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Original Article

Effects of different light sources used for dental operating microscope illumination on the visual function of operators

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ABSTRACT

Objectives: Advances in dental operative microscopes (DOMs) enable examination of root canal morphology or detection of root fractures otherwise not visible to the naked eye. However, dental therapy involving prolonged use of DOMs requires precision within a limited visual field, resulting in eye strain among users. This study examined the effects of halogen and light-emitting diode (LED) light sources on asthenopia and visual function following use of DOMs.

Methods: The study used halogen and LED light sources in DOMs. The first experiment was conducted on 6 participants with corrected visual acuity without any organic eye disease. General visual function test (calculation ability test, hand grip strength test, and ophthalmic examination) and subjective symptom questionnaire were used to evaluate the degree of fatigue before and after DOM use. The second experiment was conducted on 9 participants with spherical equivalents within ±4 diopters (D) and astigmatism of 1 D or less. Accommodative function tests (precise test for asthenopia) and a subjective symptom questionnaire (asthenopia) were used before and after use of DOM.

Results: No significant changes were noted in the degree of fatigue and ophthalmological parameters before and after the procedure with either light source or in between light sources. The tear firm breakup time was shortened after therapy, and a tendency toward dry eyes was observed while using the LED light source.

Conclusions: The halogen and LED light sources used for DOM therapy had similar effects on asthenopia of the operators, with no significant changes in visual function.

1. Introduction

Asthenopia is a complex symptom that affects patients with information technology (IT) ophthalmopathy or visual display terminal (VDT) syndrome due to overuse of personal computers (PC) or smartphones [1], and it has been a challenging issue among dentists with prolonged use of dental operative microscopes (DOMs) for dental therapy. With the widespread use of DOMs in the recent years, it has become routine to observe the endodontic condition of teeth or detect root fractures that are otherwise invisible to the naked eye [2–4]. However, repeatedly performing precision work within a limited visual field under DOM for 30 min or longer has raised concerns about its effects on visual function not only immediately after a dental therapy, but also throughout the lifetime of the dentist. Light-emitting diodes (LEDs) are currently used for displays in most models of PCs and smartphones. The LED is small, bright, highly efficient, and shock resistant. It consumes less electric power and has a longer life than an incandescent lamp or a fluorescent lamp; therefore, LED replacement of traditional lighting equipment has been recommended [5,6]. LED is also becoming the predominant light source of DOMs, replacing the halogen light source that has been used since their development. Both halogen and LED lights contain blue wavelengths (blue light)

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that are known to affect the eyes. The effect of blue light on the retina has been suggested in age-related macular degeneration (AMD). It is a major cause of blindness in Europe and the United States [7–10], and it affects the long-term exposure to blue light [11,12]. Further, use of occlusion lenses reduces accumulation of blue light and prevents development of AMD to some extent [13,14]. On the other hand, short-term exposure to blue light has shown damage to rhesus monkey RPE [15], revealing a clear relationship between degree of damage and oxygen concentration [16,17]. Reports that state that many antioxidants can reduce damage suggest that this type of damage is associated with the oxidative process [18,19]. Experimental data show that when blue light is absorbed by the retinal pigment epithelium and lipofuscin, reactive oxygen species are produced, causing strong oxidative stress in the fovea centralis, where the photoreceptor cells are most densely distributed [20,21].

Blue light also decreases the proliferative activity of vascular smooth muscle cells [22]. Continuous blue light irradiation of vascular smooth muscle promotes lipid peroxidation, which indicates oxidative stress caused by reactive oxygen species [23]. It has also been reported that blue light irradiation of human aortic smooth muscle cells significantly reduces cell proliferation and induces vasoconstriction in a time-dependent manner [24]. Blue light releases nitric oxide from the intracellular storage of mitochondria (hemoglobin and nitrosothiol) [25]. Damage to the electron transport chain of mitochondria is an important factor in the pathogenesis of various neuropathies. In addition, it is involved in insomnia by suppressing the production or secretion of melatonin and causing neurophysiological arousal [26].

The LED light source emits more blue light than the halogen light source and thus requires protective eyewear. No studies have elucidated the direct effects of regular use of DOM with LED light sources on visual function. This study examined the effects of halogen and LED light sources on asthenopia and visual function immediately after dental therapy using DOM with one of these light sources.

2. Materials and methods

2.1. Participants

Experiment 1: Six individuals (4 males and 2 females) aged 23–35 years (mean of 26.8 years), students (n = 3) or dentists (n = 3) at Kanagawa Dental University who had a corrected visual acuity of at least 1.0 without any organic eye disease except for refractive errors based on assessment by an ophthalmologist were included in the study.

Experiment 2: Nine individuals (5 males and 4 females) aged 25–30 years (mean of 27.4 years), students (n = 4) or dentists (n = 5) at Kanagawa Dental University who had a corrected visual acuity of at least 1.0 as well as a spherical equivalent value within ±4 D and astigmatism 1 D or less were included in the study. The age criteria for this experiment were set to <35 years, because age-related ophthalmological changes increase from the age of 35 years [27].

