Randomized Crossover Trial Evaluating the Impact of Senofilcon A Photochromic Lens on Driving Performance

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SIGNIFICANCE: The first contact lens to incorporate a photochromic additive was cleared by the U.S. Food and Drug Administration last year. Because any ophthalmic lens that absorbs visible wavelengths will reduce retinal illuminance, it is important to understand the impact of this new photochromic contact lens on vision and both daytime and nighttime driving performance.

PURPOSE: The purpose of this study was to evaluate the effect of senofilcon A photochromic contact lens wear on vision and driving performance under real-world conditions by comparison with a nonphotochromic contact lens and plano photochromic spectacles.

METHODS: In this randomized four-visit bilateral crossover study, 24 licensed regular drivers and established wearers of soft contact lenses were enrolled. Subjects wore in random order each of three study lens types: the investigational photochromic soft contact lens (test), a nonphotochromic soft contact lens (control 1), and plano photochromic spectacle lenses (control 2). Driver performance was assessed on a closed-circuit driving track under challenging controlled conditions. The primary endpoint was overall driving performance score calculated as a composite *Z* score of six objective metrics.

RESULTS: All 24 subjects (mean age, 29.8 years) completed the study. For nighttime driving, the adjusted mean differences in *Z* score (95% confidence interval) between test and control 1 and between test and control 2 were 0.069 (−0.045 to +0.183) and 0.117 (0.003 to 0.231), respectively. For daytime driving, mean differences were 0.101 (−0.013 to +0.216) between test and control 1 and 0.044 (−0.070 to +0.158) between test and control 2. Results demonstrated noninferiority of the test lens relative to controls for nighttime and daytime driving performance using a noninferiority margin of −0.25 *Z* score. Noninferiority was also demonstrated on all logMAR and contrast threshold testing. No adverse events were reported during the study.

CONCLUSIONS: Study results revealed no evidence of concerns with either driving performance or vision while wearing photochromic contact lenses.

Optom Vis Sci 2020;97:15–23. doi:10.1097/OPX.0000000000001466

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In the United States, road crash fatality rates at night are approximately three times higher than those for daytime driving when adjusted for distances driven.[1] Plainis and colleagues[2] noted that, in the United Kingdom, severity rate (number of fatal collisions per 100 collisions) is doubled at night compared with daytime when averaged across different road types. Pedestrians face a significantly more pronounced risk of being involved in fatal nighttime vehicle crashes than vehicle occupants.[3] A study evaluating the influence of ambient light level on fatal crashes found that some cases involving pedestrians were up to seven times greater at night than during the day.[4] Analyses of crash statistics clearly indicate that reduced lighting and poor visibility are the primary factors associated with a disproportionately high risk of fatal collisions at night, rather than other factors that vary between day and night driving, such as driver fatigue and alcohol consumption.[4,5]

Modest visual impairment can significantly hamper driving performance under nighttime conditions.[6] However, there is limited published information regarding the visual problems experienced at night by adults with normal vision, particularly those during night driving. The pupil dilates in low illumination levels, leading to increased higher-order aberrations and a larger retinal blur circle.[7] Lower illumination reduces visual acuity and contrast sensitivity.[7,8] Night myopia, whereby eyes become nearsighted in dim illumination, also contributes to the reduced acuity experienced in mesopic and scotopic conditions.[9]

Because any ophthalmic lens that absorbs visible wavelengths will reduce retinal illuminance and could thereby influence driver vision and safety, it is important to understand the impact of photochromic vision-correcting lenses on night vision. Photochromic spectacle lenses are designed so that they are relatively clear when exposed to light in the visible spectrum but become darker when exposed to ultraviolet wavelengths and some high-energy visible wavelengths (e.g., violet-blue), arising primarily from sunlight.

Because car windshields have significant ultraviolet absorption,[10] the degree of photochromic lens darkening during daytime driving depends on whether the side windows (or sun roof) are open or closed and the level of sunlight, together with the activation spectrum of the photochromic lens. The intensity of the activating light also depends upon the season, elevation, latitude, cloud cover, ozone in the stratosphere, and time of day.[11]

In April 2018, the U.S. Food and Drug Administration cleared the first contact lens to incorporate a photochromic additive that automatically darkens the lens in the presence of ultraviolet and high-energy visible light, with the slightly darkened lens returning to its clearer state when exposed to typical indoor or dark lighting conditions.[12] The ACUVUE OASYS Contact Lens with Transitions Light Intelligent Technology (Johnson & Johnson Vision Care, Inc., Jacksonville, FL) is a first-in-class photochromic soft contact lens indicated for daily use to correct vision and to reduce the effect of bright light.[12]

The objective of this randomized bilateral crossover clinical study was to evaluate the impact of photochromic soft contact lens on vision and driving performance in both daytime and nighttime lighting under real-world conditions by comparison with a nonphotochromic soft contact lens and photochromic spectacles.

