



# Changes in accommodation with visual fatigue among digital device users

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## ABSTRACT

**Background:** Visual fatigue is categorized as a complex phenomenon that decreases visual performance. The aim of the present study was to assess changes in accommodation at different levels of visual fatigue among students of a Malaysian private university using digital devices.

**Methods:** In this cross-sectional study, students regardless of sex and ethnicity were included. A comprehensive eye examination was performed. After estimating the level of visual fatigue, the amplitude of accommodation (AA), accommodation facility (AF), and monocular estimation method (MEM) were measured. The visual fatigue questionnaire was filled out by the participants. Participants were categorized based on the visual fatigue scores into low, moderate, and high visual fatigue groups. Moderate and severe visual fatigue groups were combined, as the distribution of participants was uneven across the groups. Accommodation parameters were measured for each group and compared between the two groups, i.e., the low visual fatigue group and the combined moderate to severe visual fatigue group.

**Results:** We enrolled a total of 86 students, including 29 (33.72%) men and 57 (66.28%) women, with a mean (standard deviation [SD]) age of 22.02 (1.51) years and age ranging from 19 to 26 years. By ethnicity, there were 69 (80.23%) Chinese, five (5.81%) Indian, four (4.65%) Malay, and eight (9.30%) participants from other ethnicities. Most participants were in the low visual fatigue group (54.65%), followed by the severe (25.58%) and moderate (19.77%) visual fatigue groups. AA for both eyes and AF for the right eye differed significantly between the two groups of visual fatigue: low (Group 1) and moderate-to-severe (Group 2) (both  $P < 0.05$ ). None of the accommodative parameters correlated with visual fatigue ( $P > 0.05$ ).

**Conclusions:** Binocular AA and monocular AF significantly differed between the visual fatigue groups, but MEM was comparable. However, none of the accommodative parameters correlated with visual fatigue. These perceived vision dysfunctions could affect the visual skills of students. Therefore, future studies on the relationship between the observed dysfunctions and students' reading performance are necessary.

## KEYWORDS

eye fatigue, eyestrain, asthenopia, amplitude, facility, ocular accommodation, university, students

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## INTRODUCTION

Visual fatigue is a complex phenomenon that decreases visual performance [1]. It can be classified into no, low, moderate, or severe categories [2]. Symptoms of visual fatigue include text fading or blurriness, text movement, eye strain regardless of visual acuity, headache, eye pain, double vision, or glaring [3]. Blurriness, eye strain or ache, diplopia, and headache are classified as internal symptoms, whereas dry eye, burning sensations, discomfort, and weeping are classified as external symptoms [4].

Visual display unit (VDU) users experience occupational eye problems, such as visual fatigue [5]. Factors affecting visual fatigue among VDU users include distance to the VDU position [6], background of VDU images [7], duration of VDU exposure [8-11], characteristics of the VDU workstation [12], pattern of VDU use [13], and type of work undertaken [14, 15]. Subjective reports of visual fatigue symptoms obtained under such conditions also correlate with the physiological responses of the visual system. Accommodative and vergence conditions are associated with internal symptoms, whereas dryness is associated with external symptoms [4].

Symptoms of digital eye strain have become more common owing to an increase in the use of digital devices [16]. Digital eye strain is distinguished and measured using questionnaires, or with objective assessments such as accommodative function and pupil characteristics, to provide indices of visual fatigue [17].

Scheinman and Wick classified accommodative anomalies, or the inability of the eyes to coordinate properly, into four groups: accommodative insufficiency, ill-sustained accommodation (accommodative fatigue), accommodative excess, and accommodative infacility (inertia of accommodation) [18]. The prevalence of non-strabismic binocular vision anomalies was 40% among Malaysian private university students using a VDU, and accommodation anomalies accounted for 15% [19]. Both visual fatigue symptoms and accommodative dysfunction have been reported in computer users [20].

To our knowledge, no study has correlated changes in accommodative parameters with different levels of visual fatigue among digital device users. Hence, this study aimed to assess the differences in accommodation among varying levels of visual fatigue in a cohort of university students using digital devices.

## METHODS

A cross-sectional study was conducted at the private University College Sedaya International (UCSI) University, Kuala Lumpur, Malaysia, enrolling students who used digital devices, regardless of ethnicity and sex. The study was approved by the Institutional Review Board and Ethics Committee of UCSI University. The participants were briefed on the study protocol and provided written informed consent. The tenets of the Declaration of Helsinki were observed throughout the study. This research was conducted at the UCSI Optometry Clinic between July 2019 and May 2020. A simple random sampling method was used to recruit participants.