In both experiments, the use of smartphones, wearing of contact lenses, and consumption of alcohol and caffeine were prohibited from the day before the experiment. This study was conducted with the approval of the Kanagawa Dental University Research Ethics Review Board (Approval No. 383). Before participating in this study, all participants provided informed consent after receiving sufficient explanation regarding the purpose of the study as mandated by the Declaration of Helsinki.

Extracted teeth with three independent root canals and a root curvature less than 15° were selected for the study. The root canal prepararion method was standardized up to ISO#50 for all three root canals. Furthermore, the vertical pressure filling method was used for root canal filling, which can be standardized by the same operator for the sample.

2.2. Methods

2.2.1. Overview of the experiments

In order to adjust the visual acuity to 1.0 in all participants, who were users of eyeglasses or contact lenses with appropriate correction, both experiments were conducted using a trial frame and lenses. DOMs with halogen light source (ALLEGRA 330®, Yoshida Dental Trade Distribution, Tokyo, Japan) and LED light source (PRIMA DNT NuVar®, Yoshida Dental Trade Distribution, Tokyo, Japan) were used. The measured illuminance and specifications of these DOMs are listed in Table 1.

Experiment 1 involved screening of the participants and assessment of asthenopia and accommodative function, using general ophthalmological tests (i.e., near and far visual acuity (uncorrected and corrected), refraction, intraocular pressure, pupil diameter, critical fusion frequency (CFF), modulation transfer function (MTF), tear film breakup time (BUT), and blink interval. From the results of the general visual function tests in Experiment 1, the tendency of dry eye was found in both LED and halogen light sources in the BUT test. Therefore, in Experiment 2, an accommodative function test was performed to analyze asthenopia related to dry eye. Experiment 2 involved tests highly related to asthenopia, using the screening results in Experiment 1 as reference.

2.2.2. Methods used in experiment 1

The participants performed a 30-min root canal procedure on an extracted tooth (lower first molar) inserted into a resin-blocked model under a dental stereomicroscope, with root canal preparation, filling, and removal of the filling material using a dental excavator (Gutta-Percha(GP) Remover Spear, YDM Corporation, Tokyo, Japan). Before and after the microscopic work, physical factors potentially affecting asthenopia were assessed by performing general visual function tests (calculation ability, and hand grip strength measurement, and ophthalmological tests were performed, including measurement of uncorrected and corrected visual acuity, refraction, intraocular pressure, pupil diameter, CFF, MTF, BUT, and blink intervals) and administering subjective symptoms questionnaires. This study was conducted in a double-blined manner, without notifying any of the participants, medical technologists, or ophthalmologists about the type of DOM light source used. The time schedule of the tests before and after the microscopic work was as follows:

The duration of the DOM dental work was set to 30 min. Visual function tests were performed before a 30-min dental procedure under a halogen or LED light source DOM at baseline (control group) and repeated in a similar manner after the procedure. The participants then rested for 2.5 h to avoid any procedural carryover effect on visual function, and they subsequently performed another 30-min procedure under a DOM with the other light source (halogen or LED group) (Table 2).

The baseline data before the DOM procedure was the control group, and these were compared with the test results obtained after completion of the procedure under halogen or LED light (halogen or LED group).

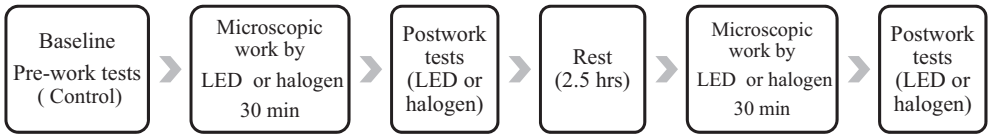
2.2.3. Methods used in experiment 2

Participants performed the same procedure using the same equipment as in Experiment 1. Before and after the microscopic work, the data from the subjective symptoms questionnaire were assessed, and ophthalmological testing for accommodative

Table 1
Measured illuminance and specifications of halogen and LED light sources used in this study.

Light source	Measured illuminance (lux)	Maximum illuminance (lux)	Color temperature (K)
Halogen	11, 116 ± 307	250, 000	3, 200
LED	11, 410 ± 107	60, 000	6, 500

Table 2
Time schedule of experiments 1 and 2.



Experiment 1 test parameters before and after the microscopic work: subjective symptoms questionnaire, simple calculation ability, hand grip strength, uncorrected and corrected visual acuity, refraction, intraocular pressure, pupil diameter, CFF, MTF, BUT, and blink interval.
Experiment 2 test parameters before and after the microscopic work: subjective symptoms questionnaire and accommodative function.

