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Visual performance with multifocal contact lenses and progressive addition spectacles

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ABSTRACT

Purpose: As presbyopia occurs, new visual demands create a need for clear vision at multiple distances. Many spectacle wearers adapt into progressive addition lenses (PAL) in order to see clearly at distance, intermediate, and near. A multifocal contact lens provides the ability to see at these same distances without the prismatic effects of a spectacle lens or the peripheral obstruction of a spectacle frame. No studies have been done to date comparing the effect of these types of presbyopic vision correction on a variety of tests of visual performance representative of everyday tasks.

Methods: A battery of visual performance tasks were completed by subjects while wearing their habitual PAL spectacles. These subjects were then fit with a multifocal contact lens and wore lenses for 2 weeks or more before completing the tasks again. These functional vision tests included assessments of coincidence anticipation timing, peripheral search and hand-eye coordination, and dynamic visual acuity. Following functional vision testing, subjects completed a preference survey comparing both types of refractive correction while performing common activities of daily living.

Results: Performance on the majority of the tests of visual performance were equivalent ($P < 0.05$) when comparing PAL spectacles and multifocal contact lenses. Survey results demonstrated a preference for multifocal contact lenses overall.

Conclusion: PAL spectacles are widely prescribed for presbyopic patients. The findings of this study suggest that in addition to providing excellent vision, multifocal contact lenses provide functional vision performance equal to PAL spectacle wear and patients may prefer them over PAL spectacles.

1. Introduction

Presbyopia is an age-related refractive condition which is characterized by the loss of accommodative ability and results in near defocus. [1] Typically, this condition affects individuals in their 5th decade of life. The number of presbyopic individuals in the US is growing as the Baby Boomer cohort has been joined by those of Generation X, making up approximately 50 % of the population. [2] Presbyopic patients have several options for near refractive correction.. Those patients who have never worn distance vision correction may be more likely to use over-the-counter reading glasses, whereas patients who have previously worn glasses full time generally transition into progressive addition lenses (PAL) which provide vision at multiple viewing distances. Refractive correction for presbyopic contact lens wearers include the use of single-vision near spectacles over their contact lenses, as well as monovision and multifocal contact lens options. Interestingly, the highest amount of contact lens wear drop out begins at the age of presbyopia onset, with some practitioners attributing this to age-related dry eye and discomfort issues [3–5], or poor vision with lenses [6,7] and others attributing this to a lack of patient knowledge of multifocal lens options [8].

PAL spectacles correct distance and near vision by creating a vertical corridor of lens powers which change as the eye shifts to positions on the lens which are used for intermediate and near distances. [9] Because of the optical design required to provide these focal points, these lenses have areas with multiple types of aberrations in their periphery [10]. This, coupled with the fact that some glasses frames can obstruct peripheral vision encourages head movement, rather than eye movement, when the wearer needs to look laterally.

Multifocal contact lenses are an option for presbyopic patients, with optical designs that provide the ability to see distance, intermediate, and near objects simultaneously. One advantage of contact lenses is their

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relative alignment with the pupil during eye movements. This differs from PAL spectacles which discourage horizontal eye movements due to the spectacle frame or zone of aberration in the periphery. [11]

Because many everyday tasks involve changing visual focus, using peripheral vision, and using eye movements to track various objects, keeping vision clear and distortion-free is ideal.

2. Purpose

There are no previously published data comparing performance with multifocal contact lenses and progressive addition spectacles on visual tasks such as coincidence anticipation timing, peripheral search and hand-eye coordination, and dynamic visual acuity. The majority of studies comparing visual performance with these refractive modalities have used visual acuity or contrast sensitivity as the primary outcome measure. The purpose of this study was to utilize a wide variety of visual and visuomotor tests to compare the performance of subjects when wearing multifocal contact lenses to the same subject when wearing progressive addition spectacles.

