 33–47.
26. Wiggins NP & Daum KM. Visual discomfort and astigmatic refractive errors in VDT use. *J Am Optom Assoc* 1991; 62: 680–684.
27. Wiggins NP, Daum KM & Snyder CA. Effects of residual astigmatism in contact lens wear on visual discomfort in VDT use. *J Am Optom Assoc* 1992; 63: 177–181.
28. Bilton N. I Live in the Future & Here's How It Works. Crown Business: New York, 2010.
29. Rosenfield M, Bababekova Y, Huang R & Hue J. Font size and viewing distance of hand-held smart phones. *Optom Vis Sci* 2010; 87: E-abstract 105697.
30. DeMarco LM & Massof RW. Distribution of print sizes in U.S. newspapers. *J Vis Impair Blind* 1997; 91: 9–13.
31. Sheedy JE & Shaw-McMinn PG. Diagnosing and Treating Computer-Related Vision Problems. Butterworth Heinemann: Burlington, MA, 2003.
32. Bailey IL. Visual acuity. In: Borish's Clinical Refraction (Benjamin WJ, editor), 2nd edition, Butterworth Heinemann: St Louis, 2006; pp. 217–246.
33. Bennett ES. Contact lens correction of presbyopia. *Clin Exp Optom* 2008; 91: 265–278.
34. Jones L & Dumbleton K. Contact lenses. In: Optometry: Science, Techniques and Clinical Management (Rosenfield M & Logan N, editors), Butterworth-Heinemann Elsevier: Edinburgh, 2009; pp. 335–355.
35. Wolffsohn JS & Davies LN. Intraocular lenses in the 21st century. *Clin Exp Optom* 2010; 93: 377–378.
36. Straker L, Jones KJ & Miller J. A comparison of the postures assumed when using laptop computers and desktop computers. *Appl Ergon* 1997; 28: 263–268.
37. Harris C & Straker L. Survey of physical ergonomics issues associated with school childrens' use of laptop computers. *Int J Ind Ergon* 2000; 26: 337–347.
38. Yang SN, Tai YC, Hayes JR, Doherty R, Corriveau P & Sheedy JE. Effects of screen luminance and text contrast on reading performance and visual discomfort of developmental readers. *Optom Vis Sci* 2010; 87: E-abstract 105247.
39. Birnbaum MH. Optometric Management of Nearpoint Vision Disorders. Butterworth-Heinemann: Boston, 1993; pp. 121–160.
40. Sheedy JE & Parsons SD. The visual display terminal eye clinic: clinical report. *Optom Vis Sci* 1990; 67: 622–626.
41. Wick B & Morse S. Accommodative accuracy to video display monitors. *Optom Vis Sci* 2002; 79s: 218.
42. Penisten DK, Goss DA, Philpott G, Pham A & West RW. Comparisons of dynamic retinoscopy measurements with a print card, a video display terminal, and a PRIO system tester as test targets. *Optometry* 2004; 75: 231–240.
43. Collier JD & Rosenfield M. Accommodation and convergence during sustained computer work. *Optom Vis Sci* 2006; 83: E-abstract 060034.
44. Tosha C, Borsting E, Ridder WH & Chase C. Accommodation response and visual discomfort. *Ophthal Physiol Opt* 2009; 29: 625–633.
45. Rosenfield M, Gurevich R, Wickware E & Lay M. Computer vision syndrome: accommodative and vergence facility. *J Behav Optom* 2010; 21: 119–122.
46. Richter HO, Bänziger T, Abdi S & Forsman M. Stabilization of gaze: a relationship between ciliary muscle contraction and trapezius muscle activity. *Vision Res* 2010; 50: 2559–2569.
47. Lie I & Watten RG. Oculomotor factors in the aetiology of occupational cervicobrachial diseases (OCD). *Eur J Appl Physiol Occup Physiol* 1987; 56: 151–156.
48. Wilkins AJ & Nimmo-Smith I. On the reduction of eyestrain when reading. *Ophthalmic Physiol Opt* 1984; 4: 53–59.
49. Wilkins A. What is visual discomfort? *Trends Neurosci* 1986; 9: 343–346.
50. Ciuffreda KJ, Scheiman M, Ong E, Rosenfield M & Solan HA. Irlen lenses do not improve accommodative accuracy at near. *Optom Vis Sci* 1997; 74: 298–302.
