Title

Accommodative and Binocular Disorders in Preteens with Computer Vision Syndrome: A Cross-sectional Study

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Abstract

Purpose: To assess computer vision syndrome (CVS) in a preteen population through an adult-validated, CVS questionnaire and to evaluate how digital devices affect accommodative and binocular vision.

Methods: We enrolled 309 preteens in this cross-sectional study. An adult-validated CVS questionnaire adapted to preteens was used for all subjects. Visual acuity testing, unilateral and alternate cover tests, and tests for accommodative and vergence responses were performed for all preteens.

Results: Mean age was 10.75 ± 0.67 (10 to 12) years. Subjects were divided into two groups: a mild CVS group with a mean CVS score ≤ 2 and a severe CVS group with a mean CVS score > 2. Between mild and severe CVS groups, statistically significant differences were found in near points of convergence (NPC) break and recovery ($p = 0.03$ and $p = 0.02$, respectively) and distance negative fusional vergence break and recovery ($p = 0.02$ and $p < 0.01$, respectively).

Conclusion: More children with severe CVS developed vergence disorders than those with mild CVS. Optometric clinical screening assessments could reduce ocular symptomatology and prevent long-term effects. However, poor optometric findings might have occurred first, and the poor convergence skills resulted in the symptoms reported while using the devices.

Keywords: computer vision syndrome; accommodative disorders; binocular vision disorders; preteens; smartphones; tables; digital devices

Introduction

Computer vision syndrome (CVS) is described as an ocular and visual disorder that develops from use of digital display devices for extended periods of time [1]. The use of digital devices has increased among children and preteens [2], and although the literature on CVS is limited for preteens relative to adults, many symptoms are similar between the two populations [3]. Currently, continuous use of digital display devices without rest periods, the inability to recognize symptoms related to visual disturbances, and the use of keyboards, chairs, and desks designed for adults make children and preteens more vulnerable to CVS compared to adults [2,4]. Symptoms may be related to the anterior surface of the eye (ocular pain, dry eye, ocular itching, and ocular irritation) [5], vision (blurred vision, visual strain, headache, visual fatigue, and double vision), or posture (shoulder and neck pain) [1]. For CVS diagnosis, questionnaires are frequently used. Diagnostic criteria are based on symptom onset, intensity, and frequency. Furthermore, the symptoms threshold changes with each questionnaire [6]. Rasch analysis [7] validates these questionnaires as a diagnostic tool, and the Computer Vision Symptom Scale (CVSS17) encompasses all of the symptoms associated with CVS [8]. Therefore, we used a modified version of the questionnaire for this study.

Excessive near work could affect ciliary muscle innervation, causing accommodative changes. If this persists over time, binocular vision function could be affected [9]. Among the most common signs of CVS, authors report accommodative changes, including decreased binocular accommodative flexibility[10] and increased accommodative response [11]. Lee et al.[12] refer to changes in binocular vision showed how in a group students the value of the near exophoria increased by about 3.73 prismatic diopters (Δ) to 5.75 Δ after four hours of use digital devices. There are authors who confirm that negative and positive fusional vergence decreased with the use of digital devices [13,14].

There is an association between ocular surface and visual symptoms. The accommodation amplitude (AA) could be related to blurring or eye strain, while ocular itching could be related to NPC disorders[12]. These subjective symptoms may be provoked by the accommodation and convergence disturbances induced during prolonged near distance activity Therefore, the aim of this study was to assess CVS in a preteen population through an adult-validated CVS questionnaire adapted to preteens and to evaluate how use of digital devices affects accommodative and binocular vision functions.

Materials and Methods

Subjects and Ethics

We enrolled 309 preteens in this prospective descriptive cross-sectional study, which was conducted from November 2019 to March 2020. Subjects were students of upper primary school, with age ranging from 10 to 12 years. The parents of all subjects included in this study provided written informed consent after being notified of all tests to be performed. The study was approved by the Ethical Committee of Andalusia and was conducted according to the tents of the Declaration of Helsinki. All preteens were from a private southern Spanish school. Inclusion criteria were: (1) preteens in upper primary school, with age ranging from 10 to 12 years and (2) monocular visual acuity (VA) ≥ 20/30 in decimal form on the Snellen scale. Exclusion criteria were: (1) more than two blank CVS questionnaire answers; (2) lack of written informed consent from parents or legal guardians; (3) any ocular or systemic disease that could affect visual examination findings; (4) active pharmacological treatment with drugs that could affect visual examination findings; (5) any previous eye surgery; and (6) binocular disorders, such phorias out of normal values or all tropias. [15] Of the 309 children, 33 were excluded after applying the inclusion and exclusion criteria. Mild CVS group was ≤ 2 in the CVS questionnaire and high CVS group was > 2 in the CVS questionnaire. In addition, the mild CVS group contained subjects without any CVS symptomatology.

