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ORIGINAL ARTICLE

Changes in visual function and optical and tear film quality in computer users

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Abstract

Purpose: To assess changes in visual function and optical and tear film quality in computer users.

Methods: Forty computer workers and 40 controls were evaluated at the beginning and end of a working day. Symptoms were assessed using the Quality of Vision questionnaire (QoV), 5-item Dry Eye Questionnaire (DEQ-5) and Symptom Assessment in Dry Eye version II (SANDE II). Tear film quality was evaluated using the Medmont E300 dynamic corneal topography tool to measure the tear film surface quality (TFSQ), TFSQ area and auto tear break-up time (TBUT). Optical quality was assessed by measuring high, low and total ocular aberrations with a Hartmann–Shack wavefront sensor. Visual performance was assessed by measuring photopic and mesopic visual acuity, photopic and mesopic contrast sensitivity and light disturbance.

Results: Poorer DEQ-5, QoV and SANDE II scores were obtained in computer workers at the end of the working day compared with controls ($p \leq 0.02$). Computer workers exhibited a higher (worse) TFSQ and TFSQ area at visit 2 compared with visit 1 ($p \leq 0.04$), while no significant differences in TBUT ($p = 0.19$) or ocular aberrations were observed ($p \geq 0.09$). Additionally, both light disturbance ($p \leq 0.04$) and mesopic and photopic contrast sensitivity worsened at several spatial frequencies ($p \leq 0.04$) throughout the working day in computer workers, while visual acuity remained unchanged ($p \geq 0.07$). In contrast, control subjects exhibited no decrease in any variable during the day.

Conclusions: While visual acuity remained unchanged, several aspects of visual function and quality of vision decreased over a day of computer use. These changes were accompanied by greater dry eye symptoms and tear film changes, which are likely to have played a fundamental role. The present study provides insight into new metrics to assess digital eye strain.

KEYWORDS
digital eye strain, dry eye, optical quality, tear film, visual function

INTRODUCTION

Dry eye disease (DED) is a multifactorial abnormality of the ocular surface, characterised by a loss of homeostasis of the tear film and accompanied by ocular symptoms, in which tear film instability, together with other factors, plays an aetiological role.[1] Visual disturbance is included as a fundamental ocular symptom in DED and greatly impacts the patient's quality of life and interferes with their ability to carry out daily functions.[2,3] Based on previous findings,

up to 44% of patients with DED report impaired visual function.[4]

The tear film–air interface is the first refractive structure of the eye that influences the optical light path to the retina. Due to the significant refractive index change from air into the tear film, abnormalities of the tear film can impact visual quality markedly.[5] Additionally, the tear film compensates for any optical irregularity of the corneal epithelium.[5] Accordingly, the optical quality of the retinal image is highly dependent on the homogeneity of the tear film.[5,6] In DED patients, deficiencies in tear film quantity or quality lead to tear film irregularities and faster break-up times, which induce aberrations and scattering, thus decreasing the quality of vision.[5,7,8] The assessment of visual and tear film quality are therefore interconnected.

Dry eye is recognised as a growing public health problem.[9] The prevalence of DED has been found to range between 5% and 50% at varying ages and has increased significantly over the past years with the escalation of risk factors; one of which has drawn particular attention recently, namely digital display use.[9,10] Indeed, substantial research has pointed to an increased prevalence of dry eye signs and symptoms amongst digital display users.[10–13] Ocular surface and tear film abnormalities, including reduced tear stability, alterations in tear volume and tear composition, increased oxidative stress and ocular surface inflammation have been found in computer workers.[10–13] This may explain the relatively high prevalence of DED observed in younger individuals (20–40 years).[9]

The reasons behind the impact of computer use on the tear film include sustained gaze, which leads to decreased blink rate and amplitude and increased ocular surface exposure due to a wider palpebral fissure associated with elevated gaze angles.[10,14,15] These factors contribute to the disruption of the tear film, which may eventually degrade image quality. As previously noted, alterations in visual function associated with DED are manifestations of tear film instability. In addition, sustained computer use has been associated with accommodative stress, which may impair visual function and contribute to symptoms of blurred vision and difficulties in refocusing frequently reported by computer users.[16] Previous research has indicated a lower visual acuity in daily computer workers compared with those reporting only occasional computer use.[17]

The aim of the present study was to assess and compare the changes in visual function as well as optical and tear film quality in groups of computer workers and non-computer workers throughout a normal working day.

Key points

- Quality of vision and tear film quality worsened throughout the working day in computer workers, whereas non-computer workers did not experience significant changes.
- Light disturbance declined throughout the normal working day in computer workers, but not in those with only occasional computer use.
- Visual acuity and optical quality remained unchanged throughout the working day, regardless of computer use.

METHODS

Participants

Eighty young Caucasian volunteers, ranging in age from 20 to 40 years old, participated in this cross-sectional, case-controlled clinical study. Workers from the School of Sciences of the University of Minho (Braga, Portugal) were invited to participate. Subjects were allocated to one of the two study groups depending on their reported time of computer use during a normal working day, that is, computer workers (computer use ≥ 4 h/day) and controls (computer use ≤1 h/day). Inclusion criteria were between 18 and 40 years of age, best-corrected distance visual acuity (BCDVA) equal to or better than 0.00 logMAR (6/6) in both eyes and either a minimum of 4 h or a maximum of 1 h of computer use during a normal working day. Exclusion criteria were health conditions which may affect the eyes, including, but not limited to Graves disease, diabetes, Sjögren syndrome or multiple sclerosis, pregnancy or breastfeeding, anterior or posterior segment pathologies, active eye allergy, history of eye surgery, binocular disorders (i.e., strabismus, amblyopia, anisometropia, etc.) and a history of contact lens wear in the past 7 days. Additionally, participants receiving treatment for dry eye, actively taking measures to reduce digital eye strain (DES; e.g., artificial tear substitutes, planned regular short breaks, use of screen filters or specialty spectacles) or taking temporary medication known to contribute to dry eye, were excluded.

The study followed the tenets of the Declaration of Helsinki, and approval was obtained from the ethical committee of the University of Minho. All participants were informed about the nature of the study and provided written consent.

Experimental design and apparatus

Visual function, optical quality and tear film quality were evaluated at the beginning (visit 1, baseline; 8.00–10.00 h) and at the end (visit 2; 16.00–18.00 h) of the working day. Additionally, the subjective quality of vision and dry eye symptoms experienced during the working day were examined. All participants worked indoors. During the study period, the school's central heating system operated at 40% humidity and a temperature of 23°C. This design was similar to that used in previous studies.[12] Visual function was assessed by measuring photopic and mesopic BCDVA

and contrast sensitivity function (CSF) using the Optec 6500 Functional Vision Analyzer (Stereo Optical, stereoptical.com).[18] Additionally, light disturbance was assessed using the Light Disturbance Analyzer (LDA; CEORLab, ceorlab.wixsite.com/ceorlab).

