ARTICLE IN PRESS

Contact Lens and Anterior Eye xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Contact Lens and Anterior Eye

journal homepage: www.elsevier.com/locate/clae

Disability glare in soft multifocal contact lenses

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ARTICLE INFO

Keywords:
Contact lens
Optical design
Contrast sensitivity
Disability glare

ABSTRACT

Purpose: The study investigated the effect of the design of multifocal contact lenses on the sensitivity to contrast and disability glare.
Methods: Contrast sensitivity was measured in 16 young adults (mean age: 25.5 ± 2.5 years) at a distance of 2 m under two conditions: no-glare and glare. Two designs (Center Near and Center Distance) of the Biofinity soft contact lens were used to simulate correction for presbyopes, while a correction with single vision trial lenses and contact lenses acted as controls.
Results: The design of the used multifocal contact lenses had a significant influence on the log area under the curve of the contrast sensitivity function (AUC-CSF). Compared to the spectacle lens correction, the AUC-CSF was significantly reduced, in case CS was measured with the Center Near design lens, under the no-glare ($p < 0.001$) and the glare condition (p: $p < 0.001$). In case of the Center Distance design contact lens, the AUC-CSF was significantly smaller in case CS was tested under glare ($p = 0.001$). Disability glare (DG) was depending on the spatial frequency and the design of the multifocal lens, while the Center Distance design produced higher amounts of DG ($p < 0.001$), compared to the other used corrections.
Conclusion: The optical design of a multifocal contact lenses has a significant impact on the contrast sensitivity as well as the disability glare. In order to dispense the best correction in terms of contact lenses, the sensitivity to contrast under no-glare and glare conditions should be tested a medium spatial frequencies.

1. Introduction

The achieved quality of vision with any method that is used to correct refractive errors, such as spectacle lenses, contact lenses or intraocular lenses, is of major importance for the success of these methods. While the correction of refractive errors with single vision solutions especially in the pre-presbyopic age normally results in a good visual performance, the use of a bifocal or multifocal contact lens correction for presbyopes can reduce the sensitivity to contrast (CS) [1,2], especially under the influence of glare [3] and wearers also experience ghost images [4] or haloes [5]. The visual performance with or without the correction of refractive errors is measured in means of the high contrast visual acuity, but it is often reported that this single measure is not a good indicator for the quality of vision [6,7]. Therefore, it is recommended that this measurement is accompanied by the measurement of the CS, either at a limited number of spatial frequencies or by the assessment of the contrast sensitivity function (CSF) that also describes the cut-off spatial frequency. Additionally, such measurement can be done with and without the presence of glare in order to measure the so called disability glare [8] or to describe the level of intraocular scatter [9]. It is also of great importance if the described and reported disadvantages of such a solution affect the quality of vision in the population that is targeted with this solution. Various studies have been conducted that described the sensitivity to contrast with various types of bifocal or multifocal contact lenses. When various indicators of the visual performance (high and low contrast visual acuity, disability glare, contrast sensitivity) were compared between different multifocal CLs (gas-permeable multifocal & soft bifocal contact lenses), Rajagopalan [2] reported an increased sensitivity to glare with such corrections, but high binocular contrast sensitivity and sufficient high as well as low contrast visual acuity. The same authors concluded that the measurement of sensitivity to contrast and glare should be included into the fitting process of such lenses. Only recently, the influence of multifocal contact lenses on the intraocular scatter as well as the disability glare became of interest. Grzegorz and colleagues [10] measured an increase in straylight and light scatter with multifocal contact lenses when compared to measurements without the contact lens that acted as a control. In their study, the authors used different

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http://dx.doi.org/10.1016/j.clae.2017.10.002
Received 3 April 2017; Received in revised form 24 August 2017; Accepted 4 October 2017
1367-0484/

Please cite this article as: Wahl, S., Contact Lens and Anterior Eye (2017), http://dx.doi.org/10.1016/j.clae.2017.10.002

contact lenses from different manufacturers. It is also of interest, if the design of a multifocal contact lens itself has a direct impact on the contrast sensitivity and the disability glare. Therefore, the aim of the current study was to investigate the influence of the design of a commercially available contact lens with two variations in their optical design (Center-Near design and Center-Distance design) on the contrast sensitivity when measured with and without glare.

