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Comparative study of visual performance with tinted soft contact lenses vs. clear soft contact lenses and tinted spectacles under bright outdoor conditions; Phase II

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Background: Research has clearly shown the advantages of performance tinted CL wear with regard to various measures of objective and subjective responses under various lighting conditions. The current study expanded upon these results.

Methods: Subjects were 38 non-presbyopic emmetropes or slight ametropes with distance Snellen acuity of 20/20 or better while wearing -0.50 D spherical Acuvue 2 CLs. Measurements of 6m tachistoscopic stereoacuity and variable distance timed and tachistoscopic texture gradient recognition were obtained with subjects wearing clear CLs, tinted spectacles, and SportSight CLs. Lens modality and test sequence were randomized.

Results: Stereoacuity results showed no statistically significant difference in stereolocalization when subjects were wearing clear CLs, SportSight CLs, or tinted spectacles. Texture gradient results using timed and tachistoscopic presentations demonstrated that it was more difficult for subjects to correctly identify the seam orientation at farther distances than nearer distances, and that subjects took more time to try to identify distant target orientation versus near target orientation. In addition, tachistoscopic presentations were not found to be significant with regard to correctness of responses at any distance with any lens modality. Subjective data indicated more physical comfort with either CL modality instead of tinted spectacles. SportSight CLs were also found to be the most visually comfortable modality, followed by tinted spectacles and then clear CLs. Furthermore, a general trend indicated that subjects felt they were able to perform best while wearing the SportSight CLs. This may partially be due to the fact that subjects noted fewer perceptions of stray light with SportSight CLs than with the other modalities. Likewise, subjects reported an equal number of perceived reflections while wearing SportSight CLs and clear CLs but significantly more while wearing tinted spectacles.

Conclusion: Objective findings demonstrated that SportSight CLs provide similar performance with regard to distance depth perception and texture gradient recognition to tinted spectacles. Subjective data indicate that visual comfort of the SportSight CLs was superior to tinted spectacles and clear CLs. Additionally, a trend in subjective data demonstrated that the subjects perceived improved performance on the tests while wearing the SportSight CLs.

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COMPARATIVE STUDY OF VISUAL PERFORMANCE WITH TINTED SOFT CONTACT LENSES VS. CLEAR SOFT CONTACT LENSES AND TINTED SPECTACLES UNDER BRIGHT OUTDOOR CONDITIONS; PHASE II

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(Note: The content of this thesis is on file with the Advisors)

Signature Page

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Randy C. Oliver: Randy grew up in Barnwell, Alberta. He attended the University of Alberta from 1995-1999 and received a Bachelor of Sciences degree in Biological Sciences. Following graduation from PUCO, Randy will work for the USAF for three years and then open a private practice.

Abstract

Background: Research has clearly shown the advantages of performance tinted CL wear with regard to various measures of objective and subjective responses under various lighting conditions. The current study expanded upon these results.
Methods: Subjects were **38** non-presbyopic emmetropes or slight ametropes with distance Snellen acuity of 20/20 or better while wearing *-0.50* D spherical Acuvue *2* CLs. Measurements of 6m tachistoscopic stereoacuity and variable distance timed and tachistoscopic texture gradient recognition were obtained with subjects wearing clear CLs, tinted spectacles, and SportSight CLs. Lens modality and test sequence were randomized.
Results: Stereoacuity results showed no statistically significant difference in stereolocalization when subjects were wearing clear CLs, SportSight CLs, or tinted spectacles. Texture gradient results using timed and tachistoscopic presentations demonstrated that it was more difficult for subjects to correctly identify the seam orientation at farther distances than nearer distances, and that subjects took more time to try to identify distant target orientation versus near target orientation. In addition, tachistoscopic presentations were not found to be significant with regard to correctness of responses at any distance with any lens modality. Subjective data indicated more physical comfort with either CL modality instead of tinted spectacles. SportSight CLs were also found to be the most visually comfortable modality, followed by tinted spectacles and then clear CLs. Furthermore, a general trend indicated that subjects felt they were able to perform best while wearing the SportSight CLs. This may partially be due to the fact that subjects noted fewer perceptions of stray light with SportSight CLs than with the other modalities. Likewise, subjects reported an equal number of perceived reflections while wearing SportSight CLs and clear CLs but significantly more while wearing tinted spectacles.
Conclusion: Objective findings demonstrated that SportSight CLs provide similar performance with regard to distance depth perception and texture gradient recognition to tinted spectacles. Subjective data indicate that visual comfort of the SportSight CLs was superior to tinted spectacles and clear CLs. Additionally, a trend in subjective data demonstrated that the subjects perceived improved performance on the tests while wearing the SportSight CLs.
Key Words: SportSight™, performance enhancement, contact lenses, colored lenses, stereoacuity, texture gradient recognition