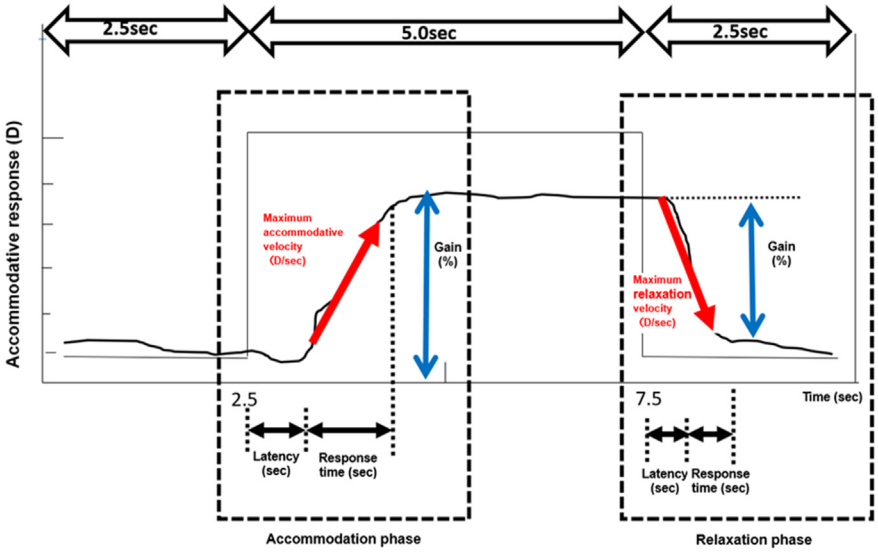


Fig. 1. Accommodative step response waveform, Latency (s): Time from the target's movement to the onset of accommodative/relaxation response. Gain (%): Relative accommodative amount, using 5 D as 100%. Maximum velocity (D/sec): Amount of accommodation/relaxation response per second at the sharpest portion of the waveform during accommodation/relaxation. Response time (s): Time from the onset of the accommodation/relaxation response until reaching the highest/lowest value.

function was performed. A 30-min time period was applied, similar to that in Experiment 1 (Fig. 1).

2.2.3.1. Test items and methods

2.2.3.1.1. Visual function test. The visual function test was carried out in the two experiments: general visual inspection (experiment 1: 1–10) and precise test for asthenopia (experiment 2: 11) to measure the degree of fatigue in the eyes.

2.2.3.1.1.1. Simple calculation ability

Calculation ability could be used to assess mental fatigue [28].

Simple calculation was performed using "Kageyama's Maths Training: The Hundred Cell Calculation Method" (Shogakukan, Tokyo, Japan), and the number of correct answers in 1 min was recorded.

2.2.3.1.1.2. Hand grip strength

Hand grip strength measurement was used to assess physical fatigue [29].

Grip strength of each hand was measured once using a dynamometer (GRIP DYNAMO METER, Takei Scientific Instruments, Niigata, Japan).

2.2.3.1.1.3. Uncorrected and corrected visual acuity

A visual acuity test is essential to determine the presence or absence of eye disease. Visual acuity test includes testing for naked-eye visual acuity, corrected visual acuity, distance visual acuity, and near visual acuity. When evaluating ophthalmology, the corrected visual acuity is mainly used. Near visual acuity at 30 cm and far visual acuity at 5 m were measured for each eye, using a Landolt ring chart or letter chart for visual acuity testing.

2.2.3.1.1.4. Refraction

The type and degree of refraction, such as hyperopia, myopia, and astigmatism, were examined. Objective ocular refraction was measured using an autorefractor keratometer (auto ref-keratometer, ARK-1, NIDEK, Aichi, Japan).

2.2.3.1.1.5. Intraocular pressure

The intraocular pressure maintaining the shape of the eyeball was measured. High intraocular pressure indicates compression of the optic nerve, and damage to the optic nerve may affect the visual field. When the intraocular pressure becomes low, the eyeball contracts and the retina wrinkles, resulting in poor vision. Intraocular pressure was measured using a fully automatic non-contact tonometer (NCT) (TX-20P, Canon, Tokyo, Japan), which blows an air puff against the cornea; the pressure is measured based on the extent of corneal flattening.

2.2.3.1.1.6. Pupil diameter

The pupil is dominated by both sympathetic and parasympathetic nerves, and the peripheral dynamics of autonomic innervation of the living body can be observed by the pupillary reflex. These changes are used to diagnose lesions of various diseases, including the central nervous system. The pupil diameter was measured using an Iriscorder pupillometer (Hamamatsu Photonics, Shizuoka, Japan) that uses infrared rays.

2.2.3.1.1.7. Critical fusion frequency (CFF)

CFF is used to assess physical factors, such as stimulus intensity, color, size, contrast, eccentricity, and visual temporal processing affected by photopic conditions and age.

CFF is the frequency at which intermittent pulses of light stimuli appear to be a continuous, unbroken stream of light. It is affected by the stimulus intensity, color, size, contrast, eccentricity, and other physical factors, including condition of light adaptation and age, and is used for evaluation of visual temporal processing. The CFF was measured using a Handy Flicker (HF-II, Neitz Instruments, Tokyo, Japan) without dark adaptation (red and yellow).

2.2.3.1.1.8. Modulation transfer function (MTF)

The ability to discriminate when the difference in brightness between an object is reduced. The minimum threshold for this ability was measured. It decreases when there is a refractive error or an abnormality in the eye optical system, such as the cornea/lens, optic nerve disease, or retinal disease. The MTF was measured using a vision contrast test system (VCTS) (VCTS-6500, Vistech Consultants, Dayton, OH), after confirmation of an approximately 50 ft-L luminance level at a distance of 3 m from the charts. The VCTS charts have five different spatial frequencies of 1.5 (A), 3 (B), 6 (C), 12 (D), and 18 (E) cycles per degree (c/d) with nine different contrasts for each frequency shown on one panel. Each chart has three different stripe patterns oriented vertically or inclined 10° to the right or left. Participants were asked whether they could correctly recognize the stripe patterns and their inclinations using each eye. A and B are categorized as low spatial frequency, C as intermediate spatial frequency, and D and E as high spatial frequency.