2. Methods

2.1. Participants

The study was approved by the Institutional Review Board of the Medical Faculty of the University of Tuebingen and the study protocol was in accordance with the Declaration of Helsinki. All subjects provided their signed consent, after the study protocol was explained, including the explanation of the nature and possible consequences of the study. In total, 16 subjects with a mean age of 25.5 ± 2.5 years and a mean spherical equivalent refractive error (SE) of −3.5 ± 4.0 D and a mean astigmatism of −0.75 ± 0.5 (range: −0.25D to −2.00D) participated.

2.2. Study protocol

In each subject, the pupil of the dominant eye was dilated and accommodation was paralyzed during the course of the study, using three drops of a cycloplegic agent (1% cyclopentolate hydrochloride; Alcon Ophthalmika GmbH, Austria). Refractive errors were measured prior to the experiment, objectively (ZEISS i.Profiler plus, Carl Zeiss Vision Gmbh, Aalen, Germany) and subjectively (ZEISS Subjective Refraction Unit, Carl Zeiss Vision Gmbh, Aalen, Germany). Correction of subjectively measured refractive errors was achieved, while the rule "maximum plus with highest visual acuity" was followed and a trial frame and trial lenses were used for the correction. All subject were wearing the following types of the Biofinity soft contact lens (Cooper Vision, Victor, USA) with a distance spherical power of 0.25D: single vision (SVL), Center-Near Design (CND) and Center-Distance Design (CDD), both with an additional power of 2.5D. An artificial pupil with a diameter of 5 mm was placed into the trial frame during the course of the study in order to assure the same pupil size between the subjects. Push-up measurements from first clear to first noticeable blur in the distal and proximal direction were performed before, in between, and after the course of the experiment to control the paralyzation of the accommodative system [11].

2.3. Measurement of contrast sensitivity and assessment of disability glare

The Tuebingen Contrast Test (TueCST) [12] was used to measure contrast sensitivity at spatial frequencies of 1, 3, 6, 12, 18, 24 and 30 cycles per degree, under no-glare and glare conditions. In case of measurements under glare, a uniform and bright annulus (luminance: 270 cd/m^2) was shown concentrically around the Gabor Patches (luminance: 40 cd/m^2) that were used as stimuli for the CS measurements. A 4-AFC paradigm with 40 trials was used to find the contrast threshold for each spatial frequency, while the presentation of the different spatial frequencies was randomized. The Gabor Patches were displayed on a LCD Display (ViewPixx 3D, VPixx Technologies, Saint-Bruno, Canada) with a 16 bit grey-resolution and a pixel resolution of 1920 × 1080. A luminance meter (Konica Minolta LS-110, Konica Minolta Inc., Tokyo, Japan) was used to control gamma correction and luminance. The contrast sensitivity was measured with all contact lenses as well as with the trial frame correction, while the test order was individually randomized for each subject. The test distance was 2 m and the subjects head was fixed, using a chin- and headrest. Prior to each measurement, with each of the contact lenses as well as with the trial frame, the best (most positive) spherical focus was subjectively determined for the test distance of 2m, while an acuity chart was displayed on the monitor and trial lenses were used to achieve the highest visual acuity. As described by Aslam, the reduction of the retinal image contrast due to intraocular light scatter, or straylight is defined as disability glare [13]. The disability glare (DG) was calculated for each single spatial frequency using the formula: $DG = \log CS_{off} - \log CS_{on}$, whereas $\log CS_{off}$ is the logarithmic contrast sensitivity without glare and $\log CS_{on}$ is the logarithmic contrast sensitivity under glare [8].

2.4. Statistics

MS Excel (Microsoft Corporation, Redmond, Washington, USA) and Matlab 2016b (The MathWorks Inc., Natick, Massachusetts, USA) were used for data processing and calculation. SPSS statistics 24 (International Business Machines Corp., Armonk, New York, USA) was used for the statistical analysis (ANOVA, Post-hoc analysis, Bonferroni correction).