We included students aged 18 to 35 years who used digital devices for  $\geq 3$  hours, had a best-corrected distance visual acuity of 6/6, and had a near visual acuity of N6 or better. The exclusion criteria were any ocular pathology, systemic disorders, history of ocular surgery or trauma, vergence anomalies, strabismus, systemic or ocular medications that would alter the accommodative status, oculomotor dysfunction, neurological/psychiatric disorders, contact lens use, and unwillingness to participate in the study.

A detailed history of each participant was documented. A comprehensive eye examination was performed, including near and distance visual acuity measurements [21], stereopsis testing [22], cover test [21], Hirschberg test [23], pupillary examination [24], measurements of near point of accommodation [25] and near point of convergence [25], confrontation visual field test [26], color vision test [27], subjective and objective refraction [28], intraocular pressure measurement [28], slit-lamp examination [28], and fundus examination [28]. Those who fulfilled the inclusion criteria were first administered a visual fatigue questionnaire. After estimating the level of visual fatigue, accommodative parameters, including amplitude of accommodation (AA), accommodation facility (AF), and monocular estimation method (MEM), were measured [18].

According to a survey conducted using the visual fatigue questionnaire designed by Rajabi-Vardanjani et al. [2], visual fatigue is classified into low, moderate, and severe categories based on the level of visual discomfort. This visual fatigue questionnaire [2] was administered to our participants to categorize the generalized visual fatigue score as low, moderate, or severe before evaluating the accommodation parameters. The questionnaire investigates visual fatigue symptoms categorized into four major areas, including four questions on eye strain, five questions on visual impairment, three questions on surface impairment of the eye, and three questions on general eye problems. The scores range from 0 to 10 according to the level of visual fatigue. The accommodation parameters (AA, MEM, AF) were then evaluated [18].

AA was measured using push-up and pull-away techniques using a Royal Air Force (RAF) rule [18]. Instructions were provided to the participant prior to measurement. The RAF rule was situated against the participant's cheek, and the rotating target on the RAF rule was positioned at 50 cm. The participant was instructed to focus on the N6 target, and the target was slowly and steadily pushed toward the participant's eye until the participant reported blurring of the target, even with the effort of blinking. AA was then compared with the normal age-adjusted value [18].

MEM is a dynamic retinoscopy method used to determine the lag and lead of accommodation [18]. Instructions were given to the participant, and an MEM card was attached to the retinoscope prior to measurement. The participant was instructed to read out the words on the MEM card, which was held at 40 cm. While the participant read the words on the MEM card, retinoscopy was performed until the point of neutralization was achieved in both the right and left eyes. Readings were recorded and categorized accordingly.

The binocular AF technique was performed using a flipper lens of  $\pm 2.0$  D [18]. Instructions were given to the participant, and a stopwatch and rock card were prepared before the measurement. The rock card of target N8 was held at a distance of 40 cm. The participant was required to make the target clear through the lens with the effort of blinking. If the participant managed to clear the letter, the participant had to flip the lens and make the next word clear. The test was conducted monocularly (right and left eye) and binocularly for one minute.

Statistical analysis of the collected data was performed using IBM SPSS Statistics for Windows (version 24.0; IBM Corp., Armonk, NY, USA). Normality of the data was assessed using the Shapiro–Wilk test. The skewness and kurtosis values were also determined. Variables are expressed as mean (standard deviation [SD]) or frequency (percentage). The moderate and severe visual fatigue groups were combined because the distribution of participants to each group was uneven. The Mann–Whitney U test was used to compare the accommodative parameters between the low visual fatigue and the combined moderate and severe visual fatigue groups. Spearman's rank correlation coefficient was used to determine the correlation between accommodation and visual fatigue. Statistical significance was set at  $P < 0.05$ .

## RESULTS

A total of 86 students were recruited: 29 men (33.72%) and 57 women (66.28%). The mean (SD) age of the study participants was 22.02 (1.51) years, ranging from 19 to 26 years. The majority were Chinese ( $n = 69$ , 80.23%), followed by Indian ( $n = 5$ , 5.81%), Malay ( $n = 4$ , 4.65%), and other races ( $n = 8$ , 9.30%). Table 1 shows the descriptive statistics for all accommodative parameters analyzed, including AA, AF, and MEM.

The low visual fatigue group was the largest ( $n = 47$ , 54.65%), followed by the severe visual fatigue ( $n = 22$ , 25.58%) and moderate visual fatigue ( $n = 17$ , 19.77%) groups. As the distribution of participants in the visual fatigue groups was unequal, the low visual fatigue group was kept as one group, whereas the moderate and severe groups were merged ( $n = 39$ , 45.35%) during analysis. Thus, accommodative parameters were compared between the two groups of visual fatigue: *low* (Group 1) and *moderate-to-severe* (Group 2). As shown in Table 2, the AA for both eyes and the AF for the right eye differed significantly between the two groups (both  $P < 0.05$ ). There was no significant correlation between any accommodative parameter and visual fatigue (Table 3).