3. Methods

3.1. Study overview

This was a prospective, open-label cross-over study of presbyopic wearers of progressive addition spectacles who were fit into multifocal contact lenses (DAILIES TOTAL1® Multifocal Water Gradient Contact Lenses, Alcon, Inc, Fort Worth, TX, USA). The study was completed under the approval of the Institutional Review Board at The Ohio State University, located in Columbus Ohio, USA. All subjects provided written consent prior to screening.

Primary outcome measures were assessment of high and low contrast sensitivity (logMAR), peripheral search and hand-eye coordination (Acuvision 1000 -time to completion and number of targets touched), coincidence anticipation timing (Bassin Anticipation Timer – timing error in milliseconds), dynamic visual acuity (number of targets read on a moving acuity chart), and the National Eye Institute 25-item Visual Function Questionnaire (VFQ-25) [12].

3.2. Subjects

Twenty four participants enrolled in the study. Two screen-failed because they did not meet study inclusion criteria. Two additional participants discontinued participation because they were unable to return for all visits. The twenty participants who completed the study ranged in age from 45 to 63 years of age with an average (standard deviation) age of 54.9 (4.7) years. Nineteen subjects were female.

3.3. Study design

A diagram of the study design can be found in Fig. 1. The initial study visit was conducted, after consenting the subjects, in order to determine eligibility. Subjects were required to be current PAL spectacle wearers with an add power of at least +1.25D. Subjects were required to have at least 20/25 distance vision OU with their spectacles to participate. Subjects were excluded if they had active ocular infections or had known health conditions that would require a change in medications during the span of the study. After confirming eligibility, subjects completed their first Functional Vision Testing Visit while wearing their habitual progressive addition spectacles. These spectacles were worn to the visit. The visual and visuomotor performance test battery included tests of high and low contrast sensitivity (logMAR), peripheral search and hand-eye coordination (Acuvision 1000 -time in seconds to completion and # of targets touched), coincidence anticipation timing (Bassin Anticipation Timer – timing error in milliseconds), dynamic visual acuity (velocity of threshold detection), and composite scores of the National Eye Institute 25-item Visual Function Questionnaire.

A contact lens fitting visit was then performed in order to fit the subject in the multifocal study lenses. The lenses were fit according to the manufacturer fitting guide. Subjects who had not previously worn contact lenses were taught to insert and remove their contact lenses. Lenses were dispensed and a contact lens follow-up visit was scheduled at least one week later. At the contact lens follow up, vision and a fitting assessment of the lenses was performed. If further refinement of the lens fitting was necessary, an additional follow-up was scheduled. Once the lens fit was finalized, the subject wore the final prescription lenses successfully for 2–4 weeks before completing the second Functional Vision testing visit with contact lens wear. This is similar to the time frame in which Fernandes et al. reported improvements in vision with multifocal contact lenses. [13] After completion of the second Functional Vision test visit, subjects were asked to complete a survey about their experience with both forms of vision correction. Subjects returned for a final visit to collect distance, near, and low contrast acuity in both refractive modalities.

4. Background of testing and application to this study

4.1. Peripheral search and hand-eye coordination

In a recent study, Yaquinto and Fogt demonstrated that performance on a clinical device intended for testing and training hand eye coordination was better for young individuals when wearing spherical contact