Introduction

Sunglasses have enjoyed immense popularity for uses such as sports, recreational activities, driving and occupational tasks since their inception. Tinted sunglasses enhance visual performance in bright conditions by reducing undesirable glare and illumination (Chung and Pease, 1999; Hovis et al, 1989). In addition, sunglasses can protect the eye from potentially harmful portions of the electromagnetic spectrum relative to premature aging of the eye.[1,2,3,4]

Protective coatings and tints designed to filter UV light are commonplace in the spectacle market. UV radiation between the wavelengths of 200 and 380 nm has been shown to cause damage to the cornea, uvea, lens and retina.' In addition to the threat posed by W radiation, the potential eye health risk related to long-term exposure to the short wavelength end of the visual spectrum has been cause for increasing concern. The so-called "Blue Light Hazard is speculated to damage the cones of the macular region of the retina. Although the research regarding the Blue Light Hazard is not conclusive, there is growing consensus amongst vision care experts that filtration of the high energy portion of the Visible Light Spectrum (VIS) is in the best interest of the general public[2]. The negative effects of chronic exposure to the Blue Light Hazard produced by man-made sources have been recognized.[4,5]

Despite the number of benefits provided by the wear of sunglasses, certain disadvantages may be associated with their use. Such disadvantages include peripheral lens distortion, lens edge image doubling or scotomas, restricted or reduced field of view, peripheral light leakage, lens surface reflections, frame discomfort, fogging or scratching of the lens, and sweat, precipitation or debris build-up on the surfaces of the lens.[6] Other disadvantages include cleaning difficulty, transport issues, storage problems, frame fit and cosmetic appearance.[6] Due to these limitations, sunglasses are often not conducive to certain sports and recreational activities, such as football, soccer and many water sports.

Due to the physical demands of their respective sports, the refractive errors of athletes are more frequently compensated for with contact lenses than with spectacles. In fact, polled certified athletic trainers reported that 95% of NCAA Division IA, 65% of Division III and 89% of professional athletes that require vision correction choose to wear contact lenses. This is also the preferred choice of optometrists, as 97% of those polled prefer contact lenses to spectacles for athletes.[7] Nearly two-thirds (62%) of polled optometrists agree that there are inherent disadvantages with current non-prescription sunglasses.[7]

In many instances, athletes may benefit from a tint that enhances comfort and visual performance, however, they may not and do not wear them due to problems with fit, stability or safety issues associated with spectacle wear. Consequently, it is not surprising that 93% of optometrists, 63% of NCAA Division IA and 86% of Division 111 certified athletic trainers and 94% of professional trainers are interested in their athletes using performance tinted contact lenses for competition. In fact, 100% of professional baseball trainers showed interest in using performance tinted contact lenses for their athletes.[7] Additionally, recent research has demonstrated that gray tinted soft contact lenses provide equal or better visual advantages than transmittance-matched spectacles, and offer superior subjective comfort.[8,9] Former St. Louis Cardinal and home run champion, Mark McGwire, has gone on record discussing the advantages of wearing yellow tinted contact lenses, citing increased peripheral vision, glare reduction, as well as clearer and crisper vision as benefits to wearing tinted soft contact lenses (SCL).[10]

