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Accommodation and convergence during sustained computer work

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Computer vision syndrome;
Fixation disparity;
Video display terminal;
Vergence

Abstract

PURPOSE: With computer usage becoming almost universal in contemporary society, the reported prevalence of computer vision syndrome (CVS) is extremely high. However, the precise physiological mechanisms underlying CVS remain unclear. Although abnormal accommodation and vergence responses have been cited as being responsible for the symptoms produced, there is little objective evidence to support this claim. Accordingly, this study measured both of these oculomotor parameters during a sustained period of computer use.

METHODS: Subjects (N = 20) were required to read text aloud from a laptop computer at a viewing distance of 50 cm for a sustained 30-minute period through their habitual refractive correction. At 2-minute intervals, the accommodative response (AR) to the computer screen was measured objectively using a Grand Seiko WAM 5500 optometer (Grand Seiko, Hiroshima, Japan). Additionally, the vergence response was assessed by measuring the associated phoria (AP), i.e., prism to eliminate fixation disparity, using a customized fixation disparity target that appeared on the computer screen. Subjects were asked to rate the degree of difficulty of the reading task on a scale from 1 to 10.

RESULTS: Mean accommodation and AP values during the task were 1.07 diopters and 0.74Δ base-in (BI), respectively. The mean discomfort score was 4.9. No significant changes in accommodation or vergence were observed during the course of the 30-minute test period. There was no significant difference in the AR as a function of subjective difficulty. However, the mean AP for the subjects who reported the least and greatest discomfort during the task was 1.55Δ BI and 0, respectively ($P = 0.02$).

CONCLUSIONS: CVS, after 30 minutes was worse in subjects exhibiting zero fixation disparity when compared with those subjects having a BI AP but does not appear to be related to differences in accommodation. A slightly reduced vergence response increases subject comfort during the task.
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Computer vision syndrome (CVS) is defined by the American Optometric Association as the combination of eye and vision problems associated with the use of computers.[1] These symptoms result from the individual having insufficient visual capabilities to perform the computer task comfortably. Environmental factors, such as ambient temperature and humidity, the type of lighting, and the setup of the workstation may also contribute to both ocular and general discomfort.[2] In 2000, it was estimated that 75% of jobs involved computer use.[3] It seems likely that this number has now increased, and when combined with online activities such as e-mail, Internet access, shopping, and entertainment, one might suggest that computer usage is now almost universal.

Additionally, previous reports have suggested that between 64% and 90% of computer users experience visual

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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.[3] These symptoms may be produced by the organization of the workstation environment, inadequate wetting of the corneal surface, near-vision abnormalities (such as accommodation-vergence difficulties), or inappropriate refractive correction (e.g., incorrect positioning of a near addition). Rossignol et al.[4] reported that the prevalence of visual symptoms increased significantly in individuals who spent more than 4 hours daily working on video display terminals (VDTs). Of these reported complaints, eyestrain or sore eyes was the most prevalent condition, and the occurrence was significantly greater for workers who used VDTs for at least 7 hours per day when compared with those who used the displays for shorter periods. After eyestrain or sore eyes, the most common symptoms in order of prevalence were burning or irritated eyes, blurred vision, tearing or itching, and red eyes.

While both accommodation and vergence have been cited as contributing to symptoms associated with computer use, there are relatively few objective data detailing how these oculomotor parameters change during computer work. Wick and Morse[5] used an objective infrared optometer to measure the accommodative response (AR) in 5 emmetropic subjects when viewing either a VDT or printed copy of the same text displayed on the monitor. They reported that 4 subjects showed an increased lag of accommodation to the VDT (mean increase, 0.33 diopters [D]) when compared with the hard copy condition. Later, Penisten et al.[6] used dynamic retinoscopy to assess the AR when subjects viewed a printed card, a VDT, or a simulated computer display. Results were presented for 2 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 print target. For examiner 1, the mean lags of accommodation for the printed card and VDT were 0.63 D and 0.72 D, respectively, whereas for the second examiner the mean lags were 0.92 D and 0.75 D, respectively. These differences were smaller than the observed levels of inter- and intra-examiner repeatability.

