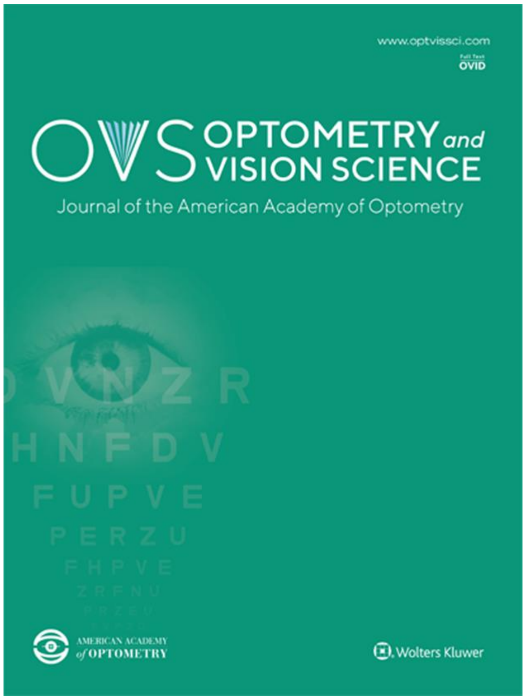

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ORIGINAL INVESTIGATION

Contrast Sensitivity with Center-distance Multifocal Soft Contact Lenses

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ABSTRACT

Significance. The contrast sensitivity function provides a more detailed assessment of vision than visual acuity. It was found that center-distance multifocal contact lens designs that are increasingly being prescribed for myopia control reduce distance photopic and mesopic contrast sensitivity in non-presbyopic patients across a range of spatial frequencies. **Purpose.** To determine the effect of center-distance multifocal soft contact lenses (MFCLs) on contrast sensitivity (CS) under photopic and mesopic conditions in non-presbyopic patients. **Methods.** Twenty-five myopic, non-presbyopic adults were fitted binocularly with three lenses: Biofinity single vision contact lens (SVCL), Biofinity D Multifocal +2.50 add, and NaturalVue Multifocal in random order. CS was measured at distance (4 m) under photopic and mesopic conditions and at near under photopic conditions. Log CS by spatial frequency and area under the log contrast sensitivity function (AULCSF) were analyzed between lenses. **Results.** Distance photopic CS at each spatial frequency was higher with the SVCL than the MFCLs ($P < .001$), but there was no difference between the MFCLs ($P = .71$). Distance mesopic CS from 1.5 to 12 cycles per degree (cpd) was higher with the SVCL than the MFCLs (all $P < .018$); however, at 18 cpd there was no difference in CS between NaturalVue and the SVCL ($P = .76$), possibly due to spurious resolution. Photopic AULCSF for the SVCL was roughly 10% greater than both MFCLs. CS at near was generally similar between lenses, only slightly lower with the NaturalVue at 11 and 15.5cpd, but AULCSF at near was not different between lenses ($P > .05$). **Conclusions.** Multifocal contact lenses reduce distance contrast sensitivity under both photopic and mesopic conditions. There is no clinically significant difference in near CS among all three lenses. These data show that MFCLs have effects on vision that are not captured by standard high-contrast visual acuity testing.

The prevalence of myopia (or nearsightedness) is increasing globally. While myopia can be corrected by standard spectacles, contact lenses, and refractive surgery, the risk of vision-threatening comorbidities such as glaucoma, retinal tears and detachments, and myopic macular degeneration rises with higher levels of myopia.[1-3] For this reason, a significant amount of research continues to study various strategies to reduce myopia onset and progression.

Animal studies have shown that simultaneous clear foveal vision and myopic retinal defocus could serve as a signal to slow eye growth, reducing myopia progression.[4] This work led to clinical studies investigating various multifocal optical modalities in attempts to slow myopia progression including multifocal spectacles,[5] orthokeratology,[6] and center-distance multifocal and dual-focus contact lenses.[7,8] To achieve the desired optical effect of simultaneous clear foveal vision and myopic retinal defocus, most center-distance multifocal or dual-focus contact lenses are designed to have the central portion of the lens optimized for distance vision, with plus power in the mid- and peripheral portions to impose myopic defocus. Differences in lens brands arise based on the amount, location, and how quickly plus power changes in the lens.[9,10] Currently in the United States, only the MiSight contact lens (CooperVision, San Ramon, CA) designed specifically for slowing myopia progression in children, is FDA approved for myopia control. However, several commercially available center-distance contact lenses that are approved for presbyopia are being studied or used off-label for myopia control, including the Biofinity Multifocal D (CooperVision, San Ramon, CA) and NaturalVue Multifocal (Visioneering Technologies, Inc.. Alpharetta, GA).[7,11,12]

With the increased use of multifocal and dual-focus contact lenses among myopic children, it is critical to understand how these lenses affect visual performance. Previous researchers have reported on aspects of visual performance including visual acuity and reading speed with these lenses among non-presbyopes.[13-16] Since measurement of the contrast sensitivity function assesses visual sensitivity to both the size and contrast of a target, it is considered to provide a better measure of spatial vision and visual sensitivity than visual acuity alone,[17] and is better correlated with identifying real-world objects.[18] Of the commercially available lenses in the United States that are routinely being used or studied for myopia control, we are only aware of published reports describing the effect of the MiSight lens on contrast sensitivity in a non-presbyopic population after full correction.[19] The complete power profiles of the MiSight, Biofinity "D" multifocal and NaturalVue multifocal have been previously published. [9,20] The MiSight lens has a center-distance concentric ring design. The central 2mm radius is for distance vision and is surrounded by rings of alternating near and distance zones. The near zones have an about +2.00D add over the distance correction.[20] The Biofinity Multifocal D with +2.50 add has the central 1.6mm radius of the contact lens optimized for distance vision and then an increase in plus power radially out to the edge of the optic zone of the lens. The NaturalVue Multifocal has an extended depth of focus design, with plus power increasing from the lens center to about a 2.8mm radius before power reduction in the periphery.[9] Studies have suggested that the design of a multifocal contact lens influences its effect on contrast sensitivity[21,22]; however, apart from the MiSight lens, it is still unknown how other multifocal contact lens designs affect contrast sensitivity at both distance and near.