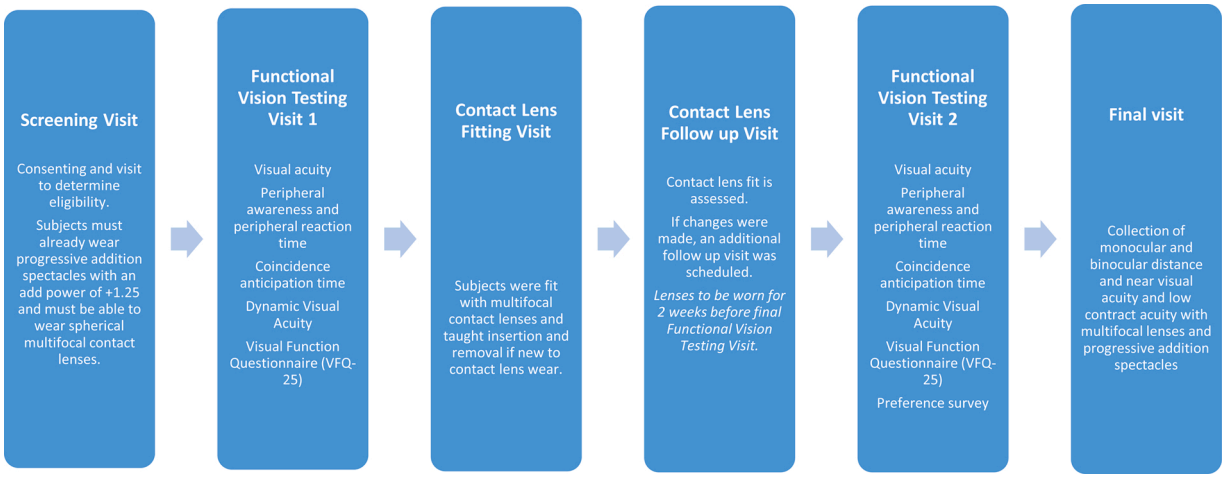

Fig. 1. Study design.

lens compared to when wearing single vision spectacle lenses. [14,15] Subjects completed the hand eye coordination task more rapidly and with greater accuracy when wearing contact lenses compared to when wearing spectacles. The device utilized in this previous investigation (AcuVision 1000, Acuvision systems) was also used in the current investigation. The AcuVision 1000 is a wall-mounted board consisting of small touch-sensitive squares.

Subjects were asked to stand in front of the AcuVision 1000. They then placed their hands on the lateral sides of the board and stepped back until their hands just reached each side. The AcuVision 1000 displays lights one at a time in random locations on the board over an angular range of about 105 degrees horizontally and 82 degrees vertically. The subject's task was to depress the lights as quickly as possible. Subjects were informed that if the light was depressed in the time window given, then the next light appeared. Subjects were told that they could move both the eyes and the head to complete the task, but that their feet should remain approximately in the starting location.

Settings for the AcuVision 1000 were speed 8 (time between lights 0.80 s) and mode full field 120. At this setting, 120 lights were displayed in each test trial. Prior to the test trial, subjects completed a practice trial with 30 lights.

4.2. Coincidence-anticipation timing

Coincidence-anticipation timing is the ability of an individual to predict when an approaching object will arrive at a particular location, and to make a response that coincides with the arrival of this object. Coincidence-anticipation timing is important in activities such as driving and sports, where an approaching object must be avoided or intercepted. The hypothesis in this experiment was that the prismatic effects in progressive addition spectacle lenses either in the distance portion of the lenses, or in the portion of the lenses adjacent to the progressive corridor as the "object" approaches, could lead to distortion of of the apparent rate of motion of an approaching object and negatively influence coincident anticipation timing responses.

In this experiment, the Bassin Anticipation Timer (Lafayette Instrument Company, Lafayette, Indiana) [16] consisting of a track of red LEDs was utilized. Subjects were seated at the end of the Bassin Anticipation timer track. The were situatied such that the track was below the eyes. The track was 3.58 m in length. The LEDs on the track were illuminated sequentially, giving the impression of an object approaching along the subject's midline.

Approach velocities included 5mph, 10mph, 15mph, and 20mph. Each of these velocities was randomly applied 10 times using a computer program. A yellow "cue" light at the end of the track opposite the subject indicated that the target was about to begin its approach. This cue light was randomly illuminated for 0.50–2 seconds to reduce anticipation. The subject's task was to push a button to coincide with illumination of the light at the end of the track closest to them. The final "target" light at the end of the track protruded through a white strip placed across the face of the Bassin Anticipation Timer. No feedback on performance was given throughout the trial.

Photodiodes placed over the cue light and the target light were used to record when these lights were illuminated. The push-button responses were recorded in synchrony with the output from these photodiodes through an analog-to-digital converter (Measurement Computing, USB-1208FS) at 2000 Hz per channel.