Materials and Measurements

Two data sheets were used to obtain the data of our study. One file with personal data (name and age), medical history (last optometric check, wearing glasses, pharmacological treatment and visual family history) and optometric data. At this point, the preteen were asked about the use or not of digital devices and which (mobile phone, tablet, computer or consoles). Other data sheet was a preteen CVS detection survey with name to link it with to the optometric data.

A CVS questionnaire validated for adults [8] was adapted to preteens in terms of vocabulary (the adaptation was done with the approval of the primary school teacher) and the number of potential answers choices to facilitate understanding (six original survey and four the questionnaire adapted). The questionnaire adapted to preteens had a greater number of items than that in the adult-validated questionnaire. In addition, last

four questions from original questionnaire were removed by repetitive. The original survey was developed for a computer work environment and did not involve recording the digital device use in hours, which is a major factor for the detection of CVS [1], so a question was added about how many time a day you use digital devices. Questions related to symptomatology were also added, as various studies link the use of digital devices with head and neck pain [1,16], the preteens were asked about headache, back and neck pain with three different questions (Do you feel head/back/neck pain after using electronic devices?) The rest of the questions referred to visual symptoms and ocular surface symptoms. To avoid answering systematically and answering bias, positive polarity was randomly assigned to some questions, whereas negative polarity was assigned to others. The answers were never arranged without order. Accordingly, the answers followed the order of "always"/"often"/"sometimes"/"never" or the reverse, but never otherwise. The survey was distributed to preteens in the classroom, Teachers together with an optometrist explained to the children how to proceed with filling out the questionnaire. Each item could be answer from 1 to 4 (minimum score was 17 and maximum 68. Mean score was calculated by the 17 item and in order to change quantitative variable into qualitative variable.

For optometric tests, the most repeatable methods that could be performed with portable equipment were selected. The monocular and binocular distance VAs were tested with Early Treatment Diabetic Retinopathy Study (ETDRS) optimized for a distance of 4 m. The monocular and binocular AA was calculated with the modified push-up method using near-vision test with Snellen charts (Optometric Promotion, Burgos, Spain), opaque occlusion for monocular tests (Optometric Promotion, Burgos, Spain) and a meter rule[17]. The accommodative posture was tested by Nott dynamic retinoscopy with a streak retinoscope (Welch Allyn Elite, Mexico FD, Mexico)[18] and near-vision card. Accommodative facility test was quantified with ±2.00 D flipper lenses (Optometric Promotion, Burgos, Spain) and near-vision card. Near point of convergence (NPC) was quantified using a pointer. Unilateral and alternate cover test was tested with translucent opaque (Optometric Promotion, Burgos, Spain). Vergence fusional were measure using 30 prism diopter (Δ) vertical and 45 Δ horizontal prism bars (Optometric Promotion, Burgos, Spain).

All measurements were obtained with the same materials and under the same photopic light conditions.

The monocular and binocular distance VA were test with the right eye, subjects read lines from left to right; with the left eye, subjects read lines from right to left; with both eyes, subjects again read lines from left to right. These directional changes were intended at avoiding memorizing of the letters leading to bias [19]. AA