We previously reported visual performance including high- and low-contrast logMAR visual acuity under photopic and mesopic conditions, and near high-contrast visual acuity with these three lenses.[13] Photopic high-contrast logMAR visual acuity (mean ± SD) was very similar between lenses (Biofinity sphere: −0.18 ± 0.06, Biofinity multifocal: -0.14 ± 0.08, NaturalVue multifocal: -0.15 ± 0.03). While there were statistically significant differences in photopic visual acuity, these one to two letter differences were not clinically meaningful. Under mesopic conditions, high-contrast visual acuity (mean ± SD) was about a line worse with the multifocal contact lenses compared with the single vision contact lens (Biofinity sphere: −0.05 ± 0.09, Biofinity multifocal: 0.03 ± 0.09, NaturalVue multifocal: 0.05 ± 0.09, $P \leq .001$). Near photopic visual acuity was also similar between lenses (mean near photopic logMAR visual acuity was -0.13 or better).

The purpose of this study was to determine the effect of two commercially available center-distance multifocal soft contact lenses on contrast sensitivity when fitted using a myopia control strategy. Distance contrast sensitivity with the two multifocal contact lenses (Biofinity Multifocal D +2.50 add and NaturalVue Multifocal) and a single vision contact lens was measured under photopic and mesopic conditions; near contrast sensitivity was measured under only photopic conditions.

METHODS

The study was approved by the University of Houston Institutional Review Board and complied with the tenets of the Declaration of Helsinki. All subjects provided written informed consent before participating in the study.

The study was a non-dispensing, randomized, single-masked crossover study. Twenty-five myopic subjects aged between 21 and 29 years participated in the study. A slit lamp examination was performed as part of determining their eligibility to participate. Subjects were excluded if they had any active anterior segment disease or pathology that affected vision or contact lens wear, a history of ocular trauma or surgery that caused abnormal vision, or were currently wearing rigid gas permeable lenses. Refractive error was determined using a standardized maximum plus to best visual acuity manifest refraction. Eligible subjects had spherical equivalent refraction of -0.75 DS to -6.00 DS after vertexing to the corneal plane and astigmatism equal to or less than 1.00 DC in each eye.

Contact Lenses

Three contact lenses were fitted binocularly in the study; Biofinity single vision contact lens (comfilcon A; CooperVision, San Ramon, CA), Biofinity Multifocal D +2.50 add (comfilcon A; CooperVision, San Ramon, CA), and NaturalVue Multifocal (etafilcon A; Visioneering Technologies, Alpharetta, GA). Both multifocal contact lenses have a center-distance design and their optical profiles have been previously described.[9] The order in which contact lenses were fitted was randomized, and subjects were masked to the contact lens they were wearing. The lenses were fit in two different study visits within a two-week period. One contact lens was fitted at the first visit and two lenses were fitted at the second visit. The manifest refraction was used to determine the initial lens power for each contact lens brand.

For the NaturalVue multifocal, the initial contact lens power placed on each eye was determined by entering the requested best corrected spectacle refraction and vertex distance into the

NaturalVue Quickstart Calculator mobile application version that was available at the time the study was conducted. For the Biofinity lenses, initial contact lens power for each eye was selected based on the spherical equivalent of the spectacle prescription after vertexing to the corneal plane. After an acceptable fit was obtained, subjects wore the contact lenses for at least 10 minutes to allow the lenses to settle. Spherical over-refraction was then performed on each eye utilizing maximum plus to best distance visual acuity. When the over-refraction resulted in an adjustment to the initial estimate of contact lens power, the on-eye contact lens power was updated, and lenses were allowed to settle for at least 10 minutes before further testing.

Contact lens centration was measured with a Haag-Streit slit lamp reticule under 10X magnification. Centration was measured from the limbus to the edge of the contact lens. Decentration of the contact lens was calculated as the temporal minus nasal overlap where positive values indicate temporal decentration of the contact lens. Binocular, high-contrast photopic and mesopic logMAR visual acuity with the contact lenses was measured using the M&S Technologies Clinical Trial Suite (M&S Technologies; Niles, IL). Near high-contrast photopic visual acuity was measured at 40 cm on an Apple iPad (Apple Inc., Cupertino, CA) with the display brightness set to maximum using a previously validated mobile application by Kingsnorth and Wolffsohn. [23] For all testing in this study, photopic room illumination was ~367.0 Lux and mesopic room illumination was <1 Lux.

Contrast Sensitivity Testing

Distance contrast sensitivity was measured binocularly at 4 m using the M&S Technologies Clinical Trial Suite Automated Contrast Sensitivity Function System (M&S Technologies; Niles, IL) under photopic and mesopic conditions. This instrument measures contrast sensitivity at 1.5, 3, 6, 12, and 18 cycles per degree using a sinusoidal bull's eye pattern as shown in Figure 1A. The target was presented on a screen illuminated at 85 cd/m^2 for photopic testing. Subjects were then dark adapted for 5 minutes and contrast sensitivity was retested under mesopic lighting conditions. A neutral density filter was placed in front of the screen to reduce the illumination to 3 cd/m^2 for mesopic testing.