4.3. Dynamic visual acuity

Dynamic visual acuity as defined here is the ability to identify a visual target (Snellen numbers) moving in a frontoparallel plane with the head fixed. [17] Dynamic visual acuity is thought to be reflective of both the accuracy of ocular tracking and visual clarity. It can be assumed that dynamic visual acuity is likely related to success in athletic endeavors such as catching or hitting a ball, and in efficient driving where one must track upcoming road signs or oncoming vehicles. It was hypothesized that with a fixed head, participants would encounter prismatic effects in their spectacles as the target moves across the field of view, and these prismatic effects will cause distortion of the ocular tracking thereby limiting participants ability to resolve moving numbers

Subjects were seated about 116.2 cm from a semi-cylindrical white screen. Their head was stabilized by a chin and forehead rest. A mirror galvanometer (Model CX-660, General Scanning Inc.) placed between the subject and the screen was used to display a small Snellen visual acuity chart on the screen at approximately eye level. The acuity chart was projected onto the mirror by a projecto-chart (Reichert Inc.). The acuity chart consisted of five rows of numbers that decreased in size from top to bottom. The top row had four numbers, the second row down had five numbers, and the remaining three rows had six numbers. The Snellen equivalents for these numbers were 20/36 (top row), 20/30 (second row), 20/24 (third row), and 20/18 (fourth row), and 20/12 (fifth row). The mirror galvanometer was controlled by a function generator (Model 182a, Wavetek), such that the visual acuity chart was moved left and right in a sinusoidal manner at 0.75 Hz. The visual angle through which the acuity chart was rotated was about 24 degrees (13 degrees left to 11 degrees right).

The subject's task was to read as many letters on the moving acuity chart as possible in 10 s. Subjects were to read out loud each row in its entirety from left to right, starting with the top row, prior to moving to the next row. The exposure time of the visual acuity chart was controlled by an electro-mechanical shutter (Melles Griot). The experimenter started the rotation of the mirror, and then manually opened the shutter with a push-button. Prior to the 10 s exposure period, subjects were given a 1 s demonstration of the moving target.

4.4. Statistical analysis and power calculation

Using findings from a previous study of single vision contact lenses versus spectacles, [15] a power calculation indicated that 20 subjects were required to achieve a power of 80 % and a significance of 5%.

Statistical analysis of the data included a paired *t*-test of the average values found for the vision and visuomotor performance tests in order to compare the performances for each test when wearing multifocal contact lenses and when wearing progressive addition spectacles.

5. Results

5.1. Visual acuity

Monocular visual acuity was collected at each study visit to ensure subjects were properly corrected before completing functional vision tasks. In the final study visit, binocular visual acuity was collected for each mode of eyewear on the same testing day. Three subjects did not return for the final binocular acuity visit due to COVID-19 concerns of the participants. Visual acuities at distance and near and low contrast distance acuities were similar between both groups. Mean binocular logMAR distance visual acuity while wearing PAL spectacles (-0.1 ± 0.07) and while wearing multifocal contact lenses (-0.02 ± 0.07) revealed that both modalities provided better than 20/20 vision at distance. Mean binocular near acuity with PAL spectacles (0.08 ± 0.09) and with multifocal contact lenses (0.1 ± 0.1) revealed average acuities in both groups were better than 20/25 and not quite 20/20 in either group in the testing situation. Binocular low contrast distance acuity was 0.01 ± 0.09 while wearing PAL spectacles, and 0.09 ± 0.09 while wearing multifocal contact lenses.