2.2.3.1.1.9. Tear film breakup time (BUT)

BUT is defined as the time measured from the opening of the eyelids until the tear film breaks down. It is used as an index of instability of the tear film and is used for diagnosis of dry eyes. One drop (approximately 40–50 μL) of topical fluorescein was instilled, and the ocular surface was observed using a slit-lamp microscope (NIDEKO, Aichi, Japan). Participants were instructed not to blink, and the time from the eyelid opening to the first appearance of a dry spot in the tear film was measured.

2.2.3.1.1.10. Blink interval

Blink interval is the time taken to open the eyelids. It is used to diagnose dry eye according to the maximum eyelid opening time. The maximum blink interval (the length of time that participants could keep their eyes open) was measured. This test has been used for simple dry eye screening.

2.2.3.1.1.11. Accommodative function

Accommodative function is a method of categorizing fatigue by observing the near and far index alternately to measure the adjustment tension time and the adjustment relaxation time, and recording the repeated measurement. Accommodative function was measured using an infrared optometer (AA-2000, NIDEK, Aichi, Japan). The HOME value was set to −0.25 D for eyeglass users. Contact lens users were instructed to wear soft contact lenses (SCLs) with appropriate correction, and the HOME value was set to −0.25 D. Stepped stimuli of 5 diopters were administered five times, and the mean values were recorded from the five waveforms obtained. The waveform of accommodative responses to stepped stimuli in the accommodation and relaxation phases (accommodative response: D) employed the accommodative function parameters of latency (s), gain (%), maximum velocity (D/s), and response time (s), respectively (Fig. 1), [30].

2.2.3.1.2. Subjective symptoms questionnaire. A subjective symptoms questionnaire survey was conducted to confirm the validity of the answers regarding subjective symptoms related to the eyes. A self-administered questionnaire on subjective ocular symptoms was administered at the same time as the ophthalmological tests to verify the participants' responses. The questionnaire was prepared with reference to a published report [31,32], and is shown in Table 3. The intensity of each symptom was numerically scored on a 3-point scale ('no' = 0, 'somewhat' = 1, 'very much' = 2). In addition, for each questionnaire item, the total score of all participants was calculated and divided by the maximum possible total score in all participants (i.e., 2 × n) and multiplied by 100 to give a percentage representing symptomatic frequency; this percentage was used as a symptom assessment index. Symptomatic frequency (%) after use of DOM was compared with the baseline symptomatic frequency.

2.2.4. Statistical analysis

First, the results of simple calculation ability, hand grip strength (mean of left and right), uncorrected and corrected visual acuity (near and far), refraction, intraocular pressure, pupil diameter, CFF (red and yellow), MTF (A to E), BUT, and blink interval were compared among the three conditions of control (baseline), halogen light, and LED light using the Friedman test. Then, for the test items with significant differences detected by the Friedman test, the Wilcoxon signed-rank test with Bonferroni correction was performed for multiple comparisons. The Wilcoxon signed-rank test with Bonferroni correction is a post-hoc test for non-parametric statistical tests. The data were compared using non-parametric statistical tests because they were not normally distributed. In addition, accommodative function data (latency, gain, maximum velocity, and response time) in both the accommodation and relaxation phases were compared between the halogen and LED light source conditions using the Wilcoxon signed-rank test. Minimum, median (interquartile range), and maximum values were calculated for presentation in figures and tables.

The level of significance was set at $P < 0.05$. For multiple comparisons among the three conditions, the level of significance after

Table 3
Subjective symptoms questionnaire (Questionnaire form).

Item	Score
1. Do you have dry eye?	0 • 1 • 2
2. Do you have eye pain?	0 • 1 • 2
3. Do you have eye fatigue?	0 • 1 • 2
4. Do you have eye redness?	0 • 1 • 2
5. Do you have inability to keep eyes open?	0 • 1 • 2
6. Do you have blurred vision?	0 • 1 • 2
7. Do you have photophobia?	0 • 1 • 2
8. Do you have impaired concentration?	0 • 1 • 2
9. Do you have stiff shoulders?	0 • 1 • 2
10. Do you have headache?	0 • 1 • 2
11. Do you have hand/arm numbness?	0 • 1 • 2

For each questionnaire item, the intensity of the symptom was numerically scored on a 3-point scale (Score 0 = No, Score 1 = Somewhat, Score 2 = Very much), and the degree of symptomatic frequency was calculated.

Table 4
The results of visual function test (Experiment 1).