Before distance contrast sensitivity testing, there was an initial training phase to familiarize subjects with the test and ensure that they understood the test and the required responses. During testing, the instrument presents the sinusoidal target at different contrasts and spatial frequencies, and the subject indicates on a tablet whether they see the target or a blank screen. Blank screens are also randomly interspersed during testing to determine the accuracy of testing.

Near contrast sensitivity was tested binocularly using the Aston contrast sensitivity application [24] at 40 cm under photopic conditions. This app has previously been shown to be reliable and repeatable at measuring contrast sensitivity at various spatial frequencies.[24] The test is an adaptation of the Campbell-Robson contrast sensitivity chart[25] and is displayed using a swept frequency design on an Apple iPad (Apple Inc., Cupertino, CA). The displayed chart is made up of sinusoidal gratings that increase in spatial frequency from left to right and in contrast from top to bottom. The subject draws a line on the iPad screen indicating the boundary of where the grating is no longer visible to them (Figure 1B). Measured spatial frequencies ranged from 0.1 to 22 cycles per degree. Each participant had to draw the line three times or until the standard deviation of the contrast sensitivity measurement at each spatial frequency was within 0.3 log contrast sensitivity units before the test ended.

Measured contrast sensitivity at each spatial frequency was converted to log contrast sensitivity for analysis. The area under the log contrast sensitivity function was calculated in MATLAB (MathWorks; Natick, MA) using the “trapz” function. In brief, the contrast sensitivity values at the measured spatial frequencies were connected with straight lines to result in a set of trapezoids from the lowest to the highest spatial frequency. Then, the area of each trapezoid was calculated, and those areas were summed to obtain the area under the contrast sensitivity function curve. The area under the log contrast sensitivity function is a useful metric that provides a single number to characterize the performance of the eye over the measured spatial frequencies.[26]

Photopic and mesopic pupil sizes were measured at both study visits with the NeurOptics VIP-300 Pupillometer (NeurOptics, Laguna Hills, CA). Subjects fixated on a distance target with their left eye, and pupil diameter was measured for the right eye under photopic and mesopic conditions. Pupil size was measured to the nearest 0.1 mm.

Statistical Analysis

This study was part of a larger study to determine visual performance with multifocal contact lenses.[13] A sample size of 24 subjects was calculated to give the study 90% power to determine a 0.1 logMAR (one line) difference in low-contrast visual acuity between lens designs at an α level of 0.05, assuming a known standard deviation of 0.15 logMAR.

Statistical analyses were conducted using IBM SPSS Statistics for Windows, version 26.0 (IBM, Armonk, NY). Pupil sizes measured across the two visits were averaged for analysis. A paired t-test was used to compare pupil size under photopic and mesopic conditions. Repeated-measures analyses of variance (ANOVAs) were used to assess differences in log contrast sensitivity and area under the log contrast sensitivity function for the different lens types and lighting conditions. For distance contrast sensitivity measurements, the repeated-measures ANOVA included three repeated factors: lighting level (photopic or mesopic), lens type (Biofinity sphere, Biofinity Multifocal D, or NaturalVue Multifocal), and spatial frequency (1.5, 3, 6, 12, or 18 cycles per degree). The repeated-measures ANOVA of the area under the log contrast sensitivity function included two factors: lighting level and lens type. For near measurements, the repeated-measures ANOVA of contrast sensitivity included factors for lens type and spatial frequency (0.1, 0.14, 0.2, 0.3, 0.4, 0.6, 0.9, 1.3, 1.8, 2.6, 3.7, 5.3, 7.6, 11, 15.5, 22.4), and the repeated-measures ANOVA of area under the log contrast sensitivity function included only lens type as a factor. When indicated, post-hoc t-tests were conducted with correction for multiple comparisons using the Benjamini-Hochberg procedure.[27]

Additionally, to assess whether pupil size under each lighting condition had an effect on contrast sensitivity, a repeated-measures analysis of covariance was conducted for both photopic and mesopic contrast sensitivity measurements. The repeated factors in the analyses were lens type and spatial frequency, with pupil size as a covariate. For analysis of the photopic contrast sensitivity data, the covariate was photopic pupil size. Mesopic pupil size was the covariate used for analysis of the mesopic contrast sensitivity data. Statistical significance was set at $P < .05$.

RESULTS

Of the 25 subjects, most were female (18, 72%), and the mean age (± standard deviation) was 24.1 ± 1.5 years (range; 21 to 29 years). All lenses fitted in the study had an acceptable fit with sufficient paralimbal coverage and slight temporal decentration. Mean ± standard deviation contact lens decentration were +0.28 ± 0.23 mm temporal (right eye) and +0.19 ± 0.26 mm temporal (left eye) for the Biofinity sphere, +0.28 ± 0.28 mm temporal (right eye) and +0.18 ± 0.29 mm temporal (left eye) for the Biofinity Multifocal, and +0.28 ± 0.21 mm temporal (right eye) and +0.14 ± 0.23 mm temporal (left eye) for the NaturalVue Multifocal. There was no difference in lens centration between the three contact lenses (P = .87).

After over-refraction on the fifty eyes that were fitted with the lenses, three eyes fitted with the Biofinity single vision lens required a change in contact lens power (mean ± SD; +0.02 ± 0.09 D, range; 0.00 D to +0.50 D), twenty-nine eyes fitted with the Biofinity multifocal contact lens required a change in lens power (mean ± SD; -0.27 ± 0.28 D, range; 0.00 D to -1.00 D), and one eye fitted with the NaturalVue multifocal required a -0.50D change in contact lens power (mean ± SD; -0.01 ± 0.07 D, range; 0.00 D to -0.50 D).