Although 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.[7] measured positive and negative relative vergence (or vergence ranges)[8] at near both at the beginning and end of an 8-hour 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.[9] found no significant change in positive or negative relative vergence at near after 5 hours of VDT work. They also reported no significant change in either distance and near heterophoria or the near point of convergence (NPC) after the work period. Similarly, Yeow and Taylor[10] also observed no significant change in NPC after short-term VDT use (up to 2.35 hours of continuous use or an average of 4 hours intermittent use in a normal working situation). In a subsequent longitudinal study, Yeow and Taylor[11] 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. Although 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[12] measured both accommodation and fixation disparity during the course of a 30-minute 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[13] used fixation disparity as a measurement of near vision fatigue after 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. However, to date, there appears to have been no assessment of the vergence response as a function of symptoms during the course of a computer task. Accordingly, the aim of the current study was to measure both accommodation and vergence during a period of sustained VDT fixation and to determine whether either the magnitude of or changes in accommodation and/or vergence were related to discomfort during the task.

Methods

The study was performed on 20 visually normal subjects having a mean age of 24 years (range, 22 to 30 years); 17 were optometry students at the State University of New York State College of Optometry, and the remaining 3 were postgraduate students at other institutions. All had best-corrected visual acuities of at least 6/6 (20/20) in each eye. None had any manifest ocular disease as evidenced from a comprehensive eye examination. The study followed the tenets of the Declaration of Helsinki, and informed consent was obtained from all subjects after an explanation of the nature and possible consequences of the study. The protocol was approved by the Institutional Review Board at the State University of New York State College of Optometry.

Subjects were required to perform a sustained fixation task consisting of reading a story aloud from a Dell Latitude D600 laptop computer (Dell Corp., Round Rock, Texas), at a viewing distance of 50 cm for a continuous 30-minute period. The words on the screen were black on white (approximately 80% contrast) in Times New Roman font (8.5 point size). All trials were run by the principal author, who had control over the computer via an auxiliary monitor and mouse.

The AR was measured objectively from the right eye using a WAM-5500 open field, infrared optometer (Grand

Seiko Co., Ltd., Hiroshima, Japan). While subjects performed the task under binocular viewing conditions, measurements of the refractive state were recorded from the right eye only. Subjects wore their habitual refractive correction during the task, and a baseline measurement of the refractive state was obtained through this correction using the infrared optometer immediately before the start of the reading task. Five measurements of the refractive state were taken, converted to spherical equivalent (i.e., sphere + half cylinder power), and averaged. The laptop computer was placed just above the optometer (*see* Figure 1) and therefore was close to the primary position for the observer. This was necessary to facilitate measurements of accommodation.

The AR was measured at 2-minute intervals during the course of the 30-minute VDT task. Subjects were instructed to focus on the last word they read (which was highlighted by the examiner to ensure that the subject knew where to fixate) while their refractive state was measured. Five consecutive measurements were taken, as described previously, with the mean being recorded.

In addition to their refractive correction, subjects wore a pair of chromatic acetate filters, comprising a red and blue filter before the right and left eye, respectively, throughout the 30-minute reading task. These allowed the measurement of the AP during the VDT task. This was achieved by superimposing a colored fixation disparity test (*see* Figure 2) over the reading material and asking the subject to indicate whether the monocular vernier markers appeared "exactly one beneath the other." The top blue vernier line was visible to the right eye while the bottom red vernier marker was only seen by the left eye. The rectangles and other markings were visible to both eyes to provide a fusion stimulus. The design of the customized fixation disparity test, with a peripheral fusion lock and good accommodative stimulus, was similar to other commercially available fixation disparity apparatus (e.g., the Sheedy Disparometer [Vision Analysis, Walnut Creek, California] or the Wesson card [created and distributed by Dr. Michael Wesson]).[14] If the monocular markers appeared to be misaligned, a horizontal prism bar was introduced before the right eye, in increasing 1Δ steps, until the subject reported alignment of the vernier targets. The lowest prism that brought the vernier markers into apparent alignment was recorded as the AP. To minimize the break during the reading task, only one measurement of AP was taken immediately after each assessment of accommodation. However, both AR and AP were assessed without any break in fixation away from the computer monitor. As soon as both the refractive state and AP had been determined, the subject continued to read aloud until the 30-minute period had elapsed and the final measurements were taken. Determination of both AR and AP took approximately 30 to 40 seconds to complete.

