



# Influence of power and the time of application of fogging lenses on accommodation

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**Abstract:** Fogging is a non-invasive technique based on the use of positive spherical power lenses to relax accommodation during refraction that is commonly used as an alternative to cycloplegic drugs. Although the mechanism of the fogging technique has been described, some aspects of its methodology remain unclear. The main purpose of this work was to determine which lens power and time of application are more suitable for achieving a successful relaxation of accommodation by analyzing the changes in accommodation when fogging lenses of different powers were placed in front of the participants' eye for a certain timespan. The results of this analysis showed, in general, that low-power lenses and timespans of less than half a minute provided the highest relaxation of accommodation. However, high inter-subject variability was found in the two variables (power and time).

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## 1. Introduction

Refraction is the process in which the ocular refractive error of an individual is measured with the aim of correcting it with the best combination of sphero-cylindrical lenses to achieve their maximum visual acuity. During the refraction procedure, accommodation should be as relaxed as possible [1]. Accommodation is the ability of the visual system to adjust its dioptric power when fixating near targets by changing the shape of the crystalline due the action of the ciliary muscle. However, accommodation is sometimes activated even when fixing distance targets, especially in young subjects. If this occurs during refraction, refractive error may be wrongly estimated under-correcting hyperopic subjects and overcorrecting myopic subjects. For this reason, a good control of accommodation during the refraction procedure is a key factor for a successful examination.

Control of accommodation can be achieved with two methodologies. The first is the instillation of cycloplegic agents, which paralyze the ciliary muscle and prevent the accommodation system from being activated, even when a near target is presented. Although they provide solid prevention of accommodation, they can cause discomfort to patients due to the relatively long-lasting blurred vision, and some adverse effects have been reported [2]. Moreover, cycloplegia is impractical in high-volume clinics due to increased chair time of the patient, besides the fact that depends on a trained clinician and the application of these diagnostic drugs requires the supervision of an ophthalmologist in some countries.

The second method is the fogging technique, which consists in adding positive spherical lenses so that the eye becomes slightly myopic. When vision is blurred due to the fogging lenses, there is a reflex response to try to sharpen the retinal image. However, the activation of accommodation does not contribute to sharpening the image, but the opposite, it deteriorates it, since the focus moves forward and farther from the retina. Sharpening of the image can only be achieved by moving the focus towards the retina via relaxation of accommodation [1]. This technique is

used during many steps of the refraction examination, such as during retinoscopy or subjective refraction, and even commercial autorefractors include fogging to control accommodation during measurements [3]. Even though this technique is widely used by optometrists and its mechanism has been described, some aspects of its methodology are unclear, such as the power of the fogging lens and the time the lens must be in front of the eye (time of application) to achieve the maximum relaxation of accommodation. Regarding the power of the lens, different studies and optometry manuals differ in their recommendations, suggesting the use of lens powers ranging from +0.75 D to +6.00 D [1,4,5]. Alternatively, other authors suggest using not a fixed value but the amount of positive power that leads to a reduction in visual acuity between 20/100 and 20/120 [1]. Although some authors agree with the use of a + 2.00 D lens [6–9], to our knowledge, very few authors have compared the effect of different powers of fogging lenses [10]. On the one hand, one may expect that the fogging lenses should have enough power to cause some relaxation of accommodation. On the other hand, very high positive powers might cause extremely blurred vision, which is known as a trigger of tonic accommodation. Tonic accommodation is defined as the myopic state of the eye reached when there is no stimulus or it is very degraded [11,12]. If it is reached, accommodation would be activated instead of relaxed. A balance in the power of the lenses should be found, thus moderate power of lenses may be most preferred in accordance with Ward and Charmann [10]. With regard to time, some authors have specified the amount of time used and tried an extended fogging during twenty minutes [8]. Others suggested that 1 or 2 minutes should be enough to provide some relaxation of accommodation [13]. However, to our knowledge, no study has specifically analyzed the effect of time on accommodation changes during the fogging technique. Considering that the time spent in the clinical practice for assessing refraction is rather short and previous studies that analyze the changes of accommodation from near to far focus showed relatively fast responses [14], a preferred time of the order of seconds would be expected. Also, there could be an interaction between the power of the lens and the required time of application, with lower power lenses kept for a longer time being as effective in relaxing accommodation as higher power lenses kept for a shorter period of time.