Average pupil size (mean ± SD) across the two study visits was significantly smaller under photopic conditions (4.2 ± 0.5 mm) than under mesopic conditions (5.8 ± 0.6 mm, $P < .001$).

Distance Contrast Sensitivity

As expected, the shape of the contrast sensitivity function under photopic lighting conforms to the typical physiological asymmetric inverted U-shaped curve with a peak around 3 cycles per degree (Figure 2). Distance contrast sensitivity depended on the lighting condition, lens type, and spatial frequency (3-way interaction; $P = .01$).

Photopic distance contrast sensitivity is shown in Figure 2A (solid lines). Photopic contrast sensitivity at each spatial frequency was higher with the single vision contact lens than with the two multifocal contact lenses ($P < .001$). Between the two multifocal contact lenses, there was no difference in contrast sensitivity across the measured spatial frequencies ($P = .71$). The observed reduction in log contrast sensitivity with the two multifocal contact lenses did not vary based on spatial frequency (lens x spatial frequency interaction, $P = .37$).

Mesopic distance contrast sensitivity is shown in Figure 2B (dashed lines). Mesopic contrast sensitivity measured between 1.5 to 12 cycles per degree was higher with the single vision contact lens than with the two multifocal contact lenses (all $P < .02$). However, at 18 cycles per degree, there was no difference in contrast sensitivity between the NaturalVue Multifocal and the single vision contact lens ($P = .76$). This was also the only spatial frequency at which there was a difference in mesopic contrast sensitivity between the two multifocal contact lenses ($P = .009$).

There was no effect of photopic pupil size on photopic contrast sensitivity ($P = .12$) or of mesopic pupil size on mesopic contrast sensitivity ($P = .20$).

Area under the log contrast sensitivity function depended on both the lighting level and the lens type (lighting level x lens interaction; $P = .004$). As shown in Figure 3, the area under the log contrast sensitivity function was higher with the single vision contact lens than with the two multifocal contact lenses under both photopic and mesopic conditions (all $P < .001$), and there was no difference in the area under the log contrast sensitivity function between the two multifocal contact lenses under both lighting conditions (all $P > .44$).

Area under the log contrast sensitivity function for each lens was higher under photopic conditions than under mesopic conditions. The reduction in the area under the log contrast sensitivity function from photopic to mesopic lighting was greater with the multifocal contact lenses (26%) than the single vision contact lens (~19%, all $P < .02$).

Near Contrast Sensitivity

Near contrast sensitivity was measured under only photopic lighting. Log contrast sensitivity at each of the measured spatial frequencies depended on both the lens type and the spatial frequency (lens x spatial frequency interaction; $P = .001$). Contrast sensitivity was generally similar between the lenses measured (Figure 4). There was a statistically significant but clinically small reduction in contrast sensitivity at 11 and 15.5 cycles/degree with the NaturalVue Multifocal compared to the single vision contact lens (both $P = .04$).

As shown in Figure 5, area under the log contrast sensitivity function was similar between lenses and there was no significant effect of lens type on the area under the log contrast sensitivity function at near ($P = .27$).

DISCUSSION

The purpose of this research was to examine the effect of the Biofinity Multifocal D with +2.50 add and the NaturalVue Multifocal on contrast sensitivity when compared with a single vision contact lens. With the increase in longitudinal studies that show the efficacy of center-distance multifocal contact lenses in slowing myopia progression,[7, 8] many myopic children are being prescribed these lenses making it important to understand their full impact on vision.

The contrast sensitivity function assesses the visibility of a spatial pattern in both size and contrast. This offers a more comprehensive measurement of vision than visual acuity, which only assesses the smallest resolvable size of a target. To the best of the authors' knowledge, this is the first study to examine the effect of the Biofinity Multifocal D and NaturalVue Multifocal contact lens designs on the contrast sensitivity function at both distance and near under different lighting conditions in a non-presbyopic population. This study suggests that these lenses generally reduce photopic and mesopic distance contrast sensitivity (Figures 2-3), but not near contrast sensitivity (Figures 4-5).

The area under the log contrast sensitivity function, a single metric to characterize the contrast sensitivity function, is lower at distance with the multifocal contact lenses than with the single vision contact lens. This result is similar to several reports of reduced contrast sensitivity with other multifocal contact lenses,[19,21,22,28] and suggests that these lenses reduce the sensitivity of the visual system over the measured range of spatial frequencies. This is expected since plus power in the optical profile of multifocal contact lenses can degrade the quality of the retinal image.[29] In addition, when combined with the average nasal decentration of the pupil, the average temporal decentration of lenses in this study can lead to the central retina being exposed to more of the plus portions of the multifocal lenses and cause further reductions in image contrast.

There was no effect of pupil size on contrast sensitivity measured under either photopic or mesopic conditions. Not finding an effect of photopic pupil size on photopic contrast sensitivity or mesopic pupil size on mesopic contrast sensitivity could be because the variability in pupil size under each lighting condition was not adequate to find an association. This study was not specifically powered to detect pupil size dependent differences in contrast sensitivity under photopic or under mesopic conditions. Further studies are needed to more comprehensively evaluate any effect of pupil size across subjects on contrast sensitivity.