Test	Control	LED	Halogen	P-value
	Median (25%, 75%)	Median (25%, 75%)	Median (25%, 75%)	
1) Simple calculation ability	53.50 (50.25, 64.00)	62.5 (47.50, 71.25)	59.00 (52.25, 65.75)	P = 0.311※
2-1) Near visual acuity (uncorrected, corrected)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	P = 1.000※
2-2) Far visual acuity (uncorrected, corrected)	1.200 (1.200, 1.200)	1.200 (0.925, 1.200)	1.000 (0.850, 1.050)	P = 0.042※※
3) Hand grip strength (mean of left and right)	43.500 (33.725, 46.000)	47.500 (34.950, 49.500)	43.750 (36.750, 48.950)	P = 0.200※
4) Refraction	△3.25 (△8.525, △1.375)	△2.95 (△8.625, △1.425)	△3.700 (△8.825, △1.425	P = 0.113※
5) Intraocular pressure	15.300 (13.400, 16.150)	16.050 (12.425, 17.425)	15.900 (12.650, 17.225)	P = 0.580※
6) Pupil diameter	6.350 (5.650, 7.075)	6.450 (6.325, 7.300)	6.700 (6.200, 6.825)	P = 0.337※
7-1) Critical fusion frequency (Red)	39.00 (38.00, 43.50)	38.00 (36.50, 41.75)	38.00 (36.25, 41.50)	P = 0.327※
7-2) Critical fusion frequency (Yellow)	40.50 (39.00, 43.25)	37.50 (33.00, 44.00)	42.00 (35.75, 45.75)	P = 0.154※
8-1) Modulation transfer function A	5.00 (5.00, 5.25)	6.00 (4.75, 6.25)	5.50 (5.00, 6.00)	P = 0.368※
8-2) Modulation transfer function B	6.00 (6.00, 6.00)	5.50 (5.00, 6.25)	5.50 (4.75, 6.25)	P = 0.368※
8-3) Modulation transfer function C	4.50 (4.00, 5.25)	4.50 (3.75, 6.00)	4.50 (3.75, 6.00)	P = 1.000※
8-4) Modulation transfer function D	4.50 (2.75, 6.00)	3.00 (2.50, 6.50)	5.50 (2.00, 6.00)	P = 0.810※
8-5) Modulation transfer function E	3.50 (1.75, 4.25)	3.50 (1.50, 6.00)	4.00 (1.50, 6.00)	P = 0.646※
9) Tear film breakup time	7.400 (5.875, 9.350)	3.550 (3.150, 4.550)	3.450 (3.275, 4.100)	P = 0.032※※
10) Blink interval	19.650 (11.075, 30.975)	24.250 (6.550, 36.175)	19.700 (8.775, 33.350)	P = 0.846※

*Friedman test, P ≥ 0.05, **Friedman test, P < 0.05; Subsequent multiple comparison test, P > 0.017.
All examination results showed no significant differences among the three conditions of control (baseline), halogen, and LED.