3. Results

3.1. Contrast sensitivity and area under the curve of the contrast sensitivity function

First of all, it was of interest, if there was an influence of the different types of corrections on the contrast sensitivity function. To compare the measured contrast sensitivity function, the area under the curve of the logarithmic contrast sensitivity function (AUC-CSF) [14] was used for the statistical analysis. The mean AUC-CSF ± 1 standard deviation, when calculated for all types of corrections and for the measurements with and without glare, can be obtained from Table 1.

The contrast sensitivity functions and the difference between the CSF for the four different corrections are shown in Fig. 1 (Fig. 1a: CSF without glare, Fig. 1b: CSF when measured under glare, Fig. 1c: difference in CSF between the two glare conditions) (Table 2).

The shape of the CSF (with or without glare) followed the typical form of the CSF, where CS is highest at medium spatial frequencies and started to decrease with increasing spatial frequencies. As expected, the CSF as well as the AUC-CSF was highest for the trial frame and single vision contact lens correction. Bonferroni corrected post-hoc analysis of the ANOVA identified no significant differences in regards of the AUC-CSF between the trial frame correction and the correction with the single vision contact lens, either under the no-glare condition ($p = 1.0$) nor under the glare condition ($p = 1.0$). A two-factor ANOVA (type of correction, test condition) revealed a significant influence of the type of correction on the AUC-CSF ($F(3120) = 25.841$, $p < 0.001$). For the trial frame correction, Post hoc analysis (Bonferroni corrected) found significant differences of AUC-CSF under both conditions (no glare, glare) when compared to the Center-Near design contact lens (no glare: $p < 0.001$, glare: $p < 0.001$). For the Center-Distance contact lens, the AUC-CSF was significantly different to the trial frame correction,

Table 1
Mean AUC-CSF ± 1 standard error of the mean for the four different types of corrections under the no-glare and glare conditions.

	Trial frame	SV contact lens	Center-Near Design contact lens	Center-Distance Design contact lens
AUC-CSF/ no-glare	21.78 ± 1.26	20.92 ± 1.25	11.92 ± 1.07	17.58 ± 1,34
AUC-CSF/ glare	19.01 ± 1.65	18.15 ± 1.43	8.66 ± 1.05	11.29 ± 1.33

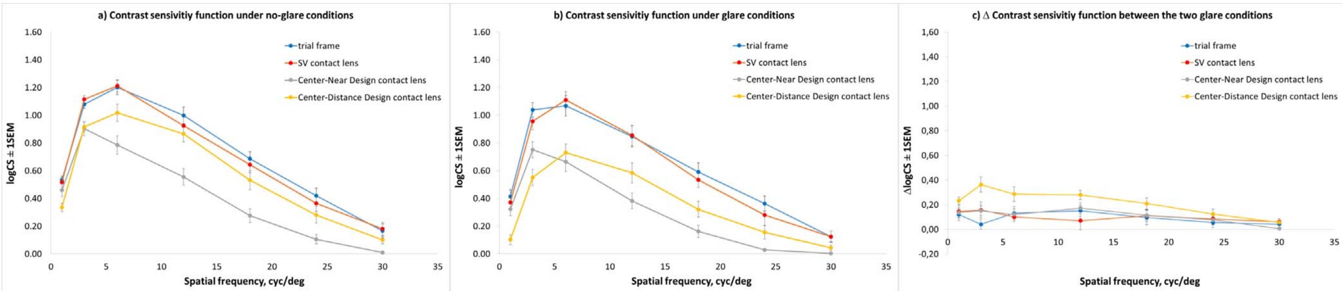

Fig. 1. Mean CSF for the different types of correction (blue: trial frame, red: SV contact lens, grey: Center-Near Design contact lens, yellow: Center-Distance contact lens), when measured under the no-glare conditions (Fig. 1a) and under the glare conditions (Fig. 1b). Fig. 1c displays the difference plots for the CSF, depending on the spatial frequency. Bars denote ± 1 standard error of the mean (SEM).

but only in case the CS was measured under glare (p = 0.001). Similar results were obtained in case the single vision contact lens was analyzed – the AUC-CSF was significantly different compared to the Center-Near design contact lens under both glare conditions (no glare: $p < 0.001$, glare: $p < 0.001$). Results for the Center-Distance design contact lens only found differences for the glare condition (p = 0.005). When both multifocal designs were compared with each other, the AUC-CSF with the Center-Distance Design contact lens was significantly higher compared to the Center-Near design contact lens, but only when CS was assessed without glare (p = 0.0112).