METHODS

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki and Good Clinical Practice Guidance. Enrolled subjects provided written informed consent before any study-related procedures. The study was approved by the Queensland University of Technology Ethics Committee. In addition, the clinical study protocol was reviewed by the U.S. Food and Drug Administration.

Study Design

This was a single-center, bilateral, nondispensing, randomized, three-treatment by three-period crossover clinical study with four visits. In the absence of a like comparator, two control lenses were selected: a nonphotochromic soft contact lens (ACUVUE OASYS; Johnson & Johnson Vision Care, Inc.) that matched the material (senofilcon A), powers, base curve, and diameter of the photochromic soft contact lens and plano gray Transitions XTRActive (Transitions Optical, Inc., Pinelass Park, FL) spectacles that resemble the photochromic transmission of the photochromic soft contact lens, worn with the nonphotochromic soft contact lens.

For driving performance evaluation, there were three levels of assignment: driving time (day and night), study lens wear (photochromic soft contact lens s, nonphotochromic soft contact lenses or photochromic spectacles), and driving route (A, B, and C). Within each driving time, subjects were randomly assigned to one of six lens wear sequences. To further reduce any potential selection bias, subjects were randomly assigned which driving route to use during each evaluation. The randomization was generated in a way that the number of subjects was balanced across each combination of driving time, study lens type, and driving route.

Every effort was made to mask both subject and examiner to lens wear type, to reduce potential bias wherever possible. To maintain consistent frame awareness across the three device conditions, the photochromic soft contact lens and nonphotochromic soft contact lens arms both involved contact lens wear with spectacle frames without spectacle lenses. However, if subjects perceived a change in light levels during contact lens wear, they could become aware that a photochromic product was being tested. Investigators involved in on-road driving data collection (examiners within the vehicle) were not involved in contact lens fitting and therefore were partially masked as to the identity of the study lens type being worn during driving evaluation. The brand name of the nonphotochromic control lens was also masked to the subject.

Participants

Habitual soft contact lens wearers of any race and ethnicity were required to have good general and ocular health with no contraindication to study participation. In addition, subjects were required to be aged 20 to 49 years at the time of screening; hold a current driver's license; drive at least once per week for more than a year; and wear distance-vision contact lenses in both eyes, best corrected to 20/20 (logMAR 0.00) or better in each eye, vertex-corrected (12 mm) spherical equivalent distance refraction in the range −1.00 to −6.00 D in each eye to encompass the majority of dispensed contact lens powers, and refractive cylinder of 1.00 D or less in each eye. All subjects were fit to a 0.00-D spherical over-refraction right eye and left eye.

A closed-road driving circuit environment was used to evaluate driving performance in good weather (i.e., no rain), with testing and data collection undertaken at the Mount Cotton Driver Training Centre in Queensland, Australia, a state government facility. The study was conducted over a 3-month period from September 17, 2017, to December 11, 2017.

Study Interventions

During each experimental condition (visual performance and driving assessments), each study lens type was worn bilaterally in a daily wear, daily disposable modality for 1- to 3-hour duration, depending on the scheduled timing and duration of testing. Study contact lenses were senofilcon A material; had a nominal base curve of 8.4 mm, 14.0 mm in diameter; and had −1.00 to −6.00 D lens powers. The investigational product contained a photochromic additive, developed by Johnson & Johnson Vision Care, Inc. in collaboration with Transitions Optical, Inc.

Outcome Measures and Assessments

Visual Performance (Visit 2)

Binocular logMAR visual acuity was tested under three conditions at 4 m: high luminance/high contrast, high luminance/low contrast, and low luminance/high contrast. High luminance was approximately 500 lux, and low luminance was approximately 1 lux and was verified with a photometer before each testing session. Multiple Early Treatment Diabetic Retinopathy Study logMAR charts were used to prevent memorization with high contrast defined as 90% and low contrast defined as 10%.

Binocular contrast sensitivity threshold was tested under two conditions. High-luminance Pelli-Robson contrast threshold was performed at 4 m with a luminance of approximately 500 lux. Low-luminance contrast threshold was performed using the Mesotest II instrument (Oculus, Inc., Arlington, WA) according to the manufacturer's instructions at a luminance approximately 1 lux. Mesotest II testing was performed with and without a glare source.

Driving Performance (Visits 3 and 4)

Driving performance evaluation consisted of six metrics that included the following:

Pedestrian recognition distance (m): The in-vehicle measurement system was used to determine the distance at which the subject (as a driver) first recognizes the presence of two pedestrians positioned at the side of the road, which was recorded by touching a pad next to the steering wheel. The pedestrians were wearing biomotion reflective tape and marched in place at randomized locations between trials. Four flashing light-emitting diodes and four retroreflective bollards were positioned around the circuit to reduce expectancy results.

Percent hazard avoidance: Participants were required to report and avoid hitting any of nine large, low-contrast gray foam "hazards" (dimensions, 220 × 80 × 15 cm) positioned orthogonally in the driving lane along the roadway; the locations of the hazards were randomized between trials.