Light disturbance is a phenomenon caused by the light from a central luminous point forming a halo surrounding the light source.[19] The LDA analyses the size and shape of the halo surrounding the bright light against a dark background under dim illumination conditions. The test requires the detection of peripheral stimuli along different semi-meridians around a central bright stimulus acting as a glare source. A detailed description of the system, light sources and measuring procedure can be found elsewhere.[20,21] This device has been used successfully to measure the effects of different conditions on visual function.[22–24] In the present study, the in-out routine was selected from the software settings; stimuli were presented from the centre to the periphery along 12 semi-meridians, in random order, until they were detected by the participant.

The following metrics related to the size and shape of the light disturbance were assessed: disturbance area (sum of the areas of all sectors formed between each pair of semi-meridians); light disturbance index (LDI, percentage of the total tested area not visible because of the light disturbance; higher values indicate greater disturbance); best-fit circle radius (BFCR, circle that best fits the polygonal shape of the disturbance area); best-fit circle irregularity (BFCI, deviation of the obtained polygonal shape from the best-fit circle; higher values indicate greater disparity from rotationally or meridionally symmetric shapes) and best-fit circle irregularity standard deviation (BFCI-SD, standard deviation of the BFCI; higher values indicate greater disturbance irregularity).

In addition, the optical quality of the eye was assessed by measuring ocular aberrations using a Hartmann-Shack aberrometer (irx3™; Imagine Eyes, imagine-eyes.com). All measurements were obtained under mesopic conditions. Aberrations were reconstructed using Zernike polynomials for pupil diameters of 3 and 5 mm – these diameters were chosen based on previous studies.[24–26] The root mean square (RMS) was calculated for lower-order aberrations (LOAs), higher-order aberrations (HOAs) up to the eighth order and total aberrations. Additionally, the Strehl ratio for HOAs was recorded.

Furthermore, tear film quality was assessed by measuring TFSQ, TFSQ area and auto tear break-up time (TBUT) using the dynamic topography tool of the Medmont E300 corneal topographer (Medmont International, medmont.com.au). The TFSQ algorithm analyses the structure of the Placido disk pattern reflected onto the tear film over time, which provides a non-invasive measure of tear film quality and stability.[27,28] TFSQ values range from 0 to 1, with higher scores corresponding to greater distortions in the ring pattern and indicating a more destabilised tear film. The TFSQ area corresponds to the percentage area assessed with a TFSQ value >0.30, while the auto TBUT is the time in seconds in which the TFSQ area is at least 5% in two consecutive images.[27,28]

Finally, subjective quality of vision and dry eye symptoms were evaluated using validated questionnaires. Subjective quality of vision was assessed using the quality of vision questionnaire (QoV).[29] The questionnaire is scored on a Rasch scale from 0 to 100 across three subscales – frequency of symptoms, severity of symptoms and how bothersome the symptoms were, with higher scores indicating worse quality of vision. Dry eye symptoms were assessed using the 5-item Dry Eye Questionnaire (DEQ-5) and Symptom Assessment in Dry Eye Questionnaire version II (SANDE II).[30,31]

Both groups underwent the same examination procedures. All measurements were taken on the same eye (the one having the better BCDVA), in the same laboratory, and by the same experienced examiner. Room temperature and humidity were monitored constantly and remained stable at 22.5 ± 0.7°C and 41 ± 5%, respectively.

Protocol

Participants were instructed to attend their first visit at the beginning of the working day. Fifteen minutes before the entry of the participants, the laboratory was set up and acclimatised. One of the experimenters checked whether each volunteer met the inclusion/exclusion criteria before initiating the study. The eye with the better photopic BCDVA acuity was recorded for subsequent measures. Participants were asked about the number of hours of computer use during a normal working day and were classified according to their responses into one of the two study groups.

Mesopic and photopic BCDVA and CSF, light disturbance, ocular aberrations and tear film quality were subsequently assessed in this sequence. The order of measurements was chosen from least disturbing to most disturbing. A brief measurement with the LDA was performed before the actual test to familiarise participants with the device and minimise learning effects. During the test run, the room lights remained on to prevent afterimage formation. For the measurement of ocular aberrations, participants were instructed to fixate on the target while maintaining normal blinking. Before each measurement, participants were instructed to blink and then keep their eyes open. Aberrations were recorded approximately 1 s after the final blink.[32] Ocular aberrations and tear film quality were measured three times, and an average value was obtained. Tear film quality was measured for 30 s, and a 1-min stabilisation period was allowed between consecutive measurements. A minimum acclimatisation period of 15 min was ensured between participants entering the room and tear film measurements. Finally, the time of the second visit was agreed upon. Participants were instructed to attend the second visit immediately after finishing work. Visit 1 lasted 30–40 min.

At the second visit, participants were asked how long they had worked on a computer and how much time

they had spent in front of other digital screens, including smartphones, tablets or other devices between the visits. Any participant with computer use between 1 and 4 h was excluded. The testing procedures were then repeated. Additionally, participants completed the QoV and DEQ-5 surveys. To match the study question, participants were instructed to respond to the questionnaires based exclusively on the symptoms they had experienced during the working day (i.e., between visits). Likewise, participants responded to the SANDE II, which asked about the difference in the severity and frequency of dry eye symptoms compared with the previous visit. Visit 2 had a duration of 15–20 min. All visits were carried out between the months of May and July.

Statistical analysis

The results were evaluated using SPSS software v.28 (IBM, ibm.com). The normality of data was assessed using the Shapiro–Wilk test. When parametric test assumptions were fulfilled, an unpaired *t*-test was used to compare baseline and demographic characteristics between the study groups. The chi-squared test was used for comparison of qualitative variables. The non-parametric Mann–Whitney *U*-test was used when parametric test assumptions were not fulfilled.

Additionally, a paired-sample *t*-test was used to examine the differences in visual function as well as optical and tear film quality before and after the working day (visit 1 and visit 2, respectively) for each study group. The Wilcoxon paired signed-rank test was used as a non-parametric alternative. In parallel, a one-sample Wilcoxon signed-rank test was used to examine if the obtained SANDE II score was significantly greater than zero.