Figure 1 Photograph of the experimental setup shows the laptop computer positioned in front of the infrared optometer. The colored filters, required for measurement of AP, are not shown here.

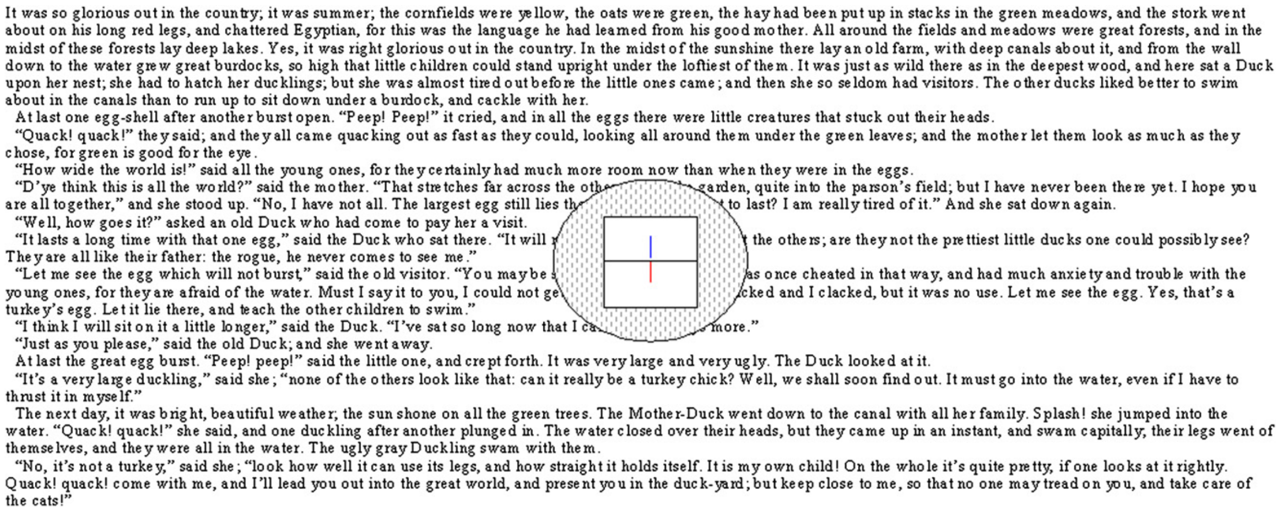
To ensure that the colored filters did not affect the measurements of accommodation, the AR was measured in a subgroup of 5 subjects viewing a near target at a distance of 40 cm. For the right eye, the mean refractive state with and without the red filter was –2.68 D (SD = 2.03) and –2.42 D (SD = 2.00), respectively (Mann-Whitney test, $P = 0.55$). For the left eye, the mean refractive state with and without the blue filter was –1.67 D (SD = 2.48) and –1.75 D (SD = 2.56), respectively (Mann-Whitney test, $P = 0.99$). Thus, the colored filters did not produce any clinically meaningful change in the AR.

Immediately after completion of the 30-minute reading period, subjects were asked to rate the level of ocular discomfort experienced during the task on a scale from 1 to 10. One was described as "negligible discomfort" while 10 was labeled "agony."

Results

When viewing the 2-dimensional stimulus, the initial mean AR before beginning the computer task was 0.84 D (SD = 0.57) The mean AR during the course of the 30-minute task is shown in Figure 3. The mean AR during the task was 1.07D, with a small increase in response as the task progressed. However, 1 factor, repeated measures, analysis of variance indicated that the change in AR over time was not significant ($P = 0.39$). The initial mean AP before beginning the computer task was 1.32Δ BI (SD = 2.08) The mean AP during the course of the 30-minute task is shown in Figure 4. Mean AP during the task was 0.74Δ BI and 1 factor, repeated measures, analysis of variance indicated that the change in AP over time was not significant ($P = 0.98$).