5.2. Peripheral search and hand-eye coordination

The AcuVision results were tabulated for each participant. The AcuVision computes the total time taken to complete the trial, the total number of correct responses (those responses where the target light was

depressed during the first 70 % of the allotted time), total late responses (those responses where the target light was depressed during the last 30 % of the allotted time), and total missed responses. In addition, the AcuVision divides responses into six quadrants (2 central and 4 peripheral). Correct, late, and missed responses were also calculated for the combined central and combined peripheral quadrants. The mean and standard deviation of the total missed responses was determined. Three participants demonstrated a total number of missed responses outside the standard deviation in both the spectacle (greater than 94) and contact lens (greater than 92) conditions. These participants were not included in the following analyses. All of the results obtained from the AcuVision for the 17 remaining subjects are shown in Table 1.

A series of paired t-tests were performed for each of these values and the results are also shown in Table 1. It should be noted that these variables cannot be completely independent. For example, the number of correct plus late responses will correlate with the number of missed responses. In addition, a subject who achieves more correct responses will generally complete the test faster.

The only significant comparison was for the central missed values, where the mean value was greater for spectacles than for contact lenses. However, in most of the comparisons the mean contact lens value suggested better performance than the mean spectacle value.

5.3. Coincidence anticipation timing

Those data from the Bassin anticipation timer were analyzed as follows. Analog data from the photodiodes aligned with the cue light and target light and the pushbutton were analyzed using a custom computer program. The computer program calculated the time between offset of the cue light and onset of the target light, and the time between the button press and onset of the target light. In some cases, there were a few extra data points, and in some cases there were fewer data points than expected. In the latter case, this is typically because a response was missed.

The mean offset or response error was calculated at each velocity for each subject as the mean time between onset of the target light and the time at which the button was pressed. These means were then averaged and the results for spectacle and contact lens wear are as shown in Table 2. Negative values indicate that the button was pressed early, prior to illumination of the target LED. Paired t-tests of spectacles versus contact lenses at each velocity revealed no significant differences ($p > 0.05$).

5.4. Dynamic visual acuity

The mean of the numbers read correctly in the spectacle wearing condition was 4.60 ± 3.25, and the mean in the contact lens wearing condition was 5.20 ± 3.69. A paired *t*-test between these means showed that the difference between them was not significant ($P = 0.40$).

Table 1
AcuVision results.

Peripheral search and hand-eye coordination resultsValue	Spectacles (±standard deviation)	Contact lenses ± standard deviation)	Paired *t* -test
Total Time (seconds)	83.48 ± 4.25	82.19 ± 3.49	$P = 0.090$
Total Correct	19.06 ± 10.45	22.82 ± 11.28	$P = 0.113$
Total Late	40.06 ± 13.37	41.24 ± 13.69	$P = 0.715$
Total Missed	60.88 ± 21.03	55.94 ± 16.82	$P = 0.184$
Central Correct	9.65 ± 5.33	11.29 ± 6.27	$P = 0.239$
Central Late	15.94 ± 4.98	17.47 ± 6.21	$P = 0.269$
Central Missed	14.41 ± 7.46	11.24 ± 5.90	$P = 0.030$
Peripheral Correct	9.41 ± 6.06	11.53 ± 5.71	$P = 0.112$
Peripheral Late	24.53 ± 9.82	23.76 ± 9.25	$P = 0.734$
Peripheral Missed	46.06 ± 14.37	44.71 ± 11.67	$P = 0.562$

Table 2
Coincidence Anticipation Timer results.

Velocity (mph)	Spectacles – Mean and standard deviation (milliseconds)	Contact lenses – Mean and standard deviation (milliseconds)
5	−173.0 ± 81.9	−190.3 ± 124
10	−94.9 ± 82.5	−110.4 ± 92.8
15	−60.1 ± 57.0	−62.3 ± 44.5
20	20.1 ± 50.5	5.4 ± 35.4

5.5. National eye institute 25-item visual function questionnaire (VFQ-25)

The mean composite score for the VFQ-25 was 91.90 (±1.1) when assessing vision with PAL spectacles, and 92.7 (±1.1) when wearing multifocal contact lenses. There was no statistical difference between these groups ($P > 0.05$).