Percentage of road signs correctly identified: Participants were instructed to report the identity of standard road signs (typically about 42 signs dependent on the route traveled) containing about 65 items of information as they drive around the circuit. This was recorded by the in-car examiners.

Sign recognition distance (m): The in-vehicle measurement system was used to measure the recognition distance for one specific road sign while the participant was driving. Longer distances are indicative of faster recognition. This was recorded by touching a pad next to the steering wheel.

Percentage of time inside the driving lane: The in-vehicle measurement system recorded time spent inside the driving lane.

Lap time (seconds): The amount of time required to start and finish one of three randomized driving routes was recorded. Each route was approximately the same distance, and course lap times lasted 9 to 10 minutes on average.

Individual overall driving performance scores were calculated as the mean of the *Z* scores of the six driving performance metrics.[13] The lap time was first inverted before the calculation of the composite scores because a shorter time is indicative of better performance. The scores were calculated for each combination of study lens (photochromic soft contact lenses, nonphotochromic soft contact lenses, or photochromic spectacles) and driving time (day, night).

Ancillary measurements included horizontal light conditions outside the car to confirm daytime and nighttime at a standard location on the track, horizontal light conditions at the plane of the eye inside the car, temperature inside the car, and pupil diameter while driving. Nighttime testing started at or after nautical twilight, which for this study was confirmed when the outside light was 10 lux or less. Daytime light needed to be 1000 lux or greater. Subjects familiarized themselves inside the car for approximately 15 minutes before starting and received verbal instructions during that time. All car windows were up. Subjects' evaluation of vision

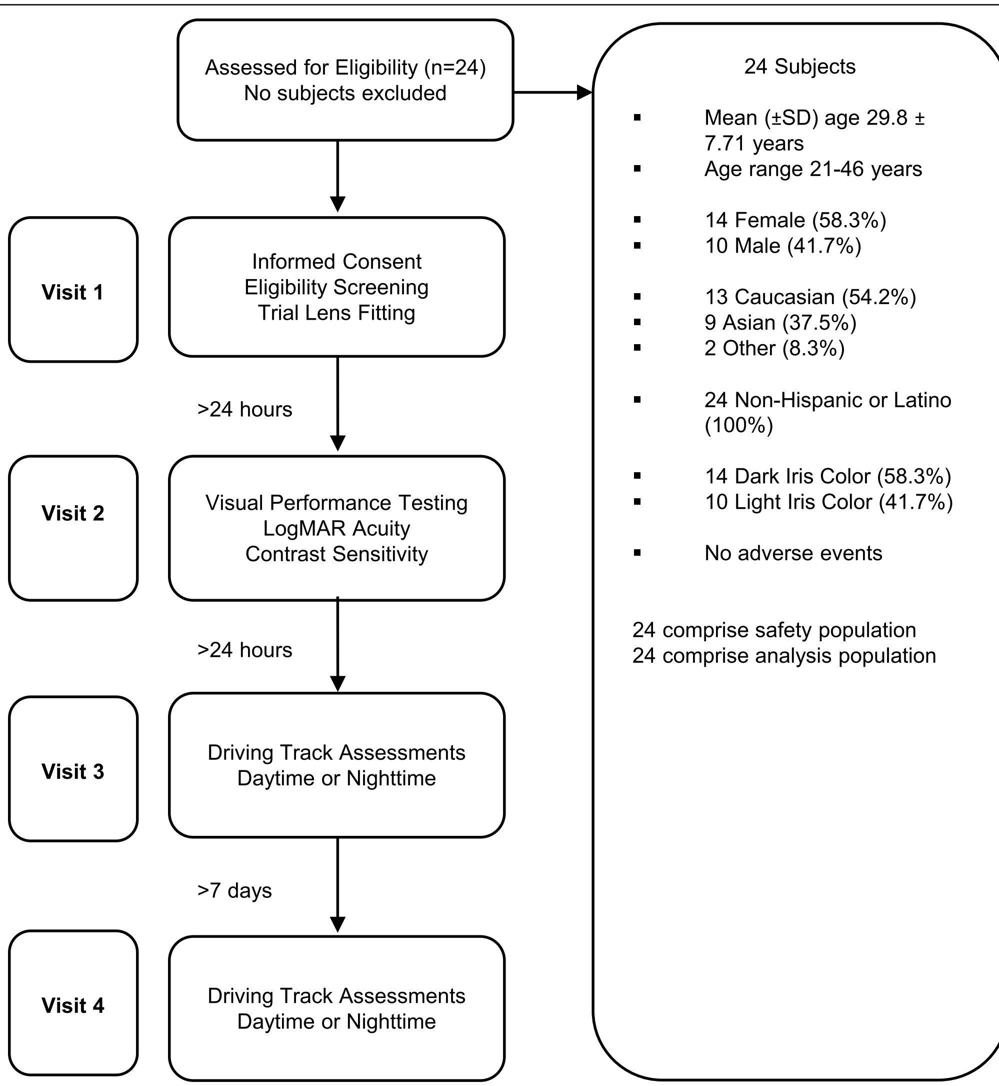

FIGURE 1. Study design, participant disposition, and baseline characteristics.

and driving performance using a survey questionnaire was also conducted at visits 3 and 4.