Discomfort scores recorded after the 30-minute task ranged from 2 to 8.5 with a mean of 4.9 (SD = 2.02). A plot of symptom scores as a function of the mean AP during the 30-minute test period is shown in Figure 5. A significant positive correlation was observed (r = 0.59; $P = 0.007$) with the highest symptom scores occurring in those subjects having either less than 1Δ BI or base-out AP. Further, subjects were divided into 2 groups based on the discomfort values. The 10 subjects reporting the highest discomfort level had a mean score of 6.6 (SD = 1.26; range, 4.5 to 8.5), whereas the 10 subjects having the lowest discomfort


It was so glorious out in the country; it was summer; the cornfields were yellow, the oats were green, the hay had been put up in stacks in the green meadows, and the stork went about on his long red legs, and chattered Egyptian, for this was the language he had learned from his good mother. All around the fields and meadows were great forests, and in the midst of these forests lay deep lakes. Yes, it was right glorious out in the country. In the midst of the sunshine there lay an old farm, with deep canals about it, and from the wall down to the water grew great burdocks, so high that little children could stand upright under the loftiest of them. It was just as wild there as in the deepest wood, and here sat a Duck upon her nest; she had to hatch her ducklings; but she was almost tired out before the little ones came; and then she so seldom had visitors. The other ducks liked better to swim about in the canals than to run up to sit down under a burdock, and cackle with her.

At last one egg-shell after another burst open. "Peep! Peep!" it cried, and in all the eggs there were little creatures that stuck out their heads.

"Quack! quack!" they said; and they all came quacking out as fast as they could, looking all around them under the green leaves; and the mother let them look as much as they chose, for green is good for the eye.

"How wide the world is!" said all the young ones, for they certainly had much more room now than when they were in the eggs.

"D'ye think this is all the world?" said the mother. "That stretches far across the oth... garden, quite into the parson's field; but I have never been there yet. I hope you are all together," and she stood up. "No, I have not all. The largest egg still lies th... to last? I am really tired of it." And she sat down again.

"Well, how goes it?" asked an old Duck who had come to pay her a visit.

"It lasts a long time with that one egg," said the Duck who sat there. "It will ... the others; are they not the prettiest little ducks one could possibly see? They are all like their father: the rogue, he never comes to see me."

"Let me see the egg which will not burst," said the old visitor. "You may be ... as once cheated in that way, and had much anxiety and trouble with the young ones, for they are afraid of the water. Must I say it to you, I could not ge... cked and I clacked, but it was no use. Let me see the egg. Yes, that's a turkey's egg. Let it lie there, and teach the other children to swim."

"I think I will sit on it a little longer," said the Duck. "I've sat so long now that I ca... more."

"Just as you please," said the old Duck; and she went away.

At last the great egg burst. "Peep! peep!" said the little one, and crept forth. It was very large and very ugly. The Duck looked at it.

"It's a very large duckling," said she; "none of the others look like that: can it really be a turkey chick? Well, we shall soon find out. It must go into the water, even if I have to thrust it in myself."

The next day, it was bright, beautiful weather; the sun shone on all the green trees. The Mother-Duck went down to the canal with all her family. Splash! she jumped into the water. "Quack! quack!" she said, and one duckling after another plunged in. The water closed over their heads, but they came up in an instant, and swam capitally; their legs went of themselves, and they were all in the water. The ugly gray Duckling swam with them.

"No, it's not a turkey," said she; "look how well it can use its legs, and how straight it holds itself. It is my own child! On the whole it's quite pretty, if one looks at it rightly. Quack! quack! come with me, and I'll lead you out into the great world, and present you in the duck-yard; but keep close to me, so that no one may tread on you, and take care of the cats!"

Figure 2 Measurement of AP. The colored vernier target appeared on the screen, superimposed over the text being read. Subjects wore red and blue filters over their right and left eyes, respectively. Any vertical misalignment was reported and horizontal prism introduced to eliminate the fixation disparity.

score had a mean score of 3.20 (SD = 0.75; range, 2.0 to 4.0). In comparing the within-task AR in these 2 groups, as shown in Figure 6, no significant difference was observed during the course of the 30-minute task (Mann-Whitney Test; $P = 0.40$). However, when examining measurements of AP during the 30-minute computer task, subjects having the lowest level of discomfort had a mean AP of 1.55Δ BI (SD = 0.48), whereas subjects having higher discomfort had a mean AP of 0.00Δ (SD = 0.30). This difference was significant (Mann-Whitney Test; $P < 0.0001$). Values of AP for the 2 symptom groups during the course of the 30-minute task are shown in Figure 7.