Based on these results, the question of whether these reductions in contrast sensitivity extend into higher spatial frequencies beyond what were measured comes to mind. As previously reported,[13, 14, 16, 30] there are no clinically significant differences in photopic visual acuity between multifocal contact lenses and single vision lenses, which shows that the high spatial frequency cut-off remains unaffected. However, under mesopic conditions, a significant reduction in visual acuity with the multifocal contact lenses is observed in addition to the reduction in the area under the log contrast sensitivity function, demonstrating that the high spatial frequency cut-off is also reduced under mesopic conditions.

Between the two multifocal contact lenses, there was no difference in the area under the log contrast sensitivity function at distance under both lighting conditions despite reductions when compared to the single vision lens, indicating that differences in the lens design between these two multifocal contact lenses did not translate to significant differences in contrast sensitivity when using the area under the log contrast sensitivity function metric. This finding is contrary to reports of a significant effect of multifocal lens design on contrast sensitivity at distance by some studies.[21,31] However, these previous studies compared multifocal lens designs that were markedly different, for instance, a center-distance versus a center-near lens[31] or monovision correction and binocularly fitted multifocal lenses.[21] Also, their study designs are sufficiently different from the current study to make comparison difficult. As expected, decreasing light levels led to reductions in contrast sensitivity.[32] However, it is also noted that reducing the light level leads to a greater reduction in the area under the log contrast sensitivity function with the multifocal contact lenses (26%) than with the single vision contact lens (~19%). This difference likely occurs because the larger pupil sizes under mesopic conditions expose the eye to more plus power in the multifocal contact lens optics, which can lead to further degradation of retinal image quality.[29] This finding is also consistent with previously reported higher reduction in visual acuity from photopic to mesopic lighting with the multifocal contact lenses than with the single vision contact lens.[13]

For the individual spatial frequencies measured, distance contrast sensitivity was always higher with the single vision contact lens than with the multifocal contact lenses except at 18 cycles per degree under mesopic conditions, where there was no difference between the Biofinity sphere and the NaturalVue Multifocal. This was an unexpected finding, and this measured improvement in contrast sensitivity at 18 cycles per degree under mesopic conditions has also been observed by García-Marqués et al with the MiSight lens.[19] Their study measured contrast sensitivity under photopic and mesopic conditions in non-presbyopic adults with a single vision contact lens (Proclear 1-day; CooperVision, San Ramon, CA) and the MiSight dual-focus lens for myopia control (CooperVision, San Ramon, CA). Similar to the current study, reductions in contrast sensitivity were observed at all measured spatial frequencies with the multifocal contact lens except at 18 cycles per degree under mesopic conditions. A possible explanation for this observation is spurious resolution. Spurious resolution is a phenomenon that allows a target to be seen at a spatial frequency that is higher than that at which the contrast of the target was first no longer perceivable. The NaturalVue Multifocal has an increase in plus power closer to the center of the lens, and greater plus power than the Biofinity Multifocal D +2.50 add design.[9] Under mesopic conditions, the increase in pupil size will expose the retina to a larger amount of plus which can lead to spurious resolution through dioptric blur. At the spatial frequencies measured in our study, this spurious resolution only occurred at 18 cycles per degree with no difference in mesopic visual acuity (which represents the cut-off special frequency) between the two multifocal contact lenses. This finding indicates that studies are needed to measure how multifocal contact lenses affect contrast sensitivity at higher spatial frequencies outside the range measured in this study.

An assessment of near vision is important because patients fitted with multifocal contact lenses for myopia control will mostly be children who require good near vision for academic success. There was no meaningful reduction in near contrast sensitivity with the multifocal contact lens designs tested.

All lenses in this study were fitted binocularly as occurs in myopia management to determine visual performance at the time of lens fitting. That said, a study limitation is that contract sensitivity was not measured beyond the day of the initial lens fitting. It is unknown whether contrast sensitivity with any of these lenses might change over time due to adaptation. Future studies should measure visual performance with multifocal contact lenses over a longer period of time. In addition, since contrast sensitivity testing is generally not sensitive to phase shifts, the results of this study may not reflect other aspects of vision such as visual acuity, which is sensitive to phase shifts.

The current study shows that distance contrast sensitivity is reduced with multifocal contact lenses, even under photopic conditions where there are no clinically significant reductions in visual acuity. These reductions in contrast sensitivity have the potential to cause subjective reports of reductions in quality of vision. It is important for clinicians to be aware of the effect of the lens designs they prescribe so they have a full understanding of their potential visual impact and recognize that visual acuity alone does not capture the full effect of multifocal contact lenses on vision.

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FIGURE LEGENDS

Figure 1. Targets for distance **(A)** and near **(B)** contrast sensitivity testing. Participants indicate on a tablet whether they see a target or blank screen for distance contrast sensitivity testing. For near testing, participants draw a line to trace the boundary of where they can see the contrast sensitivity grating (B)

Figure 2. Photopic (A, solid lines) and mesopic (B, dashed lines) distance contrast sensitivity function with different contact lens designs. Contrast sensitivity was lower with the multifocal contact lenses compared to the single vision contact lenses except at 18cpd under mesopic conditions where sensitivity with the NaturalVue Multifocal was the same as the single vision lens. Error bars represent 95% confidence interval.

Figure 3. Area under the log contrast sensitivity function (AULCSF) at distance under photopic and mesopic lighting for each contact lens type. The AULCSF is reduced with the multifocal contact lenses under both photopic and mesopic conditions, but similar between the multifocal lenses. Error bars represent 95% confidence interval.

Figure 4. Near photopic contrast sensitivity with different contact lens types. Log contrast sensitivity with the NaturalVue Multifocal was slightly reduced compared to the single vision contact lens at 11 and 15.5 cycles/degree (*, P = .04). Error bars represent 95% confidence interval.