Sample Size and Noninferiority Margin Justifications

The study was designed and powered to demonstrate noninferiority of the photochromic soft contact lens relative to nonphotochromic soft contact lens with respect to night driving performance score. The sample size of 24 subjects was considered sufficiently large to test for noninferiority with a minimum power of 80% and a two-sided type I error of 0.05. The sample size was calculated assuming no difference between the photochromic and nonphotochromic soft contact lenses, a noninferiority margin of –0.25, a variance of 0.05, and an intraclass correlation between measurements from the same subject of 0.50. The sample size calculation was conducted using the PROC POWER Procedure in SAS/STAT 14.1 software (SAS Institute Inc., Cary, NC).

The noninferiority margin was determined based on a Bayesian meta-analysis comparing historical driving performance scores of patients with corrected vision (treated) and those with uncorrected vision (untreated). The posterior mean difference was estimated to be 0.579 with 95% credible interval of 0.249 to 0.917, and the lower bound of the 95% credible interval was used as the noninferiority margin (~–0.25). The noninferiority margin and sample size calculations were based on available historical data pooled from several published vision and driving studies published between 2002 and 2014 and from an investigator-initiated study sponsored by Johnson and Johnson Vision Care.[6,8,13–17]

Statistical Methods

Overall driving performance score was analyzed using a linear mixed model for repeated measures. The final (reduced) model included sequence of lens wear; study period; driving time (day and night); lens type; first-order carryover effect and the interaction between lens type by driving time as fixed effects; and subject and driving time nested within subject as random effects. The correlation between measurements from the same subject and driving time across lens wear periods was modeled using first-order ante-dependence covariance structure (ANTE(1)). Noninferiority between investigational photochromic soft contact lens and nonphotochromic soft contact lens was concluded if the lower limit of the 95% confidence interval of the least-square mean difference was above –0.25.

Secondary outcomes were analyzed either using a linear mixed model or a generalized linear mixed model with a β distribution and the logit as the link function depending on the response. For low-luminance contrast threshold without glare using the mesopic test device Mesotest II, a marginal model for binary clustered data was considered instead using generalized estimating equation methods, as the pre-planned model failed to converge. For distance binocular visual acuity, noninferiority was concluded if the upper limit of the 95% confidence interval of the least-square mean difference was below 0.10 logMAR. Additional analyses were conducted to evaluate daytime driving performance across all study lenses and nighttime driving performance of photochromic soft contact lens compared with photochromic spectacle wear. Adjustment for multiple pairwise comparisons between study lenses, in the additional analysis, was performed using Bonferroni's method at an α level of 0.0167 (0.05/3). All planned analyses were conducted with an overall type I error rate of 5%. All statistical tests were two-sided. All data summaries and statistical analyses were performed using Statistical Analysis System software version 9.4 (SAS Institute Inc.).

RESULTS

Participant Disposition and Baseline Characteristics

The disposition and baseline characteristics of participants are detailed in Fig. 1. All 24 enrolled subjects completed all required study visits and were included in the analysis and safety populations.

Overall Driving Performance Score

For the primary hypothesis, the least-square mean difference for overall night driving performance score between photochromic soft contact lens and nonphotochromic soft contact lens was 0.069 (95% confidence interval, –0.045 to +0.183). Because the lower limit of the 95% confidence interval of the least-square mean difference was above –0.25, it was concluded that the photochromic soft contact lens was noninferior to nonphotochromic soft contact lens for night driving performance, and the primary objective of the study was met. The analysis of daytime driving performance similarly demonstrated noninferiority of the photochromic soft contact lens to nonphotochromic soft contact lens. Overall driving score results for both night and day driving performances for all three lens wear conditions are summarized in Table 1. Fig. 2 illustrates the distribution of these overall driving scores.

TABLE 1. Summary analysis of overall driving score

Driving time	Comparison	LSM difference (StdErr)*	α	CI†	Margin	Noninferiority met?‡
Nighttime	Difference: photochromic SCL–nonphotochromic SCL	0.069 (0.0574)*	0.05	(–0.045 to +0.183)	–0.25	Yes
	Difference: photochromic SCL–photochromic spectacles	0.117 (0.0573)*	0.0167	(–0.023 to +0.257)	–0.25	Yes
Daytime	Difference: photochromic SCL–nonphotochromic SCL	0.101 (0.0574)*	0.0167	(–0.039 to +0.242)	–0.25	Yes
	Difference: photochromic SCL–photochromic spectacles	0.044 (0.0573)*	0.0167	(–0.096 to +0.184)	–0.25	Yes

*Least-square mean (standard error). †Confidence intervals were calculated as $(1 - \alpha) \times 100\%$. ‡Noninferiority was concluded if the lower limit of the $(1 - \alpha) \times 100\%$ confidence interval was above –0.25. CI = confidence interval; LSM = least-square mean; SCL = soft contact lens; StdErr = standard error.