For this reason, the aim of this study was to determine the power and time of application of the fogging lenses that maximize the relaxation of accommodation. Changes in accommodation with different powers of fogging lenses were measured over time using a system that permits real-time monitoring of the accommodative response.

## **2. Materials and methods**

### *2.1. Subjects*

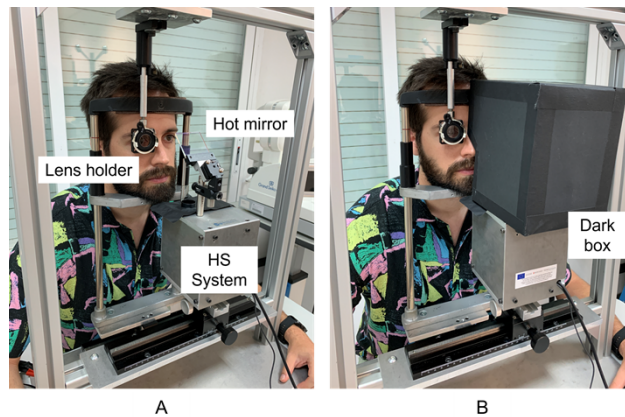
Ninety-six young adults participated in the study (67 women and 29 men). The age limit was set at 25 years to avoid a reduction in the amplitude of accommodation due to aging. The inclusion criteria were monocular best-corrected visual acuity equal to or better than 0.9 in decimal notation, objective spherical refractive error between -5.00 D and +3.00 D, astigmatism of 1.50 D or less, and pupil diameter of 3.5 mm or greater in measuring conditions. Individuals with amblyopia, strabismus, anomalies in the accommodation system or any history of ocular condition or surgery were excluded.

This study was approved by the Hospital Mutua de Terrassa Ethics Committee and followed the tenets of the Declaration of Helsinki. All participants gave their written informed consent after receiving a written and verbal explanation about the nature of the study.

### *2.2. Experimental system*

The set-up used for measuring changes in accommodation consists of a customized open-field Hartmann-Shack (HS) aberrometer [15]. A hot mirror placed in front of the eye permitted measurements using infrared light (830 nm) under natural viewing conditions. The experimental

system is able to provide estimations of the refractive state of the eye every 100 ms by paraxial curvature matching of the wavefront aberration map using the second- and fourth-order Zernike terms [16]. The system is controlled remotely through a graphical user interface (GUI) that displays the HS images in real time and the instantaneous refractive state of the eye. The HS image available in the GUI was used to ensure a correct alignment between the measured eye and the system during measurements. A lens holder where the prescription and fogging lenses were placed was coupled to the aberrometer (see Fig. 1). The measurements were performed in the stimulated contralateral eye. Hence, the fogging lenses were always placed in front of the right eye, whereas the consensual accommodation response was monitored in the left eye [17]. To occlude the left eye without interfering with the measuring system, a dark box was used as shown in Fig. 1. The visual field in the right eye was not disturbed by this configuration.



**Fig. 1.** A: View of the experimental set-up which includes the HS wavefront sensor and lens holder. B: View of the experimental set-up with the dark box placed in front of the non-fixating eye.

### 2.3. Experimental procedure

First, a brief assessment of binocular vision and accommodation was performed. The cover-uncover test was used to discard the presence of strabismus, and the amplitude of accommodation (AA) was measured by combining the push-up and push-down results to discard any anomalies or differences in accommodation between the two eyes. Then, the objective refraction was measured using the open-field autorefractor Grand Seiko WAM-5500 [18].