Finally, to quantify the changes experienced throughout the working day, the difference between visits was calculated for each variable (visit 2 – visit 1). An unpaired *t*-test or the Mann–Whitney *U*-test, depending on the distribution of data, was used to compare changes experienced throughout the working day, and the DEQ-5 and QoV scores obtained at visit 2, between groups. This analysis was similar to that of previous studies of similar nature.[13] *p*-Values of <0.05 were considered statistically significant.

Sample size was estimated *a priori*, based on the results of the first 10 participants for the primary endpoint of the study (QoV), using the G-Power tool.[33] With $\alpha = 0.05$ and power $(1-\beta) = 0.80$, the estimated sample size for each group was 30 participants (effect size = 0.75). A greater sample was recruited to account for possible study dropouts and to ensure suitable statistical power when considering the entire sample. Post-hoc analysis revealed a statistical power of 0.84 (effect size = 0.67).

RESULTS

Eighty-six Caucasian volunteers between 20 and 40 years of age were initially recruited, of whom 80 (55 women and 25 men) met the inclusion/exclusion criteria and completed both study visits. From these 80 participants, 40 (30 women and 10 men, aged 26 ± 5 years) were placed in the control group and 40 (25 women and 15 men, aged 28 ± 5 years) into the computer group. The average time between visits was 7.5 ± 1.0 h (min – max; 6.0–10.0 h). No significant differences in age ($p = 0.08$) or sex ($p = 0.23$) were observed between the groups. The average amount of computer use reported by computer workers and controls between the two visits was 7.7 ± 2.4 and 0.1 ± 0.3 h, respectively ($p < 0.001$). Additionally, the average reported time for digital device use (other than the computer) for computer workers and controls was 1.2 ± 0.6 h and 1.2 ± 0.9 h, respectively ($p = 0.56$).

Table 1 shows the mean, SD and range of optical and tear film quality variables obtained at the beginning and at the end of the working day for both study groups. Additionally, the table displays the statistical comparisons between visits and baseline variables. No significant differences between the groups were observed at baseline for any variable (all $p \geq 0.09$). Likewise, no significant differences between visits were observed in any optical or tear film variable for the control group ($p \geq 0.16$) and the SANDE II scores obtained at visit 2 were not significantly different from zero ($p \geq 0.07$). In contrast, both TFSQ and TFSQ areas were significantly higher at visit 2 compared with visit 1 in computer workers ($p \leq 0.04$), although TBUT and optical quality variables did not change significantly ($p \geq 0.09$). In parallel, the SANDE II frequency and severity scores obtained in the computer group at visit 2 were significantly greater than zero ($p < 0.001$ for both).

Table 2 shows dry eye symptoms reported by participants during the working day and the changes in optical and tear film variables between visits. The changes in RMS and Strehl ratio observed throughout the working day did not differ significantly between groups ($p \geq 0.32$). Conversely, the TFSQ and TFSQ area showed a significantly greater increase in computer workers compared with controls ($p \leq 0.04$; Figure 1). Additionally, computer workers reported significantly higher DEQ-5 and SANDE II scores than controls ($p \leq 0.02$; Figure 2).

Table 3 shows the mean, SD and range of visual function variables obtained at the beginning and end of the working day for both study groups. No significant differences were observed at baseline between the groups for any variable ($p \geq 0.07$), except for a higher mesopic contrast sensitivity at 3 cycles per degree (cpd; $p = 0.004$) in computer workers. The control group exhibited a significantly higher photopic contrast sensitivity at 1.5 and 6 cpd and mesopic contrast sensitivity at 1.5, 3 and 6 cpd after the working day compared with visit 1 ($p \leq 0.04$). Likewise, light disturbance area, LDI and light disturbance BFCR were significantly lower at the end of the working day compared with the beginning ($p \leq 0.01$), while no other significant changes were observed in this group ($p \geq 0.06$). In contrast, computer workers exhibited a lower photopic contrast sensitivity at 1.5 cpd and mesopic contrast sensitivity at

TABLE 1 Optical and tear film quality variables obtained for both study groups (control and computer workers) and statistical comparisons between visits.

	Control ($n=40$)			Computer workers ($n=40$)			Baseline comparisons
Variable	**Visit 1 (baseline)**	**Visit 2**	***p*-Value**	**Visit 1 (baseline)**	**Visit 2**	***p*-Value**	***p*-Value**
SANDE II[a]							
Frequency	—	0.1 ± 0.6 [−2.5, 2.2]	0.21[ϔ]	—	1.6 ± 1.5 [−1.1, 5.0]	<0.001*[,ϔ]	—
Severity	—	0.2 ± 0.9 [−3.0, 3.0]	0.07[ϔ]	—	1.5 ± 1.4 [0.0, 5.0]	<0.001*[,ϔ]	—
RMS (μm)							
3 mm							
LOA	0.53 ± 0.64 [0.05, 2.42]	0.55 ± 0.66 [0.06, 2.44]	0.47[‡]	0.64 ± 0.63 [0.08, 2.76]	0.65 ± 0.66 [0.08, 2.82]	0.46[‡]	0.09[¥]
HOA	0.09 ± 0.02 [0.05, 0.13]	0.08 ± 0.02 [0.05, 0.16]	0.16[‡]	0.09 ± 0.03 [0.05, 0.20]	0.09 ± 0.03 [0.06, 0.20]	0.43[‡]	0.98[¥]
Total	0.55 ± 0.63 [0.08, 2.42]	0.57 ± 0.65 [0.08, 2.44]	0.46[‡]	0.66 ± 0.65 [0.14, 2.77]	0.65 ± 0.64 [0.12, 2.83]	0.76[‡]	0.09[¥]
5 mm							
LOA	1.49 ± 1.90 [0.09, 7.13]	1.53 ± 1.94 [0.14, 7.06]	0.20[‡]	1.71 ± 1.63 [0.18, 6.19]	1.74 ± 1.66 [0.13, 6.15]	0.97[‡]	0.09[¥]
HOA	0.20 ± 0.08 [0.09, 0.36]	0.20 ± 0.07 [0.09, 0.43]	0.35[‡]	0.21 ± 0.06 [0.09, 0.46]	0.20 ± 0.07 [0.12, 0.43]	0.54[‡]	0.62[¥]
Total	1.53 ± 1.88 [0.15, 7.14]	1.57 ± 1.90 [0.19, 7.07]	0.25[‡]	1.73 ± 1.61 [0.20, 6.20]	1.76 ± 1.64 [0.21, 6.15]	0.92[‡]	0.11[¥]
Strehl ratio[b]							
3 mm	0.45 ± 0.13 [0.17, 0.76]	0.45 ± 0.15 [0.08, 0.73]	0.89[†]	0.42 ± 0.15 [0.09, 0.73]	0.45 ± 0.13 [0.19, 0.69]	0.15[†]	0.48[§]
5 mm	0.13 ± 0.11 [0.03, 0.63]	0.12 ± 0.07 [0.02, 0.39]	0.58[‡]	0.11 ± 0.08 [0.03, 0.48]	0.11 ± 0.05 [0.04, 0.26]	0.09[‡]	0.40[¥]
TFSQ	0.138 ± 0.058 [0.043, 0.291]	0.135 ± 0.054 [0.069, 0.316]	0.71[‡]	0.127 ± 0.067 [0.052, 0.417]	0.148 ± 0.082 [0.046, 0.389]	0.04*[,‡]	0.21[¥]
TFSQ area (%)	6.7 ± 6.5 [0.1, 27.4]	6.9 ± 6.4 [0.6, 26.4]	0.73[‡]	6.2 ± 7.0 [0.3, 33.9]	9.0 ± 9.9 [0.1, 38.8]	0.02*[,‡]	0.30[¥]
Auto TBUT (seconds)	12.8 ± 8.9 [2.5, 30.0]	13.0 ± 8.7 [2.4, 30.0]	0.79[‡]	15.9 ± 9.7 [2.4, 30.0]	13.6 ± 9.3 [2.5, 30.0]	0.19[‡]	0.14[¥]