SportSight CL technology eliminates virtually all of the optical deficiencies and physical limitations associated with the use of sunglasses. Through the use of a customized tint the SportSight CL is designed to reduce glare and brightness throughout the complete visual field in order to enhance comfort, and to improve contrast recognition by filtering short-wavelength light in the visible spectrum and manipulating transmission of wavelengths above 500nm.[8] By moving the tint from the spectacle plane to the corneal plane, SportSight CL's combine the numerous benefits of tinted sunglasses, while also providing the advantages inherent with contact lens wear.

Currently, the American National Standards Institute (ANSI) has not yet established specific guidelines for tinted contact lenses. Scientific research comparing the visual performance of tinted contact lenses to tinted spectacles is limited. Coffey, et al (1993) compared sports oriented visual performance between spectacle and contact lens wearers.[9] The authors reported that in comparative testing with the Pacific Visual Performance Profile Test Battery (PSVPP), the "Subjects found clear contact lenses to be superior to clear spectacles in issues related to glare, peripheral vision and likelihood of displacement with strenuous activity. Patient perceptions indicated that there may be important psychological advantages to wearing contact lenses for leisure and/or sporting activities."[9] Geis,et al (1999) found differences between the transmission characteristics of SCLs and tinted spectacles and determined the ideal visible light transmission levels for SportSight lenses.[11,12]

Since that time, numerous research projects involving SportSight lenses have been conducted to investigate their effects on visual performance. SportSight wearers were found to have significantly larger visual fields in all primary meridians as well as larger binocular fields than tinted spectacle wearers. Additionally, the "Physiological Photochromic Effect" of SportSight lenses was identified. This effect was shown to provide SportSight wearers with certain advantages in the various lighting environments over clear contact lenses and tinted spectacles.[12] Furthermore, SportSight wearers were found to exhibit increased low-contrast visual acuity with less measured facial tension (stress) in bright outdoor conditions than clear contact lens and tinted spectacle wearers.[12] In addition to the aforementioned objectively measured advantages, subjective responses demonstrated that SportSight lenses afforded significantly better subjective visual performance on numerous visual tasks,[6,12] reduced image degradation and superior subjective comfort in bright outdoor conditions.[6,12,13]

The current study is a continuation of previous research conducted at Pacific University where investigators compared effects of tinted CLs to clear CLs and tinted sunglasses on various measures of visual performance. The prior outdoor study of SportSight technology examined the differences between these modalities for high and low contrast 4m visual acuity, 6m stereoacuity and texture gradient recognition at various distances. SportSight tinted CLs were found to be superior in low contrast VA in bright light environments. Subjects also reported improved visual comfort with the SportSight tinted Cls. No differences were found in stereoacuity and texture gradient recognition at the distances tested. It is believed that the similar performance on stereoacuity and texture gradient tests through clear and tinted CL in the previous study was due to shorter test distances and longer time of recognition. In the current study, the same tinted and clear CLs were used for testing. However, the current study employed longer distances for texture gradient recognition testing, and tachistoscopic conditions were used for both stereoacuity and texture gradient recognition testing. By testing at longer distances and introducing a tachistoscopic element to the testing it is believed that the current study will better replicate the dynamic conditions encountered in sports.

The purpose of this study is to investigate whether the tinted SportSight CL's perform equal to or better than equivalent tinted spectacles and/or clear CL's in objective and subjective measures of depth perception and texture gradient recognition during tachistoscopic presentation.

Methods

Subjects:

An Institutional Review Board proposal for the use of human subjects in research was submitted and approved. Subjects were non-presbyopic emmetropes or slight ametropes selected from the Pacific University College of Optometry student body and surrounding community. All subjects were required to sign an Informed Consent Form at the time of the initial screening. Subjects were compensated fifty dollars for their participation in the project.