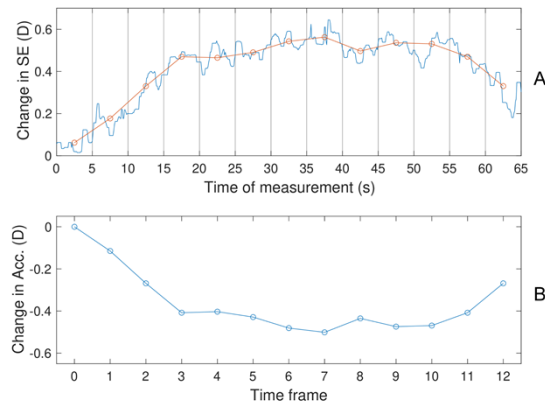
Once the preliminary examination was performed, participants sat in front of the HS aberrometer with their heads in a chinrest (Fig. 1). The participants' right eye, the fixating one, was aligned to the lens holder and the system was properly aligned to the left eye, the measured one, until the image of the pupil was at the center of the HS image. The lenses to correct the objective refractive error measured with the commercial autorefractor were placed in the lens holder, and the left eye was occluded with the dark box (Fig. 1(B)). Participants were asked to fixate on a 20/200 visual acuity chart placed at 5 m during the entire examination. If the visual acuity chart was too blurred to see any letter due to the fogging lenses, they were asked to keep looking there as if they could see the fixation target.

Monitoring of accommodation, measured as changes in the refractive state of the left eye, started 5 s before the fogging lens was placed in the lens holder. The fogging lens was then added, and it remained in front of the right eye for 60 s, while the refractive state was being monitored at a frequency of 10 Hz. After the measurement, there was a 90 s break for the subject to rest and the accommodation to return to the initial state before repeating the procedure with the following

fogging lens. Changes in accommodation were measured for lenses of +1.00 D, +2.00 D, +3.00 D, +4.00 D and +5.00 D. To counteract the effect that any order of presentation of the lenses might have, the order was selected randomly for each participant.

#### 2.4. Data processing

Data were processed using MATLAB 2020b (MathWorks, Natick, MA, USA). In addition to information about wavefront aberrations, the system also recorded information about the gray intensity levels of the HS images. These data were used as a first filter to discard images containing blinks or artifacts whose data were not valid. Each 65-s measurement was divided into windows of 5 s. The median value of the refractive state within each window was computed and considered to be representative of the entire time span. These divisions were performed to neutralize the changes in accommodation due to microfluctuations and focus the analysis on the steady-state accommodation response. Since the component of microfluctuations directly related to the adjustment of accommodation has frequency values  $< 0.6$  Hz [19], data were divided in windows of 5 s. These divisions ensured considering data from a whole microfluctuation cycle. To compute the changes in accommodation from the measured refractive state, the data were transformed into the difference between the median spherical refractive error at each window and the reference spherical refractive error, which was the median spherical refractive error of the first 5 s of measurement, corresponding to the timespan of measurement without the fogging lens (Fig. 2). With this transformation, positive values are considered an activation of the accommodation compared with the reference value, and negative values represent a relaxation of the accommodation compared with the reference value.



**Fig. 2.** Transformation of the measured data. A: The raw spherical refractive error (SRE) data were divided into 12 windows of 5 s and the median value was computed (orange circles). Positive values indicate a hyperopic shift. B: Data were transformed into accommodation (Acc.) changes. Time window 0 corresponds to the reference window for which the change in accommodation was 0. Changes towards negative values indicate relaxation of accommodation.

In addition to the aforementioned analysis, the accommodation responses to each lens were fit with a first order exponential function using the following equation (Eq.1)

$$y = y_0 + a \times (1 - e^{-t/\tau}) \quad (1)$$

where  $y$  stands for change in accommodation,  $y_0$  is the initial value of change in accommodation,  $a$  is the amplitude of the response,  $t$  is time in seconds and  $\tau$  represents a time constant which indicates the time taken to achieve the 63% of the response [20]. This analysis provided an

estimation of the performance of each lens for the entire time span without the effect of short or local accommodation variations.