was calculated with the modified push-up method, first monocular and after binocular. The accommodative posture was tested by Nott dynamic retinoscopy as the accommodative stimulus located at 40 cm, under binocular conditions. To estimate the accommodative posture, the accommodative response (1/distance in cm of the retinoscope × 10^{-2} D) was subtracted from the accommodative stimulus (1/40 × 10^{-2} D)[20]. For the accommodative facility test, ±2.00-D flipper lenses and a near-vision card located 40 cm were used [21]. If cycles per minute were fewer than seven, the monocular test was performed. In addition, during the measurement, it was recorded if subjects had difficulty seeing with the positive and/or negative lens(es). NPC was estimated under binocular conditions using a pointer as the accommodative stimulus. If the subject did not report double vision or observe loss of fixation by examiners, the NPC was "down to the nose" and considered to be 1 cm [15]. Unilateral and alternate cover tests [22] were performed for visual axis alignment, because it is the most repeatable method . The cover test was first performed to determine the presence of manifest deviations (tropia or strabismus), with the magnitude and direction. Subsequently, the presence, magnitude, and direction of heterophorias were examined with the distance and near alternate cover test. This is the most dissociating test, as it prevents binocular vision, thereby manifesting latent deviations[23]. NFV and PFV were measured with the step method, which could be performed with portable equipment. Distance and near NFVs were measured in that order. Subsequently, near and distance PFVs were measured in that order[24]. All normative values were described according the Scheiman and Wick [15]. All measurements were performed three times and the mean values were calculated. Students were doing the testing and that they were not aware of symptom scores when they did the testing.

Statistical analysis

Data were analyzed with SPSS statistics software version 26.0 for Windows (SPSS Inc., Chicago, IL, USA). Descriptive analysis was carried out with values expressed as mean ± standard deviation. Data normality distribution was assessed with the Kolmogorov–Smirnov test for all subjects and for the mild CVS group. The severe CVS group was analyzed with the Shapiro–Wilk test. Differences in mean values between mild and severe CVS groups were assessed with the Mann–Whitney U test. A correlation analysis was performed with Spearman's rho test. For all tests, a level of significance was established at 95% ($p < 0.05$).

Results

From initial 309 subjects, 33 were excluded. 3 due strabismus. 6 due amblyopia and 20 due to VA and 4 due age. Subjects with incomplete questionnaire were excluded (n=50). The study population included 114 (41.3%) girls and 162 (58.7%) boys, with a mean age of 10.75 ± 0.67 (10 to 12) years. The reliability test with Cronbach´s alpha was 0.824 with all items. The reliability test with Cronbach's alpha of 0.828 for all 17 items of CVSS17 was performed to analyze 15 ocular and visual symptoms. Cronbach's alpha ranges from 0 to 1, and an instrument with a Cronbach's alpha of 0.80 or above in considered to be reliable. Thus, the adaptation of CVSS17 in children had a high reliability. In addition, statistical analysis was carried out to determine if elimination of any items from the questionnaire improved Cronbach's alpha. The results did not show any significant changes; therefore, no questionnaire item was removed.

Questionnaire items were divided into four types: items on electronic device usage time, items on ergonomics, items on visual symptoms, and items on ocular surface symptoms. Scores were presented as (1= never, 2 = sometimes, 3=often and 4=always). The severe CVS group showed significantly worse results for all questionnaire items compared to the mild CVS group. The mild and severe CVS groups scored 1.65 ± 0.44 and 1.92 ± 0.44 points, respectively, in the electronic device usage time ($p < 0.01$), 1.68 ± 0.42 and 2.43 ± 0.49 points, respectively, in ergonomics ($p < 0.01$), 1.40 ± 0.33 and 2.33 ± 0.57 points, respectively, in visual symptoms ($p < 0.01$), and 1.43 ± 0.27 and 2.21 ± 0.54 points, respectively, in ocular surface symptoms ($p < 0.01$). According to ocular symptomatology, low CVS and high CVS achieved the following results, respectively: tired eyes: 1.87 ± 0.70 and 2.91 ± 0.70 ($P < 0.01$), ocular pain: 1.62 ± 0.62 and 2.61 ± 0.75 ($P < 0.01$), ocular burning: 1.48 ± 0.56 and 1.95 ± 0.60 ($P < 0.01$), watery eyes: 1.41 ± 0.65 and 2.27 ± 0.97 ($P < 0.01$), redness eye: 1.18 ± 0.44 and 1.77 ± 1.09 ($P < 0.01$), dry eye: 1.22 ± 0.45 and 1.89 ± 0.92 ($P < 0.01$) and eye strain: 1.26 ± 0.59 and 2.07 ± 1.04 ($P < 0.01$).