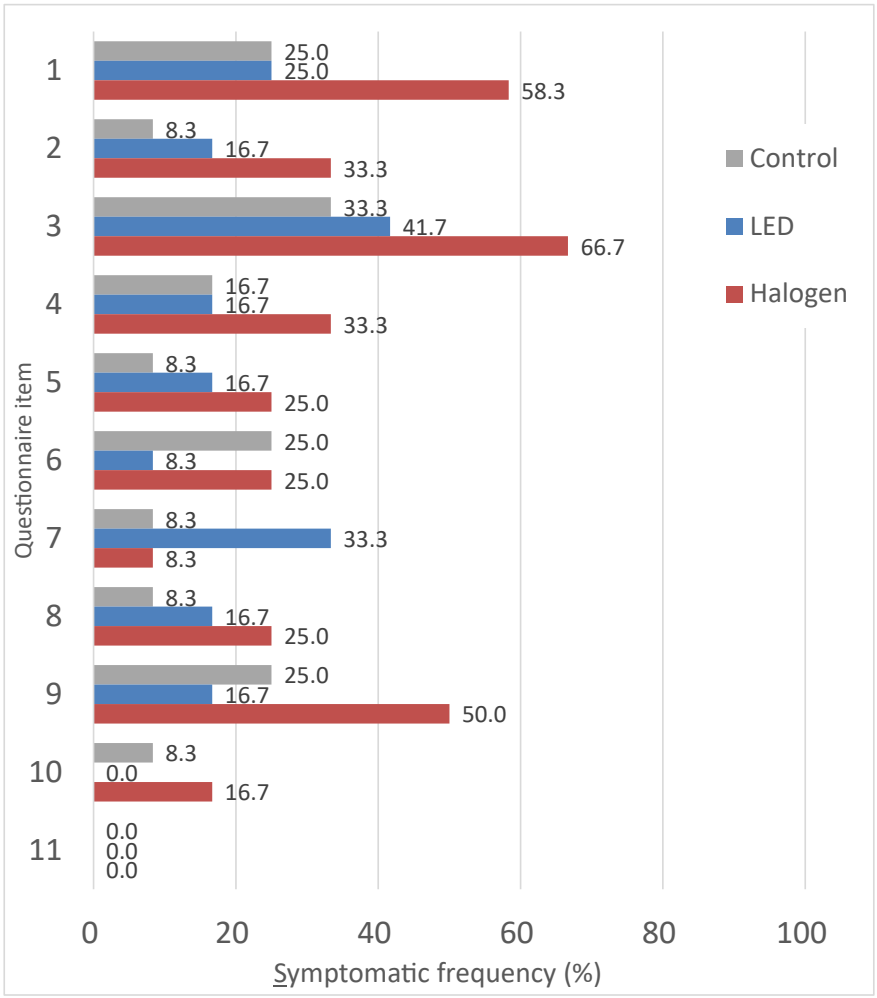


Fig. 2. Subjective symptoms questionnaire results (Experiment 1), The commonly reported symptoms are “photophobia” with LED; or “dry eye”, “eye pain”, “eye fatigue”, “eye redness”, “inability to keep eyes open”, “impaired concentration”, and “stiff shoulders” with halogen.

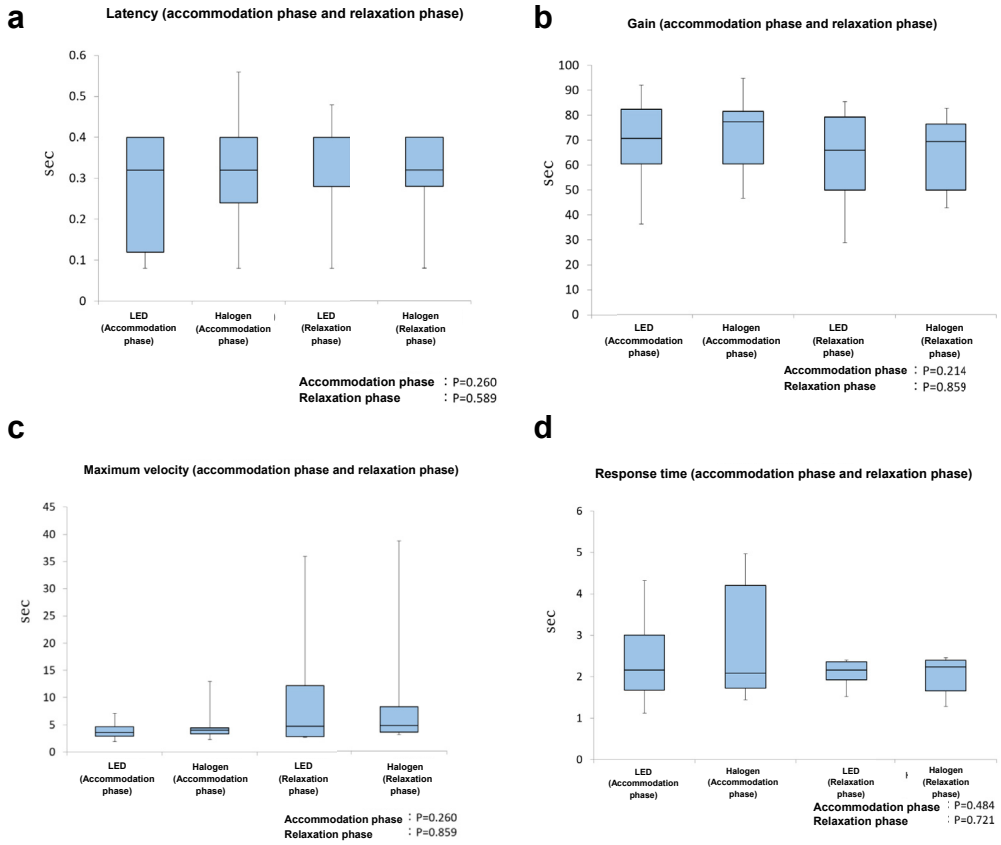


Fig. 3. Accommodative function test latency (a), gain (b), maximum velocity (c), and response time (d). No significant difference observed among the three conditions of control (baseline), LED and halogen.

Bonferroni correction was set to P = 0.017. The software IBM SPSS Statistics 23 (IBM Corp., Armonk, NY) was used to perform the statistical analyses.

3. Results

3.1. Experiment 1

3.1.1. Visual function test

3.1.1.1. Simple calculation ability. No significant difference was observed among the three conditions of control (baseline), LED, and halogen (Table 4).

3.1.1.2. Hand grip strength (mean of left and right). No significant difference was observed among the three conditions of control (baseline), LED, and halogen (Table 4).

3.1.1.3. Uncorrected and corrected visual acuity. Near visual acuity did not significantly differ among the three conditions of control (baseline), LED, and halogen. In terms of far visual acuity, the difference among the three conditions was significant by the Friedman test (P = 0.042) and not significant by the subsequent Wilcoxon signed-rank test with Bonferroni correction for multiple comparisons (P > 0.017) (Table 4).

3.1.1.4. Refraction. No significant difference was observed among the three conditions of control (baseline), LED, and halogen (Table 4).

3.1.1.5. Intraocular pressure. No significant difference was observed among the three conditions of control (baseline), LED, and halogen (Table 4).

3.1.1.6. Pupil diameter. No significant difference was observed among the three conditions of control (baseline), LED, and halogen (Table 4).

3.1.1.7. CFF. No significant difference was observed among the three conditions of control (baseline), LED, and halogen for both red and yellow (Table 4).