### 2.5. Statistical analysis

Statistical analysis was performed using commercial SPSS 29 (IBM Corp., Armonk, New York, USA). The significance level was set at 0.05. Nonparametric tests were used after checking that the variables did not follow a normal distribution using the Shapiro-Wilk test.

The maximum capacity of relaxation of accommodation for the five lenses was compared using the Friedman's test. Post-hoc comparisons were performed using the Wilcoxon signed-rank test with a Bonferroni adjustment given by the number of possible pairwise comparisons.

The effect of time on the change in accommodation due to each fogging lens was assessed using one-sample Wilcoxon signed-rank tests comparing the change in accommodation at each time window to a hypothetical median of 0.

## 3. Results

Participants' mean  $\pm$  standard deviation (SD) age was  $20.9 \pm 1.6$  years within a range from 18 to 25 years. Their mean objective spherical equivalent refraction was  $-0.83 \pm 1.44$  D, and their mean AA was  $11.11 \pm 1.63$  D.

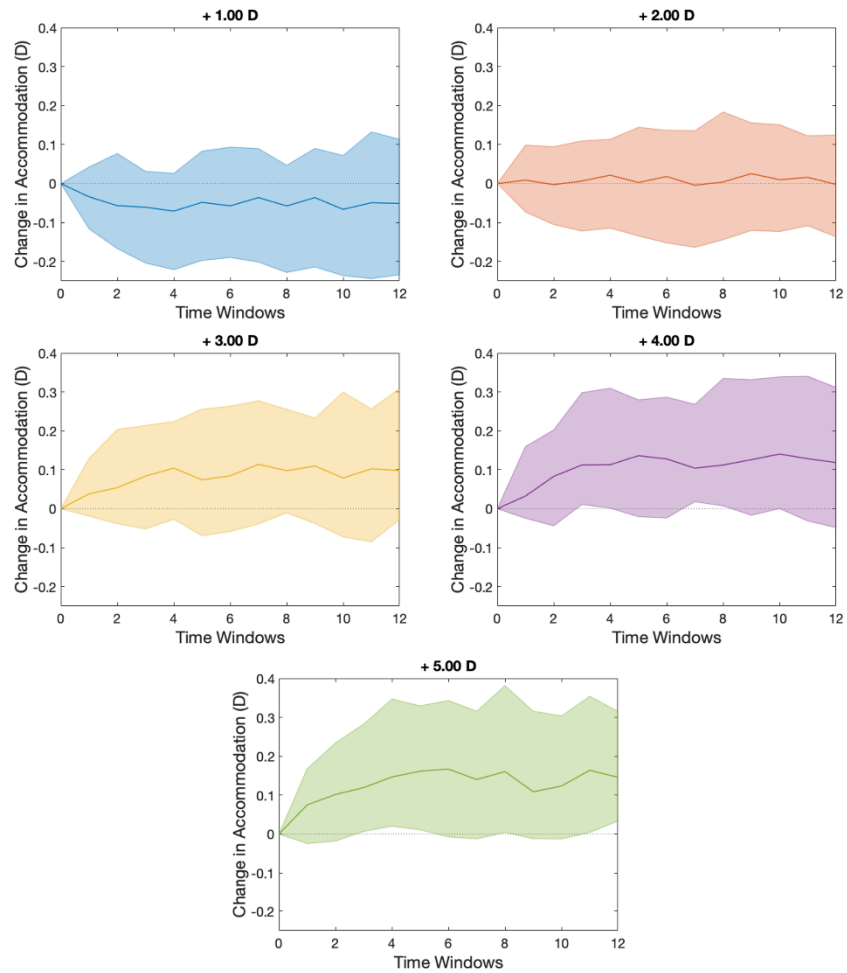
The median change in accommodation over time and the interquartile range (IQR) across all participants for each lens are shown in Fig. 3. As illustrated in Fig. 3, the higher-power lenses (+3.00 D, +4.00 D and +5.00 D) tended to stimulate the activation of accommodation, whereas the low-power lenses resulted in a certain relaxation of accommodation (+1.00 D) or maintained the change in accommodation close to 0 D (+2.00 D). Variability across participants tended to increase with time and stabilize around windows sixth and eighth as shown in Fig. 3.