Note: Data are presented as mean ± standard deviation [min, max].

Abbreviations: HOA, higher-order aberration up to the eighth order; LOA, lower-order aberration; mm, millimetres; RMS, root mean square; SANDE II, Symptom Assessment in Dry Eye questionnaire version II; TBUT, tear break-up time; TFSQ, tear film surface quality; μm, micrometres.

[a]SANDE II was completed at visit 2 and denotes the change in dry eye symptoms between visits. Statistical comparison with a value of zero (no change).

[b]Strehl ratio for higher-order aberrations.

*Denote statistically significant values ($p<0.05$).

[†]Paired sample *t*-test.

[‡]Wilcoxon paired signed-rank test.

[§]Unpaired *t*-test.

[¥]Mann–Whitney *U* test.

[ϔ]One-sample Wilcoxon signed-rank test.

TABLE 2 Dry eye symptoms during the working day, changes in optical and tear film quality between visits (visit 2 – visit 1) and statistical comparisons between groups.

Variables	Control ($n=40$)	Computer workers ($n=40$)	p-Value
DEQ-5[a]	2 ± 3 [0, 13]	4 ± 4 [0, 14]	0.02*,†
SANDE II			
Frequency	0.1 ± 0.6 [−2.5, 2.2]	1.6 ± 1.5 [−1.1, 5.0]	<0.001*,†
Severity	0.2 ± 0.9 [−3.0, 3.0]	1.5 ± 1.4 [0.0, 5.0]	<0.001*,†
RMS (μm)			
3 mm			
LOA	0.02 ± 0.09 [−0.12, 0.26]	0.01 ± 0.10 [−0.22, 0.31]	0.97†
HOA	0.0 ± 0.02 [−0.04, 0.07]	0.0 ± 0.02 [−0.04, 0.11]	0.34†
Total	± 0.08 [−0.12, 0.23]	0.00 ± 0.09 [−0.28, 0.22]	0.75†
5 mm			
LOA	0.04 ± 0.19 [−0.31, 0.52]	0.03 ± 0.38 [−0.90, 1.65]	0.43†
HOA	−0.01 ± 0.04 [−0.09, 0.09]	0.00 ± 0.05 [−0.12, 0.20]	0.96†
Total	0.04 ± 0.17 [−0.31, 0.52]	0.03 ± 0.38 [−0.90, 1.65]	0.48†
Strehl ratio[b]			
3 mm	0.00 ± 0.14 [−0.48, 0.32]	0.03 ± 0.13 [−0.40, 0.27]	0.32†
5 mm	−0.01 ± 0.08 [−0.34, 0.11]	0.00 ± 0.06 [−0.33, 0.06]	0.77†
TFSQ	−0.004 ± 0.036 [−0.092, 0.089]	0.021 ± 0.062 [−0.097, 0.250]	0.04*,†
TFSQ area (%)	−0.7 ± 4.1 [−15.2, 8.2]	2.8 ± 7.0 [−10.4, 29.8]	0.03*,†
Auto TBUT (seconds)	0.3 ± 5.7 [−20.9, 13.6]	−2.4 ± 9.4 [−24.0, 15.3]	0.29†

Note: Data are presented as mean ± standard deviation [min, max].

Abbreviations: DEQ-5, 5-item Dry Eye Questionnaire; HOA, higher-order aberration up to the 8th order; LOA, lower-order aberration; mm, millimetres; RMS, root mean square; SANDE II, Symptom Assessment in Dry Eye questionnaire version II; TBUT, tear break-up time; TFSQ, tear film surface quality; μm, micrometres.

[a]Symptoms experienced throughout the working day were assessed at visit 2.

[b]Strehl ratio for higher-order aberrations.

*Denote statistically significant values ($p < 0.05$).

†Mann–Whitney *U* test.

3 cpd ($p \leq 0.04$), along with a higher light disturbance area, LDI and light disturbance BFCR ($p \leq 0.04$) after the working day, compared with visit 1.

Finally, Table 4 shows the quality of vision reported by participants during the working day and the changes in visual function variables between visits. Computer workers exhibited a significantly greater decline in photopic contrast sensitivity at 1.5 and 18 cpd and mesopic contrast sensitivity at 1.5, 3 and 6 cpd ($p \leq 0.03$), along with a significantly greater increase in light disturbance area, LDI and light disturbance BFCR ($p \leq 0.003$) throughout the working day, compared with controls (Figure 3). Additionally, significantly higher frequency, severity and bothersome scores with the QoV were obtained in computer workers compared with controls ($p \leq 0.003$; Figure 2).

DISCUSSION

Tear film quality

In the present study, computer workers reported significantly higher dry eye symptoms (DEQ-5) throughout the working day, along with a greater increase in the frequency and severity of their symptoms (SANDE II) compared with controls. This is in accordance with the accepted theory of DES, recognised as a health problem for over 20 years.[34] Moreover, the tear film quality of computer workers became significantly worse (16.5% increase in TFSQ and 45.2% increase in TFSQ area) throughout the working day compared with controls (2.2% decrease in TFSQ and 3.0% increase in TFSQ area), indicating greater distortion and destabilisation. The hazardous effects of computer use on the ocular surface are widely acknowledged.[10–16] In a similar study, Yazici et al.[12] observed a significant worsening of dry eye signs and symptoms in computer workers throughout the working day as opposed to no significant changes in controls. In contrast, despite the changes in TFSQ and TFSQ area, the change in TBUT in computer workers was not statistically significant. TBUT decreased, on average, by more than 2 s (14.5% decrease) throughout the working day, which could be considered clinically relevant.