The following initial screening criteria were to be met by all subjects:

- Emmetropia or slight ametropia (+/- 0.50 D sph. and/or +/- 0.50 D cyl)
- 6m Static Snellen Visual Acuity of 20120 or better OD, OS, OU while wearing –0.50 D spherical Acuvue 2 CLs
- No history of ocular health disorders
- Stereopsis greater than or equal to 120" at 40 cm.

The testing order was randomized for thirty eight subjects, 12 females and 26 males, who passed the screening criteria. Subjects ranged in age from 22 to 32 years, with a mean age of 25.4.

Materials:

SportSight (TCL) and Clear Soft Contact Lenses (CLs): Paragon Vision Sciences supplied tinted and clear –0.50D spherical Vistakon Acuvue 2 lenses with a

14.0 mm diameter and 8.3 mm base curve for each subject. It should be noted that the "clear" lenses contained the standard Acuvue 2 Visitint. The SportSight lenses were custom tinted by Paragon Vision Sciences with a gray tint with 20% visible light transmission (VLT). Clear lenses had 89% VLT.

Tinted Spectacles: Eye wear of commercially available tinted, metal framed spectacles were used with an A measurement of 58mm, a B measurement of 38mm, a DBL of 15mm, and a temple length of 145 mm. The lenses were made of CR-39 plastic with a 6.0 Diopter base curve and plano power. The tint was a 20% transmission gray tint matched approximately to the VLT of the SportSight CLs.

Occlusion Goggles: NoIR goggles were used between target presentations for both the stereolocalization and texture gradient recognition tests. Two pair were used with different VLTs depending which lens modality was being tested. Though the subjects were directed to avert their eyes from the targets between presentations, the goggles were used to occlude the fine details of the tests in the event that they should try to view them. The NoIR goggles used in this project are commercially available 4% VLT and 1% VLT. The 4% VLT goggles were used when subjects were wearing the tinted spectacles and contact lenses while the 1% VLT goggles were used when subjects wore the clear CLs. This ensured a constant total VLT of less than 1% between target presentations for all three lens modalities.

Procedure: All testing was performed between the hours of 10 a.m. and 3 p.m. over the course of four weeks in April and May of 2000. This was done in an attempt to keep the angle of incident overhead sunlight at approximately 40 degrees above the horizon throughout the testing. As each subject completed a round of testing with a particular lens modality, they were asked to complete a questionnaire regarding their experience. Questions addressed physical and visual comfort, perceived performance and the presence of stray light, reflections and image ghosting. All texture gradient and stereopsis testing was randomized by modality and testing sequence.

Texture Gradient Recognition: Texture Gradient Recognition was tested using white baseballs with white seams placed at four different distances (11, 14, 17, 20m). Subjects were asked to identify the direction of the opening of each seam (see Figure 1) for three balls at each distance. The balls were screwed to 1” diameter, white PVC poles with the seams facing the subjects at each distance. The orientation of the seams on each pole was randomized at the beginning of each testing session, with neither the subjects nor the testing researcher having knowledge of the true orientations. White cotton sheets were used to cover the ground between the subjects and all the poles as well as to form a back-drop for the testing area. This was done to increase overall luminance of the testing area.

Two different test conditions were used and the order of the three test modalities was randomized for each subject. For the first test, identified as "tachistoscopic", subjects were required to identify seam orientation within a two second viewing period (i.e.; subjects were allowed to view all three balls at a given distance for two seconds and required to identify seam orientation immediately following the viewing period). For the second test, identified as "timed", subjects were allowed as much time as they desired to identify the seam orientation of all three balls at each distance. This response time was recorded to see if there was a correlation between subject response time and accuracy. For both tests, subjects were required to give a response for each of the balls, whether it was a guess or not, and their first response was the only response recorded. Each of these test presentations was further randomized by requiring subjects to sequentially identify seam orientations on poles either from the closest pole to the farthest pole or vice-versa. All of these tests were performed while wearing clear CLs, SportSight CLs and tinted spectacles, the order of which was also randomized (See Table 1). See Appendix A for Texture Gradient Recognition Protocol.