### 3.1. Effect of the power of the lens on the relaxation of accommodation

The effect of the power of the lenses on the relaxation of accommodation was analyzed in two ways. First, the amplitude of the response from the exponential fit was retrieved from the  $a$  coefficient in Eq 1 (Fig. 4). These values (with 95% confidence intervals) were -0.06 D (-0.07 D, -0.04 D), -0.02 D (-0.04 D, 0 D), 0.08 D (0.07 D, 0.09 D), 0.11 D (0.10 D, 0.13 D) and 0.13 D (0.12 D, 0.14 D) for the lenses of +1.00 D, +2.00 D, +3.00 D, +4.00 D and +5.00 D, respectively.

In the second analysis, the maximum amount of relaxation of accommodation due to fogging lenses of different powers was analyzed independently of time, also considering short accommodation variations of few seconds. For this, the maximum relaxation of accommodation of each measurement was obtained looking for the minimum value of the median accommodation among the time windows. This value was used to compute the median maximum change in accommodation for each lens. As represented in Fig. 5, the median (IQR) of the maximum change in accommodation for the lenses from +1.00 to +5.00 D in 1-D steps was -0.16 D (0.29 D), -0.11 D (0.24 D), -0.05 D (0.18 D), -0.04 D (0.23 D), and -0.07 D (0.24 D). The Friedman test showed significant differences between some of the lenses. The post-hoc Wilcoxon signed-rank tests showed that the changes in accommodation due to the +1.00 D lens differed significantly from the effects of the +3.00 D ( $p < 0.001$ ), +4.00 D ( $p < 0.001$ ) and +5.00 D ( $p < 0.001$ ) lenses. Moreover, the changes in accommodation due to the +2.00 D lens differed significantly from those caused by the +4.00 D ( $p < 0.001$ ) and +5.00 D ( $p = 0.001$ ) lenses.

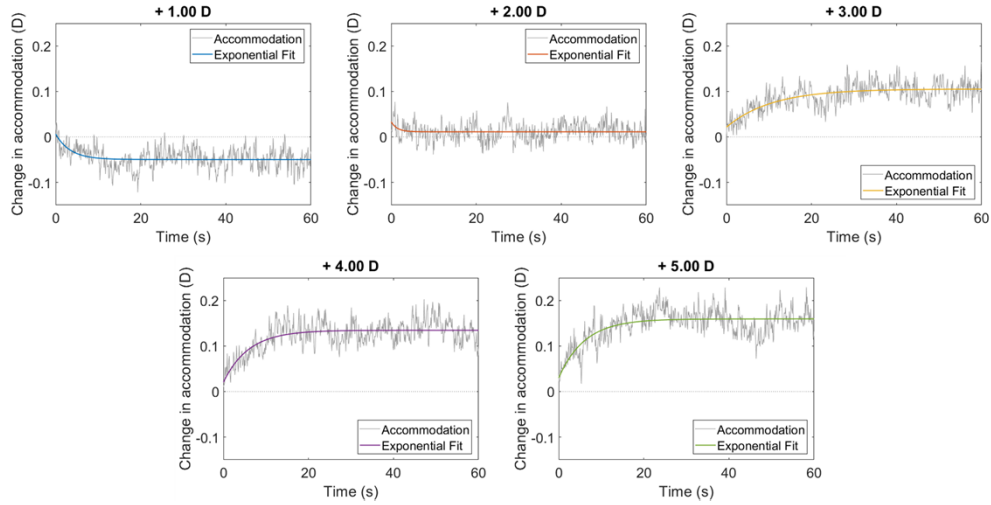
Cases with a relaxation of accommodation equal to or higher than 0.125 D were analyzed as clinically interesting cases, finding that 79.17% of the sample (76 participants) relaxed at least this amount of accommodation with at least one of the lenses. The number of participants who relaxed accommodation by 0.125 D or more with each lens, the corresponding percentage, and the median value of change in accommodation are presented in Table 1.