Figure 5. Area under the log contrast sensitivity function (AULCSF) at near was the same with all contact lens types. Error bars represent 95% confidence interval.

Figure 1

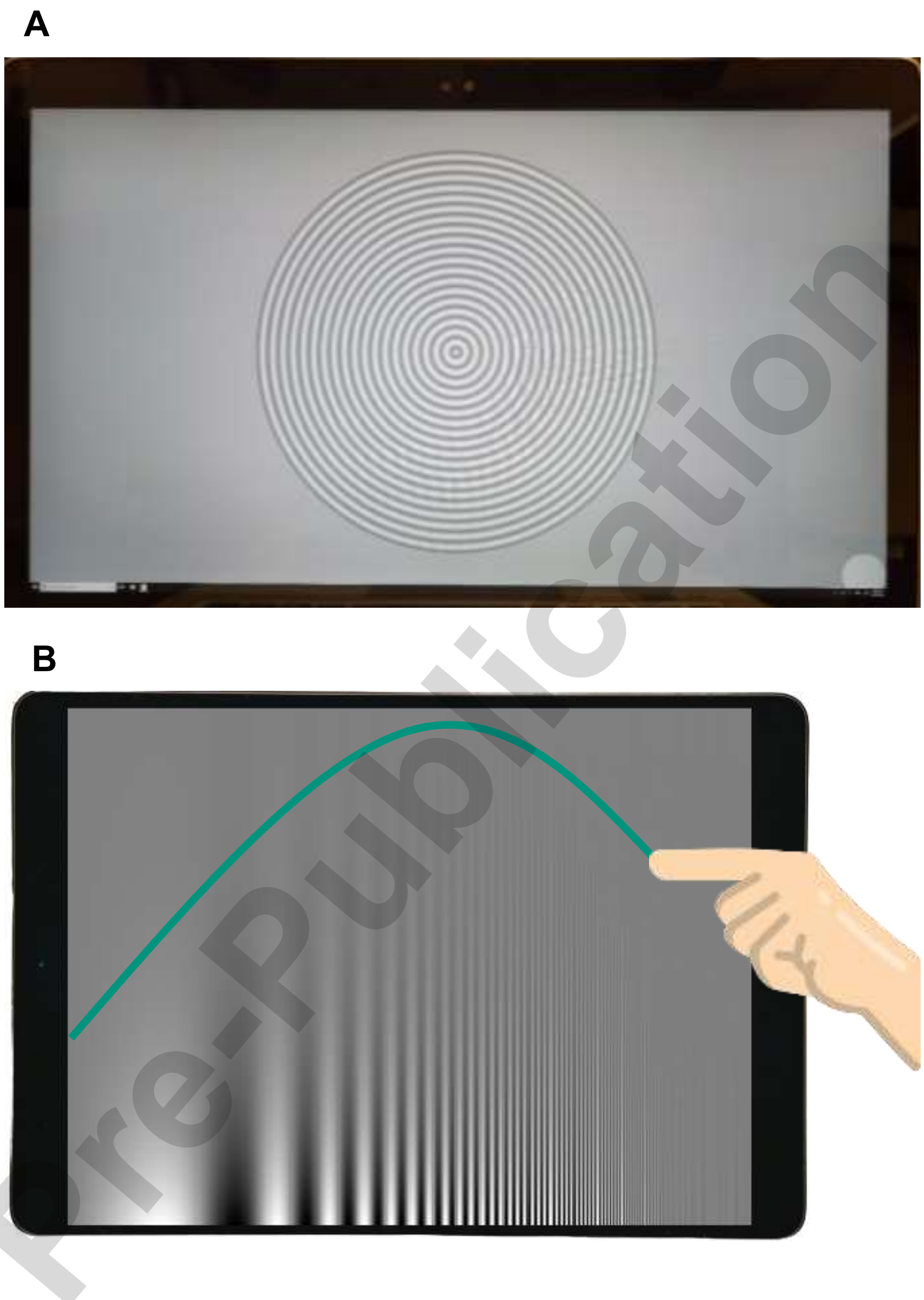
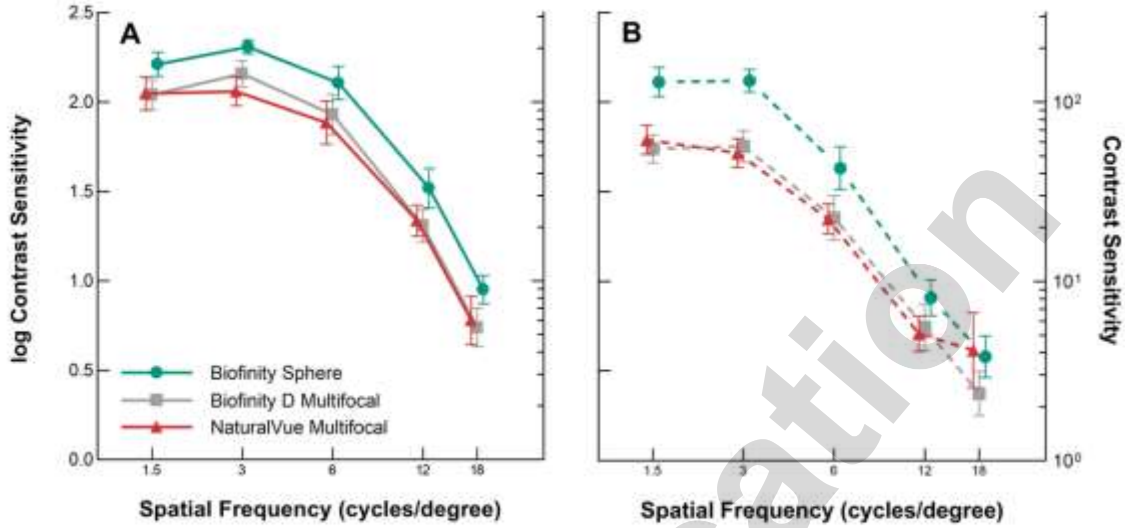
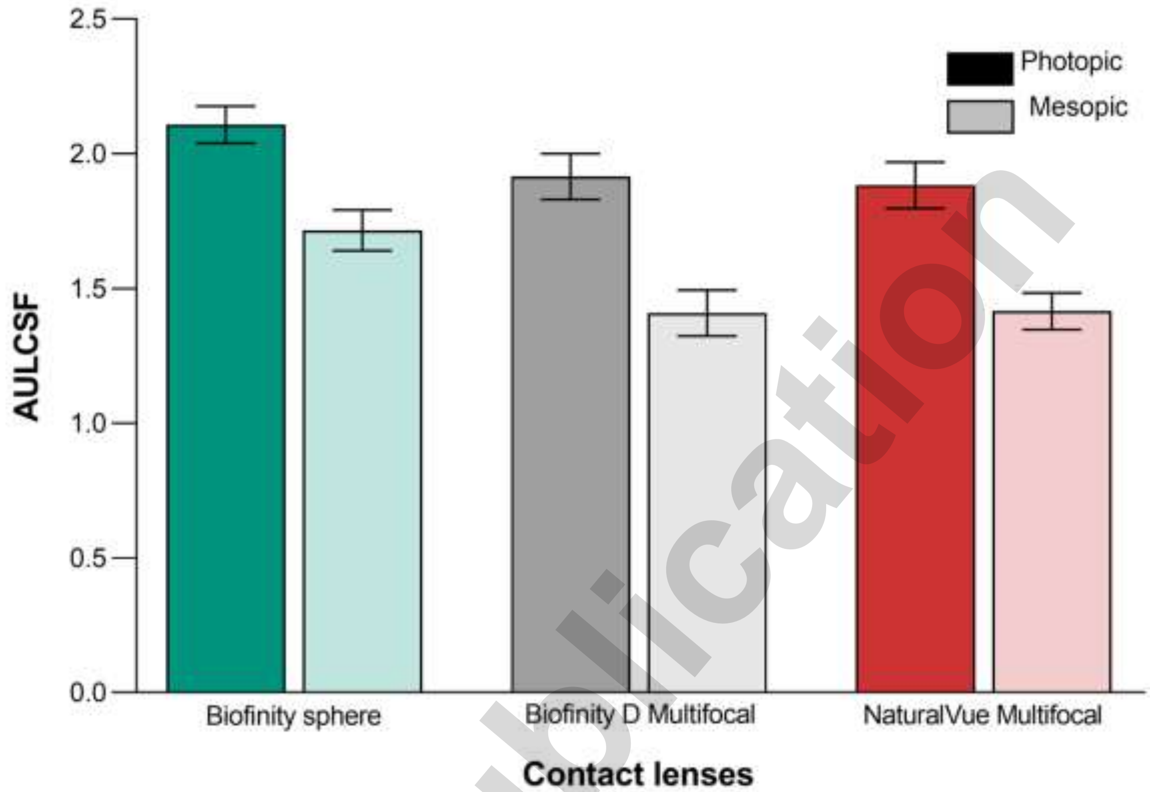