Table 1 shows subjects' optometric descriptive data, including VA, accommodation, NPC, NFV, and PFV. The average score for each item of the survey was calculated. All scores were weighted at four points. The mean CVS score was 1.75 ± 0.36 (range: 1.10–3.38). Accordingly, subjects were divided into two groups: a mild CVS group with a mean CVS score < 2 and a severe CVS group with a mean CVS score > 2. The mild CVS group included 69 (37.9%) girls and 113 (62.1%) boys, with a mean age of 10.68 ± 0.64 years; the severe CVS group included 20 (45.5%) girls and 24 (54.5%) boys, with a mean age of 10.89 ± 0.72 years. Table 2 shows the descriptive optometric variables between mild and severe CVS groups and *p*-

values for the differences. For the variables with significant differences or trend towards significant differences, the effect size was calculated using Cohen's d. Between mild and severe CVS groups, statistically significant differences were found in NPC break (U = 4820.50, $p = 0.03$) and recovery (U = 4828.50, $p = 0.02$), with medium size effects of 0.42 and 0.38, respectively, near NFV break (U = 3343.50, $p = 0.08$) and recovery (U = 3300.00, $p = 0.06$), with small size effects of 0.31 and 0.33, respectively, and distance NFV break (U = 3179.50, $p = 0.02$) and recovery (U = 3023.00, $p < 0.01$), with small and medium size effects of 0.34 and 0.43, respectively. Figure 1 shows the statistically significant differences in optometric variables between mild and severe CVS groups as box and plot graphs. No statistically significantly strong correlations were found.

Discussion

This observational descriptive cross-sectional study assessed CVS in preteens, with age ranging from 10 to 12 years, through a survey validated for adults and adapted for preteens. We performed optometric examination, including clinic history, VA, tropias and phorias, accommodation variables, and PFV and NFV, to investigate the relationship of these variable to the use of digital devices. Statistically significant differences were found in NPC and distance NFV, and the difference tended to be significant in near NFV.

In our study, 182 and 44 preteens were categorized under the mild and severe CVS groups, respectively, according to the symptomatology analyzed. Based on that symptomatology, we divided subjects on four bases. The first basis was the exposure time to digital devices owing to the evidence of its influence on CVS according to Tawil et al. [1], who conducted a study on the prevalence of symptoms in college students with CVS from computer use and determined its association with the use of digital devices for more than 5 h, and according to other authors, who reported an increase in CVS symptomatology to be related to the time of use of digital devices (computer) [25,26]. These results were consistent with the results of our study in which preteens in the severe CVS group reported longer time of use of digital devices. The second basis was ergonomics according to Mowatt et al. [27], who conducted a study involving university students with CSV from computer and handheld use and determined that 75.1% of students had neck pain, and according to other authors, who concluded the same regarding both headache and neck pain from use of computer, mobile phone and laptops. [26,28,29]. These results were consistent with the results of our study in which subjects in the severe CVS group reported a greater severity of these symptoms. The third basis was visual

symptomatology according to Antona et al. [30], who conducted a study involving 54 subjects using smartphone with visual difficulties and determined that all scores were more unfavorable in subjects who used digital devices, and according to other authors, who conducted studies on high-school students using mobile phones and laptops and determined that the percentages of these symptoms increased as the hours of digital device use increased [27,31]. These results were consistent with the results of our study in which preteens in the severe CVS group reported blurred vision, difficulty reading, diplopia, and other items included in this symptomatology, which could lead to poor performance at school[32]. The fourth basis was ocular surface symptoms since they are mostly reported by preteens with severe CVS (ocular burning, stinging, and redness, watery eyes, excessive blinking to relieve dry eyes) are the result of dry eyes. A study involving adolescents showed that a longer time of use of smartphones increased the onset of ocular surface symptomatology [33]. Young et al. [34] conducted a study involving 51 subjects who used digital devices (computer) and 20 control subjects who underwent different tests for the diagnosis of dry eyes, concluding that one in three users had symptoms of dry eyes. Furthermore, Moon et al. [5] conducted a study on the prevalence of ocular surface symptomatology associated with the use of digital devices (smartphone) in children of urban and rural environments and concluded that children in the urban environment who used digital devices for longer and spent less time outdoors had a higher prevalence of ocular surface symptomatology. Our sample of students also came from an urban environment, matching the data and adding relevance to the need to control the use of digital devices in children.