51. Simmers AJ, Gray LS & Wilkins AJ. The influence of tinted lenses upon ocular accommodation. *Vision Res* 2001; 41: 1229–1238.
52. O'Connor PD, Sofo F, Kendall L & Olsen G. Reading disabilities and the effects of colored filters. *J Learn Disabil* 1990; 23: 597–603, 620.
53. Rosenfield M. Accommodation. In: The Ocular Examination. Measurement and Findings (Zadnik K editor), Saunders: Philadelphia, 1997; pp. 87–121.
54. Watten RG, Lie I & Birketvedt O. The influence of long-term visual near-work on accommodation and vergence: a field study. *J Hum Ergol* 1994; 23: 27–39.
55. Evans BJW. Binocular vision assessment. In: Optometry: Science, Techniques and Clinical Management (Rosenfield M & Logan N, editors), Butterworth-Heinemann Elsevier: Edinburgh, 2009; pp. 245–246.
56. Nyman KG, Knave BG & Voss M. Work with video display terminals among office employees. *Scand J Work Environ Health* 1985; 11: 483–487.
57. Yeow PT & Taylor SP. Effects of short-term VDT usage on visual functions. *Optom Vis Sci* 1989; 66: 459–466.
58. Yeow PT & Taylor SP. Effects of long-term visual display terminal usage on visual functions. *Optom Vis Sci* 1991; 68: 930–941.
59. Jaschinski-Kruza W. Fixation disparity at different viewing distances of a visual display unit. *Ophthal Physiol Opt* 1993; 13: 27–34.
60. Jaschinski W. The proximity-fixation-disparity curve and the preferred viewing distance at a visual display as an indicator of near vision fatigue. *Optom Vis Sci* 2002; 79: 158–169.
61. Jenkins TCA, Pickwell LD & Yekta AA. Criteria for decompensation in binocular vision. *Ophthal Physiol Opt* 1989; 9: 121–125.

62. Pickwell LD, Kaye NA & Jenkins TCA. Distance and near readings of associated heterophoria taken on 500 patients. *Ophthal Physiol Opt* 1991; 11: 291–296.
63. Karania R & Evans BJ. The Mallett fixation disparity test: influence of test instructions & relationship with symptoms. *Ophthal Physiol Opt* 2006; 26: 507–522.
64. Sheedy JE & Saladin JJ. Exophoria at near in presbyopia. *Am J Optom Physiol Opt* 1975; 52: 474–481.
65. Uchino M, Schaumberg DA, Dogru M *et al.* Prevalence of dry eye disease among Japanese visual display terminal users. *Ophthalmology* 2008; 115: 1982–1998.
66. Blehm C, Vishnu S, Khattak A *et al.* Computer vision syndrome: a review. *Surv Ophthalmol* 2005; 50: 253–262.
67. Tsubota K & Nakamori K. Dry eyes and video display terminals. *N Engl J Med* 1993; 328: 584–585.
68. Patel S, Henderson R, Bradley L *et al.* Effect of visual display unit use on blink rate and tear stability. *Optom Vis Sci* 1991; 68: 888–892.
69. Schlote T, Kadner G & Freudenthaler N. Marked reduction and distinct patterns of eye blinking in patients with moderately dry eyes during video display terminal use. *Graefes Arch Clin Exp Ophthalmol* 2004; 242: 306–312.
70. Gowrisankaran S, Sheedy JE & Hayes JR. Eyelid squint response to asthenopia-inducing conditions. *Optom Vis Sci* 2007; 84: 611–619.
71. Himebaugh NL, Begley CG, Bradley A & Wilkinson JA. Blinking and tear break-up during four visual tasks. *Optom Vis Sci* 2009; 86: 106–114.
72. Jansen ME, Begley CG, Himebaugh NH & Port NL. Effect of contact lens wear and a near task on tear film break-up. *Optom Vis Sci* 2010; 87: 350–357.
73. Sheedy JE, Gowrisankaran S & Hayes JR. Blink rate decreases with eyelid squint. *Optom Vis Sci* 2005; 82: 905–911.
74. Acosta MC, Gallar J & Belmonte C. The influence of eye solutions on blinking and ocular comfort at rest and during work at video display terminals. *Exp Eye Res* 1999; 68: 663–669.