Figure 2



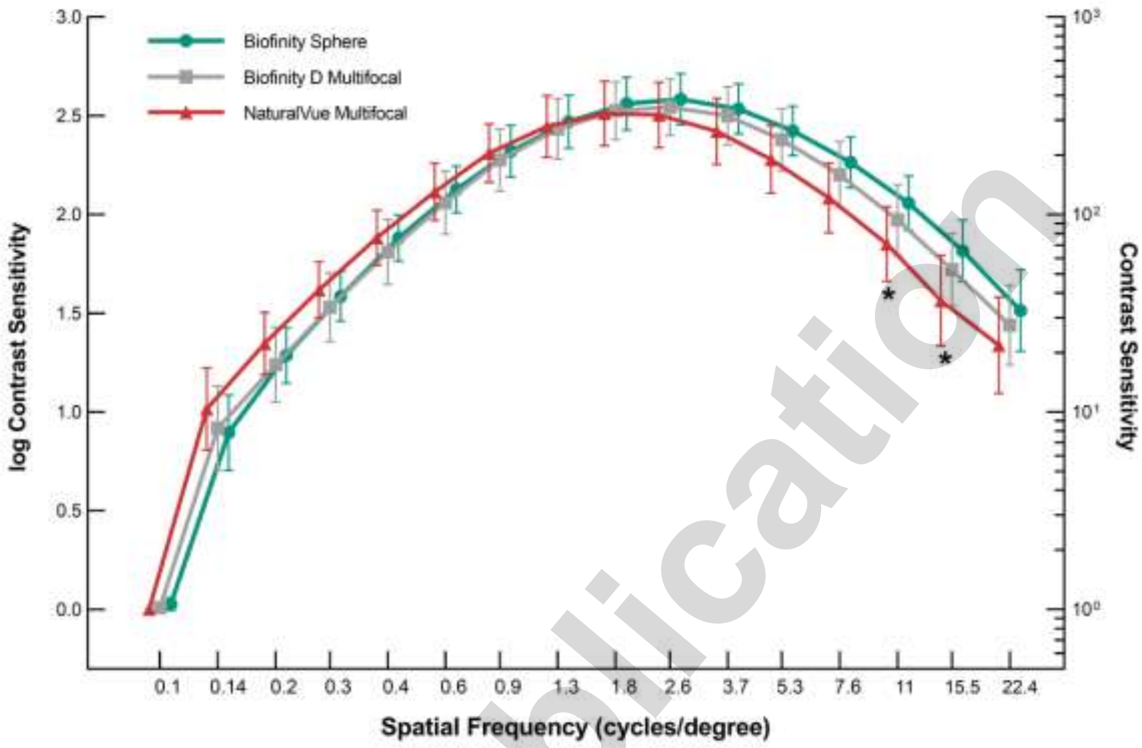
A
B
log Contrast Sensitivity
Contrast Sensitivity
Spatial Frequency (cycles/degree)
Spatial Frequency (cycles/degree)
Biofinity Sphere
Biofinity D Multifocal
NaturalVue Multifocal
2.5
2.0
1.5
1.0
0.5
0.0
1.5
3
6
12
18
10^2
10^1
10^0