If we focus on optometric variables, certain values could be affected by the use/abuse of digital screens in children, such as NPC, which was at a significantly farther point in the severe CVS group than in the mild CVS group. Similarly, Lee et al.[12] reported how NPC increased in a group of 50 students after playing video games for 4 h without interruption. Furthermore, near PFV break and recovery were lower in the severe CVS group than in the mild CVS group although without statistical significance (p = 0.20 and 0.10, respectively). In contrast, near NFV break and recovery were significantly lower in the severe CVS group than in the mild CVS group. Porcar et al. [35] evaluated the presence of binocular dysfunctions in 89 users of flat-panel displays without strabismus and determined that a common alteration was the difficulty in relaxing convergence. Watten et al. [36] measured both PFV and NFV and reported reductions in both parameters with the use of digital devices (VDT), suggestive of their ability to decrease divergence and convergence.

As for accommodation data, monocular and binocular AA is slightly decreased in both groups according to Donders. These results are in line with other studies. Jaiswal et al. [37] in a bibliographic review reports a decrease in the amplitude of accommodation among users of digital screens (smartphone, tablets and computers). A recent study reported that during mandatory confinement in the coronavirus disease pandemic, adolescents used digital devices (computer) for a longer time [38]. This could be a cause of occurrence of ocular surface symptomatology [26].

The study had some limitations. First, the distribution of subjects with severe and mild CVS was irregular, which could have led to statistical bias. Second, no follow-up was carried out for evaluation of symptoms. Third, the study was carried out in a private school where most students are likely to use digital devices. Therefore, a future study should be conducted in a population with different socioeconomic characteristics. Finally, poor optometric findings might have occurred first, and the poor convergence skills resulted in the symptoms reported while using the devices.

For all the above reasons, we believe that our results confirm more preteens with severe CVS developed vergence disorders compared to those with mild CVS. Optometric clinical screening assessments could reduce ocular symptomatology and prevent long-term effects. Parental awareness and training on CVS are essential to promote its prevention.

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Declarations

Funding: None.

Conflicts of interest: Authors declare that they have no competing interest.

Ethics approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the tenets of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent to participate: All subjects included in this study were adequately informed verbally and in writing of the benefits, characteristics, and risks of the study. All subjects provided written informed consent prior to the study.

Consent for publication: All authors consent for the publication of this article.

Availability of data and material: Data are available from the corresponding author on reasonable request.