3.2. Disability glare

The contact lens with the Center-Near design resulted in the lowest contrast sensitivities (when measured with and without glare), when compared to the Center-Distance design, the trial frame correction and the single vision contact lens. The question arises, if a multifocal contact lens with this type of design results not only in a lower perceivable contrast when compared to the Center-Distance design, but also in a lower disability glare. Table 2 summarizes the mean disability glare ± 1 standard error of the mean for each method of correction and for the single spatial frequencies.

Fig. 2 shows the mean disability glare ± 1 standard error of the mean for the single spatial frequencies and for the four different corrections.

As can be observed from Fig. 2, the mean disability glare (DG) was different between the types of correction and was depending on the tested spatial frequency. In general, the DG with trial frame correction, SV contact lens and CND contact lens was always smallest, while the DG was elevated in case the CDD contact lens was used. Statistical analysis (Univariate Analysis of Variance) revealed significant interactions within the type of correction ($F(1,3) = 12.157$, $p < 0.001$) and the tested spatial frequencies ($F(1,6) = 4.896$, $p < 0.001$), but no significant interaction between the type of correction and the spatial frequencies ($F(1,18) = 1.095$, $p = 0.354$). Post hoc analysis with Bonferroni correction found significant differences between the Center-Distance Design contact lens and all other methods of correction (trial frame: $p < 0.001$; SV CL: $p < 0.001$; CND CL: $p < 0.001$). Analysis of the single spatial frequencies revealed significant differences

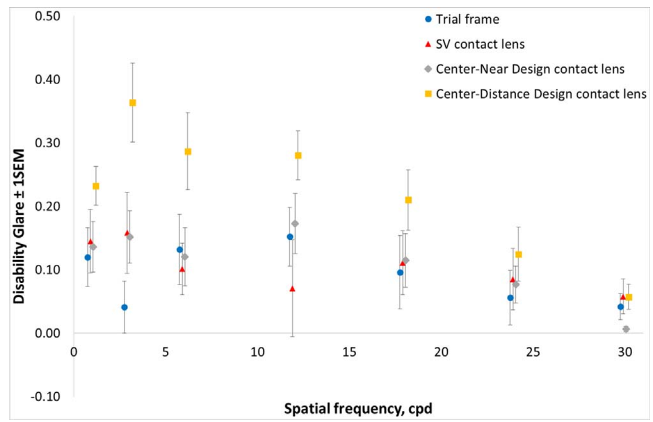

Fig. 2. Mean disability glare dependent on the type of correction (blue: trial frame, red: SV contact lens, grey: Center-Near Design contact lens, yellow: Center-Distance Design contact lens) and the spatial frequency. Bars denote ± 1 standard deviation.

between the highest spatial frequency (30 cpd) and the spatial frequencies 1 cpd (p = 0.007), 3 cpd (p = 0.001), 6 cpd (0.006) and 12 cpd (p = 0.002).

4. Discussion

The current study evaluated the influence of the design of multifocal contact lenses, single vision spectacle lenses and contact lenses on the contrast sensitivity when measured with and without glare, as well as the disability glare.

4.1. Contrast sensitivity function and area under the curve

Using single vision solutions to correct refractive errors for a defined distance (2 m in the current study) results in high quality vision, as reflected by the sensitivity to contrast. This finding was true for both investigated parameters: when contrast sensitivity was measured with and without the presence of glare. In case, a multifocal contact lens was used, specific reductions of the sensitivity to contrast were observed. In case the CND CL was used, the CSF was reduced for both conditions:

Table 2
Mean disability glare ± 1 standard error of the mean for the different methods of correction (Trial frame, SV CL = single vision contact lens, CND CL = Center-Near Design contact lens, CDD CL = Center-Distance Design contact lens), separated for each spatial frequency.