Howard Dolman: The Howard Dolman test is designed to measure stereoacuity at distance. It utilizes a box-like apparatus that houses two vertically oriented rods that are viewed through a window by the subject. One of the rods stays in a fixed position and the other is moved toward or away from the subject by the examiner. The subject is then asked to identify when the moveable rod is located the same distance from him/her as the fixed rod. The distance between the rods is then measured and analyzed to determine the subject's stereoacuity level. The front of the device used in this project was covered in white tag-board and white cotton sheets were draped behind the device and placed on the ground between the apparatus and the subject. This was done to increase reflection of sunlight during testing. As with the Texture Gradient Recognition, all Howard Dolman presentations were randomized for each subject (See Table 1). That is, target presentations proceeded from far (behind the stationary dowel) to near or vice-versa depending on the subject. Subjects stood six meters from the front of the apparatus and were required to give a response at the end of each presentation period. Each presentation period lasted two seconds. Each subject underwent testing using the Howard Dolman under all three lens conditions. See Appendix B for Howard Dolman Protocol.

Table 1. Test sequence for each subject. TG-F = Texture Gradient with Flash (tachistoscopic) presentation; TG-T = Texture Gradient with Timed presentation; HD = Howard Dolman; N/F = Presentations begin at near and proceed to far; F/N = Presentations begin at far and proceed to near.

	Test Sequence		
Subject	1	2	3
1, 9, 17, 25, 33	TG-F (N/F)	TG-T (N/F)	HD (N/F)
2, 10, 18, 26, 34	TG-F (F/N)	TG-T (F/N)	HD (N/F)
3, 11, 19, 27, 35	TG-F (N/F)	TG-T (N/F)	HD (F/N)
4, 12, 20, 28, 36	TG-F (F/N)	TG-T (F/N)	HD (F/N)
5, 13, 21, 29, 37	HD (N/F)	TG-F (N/F)	TG-T (N/F)
6, 14, 22, 30, 38	HD (N/F)	TG-F (F/N)	TG-T (F/N)
7, 15, 23, 31	HD (F/N)	TG-F (N/F)	TG-T (N/F)
8, 16, 24, 32	HD (F/N)	TG-F (F/N)	TG-T (F/N)

Table 2. Lens modality sequence for each subject. TCL = SportSight tinted contact lens; CCL = Acuvue 2 clear contact lens; TSP = Tinted spectacle lens.

	Lens Modality Sequence		
Subject	1	2	3
1,5,9,13,17,21,25,29,33,37	CCL	TSP	TCL
2,6,10,14,18,22,26,30,34,38	TSP	CCL	TCL
3,7,11,15,19,23,27,31,35	TCL	CCL	TSP
4,8,12,16,20,24,28,32,36	TCL	TSP	CCL

Results

Objective Data:

Clear CLs were used as controls to ensure that any possible differences or variations in performance with SportSight CLs were due to the difference in lens modality (i.e., CL versus spectacle), not specific contact lens modality. More specifically, the clear CLs as well as the lenses with the SportSight Tint, were Acuvue 2 lenses to eliminate potential CL induced variability.

Stereoacuity data were analyzed using repeated-measures analysis of variance (ANOVA) tests. Mean stereoacuity (and corresponding standard deviation) results in arc seconds are as follows: Clear CLs: -26.09 (8.24), SportSight CLs: -26.78 (9.14) and Tinted Spectacles: -25.74 (9.07). Negative values indicate that the moveable rod was localized behind the plane of reference. The analysis of variance demonstrated no significant difference in stereoacuity between the three test conditions $F(2, 74) = 0.26$, $p = 0.775$. The range of the responses in arc seconds (and corresponding s.d.s) are as follows: Clear CLs: 14.36 (6.39), SportSight CLs: 11.78 (5.81) and Tinted Spectacles: 13.23 (7.29). ANOVA shows that there is no significant difference in the ranges of responses between the three modalities $F(2,74) = 2.73$, $p – 0.095$. That is, it was equally difficult for the subject to properly stereolocalize the target under all three lens conditions.