3.1.1.8. MTF. No significant difference was observed among the three conditions of control (baseline), LED, and halogen for A to E (Table 4).

3.1.1.9. BUT (Tear film breakup time). The Friedman test showed a significant difference among the three conditions (P = 0.032), but the subsequent Wilcoxon signed-rank test with Bonferroni correction for multiple comparisons showed no significant difference (P > 0.017) (Table 4). However, the BUT was shortened for both LEDs and halogens, indicating a tendency toward dry eye after the microscopic procedure.

3.1.1.10. Blink interval. No significant difference was observed among the three conditions of control (baseline), LED, and halogen (Table 4).

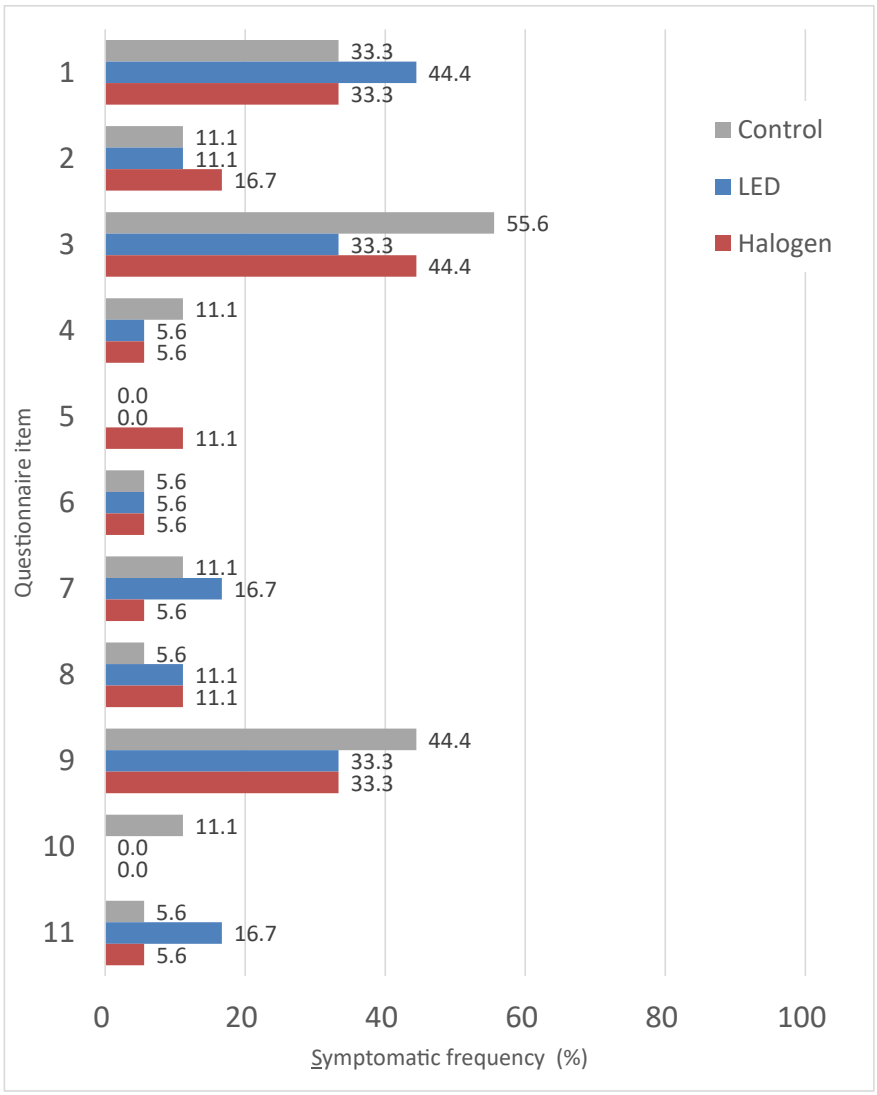


Fig. 4. Subjective symptoms questionnaire results (Experiment 2). The commonly reported symptoms are "dry eye", "photophobia", and "hand/arm numbness" with LED; or "inability to keep eyes open" with halogen.

3.1.2. Subjective symptoms questionnaire

The commonly reported symptoms in Experiment 1 were "photophobia" with LED; or "dry eye", "eye pain", "eye fatigue", "eye redness", "inability to keep eyes open", "impaired concentration", and "stiff shoulders" with halogen (Fig. 2).

3.2. Experiment 2

3.2.1. Accommodative function

Since some participants in Experiment 1 experienced accommodative contraction and poor relaxation of the ciliary muscle when working with LED DOMs compared with halogen DOMs, the accommodative function was again examined in a larger number of participants in Experiment 2. The results showed no significant difference between the two conditions of LED and halogen (Fig. 3).

3.2.2. Subjective symptoms questionnaire

The commonly reported symptoms in Experiment 2 were "dry eye", "photophobia", "hand/arm numbness" with LED; or "inability to keep eyes open" with halogen (Fig. 4).