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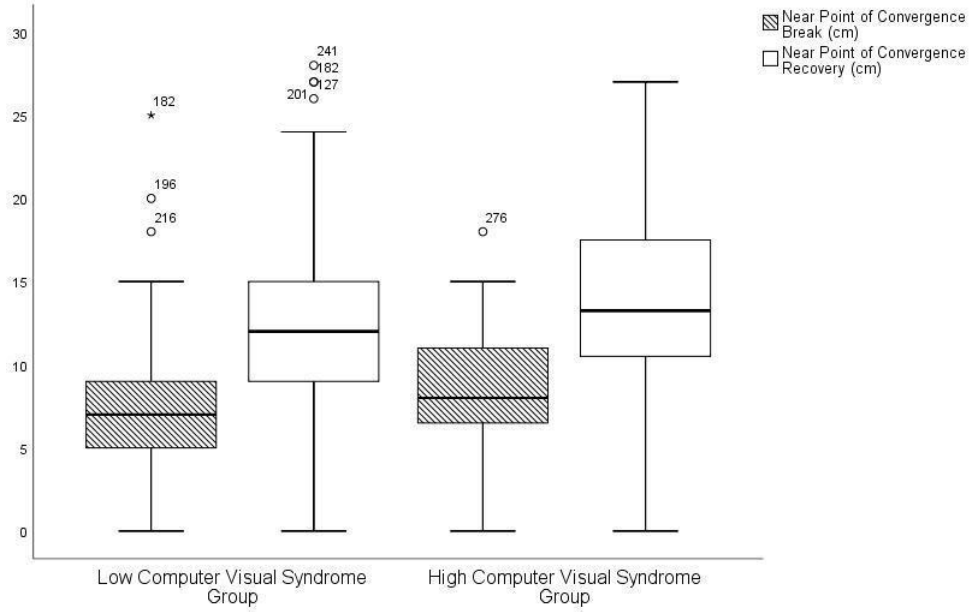
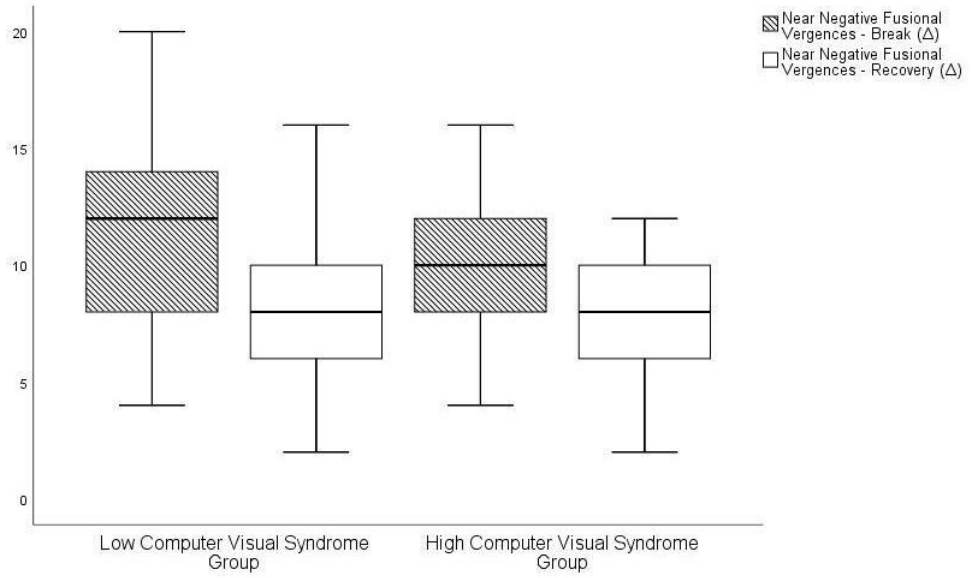
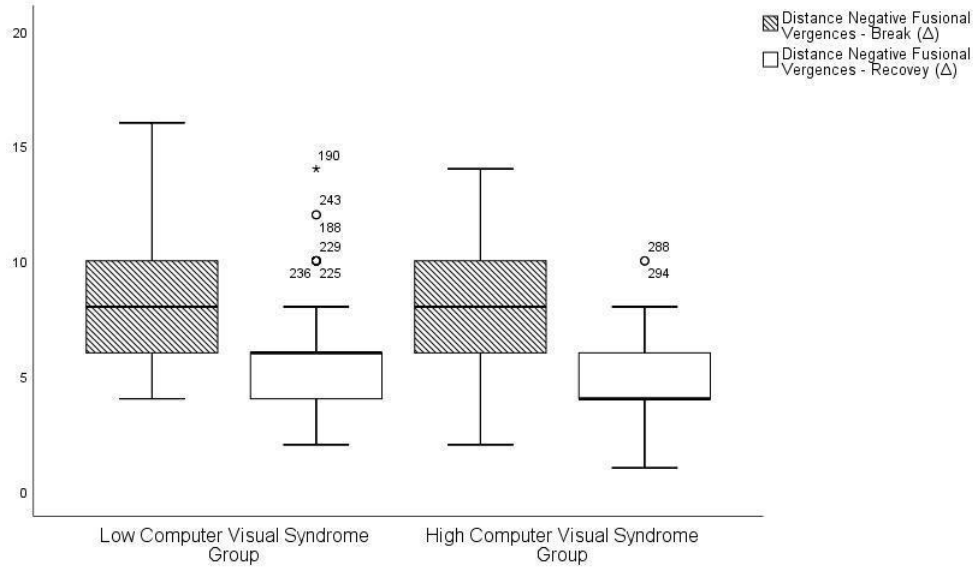
Figure Legends

Figure 1. Box and plot graphs of the comparison between mild and severe computer vision syndrome. Up: near point of convergence break and recovery (expressed in cm). Middle: near negative fusional vergence break and recovery (expressed in prism diopters, Δ). Down: distance negative fusional vergence break and recovery (expressed in prism diopters, Δ).