75. Harrison WW, Begley CG, Liu H, Chen M, Garcia M & Smith JA. Menisci and fullness of the blink in dry eye. *Optom Vis Sci* 2008; 85: 706–714.
76. Abelson MB & Holly FJ. A tentative mechanism for inferior punctuate keratopathy. *Am J Ophthalmol* 1977; 83: 866–869.
77. Collins MJ, Iskander DR, Saunders A, Hook S, Anthony E & Gillon R. Blinking patterns and corneal staining. *Eye Contact Lens* 2006; 32: 287–293.
78. Portello JK, Rosenfield M & Chu CA. Incomplete blinks and computer vision syndrome. *Optom Vis Sci* 2010; 87: E-abstract 105993.
79. Chu CA, Rosenfield M & Portello JK. Computer vision syndrome: blink rate and dry eye during hard copy or computer viewing. *Optom Vis Sci* 2010; 87: E-abstract 100698.
80. Portello JK & Rosenfield M. Effect of blink rate on computer vision syndrome. *Optom Vis Sci* 2009; 86: E-abstract 95828.
81. Jainta S & Jaschinski W. Fixation disparity: binocular vergence accuracy for a visual display at different positions relative to the eyes. *Hum Factors* 2002; 44: 443–450.
82. Ripple PH. Variation of accommodation in vertical directions of gaze. *Am J Ophthalmol* 1952; 35: 1630–1634.
83. Takeda T, Neveu C & Stark L. Accommodation on downward gaze. *Optom Vis Sci* 1992; 69: 556–561.
84. Shimmura S, Shimazaki J & Tsubota K. Results of a population-based questionnaire on the symptoms and lifestyles associated with dry eye. *Cornea* 1999; 18: 408–411.
85. Gayton JL. Etiology, prevalence, and treatment of dry eye disease. *Clin Ophthalmol* 2009; 3: 405–412.
86. Xu L, You QS, Wang YX & Jonas JB. Associations between gender, ocular parameters and diseases: the Beijing eye study. *Ophthal Res* 2010; 45: 197–203.
87. Guillon M & Maïssa C. Tear film evaporation – effect of age and gender. *Cont Lens Anterior Eye* 2010; 33: 171–175.
88. Maïssa C & Guillon M. Tear film dynamics and lipid layer characteristics – effect of age and gender. *Cont Lens Anterior Eye* 2010; 33: 176–182.
89. Schaumberg DA, Sullivan DA, Buring JE & Dana MR. Prevalence of dry eye syndrome among US women. *Am J Ophthalmol* 2003; 136: 318–326.
90. Schaumberg DA, Dana MR, Buring JE & Sullivan DA. Prevalence of dry eye disease among US men: estimates from the Physicians' Health Studies. *Arch Ophthalmol* 2009; 127: 763–768.
91. Moss SE, Klein R & Klein BEK. Prevalence of and risk factors for dry eye syndrome. *Arch Ophthalmol* 2000; 118: 1264–1268.
92. Moss SE, Klein R & Klein BEK. Long-term incidence of dry eye in an older population. *Optom Vis Sci* 2008; 85: 668–674.
93. York M, Ong J & Robbins JC. Variation in blink rate associated with contact lens wear and task difficulty. *Am J Optom Arch Am Acad Optom* 1971; 48: 461–467.
94. Pointer JS. Eyeblink activity with hydrophilic contact lenses. A concise longitudinal study. *Acta Ophthalmol* 1998; 66: 498–504.
95. Nichols JJ, Ziegler C, Mitchell GL & Nichols KK. Self-reported dry eye disease across refractive modalities. *Invest Ophthalmol Vis Sci* 2005; 46: 1911–1914.
96. The definition and classification of dry eye disease: report of the definition and classification subcommittee of the international dry eye workshop (2007). *Ocul Surf* 2007; 5: 75–92.
97. Bayetto K & Logan RM. Sjögren's syndrome: a review of aetiology, pathogenesis, diagnosis and management. *Aust Dent J* 2010; 55 (Suppl 1): 39–47.
98. Henning RA, Jacques P, Kissel GV, Sullivan AB & Alteras-Webb SM. Frequent short rest breaks from computer work: effects on productivity and well-being at two field sites. *Ergonomics* 1997; 40: 78–91.
99. Shaw-McMinn PG. CVS: the practical and the clinical. *Rev Optom* 2001; 138: 78–88.