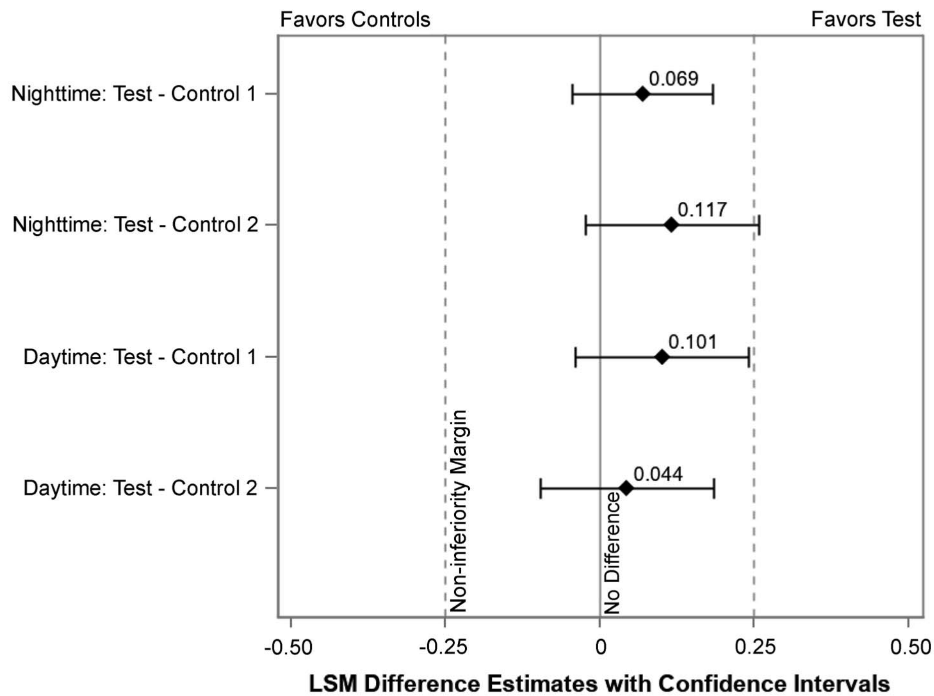

FIGURE 2. Least-square mean difference estimates and 95% confidence intervals with respect to overall driving scores. Test lens was senofilcon A soft contact lens (SCL) with photochromic additive worn with spectacle frames without lenses, control 1 was a marketed nonphotochromic senofilcon A SCL worn with spectacle frames without lenses, and control 2 was photochromic Transitions XTRActive-gray spectacles worn with a marketed clear senofilcon A contact lens. Overall driving performance score was calculated as a composite *Z* score of six objective metrics, and 24 subjects were included in the analysis population. Results demonstrate noninferiority of the photochromic SCL to nonphotochromic SCL and photochromic spectacles for both nighttime and daytime driving performance using a noninferiority margin of –0.25 *Z* score.

Visual Performance

The photochromic soft contact lens was noninferior to nonphotochromic soft contact lens using a noninferiority margin of 0.10 logMAR for low-luminance, high-contrast distance visual acuity (logMAR) because the upper limit of the 95% confidence interval was below 0.10 log. LogMAR acuity results are shown in Table 2.

Contrast Sensitivity Threshold

For high-luminance binocular contrast threshold (Pelli-Robson), there were no differences found between the photochromic soft contact lens and the control lenses. Table 3 lists all contrast threshold results. Analyses of low-luminance contrast threshold for the photochromic soft contact lens compared with photochromic spectacles failed to demonstrate no difference; the results

TABLE 2. Summary analysis of visual acuity

Lighting condition	Comparison	LSM estimate (StdErr)*	α	CI†	Margin	Noninferiority met?‡
Low luminance, high contrast	Difference: photochromic SCL–nonphotochromic SCL	–0.03 (0.008)*	0.05	(–0.04 to –0.01)	0.10	Yes
	Difference: photochromic SCL–photochromic spectacles	–0.05 (0.007)*	0.05	(–0.06 to –0.03)	0.10	Yes
High luminance, high contrast	Difference: photochromic SCL–nonphotochromic SCL	–0.01 (0.006)*	0.05	(–0.02 to 0.00)	0.10	Yes
	Difference: photochromic SCL–photochromic spectacles	–0.01 (0.006)*	0.05	(–0.02 to 0.00)	0.10	Yes
High luminance, low contrast	Difference: photochromic SCL–nonphotochromic SCL	–0.03 (0.010)*	0.05	(–0.05 to –0.01)	0.10	Yes
	Difference: photochromic SCL–photochromic spectacles	–0.04 (0.010)*	0.05	(–0.06 to –0.02)	0.10	Yes

*Least-square mean (standard error). †Confidence intervals were calculated as $(1 - \alpha) \times 100\%$. ‡Noninferiority was concluded if the upper limit of the $(1 - \alpha) \times 100\%$ confidence interval was less than 0.10 logMAR. CI = confidence interval; LSM = least-square mean; SCL = soft contact lens; StdErr = standard error.