Discussion

The findings of the current study suggest that symptoms associated with computer use may be related to an increased vergence response during VDT operation but are unlikely to result from a change in the AR. Subjects who converged accurately on the screen (as demonstrated by zero fixation disparity) were more likely to be symptomatic than those exhibiting exo fixation disparity. No difference in accommodation was observed between the symptomatic and asymptomatic groups.

In the current study, subjects were asked to rate the level of ocular discomfort experienced during the task on a scale from 1 to 10. A recent study in our laboratory (paper in preparation) recorded symptoms after a sustained period of reading from a computer monitor either through the distance refractive correction or with a supplementary –1.00 D or –2.00 D oblique cylinder added over these lenses. Additionally, the distance correction condition was repeated on 2 occasions in 12 subjects to assess the repeatability of the symptom questionnaire. The results showed no significant difference between the habitual

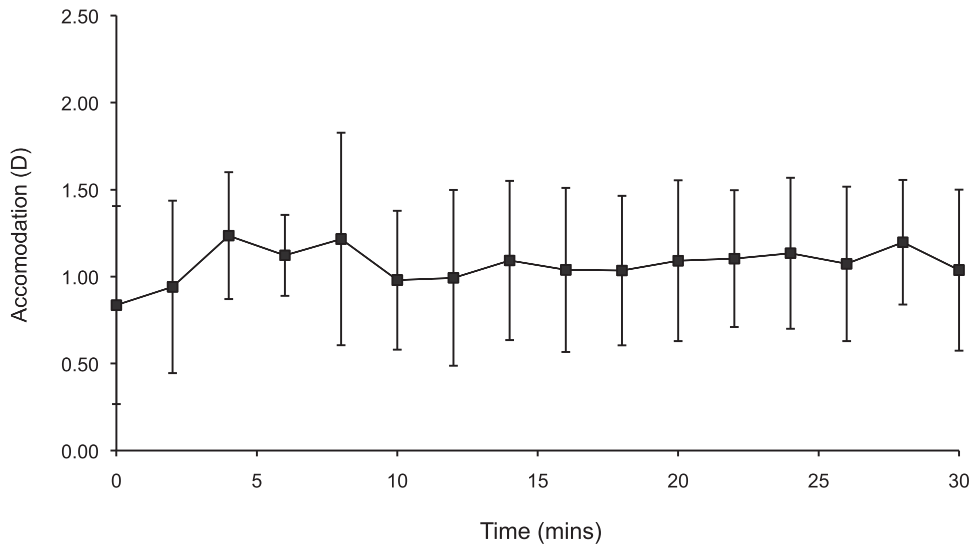


Figure 3 Mean value of AR (N = 20) during the course of the 30-minute computer task. Error bars indicate ±1 SD.

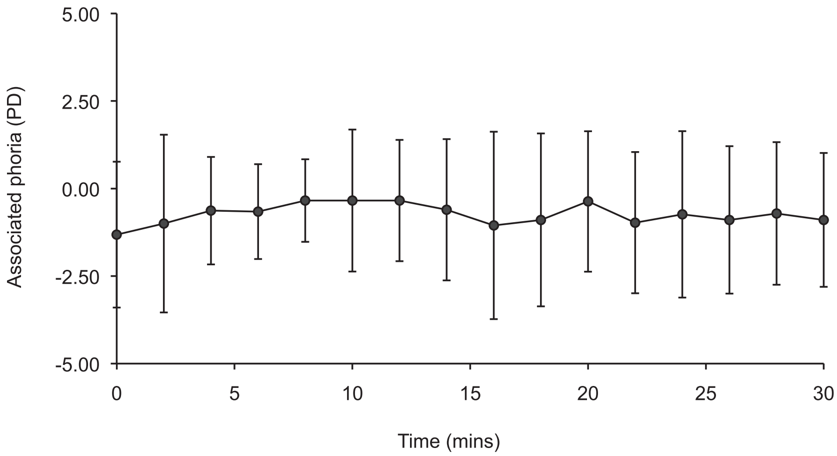


Figure 4 Mean value of AP (N = 20) in prism diopters (PD) during the course of the 30-minute computer task. Error bars indicate ±1 SD.

correction conditions but did show a significant increase in post-task symptoms. The 95% limits of agreement of the mean symptom score (1.96 multiplied by the standard deviation of the differences[15]) was ±1.25. This is considerably larger than the difference in mean discomfort scores for the most and least symptomatic subgroups reported here, with mean scores of 6.6 and 3.2, respectively.