4. Discussion

DOM is particularly useful for precision dental treatment and has recently been used increasingly among dentists. However, asthenopia is commonly observed among DOM operators [31,33]. According to a report by Komiya et al., microscopic work for at least 4 h per day was correlated with decreased visual acuity, and the authors suggested that the decreased visual acuity or worsening of asthenopia symptoms may be due to prolonged watching of objects through the microscope eyepiece lenses and reduced blinking [34].

In the present study, the analysis of the Experiment 1 data from the three conditions (control/baseline, halogen, and LED) showed significant differences in far uncorrected visual acuity, corrected visual acuity, and BUT. The subsequent multiple comparison test with Bonferroni correction showed that the results for both visual acuity and BUT were above the significance level. However, BUT tended to be shorter after the completion of DOM work for both halogens and LEDs. BUT is used as a measure of tear film stability, and its shortening indicates a tear abnormality. In addition, shortened BUT (5 s or shorter) and other subjective symptoms are diagnostic criteria for dry eye disease [35].

In this study, dry eye was diagnosed on the basis of the BUT data and subjective symptoms questionnaire in 17% of participants before DOM procedure, in 50% of participants after DOM procedure under the LED light source, and in 83% of participants after DOM procedure under the halogen light source. Thus, decreased blinking due to DOM use could cause dry eyes. Since dry eyes owing to short-BUT mainly manifests as asthenopia, which results from impaired accommodation [36], accommodative function was assessed in Experiment 2.

The accommodative function test showed that use of the LED light source more commonly resulted in accommodative contraction and poor relaxation of the ciliary muscle, but the difference was not significant. LED light contains intense blue light with a wavelength of approximately 450 nm and has marked spectral characteristics, while halogen lamps emit light of various wavelengths and colors that are similar to natural light without particular wavelength dominance. Blue light relative to light of other colors has short wavelengths, and thus tends to be scattered by particles in the air, thereby causing blurring and chromatic aberration [37]. Furthermore, the tendency toward blurring of letters or images due to the focus in front of the retina forces the eyes to work harder to accommodate. This places a burden on the accommodative function, causing asthenopia [5]. Experiment 2 revealed a tendency toward accommodative contraction and poor relaxation of the ciliary muscle, which was speculated to be due to excessive accommodation in order to maintain clear vision.

The subjective symptoms questionnaire found a tendency toward “photophobia” with the use of LED light but not halogen light, presumably due to the difference in color temperature between the two light sources. The color temperature, measured in Kelvin (K), is the absolute temperature of light. It has been reported that the use of lighting with lower color temperatures in living rooms at night can make the space more comfortable [38]. Under the same illuminance, the light with a higher color temperature is brighter.

In this study, the results of the subjective symptoms questionnaire showed no significant differences for all questionnaire items. Presumably, with the 3-point rating scale employed for each questionnaire item in this study, the number of categories could be too small to clearly differentiate between the lowest and highest ratings, thus failing to detect significant differences.

This study showed no significant differences between the halogen and LED light sources in terms of the extent of asthenopia or the ophthalmological data, indicating that LED and halogen light can be used similarly. However, the high intensity of the LED light was associated with photophobia, resulting in eye fatigue and discomfort warranting light intensity reduction measures and blue light filtration to reduce photophobia, especially when observing the tooth enamel or other materials that are very light reflective [39]. In addition, this study revealed a tendency toward dry eye after performing the procedure under DOM guidance, indicating the need for measures to prevent asthenopia occurrence and worsening, such as the use of ophthalmic solutions. For both medical and dental operative microscopes, the use of the LED light source in place of the conventional halogen light source has become increasingly common. This increasing popularity of LED lighting is attributable to its advantages including: (1) high color temperature with high brightness even with lower illumination, (2) environmental friendliness, (3) little heat emission, and (4) high luminous efficiency. To the best of our knowledge, this is the first report to investigate the effects of different DOM light sources on asthenopia and visual function in dentists after performing surgery under DOM guidance. However, given that dental surgery using DOM is applied not only for endodontic therapy but also for a wide range of therapies, further studies involving other types of therapeutic procedures and more participants are needed.

Although DOM is useful in dental treatment, the advantages and disadvantages of the microscope light sources should be weighed before light source selection and use.

5. Conclusion

Conventional halogen and more recent LED light sources of DOM did not significantly differ in their effects on the operator's asthenopia or visual function. However, LED lighting was associated with eye fatigue and discomfort due to the overly bright visual field, warranting alleviating measures, such as light intensity adjustment and blue light filtration.

Ethical approval

This study was conducted after approval of the Kanagawa Dental University Research Ethics Review Board (Approval No. 383).

Declaration of competing interest

The authors declare no competing interest.

CRediT authorship contribution statement

Kengo Nakahira: Data curation, Formal analysis, Investigation, Writing - original draft. **Noriko Mutoh:** Conceptualization, Validation, Writing - review & editing. **Shinya Fuchida:** Statistical analysis and interpretation of data. **Tatsuo Yamamoto:** Statistical analysis and interpretation of data. **Masumi Kimijima:** Ophthalmological tests and analysis and interpretation of data. **Yoshiaki Ichibe:** Ophthalmological tests and analysis and interpretation of data. **Nobuyuki Tani-ishii:** Writing - review & editing, Investigation.

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