In the texture gradient portion of the project, both timed and tachistoscopic presentations were performed. Tachistoscopic data will be addressed first. Responses were analyzed to compare the total number of correct versus incorrect responses per ball at a given distance for each modality. The total number of responses at each distance was 114 (38 subjects X 3 balls per distance). (See table 3)

Table 3. Subject responses to Texture Gradient recognition at different test distances with Flash presentation. TCL = SportSight tinted contact lens; CCL = Acuvue 2 clear contact lens; TSP = Tinted spectacle lens.

Lens Modality	TCL				CCL				TSP			
Test Distance, m	11	14	17	20	11	14	17	20	11	14	17	20
Total Correct Responses	66	57	40	37	73	52	40	36	71	56	34	35
Total Incorrect Responses	48	57	74	77	41	62	74	78	43	58	80	79

X^2 analysis demonstrates that testing distance had a significant effect on the number of correct responses. That is, it was more difficult for the subjects as a group to correctly identify the seam orientation at farther distances than nearer distances [Omnibus (Complete Independence): $X^2(17) = 84.2$, $p = 0.0001$ Main Effect of Distance: $X^2(3) = 81.8$, $p = 0.000$. Additionally, lens modality was found not to be significant with regard to the correctness of responses at any distance [Main Effect of Lens: $X^2(2) = 0.12$, $p = 0.9391$. Furthermore, the interaction effect of distance and lens modality was found to be significant [Interaction Effect of Distance & Lens: $X^2(11) = 84.2$, $p = 0.0001$.

Similar analysis was also performed on the timed portion of texture gradient recognition data. Responses were analyzed to compare the total number of correct versus incorrect responses per ball at a given distance for each modality. The total number of responses at each distance was 114 (38 subjects X 3 balls per distance). (See table 4)

Table 4. Subject responses to Texture Gradient recognition at different test distances with Timed presentation. TCL = SportSight tinted contact lens; CCL = Acuvue 2 clear contact lens; TSP = Tinted spectacle lens.

Lens Modality	TCL				CCL				TSP			
Test Distance, m	11	14	17	20	11	14	17	20	11	14	17	20
Total Correct Responses	83	56	58	38	81	65	45	46	85	63	48	39
Total Incorrect Responses	31	58	56	76	33	49	69	68	29	51	66	75

X^2 analysis demonstrates that testing distance had a significant effect on the number of correct responses. That is, it was more difficult for the subjects to correctly identify the seam orientation at farther distances than nearer distances [Omnibus (Complete Independence): $X^2(17) = 109.8$, $p = 0.0001$ Main Effect of Distance: $X^2(3) = 103.3$, $p = 0.000$. Additionally, lens modality was found not to be significant with regard to the correctness of responses at any distance [Main Effect of Lens: $X^2(2) = 0.02$, $p = 0.9881$. Furthermore, the interaction effect of distance and lens modality was found to be significant [Interaction Effect of Distance & Lens: $X^2(11) = 109.8$, $p = 0.0001$.

Time of response data was also analyzed to determine whether or not the lens modality had a significant effect on the amount of time used by subjects to identify seam orientation. (See table 5)

Table 5. Mean response times to Texture Gradient recognition at different test distances with Timed presentation. TCL = SportSight tinted contact lens; CCL = Acuvue 2 clear contact lens; TSP = Tinted spectacle lens.