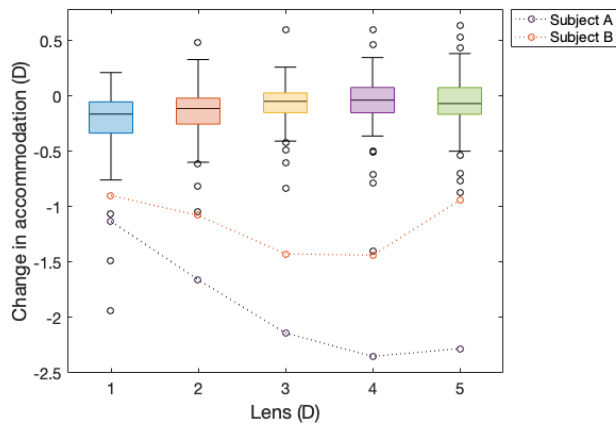
**Fig. 3.** Median change in accommodation with time. The shaded areas represent interquartile ranges (IQR). Time windows 0 correspond to the reference window for which the IQR is 0 D.

**Table 1.** Number of participants and percentage of the sample who exhibited a relaxation of accommodation equal to or greater than 0.125 D for each lens, and median (IQR) value of relaxation achieved.

| Lens (D) | n  | %    | Median (IQR) (D) |
|----------|----|------|------------------|
| + 1.00   | 57 | 59.3 | -0.29 (0.23)     |
| + 2.00   | 45 | 46.9 | -0.27 (0.24)     |
| + 3.00   | 33 | 33.3 | -0.21 (0.23)     |
| + 4.00   | 33 | 32.3 | -0.24 (0.21)     |
| + 5.00   | 31 | 30.2 | -0.22 (0.33)     |



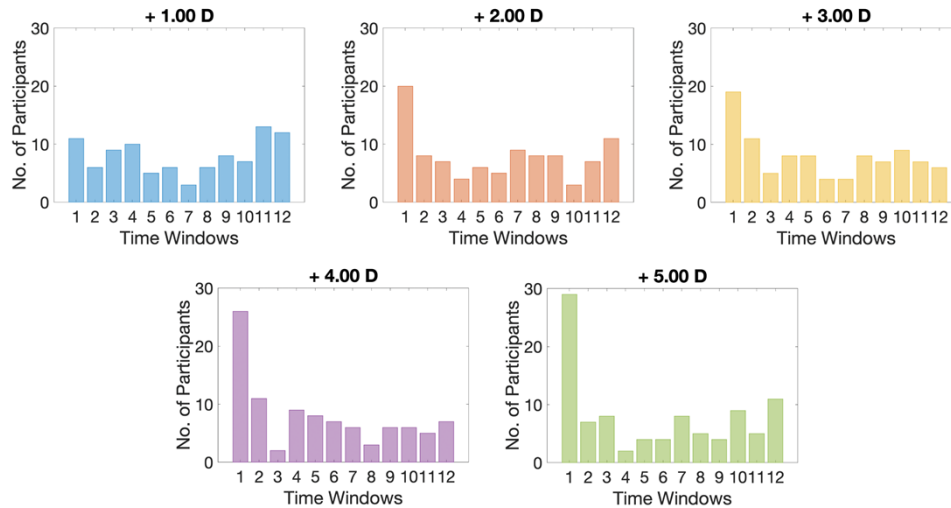
**Fig. 4.** Exponential fit to the accommodative responses to each lens.



**Fig. 5.** Boxplots of the change in accommodation due to each fogging lens. Outliers are represented by the black circles. Data of participants A and B, whose measures are outliers for all lenses, have been highlighted with different colors.