In patients with DED, the loss of homeostasis of the tear film creates an irregularity, which diminishes optical and visual quality.[5–8] In the present study, computer workers reported lower quality of vision throughout the working day compared with controls, with a higher frequency, severity and bothersome nature of symptoms (QoV). Overall, the

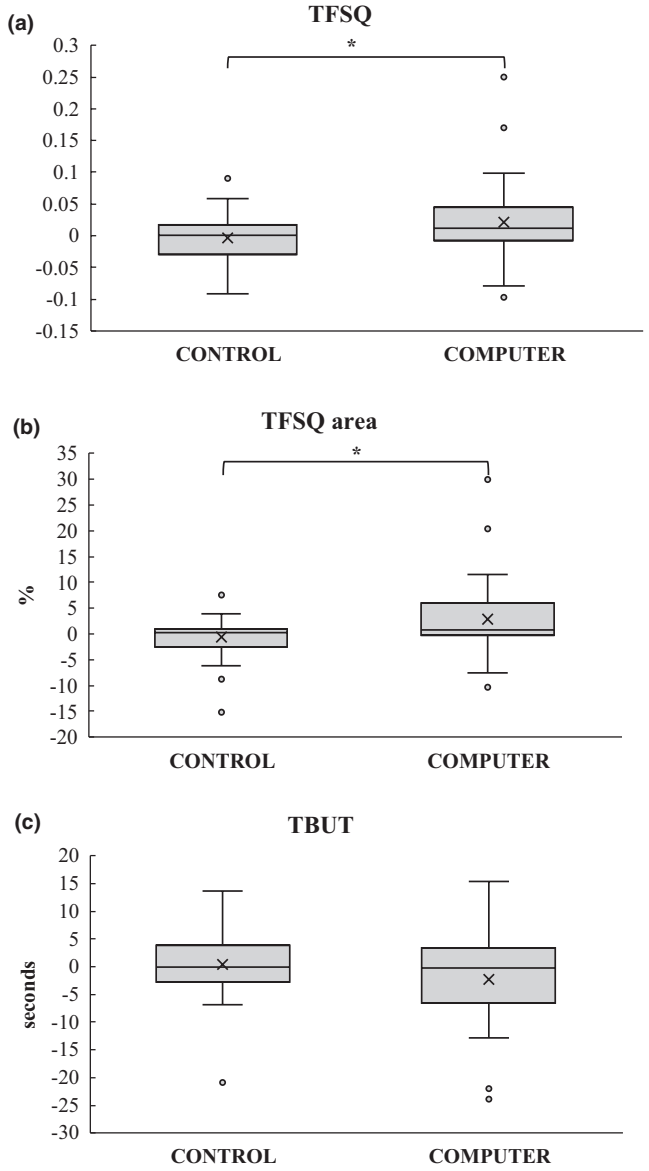

FIGURE 1 Boxplots of the changes in tear film quality between visits (visit 2 – visit 1) in both study groups (control and computer workers). (a) Tear film surface quality (TFSQ), (b) TFSQ area and (c) tear break-up time (TBUT). *Indicates statistical significance ($p < 0.05$).

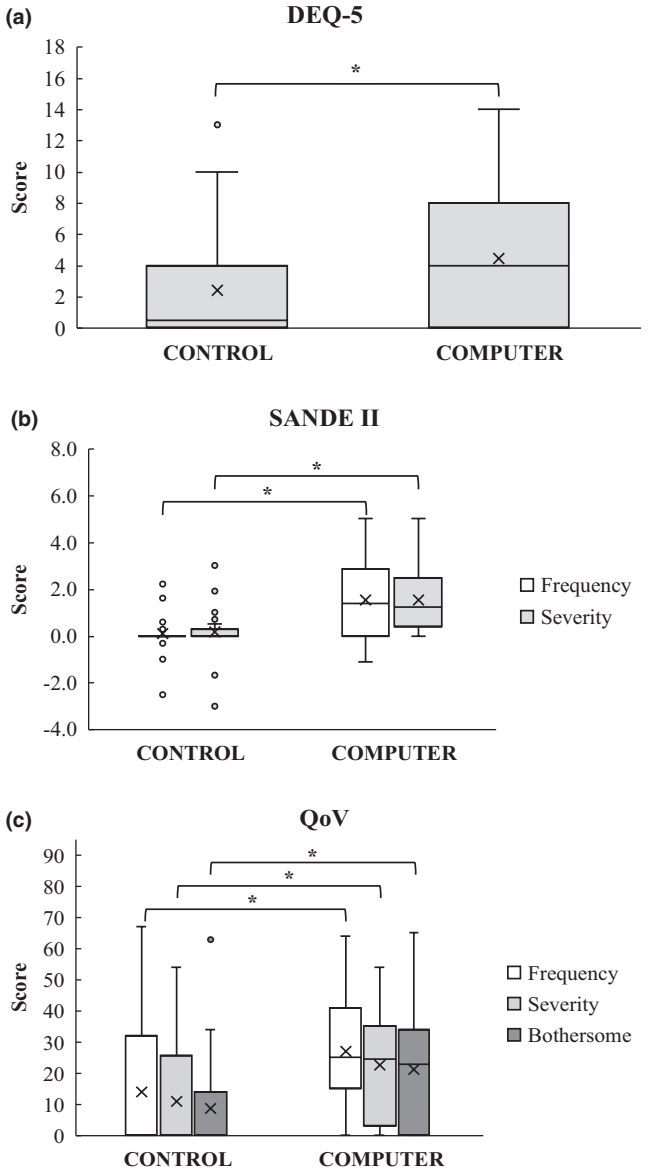

FIGURE 2 Boxplots of the symptoms experienced during the working day in both study groups (control and computer workers). (a) 5-item Dry Eye Questionnaire (DEQ-5), (b) Symptom Assessment in Dry Eye version II (SANDE II), (c) Quality of Vision questionnaire (QoV). *Indicates statistical significance ($p < 0.05$).

disruption of the tear film resulting from sustained gaze associated with computer use may have degraded subjective visual quality in computer users.

Nevertheless, it should be noted that the ocular symptoms associated with DES are often split into two main categories. The first group, termed external symptoms, is related to dry eye, while the second group, termed internal symptoms, is linked to accommodative and/or binocular vision stress.[35,36] Among these symptoms are vision-related symptoms such as blur, double vision, halos, difficulty in refocusing or sensitivity to bright lights which may be associated with one or both categories, simultaneously. Accordingly, the lower quality of vision reported throughout the day by frequent computer users in the present study was anticipated, and may be attributable not only to a decline in tear film quality but also to accommodative stress.[37] Equally, it should be noted that, as opposed to the controls, computer workers spent most of their working day performing visually demanding tasks. This may have increased their awareness of these symptoms.