	Spatial frequency						
	1	3	6	12	18	24	30
Trial frame	0.12 ± 0.05	0.04 ± 0.04	0.13 ± 0.06	0.15 ± 0.05	0.10 ± 0.06	0.06 ± 0.04	0.04 ± 0.02
SV CL	0.14 ± 0.05	0.16 ± 0.06	0.10 ± 0.04	0.07 ± 0.08	0.11 ± 0.05	0.09 ± 0.05	0.06 ± 0.03
CND CL	0.14 ± 0.04	0.15 ± 0.04	0.12 ± 0.05	0.17 ± 0.05	0.11 ± 0.04	0.08 ± 0.03	0.01 ± 0.00
CDD CL	0.23 ± 0.03	0.36 ± 0.06	0.29 ± 0.06	0.28 ± 0.04	0.21 ± 0.05	0.12 ± 0.04	0.06 ± 0.02

with and without glare. For the CDD CL, a significant reduction was only observed, when the CSF was measured under glare conditions. In case, different multifocal solutions (spectacle lens or contact lens) where used, Collins and colleagues [15] observed a non-significant reduction of the CSF, when comparing spectacle lens solutions (bifocal or trifocal) to multifocal contact lens solutions (soft progressive bifocals, soft concentric bifocals, monovision, modified monovision and hard crescent segment bifocals). Significantly higher CS under monocular conditions for all tested spatial frequencies (1.5 cpd–18 cpd) were found by Llorente −Guillemot [16] and colleagues during photopic distance vision in a cross-over study, where presbyopes where either fitted with a high addition multifocal contact lens (PureVision) or spectacles. In case, the CS was measured under mesopic conditions and different levels of glare, the differences got less with an increasing amount of glare [16]. Measuring contrast sensitivity at the same spatial frequencies as Llorente-Guilemot [16], Rajagopalan [2] found higher CS at low to medium spatial frequencies (1.5, 3 and 6cp) when CS was measured with gas permeable multifocal contact lenses compared to progressive additional spectacle lenses. When comparing CS within the different contact lens groups (gas permeable multifocal contact lenses, soft bifocal contact lenses and gas permeable monovision lenses), gas permeable multifocal contact lenses had higher CS compared to the other contact lens solutions. Analyzing the differences of the AUC-CSF, significant differences were found between monovision and multifocal gas permeable contact lenses ($p < 0.001$) and gas permeable monovision as well as soft bifocal contact lenses ($p < 0.001$). In all of the earlier studies, different multifocal design for contact lenses were compared to each other or to spectacle lens solution, but no one has yet studied the influence of the design of a multifocal contact lens solution on the CSF in terms of the AUC-CSF.