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 BI AP. The notion that having exo fixation disparity at near may be more comfortable than accurate vergence differs from that of earlier work, indicating a positive relationship between AP and symptoms.[16-19] However, it should be noted that the range of BI AP found in the low-symptom group was relatively small (mean, 1.55Δ; range, 0.78 to 2.33Δ). Interestingly, the Optometric Extension Program system of case analysis regards exophoria at near as desirable because it provides a "buffer" to overconvergence.[20] Further, Sheedy and Saladin[21] reported that the mean fixation disparity in a group of nonpresbyopic subjects was 0.17 minutes exo, with a relatively wide standard deviation (±5.54 minutes). Accordingly, 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.

It should also be noted that the current study measured AP using a customized device, which included a peripheral, but not a central fusion lock. It has been observed that fixation disparity is generally smaller and less variable when tested with a central fusion lock.[22-24] However, Ukwade[14] indicated that for diagnostic purposes, the wider range of findings obtained using an instrument that only has a peripheral fusion lock may be preferable. Fixation disparity may also vary with target clarity and luminance.[25,26] Given that the target was presented on a computer monitor rather than using an internally illuminated box, one might

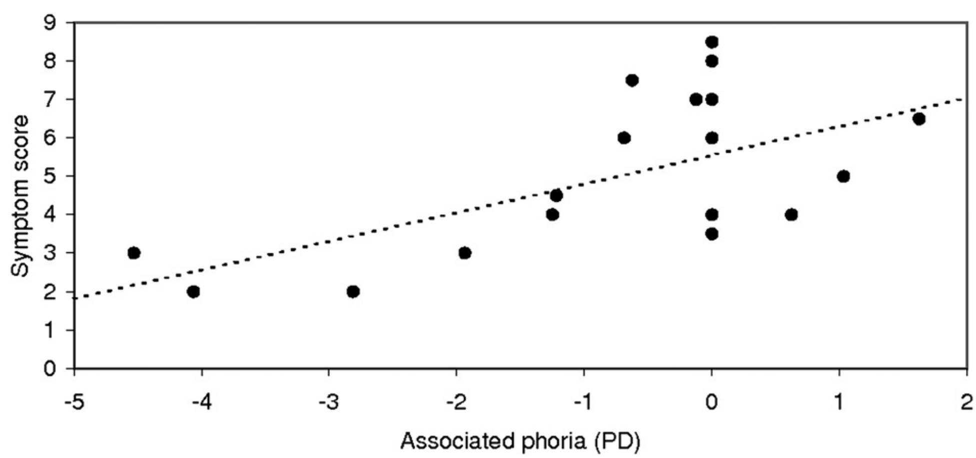


Figure 5 Symptom scores as a function of AP. A significant positive correlation was observed (r = 0.594; *P* = 0.007). The equation of the linear regression line was y = 0.75x + 5.55.

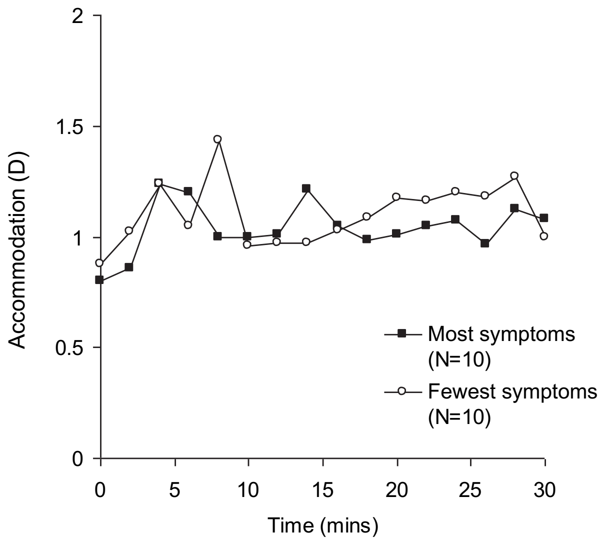


Figure 6 Mean value of AR during the course of the 30-minute computer task for the 10 subjects reporting the most and fewest symptoms, respectively. Error bars have been omitted for clarity.

speculate that variation in the method of presenting the targets may also account for some of the differences between the current and previous studies.