Optical quality

There is evidence that dry eye and HOAs are associated, and that tear film metrics are correlated with HOAs.[38] However, in the present study, the reduction in tear film quality observed in computer workers throughout the

TABLE 3 Visual function variables obtained for both study groups (control and computer workers) and statistical comparisons between visits.

	Control ($n=40$)			Computer workers ($n=40$)			Baseline comparisons
Variable	**Visit 1 (baseline)**	**Visit 2**	***p*-Value**	**Visit 1 (baseline)**	**Visit 2**	***p*-Value**	***p*-Value**
Photopic BCDVA (logMAR)	−0.09 ± 0.05 [−0.20, 0.00]	−0.10 ± 0.05 [−0.20, 0.00]	0.57†	−0.07 ± 0.04 [−0.14, 0.00]	−0.07 ± 0.06 [−0.14, 0.10]	0.07†	0.07§
Mesopic BCDVA (logMAR)	0.01 ± 0.08 [−0.18, 0.14]	−0.01 ± 0.08 [−0.14, 0.14]	0.06†	0.03 ± 0.07 [−0.06, 0.20]	0.03 ± 0.09 [−0.10, 0.20]	0.90‡	0.49¥
Photopic CSF (dB)							
1.5 cpd	47 ± 20 [25, 100]	52 ± 22 [25, 100]	0.04*,‡	47 ± 20 [25, 100]	40 ± 18 [25, 100]	0.04*,‡	0.84¥
3 cpd	115 ± 32 [40, 160]	116 ± 27 [80, 160]	0.81‡	104 ± 31 [40, 160]	104 ± 29 [40, 160]	0.93‡	0.28¥
6 cpd	95 ± 34 [33, 180]	111 ± 39 [23, 180]	0.02*,‡	99 ± 34 [33, 180]	95 ± 43 [12, 180]	0.85‡	0.59¥
12 cpd	52 ± 25 [11, 120]	56 ± 26 [11, 120]	0.19‡	53 ± 28 [15, 120]	51 ± 29 [0, 120]	0.50‡	0.92¥
18 cpd	19 ± 12 [4, 46]	23 ± 13 [4, 65]	0.06‡	21 ± 12 [4, 65]	18 ± 10 [0, 33]	0.09‡	0.64¥
Mesopic CSF (dB)							
1.5 cpd	52 ± 22 [25, 100]	59 ± 21 [25, 100]	0.03*,‡	57 ± 27 [25, 100]	50 ± 20 [18, 100]	0.17‡	0.52¥
3 cpd	96 ± 31 [40, 160]	110 ± 30 [57, 160]	0.006*,‡	116 ± 29 [40, 160]	102 ± 30 [40, 160]	0.005*,‡	0.004*,¥
6 cpd	63 ± 30 [16, 128]	71 ± 34 [16, 128]	0.02*,‡	70 ± 29 [12, 128]	67 ± 38 [0, 180]	0.45‡	0.20¥
12 cpd	25 ± 15 [0, 60]	26 ± 15 [0, 60]	0.48‡	22 ± 14 [0, 60]	22 ± 14 [0, 43]	0.98‡	0.56¥
18 cpd	9 ± 8 [0, 46]	9 ± 5 [0, 17]	0.41‡	7 ± 6 [0, 23]	7 ± 5 [0, 17]	0.82‡	0.31¥
Light disturbance							
Disturbance area (mm^2)	2040 ± 1107 [752, 5184]	1860 ± 869 [768, 4672]	0.01*,‡	2182 ± 1393 [768, 8336	2429 ± 1370 [768, 6928]	0.04*,‡	0.74¥
LDI (%)	10.15 ± 5.50 [3.74, 25.78]	9.25 ± 4.32 [3.82, 23.24]	0.01*,‡	10.85 ± 6.93 [3.82, 41.46]	12.09 ± 6.82 [3.82, 34.46]	0.04*,‡	0.74¥
BFCR (mm)	25.1 ± 6.7 [16.0, 41.3]	24.2 ± 5.4 [16.0, 39.3]	0.02*,†	26.0 ± 7.2 [16.0, 52.7]	27.5 ± 7.2 [16.9, 48.0]	0.02*,‡	0.70¥
BFCI (mm)	0.58 ± 0.59 [0.00, 1.80]	0.65 ± 0.70 [0.00, 2.91]	0.46‡	0.51 ± 0.34 [0.00, 1.41]	0.47 ± 0.38 [0.00, 1.66]	0.48‡	0.55¥
BFCI-SD (mm)	3.76 ± 2.20 [0.00, 9.48]	3.47 ± 1.57 [0.00, 7.52]	0.59‡	3.91 ± 1.70 [0.00, 9.84]	4.21 ± 1.61 [0.00, 8.91]	0.25‡	0.95¥

Note: Data are presented as mean ± standard deviation [min, max].

Abbreviations: BCDVA, best-corrected distance visual acuity; BFCI, best-fit circle irregularity; BFCI-SD, standard deviation of best-fit circle irregularity; BFCR, best-fit circle radius; cpd, cycles per degree; CSF, contrast sensitivity function; dB, decibel; LDI, light disturbance index; mm, millimetres; QoV, Quality of Vision questionnaire.

*Denote statistically significant values ($p<0.05$).

†Paired sample *t*-test.

‡Wilcoxon paired signed-rank test.

§Unpaired *t*-test.

¥Mann–Whitney *U* test.

TABLE 4 Quality of vision during the working day, changes in visual function between visits (visit 2 – visit 1) and statistical comparisons between groups.