4.2. Disability glare

Statistical analysis revealed a significant dependency of the disability glare on the type of correction as well as the tested spatial frequency. Significant differences between the Center-Distance Design contact lens and all other methods of correction (trial frame: $p < 0.001$; SV CL: $p < 0.001$; CND CL: $p < 0.001$) were found. Additionally, it was observed that DG is significantly different between the highest spatial frequency (30 cpd) and the spatial frequencies 1 cpd ($p = 0.007$), 3 cpd ($p = 0.001$), 6 cpd (0.006) and 12 cpd ($p = 0.002$). These results indicate that disability glare is highest at low to medium spatial frequencies, where the sensitivity to contrast is limited due to the different weighting of spatial frequencies in the visual cortex [17]. This observation is supported by findings from Abrahamsson & Sjöstrand [8] as well as van Den Berg [18] where the authors concluded that there is only a weak correlation between the visual acuity (that is equivalent to the cut-off frequency of the CSF) and glare. In contradiction, Llorente-Guillemot and colleagues describe an influence of induced glare on the sensitivity to contrast especially at medium and spatial frequencies [16]. As mentioned earlier, the effect of straylight on the sensitivity to contrast is only minor, especially when compared to the effect of blur or the correction with bifocal or multifocal implants or contact lenses [18]. By comparing the two multifocal contact lenses, one could conclude that the Center-Near design contact lens might be the better solution for the correction of presbyopia, since the disability glare with this design was lower and similar to the disability glare that was measured with the trial frame correction and the single vision contact lens. The question arises, why the trial frame correction and single vision contact lens provided a high contrast sensitivity to the wearer (in contrast to the CND contact lens) but resulted in a similar disability glare. Additionally, the results with the CDD contact lens indicate a much better sensitivity to contrast (when compared to the CND CL), but also in a much higher DG. Since the same contact lenses (same material, same refractive power, same diameter and same base curve) were used during the course of the study, the effect of the material on the observed effects was reduced to a minimum. In contradiction, Labuz and colleagues [10] concluded that the observed increased straylight with the Air Optix contact lens was attributed to the material of the lens. Therefore, it can be concluded that the optical design of the lens causes the higher amount of disability glare to the wearer. The question arises, what is the best optical design that provides the wearer with an adequate sensitivity contrast, high visual acuity but only minor disability glare. The measurements revealed that the sensitivity to contrast at a spatial frequency of 30cpd was higher than 1logCS and it can be concluded that the subjects had an average visual acuity of 0.0 logMAR or better in the tested eye. Also other authors report a visual acuity of 0.0 logMAR or better in case the vision is corrected with multifocal contact lenses [1,16,19]. One has to keep in mind that the experiments that were conducted during the course of the current study included only young subjects, without known ocular diseases or increased straylight due to for example an early stage of cataract. In order to give a recommendation regarding the optical design of a multifocal contact lens that provides all three performance parameters (high visual acuity, comparable CSF with monofocal solution and only minor DG), a study with presbyopic participants is needed, where all parameters (including measurements at different distances) are measured.

4.3. Aberrations in soft multifocal contact lenses and their influence on contrast sensitivity

The design of a multifocal contact lens significantly affected the sensitivity to contrast (under no-glare as well as glare conditions) and the level of the disability glare that was depending on the spatial frequency. Analyzing the optical design of soft multifocal contact lenses and their influence on the aberrations of the eye, studies found significant differences, especially for the primary spherical aberration [20,21]. Peyre and colleagues [20] measured optical aberration with a Center-Near as well as Center-Distance design soft multifocal contact lens and found that in case the Center-Distance contact lenses was worn, the positive spherical aberration increased. Results with the Center Near contact lenses lead to an inversion of the sign of the spherical aberration. Recently, this findings were confirmed by Fedtke et al., where the authors found an increase in the primary spherical aberration with a Center-Distance multifocal soft contact lens and a decrease in case different Center-Near contact lenses were worn [21]. As it is known that straylight is increased, in case a multifocal contact lens is worn [10], the increased amount of scatter in conjunction with the increased or decreased spherical aberration might affect the visual performance of the wearers eye. Investigating the influence of spherical aberration on the contrast sensitivity, it was concluded that inducing spherical aberration, especially in the presence of scatter, does not decrease the sensitivity to contrast but even slightly increases the contrast sensitivity [22]. In contrast and when multifocal intraocular lenses are considered, it was shown that these lenses increases the amount of spherical aberration and lead to an reduction in the sensitivity to contrast [23]. Additionally, it is known that reducing the spherical aberration due to the use of monofocal aspherical designs increases the sensitivity to contrast, when compared to the contrast sensitivity with spherical intraocular lenses [24,25]. Inferentially, it cannot be concluded if the observed differences between the Center-Near and Center-Distance design of the soft multifocal contact lenses are caused by their influences on the higher aberrations of the eye.

5. Conclusion

The current study gave the possibility to investigate the effect of the optical design of soft multifocal contact lenses on the contrast sensitivity at different spatial frequencies, when measured under no-glare and glare conditions. In order to provide the best possible offer/solution for presbyopes who want to correct their refractive error with contact lenses, the use of a Center-Distance or Center-Near design can be recommended, but currently it can't be concluded which design is better for application in the real world environment.

Conflicts of interest

None.

Acknowledgments

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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