These findings also differ from those of Jaschinski,[13] who reported that near vision fatigue was associated with greater exo (or less eso) fixation disparity as the target is brought closer to the observer. Accordingly, they suggested that symptomatic subjects would tend to prefer a longer viewing distance to minimize exo fixation disparity. However, this result occurred in individuals who indicated that viewing the screen at 50 cm was "too near." Subjects who were initially comfortable at this working distance may prefer a reduced vergence response during the course of the task. If this is indeed the case, then one might consider the introduction of prism to induce small amounts of exo fixation disparity. Current work in our laboratory is evaluating the effectiveness of such prisms.

The relatively small mean difference in AP (1.55Δ) between the high and low symptom groups in the current study should be noted. Therefore, we suggest that although the slightly increased vergence response may contribute toward symptoms, other factors such as dry eye, the type of refractive correction worn (especially in presbyopes), and ergonomic factors associated with the organization of the computer workstation may also play a significant role in the etiology of CVS. Although it was not possible to standardize all of these factors, it seems unlikely that these conditions varied sufficiently to produce any change in objective or subjective responses during the course of the 30-minute trial. An additional factor to consider is the gaze angle adopted during computer work. In the current study, because of the restrictions imposed by the use of the objective optometer to measure accommodation, the laptop computer was placed in primary gaze. Desktop computer monitors are commonly positioned at this angle of gaze. In contrast, laptop computers are more typically used in downward gaze. Because the angle of gaze can on occasions alter either the accommodative and/or vergence response,[27-29] changing this viewing angle may impact the level of symptoms experienced. Future studies should also explore longer task durations in a larger population to determine whether the vergence or accommodation responses change or become increasingly variable with more extended tasks, because previous investigations have found that the magnitude of CVS may vary with task duration.[4]

The findings of this study indicate that the symptoms associated with computer use do not result from variations in accommodation during the course of the 30-minute computer task. A smaller vergence response may reduce symptoms, although the mean difference between the 2 groups, although statistically significant, was relatively small. Although all subjects had normal accommodation and vergence responses, it is not possible to rule out other CVS etiologies that might result from eye movement

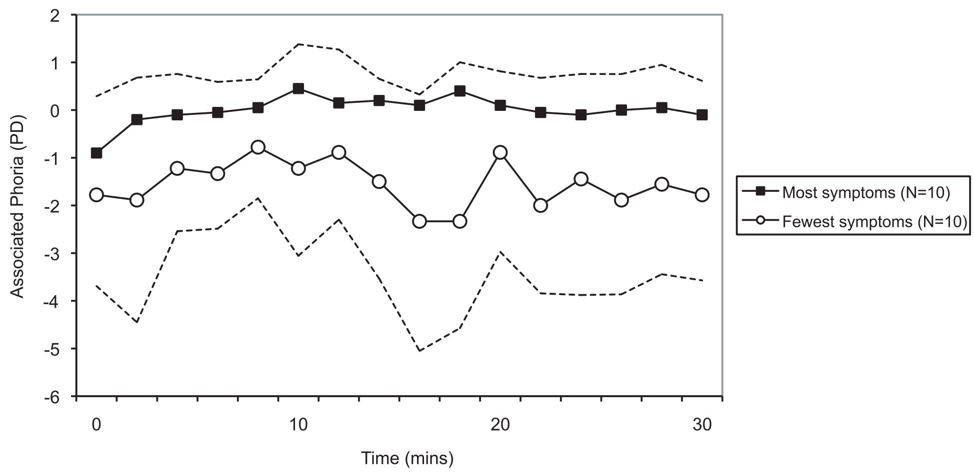


Figure 7 Mean value of AP in PD during the course of the 30-minute computer task for the 10 subjects reporting the most and fewest symptoms, respectively. The upper and lower dashed lines represent the 95% confidence limits for the most symptoms and fewest symptoms subgroups, respectively.

disorders or tear layer abnormalities. Therefore, it seems likely that discomfort can result from multiple etiologies, rather than a single underlying cause. In view of the extremely high prevalence of this condition and the almost universal use of computers in modern society, it is critical that practitioners question patients (of all ages) about CVS and examine those parameters that may be responsible for or predictive of symptoms.

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