Variables	Control ($n=40$)	Computer workers ($n=40$)	p-Value
QoV[a]			
Frequency	14 ± 20 [0, 67]	27 ± 19 [0, 64]	0.003*,‡
Severity	11 ± 16 [0, 54]	23 ± 17 [0, 54]	0.002*,‡
Bothersome	9 ± 16 [0, 63]	21 ± 19 [0, 65]	0.001*,‡
Photopic BCDVA (logMAR)	0.00 ± 0.03 [−0.10, 0.04]	0.02 ± 0.05 [−0.06, 0.14]	0.19‡
Mesopic BCDVA (logMAR)	−0.02 ± 0.06 [−0.20, 0.10]	0.00 ± 0.09 [−0.22, 0.18]	0.18‡
Photopic CSF (dB)			
1.5 cpd	5 ± 15 [−29, 35]	−7 ± 19 [−64, 29]	0.003*,‡
3 cpd	1 ± 29 [−46, 120]	−1 ± 30 [−80, 57]	0.98‡
6 cpd	16 ± 38 [−64, 116]	−1 ± 32 [−64, 64]	0.06‡
12 cpd	4 ± 22 [−55, 60]	−2 ± 20 [−77, 42]	0.26‡
18 cpd	3 ± 10 [−21, 32]	−2 ± 10 [−42, 21]	0.02*,‡
Mesopic CSF (dB)			
1.5 cpd	7 ± 17 [−35, 50]	−7 ± 26 [−64, 35]	0.03*,‡
3 cpd	14 ± 26 [−46, 80]	−14 ± 25 [−57, 46]	<0.001*,‡
6 cpd	8 ± 21 [−64, 64]	−3 ± 30 [−67, 64]	0.03*,‡
12 cpd	1 ± 11 [−28, 32]	0 ± 10 [−28, 15]	0.83‡
18 cpd	−1 ± 7 [−34, 9]	1 ± 5 [−15, 13]	0.56‡
Light disturbance			
Disturbance area (mm^2)	−180 ± 404 [−1136, 400]	247 ± 725 [−1408, 2736]	0.002*,‡
LDI (%)	−0.89 ± 2.00 [−5.65, 1.99]	1.23 ± 3.61 [−7.00, 13.60]	0.002*,‡
BFCR (mm)	−0.9 ± 2.5 [−6.0, 3.3]	1.5 ± 3.9 [−5.3, 14.0]	0.003*,‡
BFCI (mm)	0.07 ± 0.73 [−1.51, 1.87]	−0.04 ± 0.45 [−0.99, 0.89]	0.42†
BFCI-SD (mm)	−0.29 ± 1.78 [−5.15, 3.00]	0.30 ± 1.78 [−5.46, 5.09]	0.24‡

Note: Data are presented as mean ± standard deviation [min, max].

Abbreviations: BCDVA, best-corrected distance visual acuity; BFCI, best-fit circle irregularity; BFCI-SD, standard deviation of best-fit circle irregularity; BFCR, best-fit circle radius; cpd, cycles per degree; CSF, contrast sensitivity function; dB, decibel; LDI, light disturbance index; mm, millimetres; QoV, Quality of Vision questionnaire.

[a]Symptoms experienced throughout the working day were assessed at visit 2.

*Denote statistically significant values ($p < 0.05$).

†Unpaired *t*-test.

‡Mann–Whitney *U*-test.

working day was not accompanied by significant changes in ocular HOAs or the Strehl ratio. Previous research revealed that the retinal image quality of individuals with aqueous tear-deficient dry eye and ocular surface damage is impaired immediately after blinking.[39] In contrast, for patients with dry eye associated with short tear film stability but an absence of tear deficiency, image quality deteriorates over time as the tear film stability decreases, but remains adequate just after the blink, thus leading to fluctuations in vision.[40,41] As aforementioned, digital devices induce tear film instability through alterations in the blinking pattern, resulting in evaporative dry eye.[10] In the present study, ocular aberrations were measured shortly after blinking. Therefore, despite mild tear film abnormalities caused by viewing a digital screen, the tear film of computer workers remained stable at the time of measuring ocular aberrations. This could explain why no changes in optical quality were observed with computer use. Future studies are required to confirm these findings and to assess dynamic changes in optical quality in computer users.

Blurred vision is a symptom commonly associated with DES which could result from an inaccurate accommodative response during a computer task or a failure to relax accommodation fully following near vision demands.[37] This temporal accommodative spasm results from the overstimulation of the eye's accommodative mechanism and leads to an increase in ocular refractive power known as near-work-induced transient myopia or pseudomyopia.[42] Refractive errors are in essence LOAs. Additionally, total ocular aberrations and HOAs have been shown to change significantly with changes in accommodation.[43] In the present study, no significant changes in total aberrations, LOA or HOA were observed throughout the working day in computer workers; thus changes in refraction or the accommodative response were unlikely.