5.6. Preference survey

After completing all visits, subjects were asked to complete a survey indicating their preference for using their PAL spectacles or the multifocal contact lenses in the following scenarios: watching television, using their phone, using a computer, dining out, driving, playing sports, working out, and reading. Subjects were able to chose PAL, contact lenses, no difference, or not applicable for each scenario. The survey results can be found in Table 3.

5.7. Adverse events

No subjects experienced any adverse events during study visits and no study participants reported any adverse events during the study period.

6. Discussion

Studies have shown that visual quality of life is higher with contact lens compared to spectacle wear. [18,19] These studies, however, did not compare these modalities in a presbyopic population. The findings in this study demonstrate that overall, participants preferred multifocal contact lens wear to PAL spectacle wear, with 70 % (14) of the subjects preferring the contact lenses, 20 % (4) saying there was no difference between the two modalities, and 10 % (2) prefering their PAL spectacles overall.

Spectacles have a number of features that may reduce performance compared to the non-spectacle wearing condition on functional vision tasks, where peripheral objects must be localized or when the eyes must continuously track an object in order to discriminate details of that object. Spectacles manifest prismatic deviations that can distort the apparent locations of peripheral objects. Further, although individuals wearing myopic spectacles would be expected to have a larger visual field compared to the non-spectacle lens wearing condition, this increase

Table 3
Preference survey results.

Quality of Life Scenario	Prefers multifocal CL	Prefers PAL	No Preference	N/A
Watching television	5	3	12	0
Using your phone	6	7	5	2
Using your computer	9	7	4	0
Dining out	14	2	4	0
Driving	6	7	6	1
Playing sports	11	1	2	6
Working out	14	0	4	2
Reading a book/ magazine/newspaper	4	9	4	3
OVERALL Preference	14	4	2	0

is blunted by the spectacle frame and perhaps the edge of the lens. Functionally, at least the far peripheral visual field with spectacle lens wear will be reduced compared to the contact lens wearing condition. Lastly, aberrations in the periphery of spectacle lenses may also be expected to reduce visual discrimination of peripheral objects. In addition, there are distortions outside the near corridor in PAL lenses that could potentially affect performance on the functional tests in this study.

The shortcomings of spectacle lenses of all prescriptions are not difficult for patients to overcome, as long term wear generally allows patients to adapt to moving the head more to utilize the optical center of spectacle lenses. [20] This adaptation is even more critical when a patient is adapting to PAL spectacles. Despite the need for adaptation, a large number of presbyopic patients successfully wear PAL spectacles. Because this modality is widely used with success, it was valuable to use PAL wear as a comparator to the multifocal contact lens in this study. In all of the functional vision tests performed as part of this study, performance with multifocal contact lenses was similar to that of progressive addition spectacles. In the case of the peripheral localization and hand-eye coordination task (AcuVision 1000), performance with multifocal contact lenses was better numerically than with spectacles although only one of the comparisons between spectacles and contact lenses was statistically significant. In the case of the dynamic visual acuity measure, performance was also better numerically with multifocal contact lenses than with spectacles, although no statistical difference was seen. Given that statistical significance was not reached, it can be concluded that for this particular battery of functional vision tasks, performance was similar between PAL spectacles and multifocal contact lenses. Survey responses of various scenarios of daily life revealed a greater preference for multifocal contact lens wear for many daily tasks and, overall, participants preferred multifocal contact lenses over PAL spectacles. This is similar to the results of a study of early presbyopes in which participants favorably rated their satisfaction with vision when wearing multifocal contact lenses [21]. As with all unmasked studies, it is possible that bias may play a role in the preference responses.

One factor of note is that all participants were habitual PAL spectacle wearers who were then moved to multifocal contact lenses. This study was not designed to be a randomized comparison, but the results show that PAL wearers may be excellent candidates for multifocal contact lenses. The similar measured performance along with patient preference for MFCL wear may indicate that moving patients from PALs to MFCLs is an easy transition and may not be a realistic barrier to fitting these lenses after all. The results of this study should encourage more practitioners to recommend multifocal contact lenses to their presbyopic patients.

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