TABLE 3. Summary analysis of contrast sensitivity

Visual performance test	Light condition	Comparison	Odds ratio	α	CI*	P	Statistically different?
Mesotest II	Low luminance, low contrast — with glare	Photochromic SCL over nonphotochromic SCL	2.26	0.05	(0.45–11.47)	.31	No
		Photochromic SCL over photochromic spectacles	5.00	0.05	(0.98–25.43)	.05	No
	Low luminance, low contrast — without glare	Photochromic SCL over nonphotochromic SCL	3.16	0.05	(0.44–22.60)	.25	No
		Photochromic SCL over photochromic spectacles	63.60	0.05	(4.29–943.23)	.002	Yes (favors test)
Pelli-Robson	High luminance	Photochromic SCL over nonphotochromic SCL	1.01	0.05	(0.94–1.09)	.69	No
		Photochromic SCL over photochromic spectacles	1.01	0.05	(0.94–1.09)	.72	No

*Confidence intervals were calculated as (1 – α) × 100%. CI = confidence interval; SCL = soft contact lens.

were in favor of the photochromic soft contact lens. The odds ratio was very high (63.3). The Mesotest II was also used to evaluate low-luminance contrast threshold with glare, with the same outcome as the no-glare condition. Interestingly, the photochromic soft contact lens separated itself more from the comparator control lenses as the target contrast decreased.

Driving Performance Outcome Measures

The results for the six individual driving metrics during daytime and nighttime driving are summarized in Tables 4 and 5, respectively. The test lens was either no different or better than the control lenses in all instances.

Ancillary Analyses

All subjects completed a subjective paper-administered vision and nighttime driving questionnaire that captured participant-reported experiences for each lens type. These patient-reported outcomes are presented in Table 6. "Strongly agree" and "agree" responses for a series of vision and driving items exceeded 91% for all items while wearing the photochromic soft contact lens,

TABLE 4. Summary analysis of daytime driving metrics

Driving metric	Parameter type	Comparison	Estimate†	α	CI‡	P	Statistically different?
Pedestrian recognition distance	LSM difference (StdErr)*	Photochromic SCL–nonphotochromic SCL	4.5 (5.11)*	0.0167	(–8.2 to +17.3)	>.99	No
		Photochromic SCL–photochromic spectacles	6.6 (5.10)*	0.0167	(–6.1 to +19.4)	.60	No
Sign recognition distance	LSM difference (StdErr)*	Photochromic SCL–nonphotochromic SCL	7.5 (3.44)*	0.0167	(–1.0 to +16.1)	.10	No
		Photochromic SCL–photochromic spectacles	0.1 (3.44)*	0.0167	(–8.4 to +8.7)	>.99	No
Percentage of signs correctly identified	Odds ratio	Photochromic SCL over nonphotochromic SCL	1.07	0.0167	(0.86–1.33)	>.99	No
		Photochromic SCL over photochromic spectacles	1.04	0.0167	(0.83–1.29)	>.99	No
Hazard avoidance	Odds ratio	Photochromic SCL over nonphotochromic SCL	0.47	0.0167	(0.07–3.41)	>.99	No
		Photochromic SCL over photochromic spectacles	0.93	0.0167	(0.17–4.96)	>.99	No
Lane keeping	Odds ratio	Photochromic SCL over nonphotochromic SCL	0.93	0.0125	(0.78–1.09)	.97	No
		Photochromic SCL over photochromic spectacles	1.01	0.0125	(0.85–1.19)	>.99	No
Lap time	LSM difference (StdErr)*	Photochromic SCL–nonphotochromic SCL	–2.1 (2.09)*	0.0125	(–7.6 to +3.3)	>.99	No
		Photochromic SCL–photochromic spectacles	–1.3 (2.09)*	0.0125	(–6.7 to +4.2)	>.99	No

*Least-square mean (standard error). †Estimate is based on the parameter type. ‡Confidence intervals were calculated as (1 – α) × 100%. CI = confidence interval; LSM = least-square mean; SCL = soft contact lens; StdErr = standard error.