**Table 1. Accommodation parameter values among study participants**

Accommodative Parameters	Mean $\pm$ SD (Range)
Right Eye AA (D)	10.46 $\pm$ 2.00 (7.00 to 17.40)
Left Eye AA (D)	10.67 $\pm$ 2.18 (7.00 to 18.18)
Both Eye AA (D)	11.64 $\pm$ 2.45 (6.75 to 18.75)
Right Eye AF (CPM)	9.94 $\pm$ 4.81 (0.00 to 22.00)
Left Eye AF (CPM)	10.09 $\pm$ 4.60 (1.00 to 21.00)
Both Eye AF (CPM)	10.83 $\pm$ 3.93 (3.00 to 19.00)
Right Eye MEM (D)	0.65 $\pm$ 0.53 (-1.25 to 1.75)
Left Eye MEM (D)	0.67 $\pm$ 0.53 (-1.00 to 1.75)

Abbreviations: SD, standard deviation; AA, amplitude of accommodation; D, dioptres; AF, accommodation facility; CPM, cycles per minute; MEM, monocular estimation method.

Table 2. Comparison of accommodative parameters between low (Group 1) and moderate-to-severe (Group 2) visual fatigue groups

Accommodative Parameters	Visual Fatigue Group	Mean $\pm$ SD	P-value*
Right Eye AA (D)	Group 1 (n = 47)	10.67 $\pm$ 1.90	0.104
	Group 2 (n = 39)	10.20 $\pm$ 2.13	
Left Eye AA (D)	Group 1 (n = 47)	10.89 $\pm$ 2.26	0.181
	Group 2 (n = 39)	10.41 $\pm$ 2.09	
Both Eyes AA (D)	Group 1 (n = 47)	12.00 $\pm$ 2.48	<b>0.047</b>
	Group 2 (n = 39)	11.21 $\pm$ 2.36	
Right Eye AF (CPM)	Group 1 (n = 47)	10.85 $\pm$ 4.98	<b>0.049</b>
	Group 2 (n = 39)	8.84 $\pm$ 4.41	
Left Eye AF (CPM)	Group 1 (n = 47)	11.00 $\pm$ 4.67	0.074
	Group 2 (n = 39)	8.99 $\pm$ 4.32	
Both Eyes AF (CPM)	Group 1 (n = 47)	11.01 $\pm$ 4.20	0.682
	Group 2 (n = 39)	10.62 $\pm$ 3.61	
Right Eye MEM (D)	Group 1 (n = 47)	0.62 $\pm$ 0.54	0.758
	Group 2 (n = 39)	0.69 $\pm$ 0.53	
Left Eye MEM (D)	Group 1 (n = 47)	0.62 $\pm$ 0.53	0.456
	Group 2 (n = 39)	0.72 $\pm$ 0.54	

Abbreviations: SD, standard deviation; AA, amplitude of accommodation; D, dioptres; AF, accommodation facility; CPM, cycles per minute; MEM, monocular estimation method. P-values < 0.05 are shown in bold (\*the Mann-Whitney U test was used).

Table 3. Correlation between visual fatigue and accommodation parameters in study participants

Accommodative parameters	r	P-value*
Right Eye AA (D)	-0.133	0.221
Left Eye AA (D)	-0.107	0.327
Both Eyes AA (D)	-0.148	0.174
Right Eye AF (CPM)	-0.143	0.188
Left Eye AF (CPM)	-0.122	0.265
Both Eyes AF (CPM)	+0.047	0.664
Right Eye MEM (D)	+0.031	0.777
Left Eye MEM (D)	+0.109	0.317

Abbreviations: SD, standard deviation; AA, amplitude of accommodation; D, dioptres; AF, accommodation facility; CPM, cycles per minute; MEM, monocular estimation method. Note: r, Correlation coefficient (\*the Spearman's rank correlation test was used).

## DISCUSSION

We found no significant correlation between any of the accommodative parameters and different levels of visual fatigue among students who used a digital device for  $\geq 3$  h and had a best-corrected distance visual acuity of 6/6. Except for binocular AA and monocular AF, the accommodative parameters were comparable between the low and moderate-to-severe visual fatigue groups. We considered digital device use for more than three hours as long-term use that leads to physiological changes in visual function [16]. Moreover, ocular fatigue and ocular surface changes appear with use of computers for more than two hours [29].

A systematic review of 21 articles on the effects of e-learning during the coronavirus disease 2019 (COVID-19) lockdown identified the development or exacerbation of visual problems in children, such as visual fatigue, vergence, and accommodation disturbances, associated with the increased dependence on digital devices [30]. Furthermore, a recent systematic review and meta-analysis of 45 randomized controlled trials with 4497 participants found no high-certainty evidence of reduction in visual fatigue scores or symptoms after treatment of computer vision syndrome [31]. These studies signify the impact of digital device use on ocular health and the importance of prevention and early detection of visual fatigue induced by digital device use.