### 3.2. Effect of the time of application on the relaxation of accommodation

The effect of the time of application of each lens was assessed with two different approaches. First, the preferred time window for achieving the maximum relaxation for each lens was studied. As described in section 3.1, the maximum relaxation of accommodation of each measurement was obtained by looking for the minimum value of the median of accommodation among the time windows. In Fig. 6, bar charts representing the number of participants who achieved the maximum relaxation of accommodation in each time window are shown.



**Fig. 6.** Bar charts representing the number of participants who achieved the maximum relaxation of accommodation in each time window.

Additionally, the One-Sample Wilcoxon Signed Rank Test was used to compare the median change in accommodation at each time window to a hypothetical median of 0 (no change in accommodation). For lenses of +3.00 D, +4.00 D and +5.00 D, statistically significant positive differences were found for all windows, suggesting significant activation of accommodation throughout the whole measurement. The same test showed no statistically significant differences with the +2.00 D lens for any window. For the +1.00 D lens, the changes in accommodation were significantly different from 0 with negative differences, suggesting changes towards relaxation of accommodation in the second, third, fourth, fifth, eighth, and tenth time windows.

The time constant  $\tau$  retrieved from the exponential fit using Eq. (1) (with 95% confidence intervals) was 3.46 s (2.14 s, 4.77 s) for the +1.00 D lens, 1.42 s (-0.36 s, 3.21 s) for the +2.00 D lens, 10.62 s (8.68 s, 12.55 s) for the +3.00 D lens, 5.94 s (4.94 s, 6.93 s) for the +4.00 D lens and 6.08 s (5.12 s, 7.04 s) for the +5.00 D lens.

## 4. Discussion and conclusions

This study aimed to determine which positive spherical lens power and time of application were more adequate to achieve a successful relaxation of accommodation with the fogging technique.

Fogging has been shown to provide some effect in terms of relaxation of accommodation, causing a change equal to or higher than 0.125 D in 79.17% of the examined participants with at least one of the lenses. When analyzing the maximum capacity of relaxation of accommodation independently of time, all lenses provided a certain relaxation although the changes were modest. In this regard, the lens of +1.00 D was the one that produced changes in accommodation of at least 0.125 D to a higher number of participants (59.3%), and this proportion decreased with the power of the lenses. Furthermore, the lens of +1.00 D was the only one providing changes



towards relaxation of accommodation during the whole measurement, as shown by the plots of the change in accommodation over time in Fig. 3 and Fig. 4. The lens of +2.00 D elicited no changes in accommodation, as the median change in accommodation remained statistically equal to 0 at all time windows. Moreover, lenses of higher power (+3.00 D, +4.00 D and +5.00 D) seemed to lead to the opposite effect of what would be desired and resulted in an increase in accommodation. This shift could be due to the tonic accommodation or dark focus [11,12] led by the high blur caused by the higher power lenses. As can be seen in Fig. 3 and Fig. 4, the higher the power of the lens, the higher the activation of the accommodation. From this, it could be hypothesized that for even higher-power lenses the total number of subjects reaching the dark focus may increase and the median accommodation could be even higher. These results question the fogging methods used by some authors who use fogging lenses of between +2.00 D and +6.00 D and may not be achieving a successful relaxation of accommodation. The results obtained in this study are comparable with the results obtained by Ward and Charmann (1987), who proposed using lenses between +1.50 D and +2.00 D for the fogging technique as higher power lenses led to an increase in accommodation [10]. Regarding the variability of the changes in accommodation across participants, wide interquartile ranges showed high variability in the effect of the lenses. This can be related to the high inter-subject variability in the stimulus-response function and tonic accommodation that has been reported previously in the literature [21]. This implies that the response to fogging lenses will depend on the individual participant; hence it is difficult to recommend a single lens that would work appropriately for everyone.