TABLE 5. Summary analysis of nighttime driving metrics

Driving metric	Parameter type	Comparison	Estimate†	α	CI‡	P	Statistically different?
Pedestrian recognition distance	LSM difference (StdErr)*	Photochromic SCL–nonphotochromic SCL	4.7 (7.93)*	0.05	(–11.4 to +20.7)	.55	No
		Photochromic SCL–photochromic spectacles	8.1 (7.93)*	0.0167	(–11.7 to +27.9)	.93	No
Sign recognition distance	LSM difference (StdErr)*	Photochromic SCL–nonphotochromic SCL	17.8 (5.29)*	0.05	(7.07–28.54)	.001	Yes (favors test)
		Photochromic SCL–photochromic spectacles	17.8 (5.29)*	0.0167	(4.53–31.11)	.005	Yes (favors test)
Percentage of signs correctly identified	Odds ratio	Photochromic SCL over nonphotochromic SCL	0.98	0.05	(0.82–1.16)	.79	No
		Photochromic SCL over photochromic spectacles	0.96	0.0167	(0.78–1.18)	>.99	No
Hazard avoidance	Odds ratio	Photochromic SCL over nonphotochromic SCL	0.76	0.05	(0.33–1.74)	.51	No
		Photochromic SCL over photochromic spectacles	1.57	0.0167	(0.61–4.06)	.75	No
Lane keeping	Odds ratio	Photochromic SCL over nonphotochromic SCL	0.97	0.0125	(0.82–1.14)	>.99	No
		Photochromic SCL over photochromic spectacles	1.17	0.0125	(0.99–1.39)	.07	No
Lap time	LSM difference (StdErr)*	Photochromic SCL–nonphotochromic SCL	3.2 (4.32)*	0.0125	(–8.1 to +14.4)	>.99	No
		Photochromic SCL–photochromic spectacles	–8.6 (4.33)*	0.0125	(–19.8 to +2.7)	.21	No

*LSM (StdErr). †Estimate is based on the parameter type. ‡Confidence intervals were calculated as (1 − α) × 100%. CI = confidence interval; LSM = least-square mean; SCL = soft contact lens; StdErr = standard error.

compared with 83% for nonphotochromic soft contact lens and 79% for photochromic spectacles.

Safety Evaluation

No adverse events were reported during the study. No grade 3 or greater slit lamp findings were observed at any study visit, and no corneal infiltrates were reported. All eyes were classified as having an acceptable lens fit across study lenses.

DISCUSSION

The authors have described a randomized, single-center, crossover study that evaluated night and day driving performance and visual performance of 24 participants wearing senofilcon A contact lenses containing a photochromic additive in comparison with nonphotochromic soft contact lenses and photochromic spectacles. The primary hypothesis of noninferiority with respect to overall nighttime driving performance of the photochromic soft contact lens compared with nonphotochromic soft contact lens was met. All remaining analyses showed that the photochromic soft contact lens was either no different, noninferior, or superior to nonphotochromic soft contact lens or photochromic spectacles.

Visual Performance

Visual performance measurements captured a wide range of visual conditions typically encountered while driving. The visual performance results showed a 0.5 to 2.5 letter improvement in logMAR acuity depending on the condition, with low-luminance testing showing the greatest advantage with the test lens. This advantage is likely due to an improved optical quality of the test lens inherent in its manufacturing process, rather than the small residual tint under low luminance. Similarly, the analysis of contrast sensitivity showed movement in favor of the test lens under low-luminance conditions. The low-luminance low-contrast odds ratio of 63.3 for photochromic soft contact lens over photochromic spectacles was a product of circumstance. Subjects were able to correctly identify 99, 99, and 90% of the letters while wearing photochromic soft contact lenses, nonphotochromic soft contact lenses, and photochromic spectacles, respectively. Small differences translate into large odds ratios when the results are clustered toward one end of possible responses. The 9% difference between nonphotochromic soft contact lens and photochromic spectacles indicates an effect of wearing the photochromic spectacles during Mesotest II testing. It is unknown whether the back-illuminated Mesotest II test caused any reflections on the spectacle lens or whether the overall retinal luminance was decreased appreciably because of the polycarbonate lens material.

Driving Performance

The closed road conditions involved standardized assessments. All participants faced the same or similar circuit evaluation, and instrumented vehicles were used to provide objective data. Moreover, the driving track paradigm used has been successfully adopted in a multitude of different driving studies. The randomized crossover design further allows evaluation of investigational devices within

TABLE 6. Subjective questionnaire responses after night driving by lens type

Item	"Strongly agree" or "agree," n (%) Photochromic SCL	Nonphotochromic SCL	Photochromic spectacles
I was satisfied with the quality of my vision.	24 (100)	21 (87.5)	21 (87.5)
I was able to accurately judge distance.	23 (95.8)	21 (87.5)	21 (87.5)
I was able to clearly read car gauges (e.g., speedometer) without straining.	23 (95.8)	22 (91.7)	23 (95.8)
My vision easily adjusted when I looked from the road to the speedometer and back.	24 (100)	21 (87.5)	22 (91.7)
My vision easily adjusted when I looked in the rear-view mirror and then back to the road.	22 (91.7)	20 (83.3)	19 (79.2)
With these lenses, I felt confident to drive.	24 (100)	23 (95.8)	19 (79.2)
	"Strongly disagree" or "disagree," n (%)		
Item	**Photochromic SCL**	**Nonphotochromic SCL**	**Photochromic spectacles**
I sometimes could not read street signs as soon as I wanted to.	12 (50.0)	9 (37.5)	6 (25.0)
I sometimes wished my vision was better.	13 (54.2)	6 (25.0)	5 (20.8)
I noticed a glare effect in dim lighting.	16 (66.7)	12 (50.0)	11 (45.8)
I noticed a double image around distance objects.	23 (95.8)	23 (95.8)	20 (83.3)
	"No difficulty" or "a little difficulty," n (%)		
Item	**Photochromic SCL**	**Nonphotochromic SCL**	**Photochromic spectacles**
Seeing road hazards in time to avoid them	21 (87.5)	20 (83.3)	17 (70.8)
Keeping in your lane	24 (100)	23 (95.8)	21 (87.5)

SCL = soft contact lens.

the same subjects and thereby eliminates between-subject variability. It is considered highly unlikely that the sequence of lens wear or order of testing influenced the reported findings.