The study validating the visual fatigue questionnaire used in this study showed high specificity and sensitivity [2]. The distribution of participants was unequal in our study, as 47 (54.65%) had low visual fatigue, 22 (25.58%)

had severe visual fatigue, and 17 (19.77%) had moderate visual fatigue. Using a different questionnaire, Borsting et al. [3] also found different frequencies in the three categories: 83% in the low category, 16% in the moderate category, and only 1% in the high category [3].

In our study, the low visual fatigue group had better binocular AA and AF for the right eye than the moderate-to-severe visual fatigue group. Thus, the clinical measure of accommodation could be useful in prolonged near work as it leads to visual fatigue. Chase et al. [32] found an increase in the lag of accommodation in high discomfort groups over time, with lags remaining stable in the low discomfort group, suggesting that the discomfort may be attributed to an increase in accommodative lag [32]. We found no significant differences in the lag of accommodation between the groups of visual fatigue; this could be due to the merging of visual fatigue groups before the analysis, or due to differences in the number of participants in each visual fatigue category.

The correlation between the visual fatigue groups and accommodation was computed for each accommodative parameter, and the results were not significant. The strength of correlation was categorized according to the *r* value [33]. Although not significant, a weak negative correlation was found between AA or AF for the right, left, and both eyes with visual fatigue. A negative correlation suggests a slight decrease in accommodative parameters as the visual fatigue scores increase.

In a study by Shrestha et al. [20], accommodative infacility and tired eye were the most common ocular abnormalities among 76 video display terminal users, with a mean (SD) age and daytime computer use of 25.8 (5) years and 6.9 (2.6) hours, respectively. However, the authors found no significant correlation between ocular abnormalities and symptoms [20]. Our investigation of 86 students with a mean age of 22.02 (1.51) years, who used digital devices for  $\geq 3$  hours and had different levels of visual fatigue, binocular AA and monocular AF differed between the groups with low versus moderate-to-severe visual fatigue. We did not detect a significant correlation between any of the accommodative parameters and visual fatigue among the students with different levels of visual fatigue.

Tosha et al. [34] used the Conlon Visual Discomfort Questionnaire to investigate the association between accommodative responses and visual fatigue among college students. Similar numbers of participants were grouped into high- and low-discomfort groups. The authors found a lag in accommodation in the high-discomfort group but a stable accommodation response in the low-discomfort group [34]. This discrepancy between their results and those of the current study could be due to the use of different questionnaires.

During the COVID-19 lockdown, Bahkir et al. [35] conducted an online survey of 407 digital device users with a mean age of 27.4 years and a mean (SD) daytime device use of 8.65 (3.74) hours. They found that 62.4% experienced sleep disturbances, 95.8% reported at least one symptom related to digital device use, and 56.5% declared an increase in the frequency and intensity of these symptoms during the COVID-19 lockdown [35]. We collected no such data from our participants, and the comparison of daytime device use between pre- and mid-lockdown conditions was not the aim of this study. However, observing some accommodative abnormalities among young digital device users with visual fatigue could imply an association between sleep disorders, visual fatigue, and accommodative abnormalities in these individuals. Further investigations are warranted to elucidate the possible clinical correlations.

In our study, binocular AA and monocular AF differed significantly between the visual fatigue groups. These findings could be useful for spreading awareness of visual fatigue among university students and emphasizing the necessity of managing binocular vision anomalies associated with visual fatigue in this active age group. The limitation of this study was the sample size, which was restricted due to time constraints as the COVID-19 pandemic began. Future studies on vergence changes in different categories of visual fatigue, analyzing larger cohorts of digital device users, could improve our understanding of the impact of accommodation and vergence on visual fatigue. Future studies including participants with different durations of digital device use could provide more practical results, just as Mohan et al. [36] found that children attending online classes longer than 4 hours experienced more deterioration of binocular vergence and accommodation parameters than those attending less than 4 hours [36]. Perhaps these perceived vision dysfunctions could affect the visual skills of students. Thus, future studies on the relationship between the observed dysfunctions and students' reading performance [37] are necessary.

## CONCLUSIONS

Binocular AA and monocular AF significantly differed according to visual fatigue severity in young digital device users. However, MEM values did not differ, and no statistically significant correlation was observed between accommodation and visual fatigue. Future studies with more participants and including values of vergence parameters could provide more robust conclusions regarding the impact of accommodation and vergence on various levels of visual fatigue in young digital device users.



## ETHICAL DECLARATIONS

**Ethical approval:** The study was approved by the Institutional Review Board and Ethics Committee of UCSI University. The participants were briefed on the study protocol and provided written informed consent. The tenets of the Declaration of Helsinki were observed throughout the study.

**Conflict of interests:** None

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