Figure 3



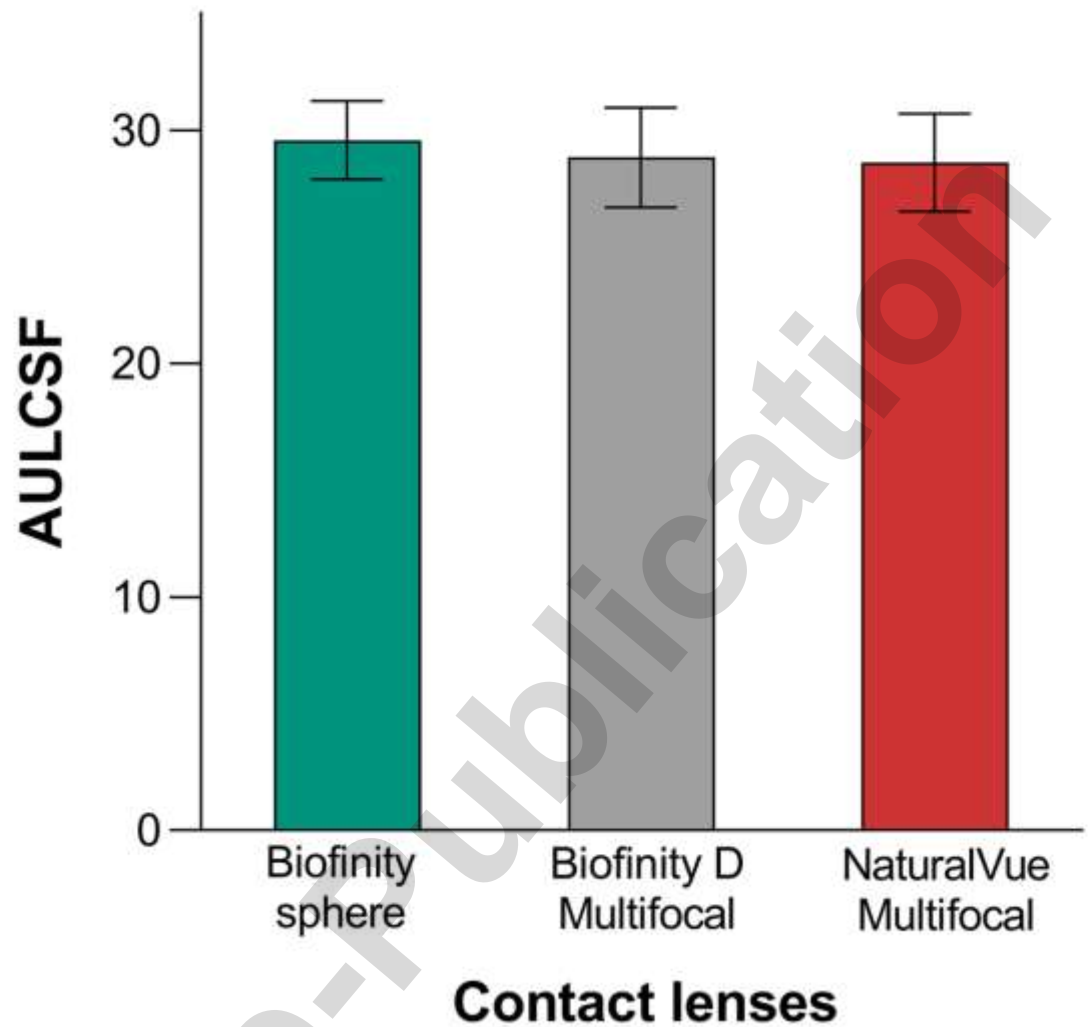
2.5
2.0
1.5
1.0
0.5
0.0
AULCSF
Photopic
Mesopic
Biofinity sphere
Biofinity D Multifocal
NaturalVue Multifocal
Contact lenses

Figure 4



Biofinity Sphere
Biofinity D Multifocal
NaturalVue Multifocal
log Contrast Sensitivity
Contrast Sensitivity
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10^3
10^2
10^1
10^0
*
*
0.1
0.14
0.2
0.3
0.4
0.6
0.9
1.3
1.8
2.6
3.7
5.3
7.6
11
15.5
22.4
Spatial Frequency (cycles/degree)

Figure 5


AULCSF
30
20
10
0
Biofinity sphere
Biofinity D Multifocal
NaturalVue Multifocal
Contact lenses