In the current study, the photochromic soft contact lens improved sign recognition distance by 19% during nighttime driving conditions compared with nonphotochromic soft contact lens and photochromic spectacles. The metric of sign recognition distance has been used in previously published studies of vision and nighttime driving performance,[8,18] with comparable values with those recorded in our study reported for both younger and presbyopic participants. A relative increase in nighttime sign recognition distance is a positive finding, allowing a driver more time for navigational decisions and necessary avoidance maneuver. Longer visual reaction times imply significantly increased stopping distances.[2] The reason for the increased sign recognition distance during night driving is unknown. It is plausible, however, that the mild improvement observed in low-luminance logMAR acuity and contrast sensitivity contributed to the finding. An improvement in contrast sensitivity is known to increase recognition distance while driving.[19]

During daytime driving, subjects wearing the photochromic soft contact lens were able to recognize a sign approximately 7.5 m further than that observed with the nonphotochromic soft contact lens but showed no difference in sign recognition distance compared with photochromic spectacles. Sign recognition distance during the day may therefore have been influenced by a slight activation of the photochromic lenses inside the car. Automobile glass is not impermeable to ultraviolet radiation, and no international or industry standards currently exist with respect to radiation transmission. Automakers specify glass with a given Sun Protection Factor to protect drivers and car fabric and to cool down the interior. The amount of ultraviolet protection can vary between cars and even between windows within a vehicle. In terms of ultraviolet transmittance, an example windshield of a car transmits 2 to 3% and side windows transmit 33 to 48%.[20]

Participants in the current study comprised young adults and habitual contact lens wearers, and applicability of the findings to a broader heterogeneous adult population may therefore be limited. In general, older adults tend to be more sensitive to bright light and changing light conditions, and it is not known whether driving safety and performance outcomes would differ substantially in a sample that included older drivers. In a study of nighttime driving among older drivers (mean age, 71.8 years), pedestrian detection decreased by 38% in the presence of intermittent glare.[21] Another study found that older drivers recognized pedestrians at approximately half the distance of younger drivers.[22] Future studies might examine nighttime and daytime driving performance in a sample that includes older adults, as well as naive, unadapted contact lens wearers.

Attenuation of sunlight via photochromic darkening may be particularly beneficial in reducing discomfort experienced under bright light conditions. In a randomized crossover study involving healthy adults with a mean ± SD age of 45.6 ± 13.2 years, photochromic spectacles were found to significantly increase the ability to cope with intense broadband and shortwave lighting conditions, improving glare disability and photostress recovery times.[23] Similar improvements in visual function were recently reported with the senofilcon A photochromic contact lens compared with a nonphotochromic contralateral control (Hammond B, et al. OVS 2018;95:E-abstract 180018).

In conclusion, clinical data did not reveal any evidence of impaired or diminished driving and vision performance among participants wearing the senofilcon A–based contact lens with photochromic additive assessed during nighttime and daytime driving sessions; that is, outcomes were no worse than those observed for reference control groups. Senofilcon A lenses containing a photochromic additive may therefore be considered substantially equivalent to clear ACUVUE OASYS soft contact lenses but with the benefit of light attenuation. The option of a contact lens with effective light-adaptive photochromic technology may help address an important unmet need, providing wearers with the combined benefit of vision correction and a dynamic photochromic filter to help continuously balance the amount of light entering the eye, including filtering high-energy visible light and blocking ultraviolet rays.

ARTICLE INFORMATION

Submitted: April 12, 2019

Accepted: October 14, 2019

Funding/Support: Johnson and Johnson Vision Care.

Conflict of Interest Disclosure: The authors listed report a financial conflict of interest (JRB, YT, JC). The sponsor provided financial and material support but had no role in study conduct, data acquisition, and interpretation.

Study Registration Information: ClinicalTrials.gov Identifier: NCT03330275, registered October 17, 2017. Clinical study protocol can be accessed via the ClinicalTrials.gov database.

Author Contributions and Acknowledgments: Conceptualization: JRB, YT; Formal Analysis: YT, JC; Project Administration: JRB; Resources: JRB; Supervision: JRB; Writing – Original Draft: JRB; Writing – Review & Editing: JRB, YT, JC.

The authors are grateful to Michael Collins, Joanne Wood, Hamish McNeill, Alexander Black, and Stephen Vincent of Queensland University of Technology, School of Optometry and Vision Science, for their contribution as study investigators and examiners. Medical writing support was provided by Rod McNeil Associates.

Presented at the American Academy of Optometry 2018 Annual Meeting, November 2018, San Antonio, TX.

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