Regarding the amount of time the lenses should remain in front of the eye to achieve the maximum relaxation, our results showed that, according to the number of participants who achieved maximum relaxation in each window for the +1.00 D lens, any time window stood out among the others. For the other lenses, a large number of participants exhibited the maximum relaxation of accommodation in the first time window. It should be noted that this window was determined as the one when the minimum accommodation was achieved. As shown in Fig. 3, the lenses of +2.00 D, +3.00 D, +4.00 D and +5.00 D tended to activate accommodation or produced minimal change. Therefore, what most participants exhibited at the first time window might have not been a true relaxation of accommodation compared to the reference value, but the minimum accommodation before it started to increase due to the lenses. When comparing the median accommodative change of each time window to a hypothetical median of 0, for the +1.00 D lens (the only lens that provided some relaxation), windows two, three, four, five, eight and ten were significantly different from 0, while no statistically significant differences were found for the other windows. Furthermore, the time constant  $\tau$  was 3.46 s (2.14 s, 4.77 s). Taken together, these results suggest that significant changes in accommodation were achieved in the range of 5 to 25 s after placing the fogging lenses in front of the eye and again in the later windows (eighth and tenth). In addition, as shown in Fig. 3, the interquartile ranges increased slightly with time until they stabilized around windows sixth and eighth. According to previous studies, accommodation dynamics are relatively fast [14]. For this reason, changes in accommodation are expected to occur on the order of seconds. The results of this study suggest that time periods shorter than those proposed by other authors [8,13] provide the desired relaxation of accommodation. Longer periods do not seem to provide a stronger effect on accommodation. Instead, they could even lead to a slight activation of accommodation. Moreover, our results showed no interaction between the effects of the power of the lens and the time of application.

It should be noted none of the individuals who participated in this study had anomalies in the accommodative system, and all had refractive errors ranging from low myopia to moderate hyperopia. Individuals with latent hyperopia might exhibit different accommodative behaviors. In this regard, the amount of power that elicits the greatest relaxation of accommodation for latent hyperopes might be different and depend on the amount of refractive error, as can be seen in the examples of subjects A and B in Fig. 5, which are represented as outliers due to the

large changes in accommodation. Thus, the findings of this study should not be generalized to a broad population with accommodative dysfunctions or anomalous behaviors. Further research is required to study the accommodative behavior of moderate and high hyperopes during the fogging technique.

Accommodation was monitored as changes in the spherical refractive state of the eye with a custom-developed HS aberrometer when fogging lenses of different powers were presented in front of the eye. The computation of the refractive state was based on paraxial curvature matching using the second- and fourth-order coefficients of the Zernike decomposition, whose estimations showed a good correspondence with the subjective refraction [16]. These refractive estimations were performed over a fixed pupil of 3.5 mm. Some authors have reported differences in the estimated accommodative response as a function of the metrics used due to the influence of higher-order aberrations (HOA) [22]. In our measurements, because accommodation was not stimulated, we expected a minimum impact of the HOA on the measured accommodation response. The influence of HOA and variations in pupil size should be considered in future studies.

The baseline objective refraction used to analyze changes in accommodation was measured using the Grand Seiko WAM 5500. The autorefractor measurement was chosen as the baseline to replicate the conditions in clinical practice, where it is commonly used as the starting point of the refraction procedure. This open-field autorefractor has been proven to have good agreement with the subjective refraction and produce less instrumental myopia than other closed-field autorefractors [18,23], which could slightly change the value of the effect caused by the lenses in the accommodation if it had been measured with a closed-field autorefractor. However, the final conclusions would be similar because any change in the data should be proportional to all lenses.

In conclusion, the use of low-power lenses in the fogging technique can provide certain stabilization of accommodation and even low levels of relaxation in a population with normal accommodative function. The +1.00 D lens elicited the greatest level of accommodation relaxation. Regarding the effect of time, there was no clear trend towards achieving the best level of relaxation in a specific time window, although less than half a minute seemed to be sufficient to reach the maximum capacity of the lens. In general, a lot of variability between subjects has been found, which indicates that there is no ideal formula for the fogging technique. Rather, individual solutions using systems with real-time monitoring may play a significant role in ensuring a good control of accommodation during refraction procedures.

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**Disclosures.** The authors declare no conflicts of interest.

**Data availability.** Data underlying the results presented in this paper are not publicly available at this time but may be obtained from the authors upon reasonable request.

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