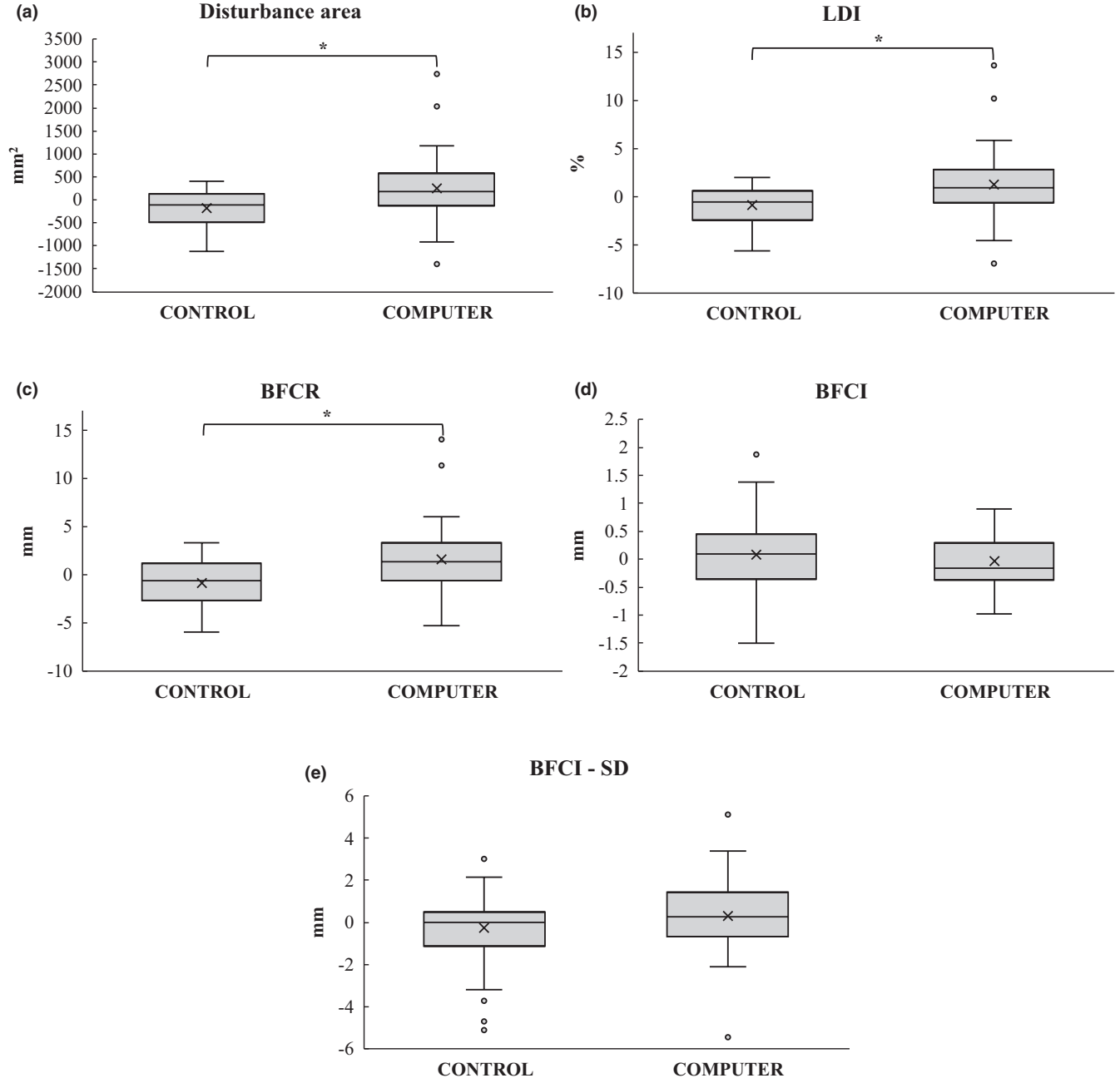

FIGURE 3 Boxplots of the changes in light disturbance between visits (visit 2 – visit 1) in both study groups (control and computer workers). (a) Disturbance area, (b) light disturbance index (LDI), (c) best-fit circle radius (BFCR), (d) best-fit circle irregularity (BFCI) and (e) standard deviation (SD) of best-fit circle irregularity. *Indicates statistical significance ($p < 0.05$).

Visual function

In the present study, computer workers exhibited a significant increase in light disturbance throughout the working day. More specifically, an average increase of 11.3% was observed in the size of the disturbance halo (disturbance area, LDI and BFCR), although not in its shape or regularity (BFCI and BFCI-SD). Previous research has reported greater forward light scattering in dry eyes than normal eyes, which explains the symptom of glare often reported by individuals with DED.[44] Likewise, Himebaugh et al.[45] described the formation of scatter-producing microaberrations associated with areas of tear break-up, which contribute to image degradation. Accordingly, the degradation of the tear film with computer use might have increased light scattering in the group of computer workers without observable changes in ocular aberrations, thereby leading to a greater disturbance of the central glare source in the LDA. This increase in light disturbance probably contributed to the decline in the quality of vision reported by computer workers at the end of the working day. On the contrary, light disturbance significantly improved in non-computer workers.

This could be attributed to unavoidable learning effects, although the differences (<1%) are within the sensitivity of the device. This is particularly relevant since it implies that the true increase in light disturbance in computer workers might be greater than that observed in our data.

Tear instability can also precipitate significant reductions in visual acuity and contrast sensitivity.[46,47] In the present study, both photopic and mesopic contrast sensitivity decreased more in computer workers compared with controls at several spatial frequencies. This decrease could be related to the increase in light scattering which produces veiling luminance on the retina and reduces the contrast of the retinal image. Toda et al.[47] observed that visual performance significantly declined during concentrated visual work and concluded that under conditions in which blinking is restricted, such as computer work, visual performance could be compromised. More specifically, the decline in contrast sensitivity observed in the present study was most noticeable at lower spatial frequencies. This is in line with previous research which demonstrated low spatial-contrast sensitivity in dry eyes.[48] In parallel, recent findings have suggested that visual fatigue is associated with changes in clinical visual measures and basic visual functions, including contrast sensitivity.[49] Conversely, in the present study, photopic and mesopic visual acuity was unchanged in both groups. This is in contrast with previous research, which reported significantly lower visual acuity in daily computer workers compared to those with occasional computer use.[17]

The present study has some limitations to consider. The investigation was carried out at only one centre, which may have introduced selection bias. In addition, recruitment by means of advertisement could have induced a higher prevalence of symptomatic individuals than expected in the general population. Due to the subjective evaluation of symptoms, a nocebo effect on the results cannot be completely ruled out. Additionally, although methodological choices were made to prevent learning effects, some may have influenced the data. Nevertheless, potential learning effects are not expected to differ between groups and comparisons should not be affected. Moreover, dynamic changes in ocular aberrations over the interblink interval were not assessed. Therefore, the ocular aberrations quantified here are only representative of participants' optical quality at a particular time after blinking. However, the present study establishes the basis for future work which could assess dynamic aberrations in computer users. Although participants were instructed to attend the second visit immediately after finishing work, it is possible that transient changes may have declined on their way to the laboratory, that is, prior to the measurements. Nevertheless, all of the participants were workers of the School of Sciences and measurements were taken as soon as they arrived at the laboratory; thus, the washout period was minimal. In addition, the study was not blinded. Consequently, the examiner was aware of which group the participant was assigned and observer bias cannot be completely ruled out. Finally, due to the lack of studies assessing the effects of computer use on visual function and quality, there is limited comparison of our results to similar previous studies.

In conclusion, computer workers exhibited greater dry eye symptoms, along with a decline in the perceived quality of vision, tear film quality and contrast sensitivity throughout the working day, while no worsening was observed in any variable in workers with only occasional computer use. Similarly, computer workers exhibited an increase in light disturbance throughout the working day as opposed to no change in non-computer workers. In contrast, optical aberrations remained unchanged in both groups. Further studies are needed to confirm these findings and to deepen our understanding of the effects of digital screens on visual performance and the quality of vision. Likewise, the effects of accommodative and binocular vision stress, as well as workstation design, on the quality of vision and the visual function of computer workers requires investigation in specifically designed studies. This investigation provides insight into new metrics that can be used to measure changes in visual quality objectively and quantitatively through the analysis of light disturbance.

AUTHOR CONTRIBUTIONS

Cristian Talens-Estarelles: Conceptualization (lead); data curation (equal); formal analysis (lead); funding acquisition (equal); investigation (lead); methodology (lead); writing – original draft (lead). **María Mechó-García:** Data curation (equal); investigation (equal); methodology (equal); writing – review and editing (equal). **Colm McAlinden:** Formal analysis (equal); methodology (equal); supervision (equal); validation (equal); writing – review and editing (equal). **Alejandro Cerviño:** Conceptualization (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); supervision (equal); writing – review and editing (equal). **Santiago García-Lázaro:** Conceptualization (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); supervision (equal); writing – review and editing (equal). **José Manuel González-Méijome:** Conceptualization (equal); data curation (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); resources (lead); supervision (lead); writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

José Manuel González Méijome has a proprietary interest in the light disturbance analyzer.

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