Computer Visual Syndrome Groups

Table 1. Descriptive optometric analysis of the entire sample

Optometric Variable	Mean	SD	Minimum	Maximum
RE Visual Acuity (Decimal Scale)	1.12	.15	.80	1.25
LE Visual Acuity (Decimal Scale)	1.12	.14	.80	1.25
BE Visual Acuity (Decimal Scale)	1.20	.10	1.00	1.25
RE Accommodation Amplitude (D)	11.13	2.65	4.00	25.00
LE Accommodation Amplitude (D)	11.18	2.76	4.26	25.00
BE Accommodation Amplitude (D)	11.18	2.98	5.13	33.33
Accommodative Posture (D)	.20	.31	-1.50	1.25
Binocular Accommodation Facility Test (cpm)	8.58	3.58	.00	17.00
RE Monocular Accommodation Facility Test (cpm) (n=80)	5.61	3.13	0.00	14.50
LE Monocular Accommodation Facility Test (cpm) (n=80)	5.98	3.67	0.00	15.00
Near Phorias (Δ)	-1.54	2.31	-14.00	8.00
Distance Phorias (Δ)	-.13	1.12	-16.00	2.00
NPC Break (cm)	7.09	4.60	.00	37.00
NPC Recovery (cm)	11.58	6.64	.00	43.00
Near NFV - Break (Δ)	11.03	2.96	4.00	20.00
Near NFV - Recovery (Δ)	8.20	2.72	2.00	16.00
Distance NFV - Break (Δ)	8.42	2.27	2.00	16.00
Distance NFV - Recovery (Δ)	5.80	2.01	1.00	14.00
Near PFV - Break (Δ)	14.94	6.57	2.00	40.00
Near PFV - Recovery (Δ)	11.42	5.80	1.00	40.00
Distance PFV - Break (Δ)	18.85	7.84	4.00	40.00
Distance PFV - Recovery (Δ)	14.02	6.69	1.00	40.00
SD: Standard Deviation; RE: Right eye; LE: Left eye; BO: Both eyes; cm: centimetre; D: Dioptre; NPC: Near point of Convergence; NFV: Negative fusional vergences; PFV: Positive fusional vergences; Δ: prism diopters; Negative Phoria indicate Exophoria; Negative Accommodative Posture is Lag; Positive Accommodative Posture is Lead;				

Table 2. Optometric variables differences between low and high computer visual syndrome groups

	Computer Visual Syndrome (CVS) Groups				p value
	Low CVS		High CVS		
	Mean	SD	Mean	SD	
RE Visual Acuity (Decimal Scale)	1.12	.15	1.09	.15	0.15
LE Visual Acuity (Decimal Scale)	1.13	.14	1.10	.14	0.15
BE Visual Acuity (Decima Scale)	1.20	.10	1.20	.10	0.58
RE Accommodation Amplitude (cm)	9.40	2.16	9.42	2.91	0.53
RE Accommodation Amplitude (D)	11.23	2.73	11.23	2.30	0.53
LE Accommodation Amplitude (cm)	9.30	2.06	9.81	2.86	0.68
LE Accommodation Amplitude (D)	11.35	2.93	10.77	2.21	0.68
BE Accommodation Amplitude (cm)	9.33	2.09	9.93	2.64	0.17
BE Accommodation Amplitude (D)	11.32	3.06	10.67	2.60	0.17
Accommodative Posture (cm)	44.17	5.85	43.98	4.87	0.92
Accommodative Posture (D)	.20	.32	.20	.28	0.92
Accommodation Facility Test (cpm)	8.67	3.43	9.12	3.73	0.58
Near Tropias (Δ)	.00	.00	.00	.00	0.99
Distance Tropia (Δ)	.00	.00	.00	.00	0.99
Near Phorias (Δ)	-1.39	2.14	-1.82	2.43	0.36
Distance Phorias (Δ)	-.12	.70	-.32	2.44	0.31
NPC Break (cm)	6.88	4.21	8.82	5.88	<0.05
NPC Recovery (cm)	11.45	6.14	13.94	7.67	<0.05
Near NFV - Break (Δ)	11.21	3.02	10.27	2.85	0.08
Near NFV - Recovery (Δ)	8.35	2.74	7.45	2.57	0.06
Distance NFV - Break (Δ)	8.52	2.20	7.73	2.57	<0.05
Distance NFV - Recovery (Δ)	5.92	2.00	5.05	2.08	<0.01
Near PFV - Break (Δ)	15.18	6.49	14.14	7.41	0.20
Near PFV - Recovery (Δ)	11.69	5.62	10.61	6.97	0.10
Distance PFV - Break (Δ)	18.84	7.68	18.59	9.52	0.69
Distance PFV - Recovery (Δ)	13.97	6.45	13.55	8.15	0.53
SD: Standard Deviation; RE: Right eye; LE: Left eye; BO: Both eyes; cm: centimeter; D: Diopter; NPC: Near point of Convergence; NFV: Negative fusional vergences; PFV: Positive fusional vergences					