Lens Modality	TCL				CCL				TSP			
Test Distance, m	11	14	17	20	11	14	17	20	11	14	17	20
mean, sec	5.84	5.45	5.05	5.79	5.98	4.73	5.75	5.52	4.74	5.18	5.29	5.01
standard deviation	2.38	1.34	1.45	1.98	2.22	1.30	2.50	1.78	1.92	2.27	1.92	1.61

Analysis of variance demonstrated that testing distance had a statistically significant effect on the amount of time used by subjects to identify seam orientation $F(3,111) = 3.05$, $p = 0.031$. Typically, subjects took longer to identify seam orientation at greater target distances than at near target distances. The main effect of lens modality was also found to be significant with regard to the amount of time required $F(2,74) = 5.81$, $p = 0.005$. On average, subjects required about the same amount of time to make responses using clear CLs and SportSight CLs (5.50 sec versus 5.53 sec, respectively), and slightly less time using tinted spectacles (5.06 sec). Finally, interaction effect of the testing distance and lens modality was also found to be significant $F(6,222) = 11.35$, $p = 0.000$.

Subjective Data:

Subjective responses were recorded to determine if there was a significant difference in physical and visual comfort and perceived performance between the various lens modalities. (See table 6)

Table 6. Number of scaled score responses to subjective questions regarding Physical Comfort, Visual Comfort, and overall Visual Performance with each lens modality (see Appendix for exact wording of questions). TCL = SportSight tinted contact lens; CCL = Acuvue 2 clear contact lens; TSP = Tinted spectacle lens; 1 = Poor, 5 = Excellent.

	Physical Comfort			Visual Comfort			Visual Performance		
Score	TCL	CCL	TSP	TCL	CCL	TSP	TCL	CCL	TSP
1	0	0	0	1	4	0	2	3	2
2	3	1	1	1	8	1	4	7	5
3	4	6	7	4	9	7	15	18	16
4	16	16	19	17	12	18	12	9	13
5	15	15	10	15	5	11	5	1	1
Weighted Average	4.13	4.18	4.03	4.16	3.16	4.05	3.37	2.95	3.16

X^2 analysis demonstrated that there was not a significant difference in physical comfort between lens modalities $X^2(6) = 4.02$, $p = 0.674$. A general trend suggested that both CL modalities were more comfortable than the tinted spectacles (TCL = CCL > TSP) but the difference was not significant. X^2 analysis found that there was a significant difference in the visual comfort noted by the subjects between the three lens modalities X^2 (8) = 23.00, p = 0.003. More specifically, SportSight CLs were found to be the most visually comfortable followed by tinted spectacles and then clear CLs (TCL > TSP > CCL). X^2 analysis further demonstrated that there was no significant difference in perceived performance between the modalities while performing the tests X^2 (8) = 6.73, p = 0.566. While not significant, the general trend in subject responses was that they perceived the best performance while wearing SportSight CLs, followed by tinted spectacles and then clear CLs (TCL>TSP>CCL).

Subjective data was also collected to determine whether or not subjects noticed stray light, reflections and ghosting of images while wearing the various lens modalities. (See table 7)

Table 7. Number of subjects reporting presence of Stray Light, Reflections, and Ghosting with each lens modality (see Appendix for exact wording of questions). TCL = SportSight tinted contact lens; CCL = Acuvue 2 clear contact lens; TSP = Tinted spectacle lens; 1 = Very noticeable, 5 = Not noticeable.

	Stray Light			Reflections			Ghosting		
Present?	TCL	CCL	TSP	TCL	CCL	TSP	TCL	CCL	TSP
Yes	1	12	17	1	1	12	3	2	2
No	37	26	20	37	37	25	35	36	35

X^2 analysis demonstrated a difference in perception of stray light between the modalities $chi^2(2) = 18.78$, $p = 0.000$. More specifically, SportSight CLs elicited the fewest noted perceptions of stray light, followed by clear CLs, then tinted spectacles (TCL < CCL < TSP). X^2 analysis also showed a significant difference in the amount of perceived reflections between the modalities. Subjects reported an equal number of perceived reflections while wearing SportSight CLs and clear CLs but perceived significantly more while wearing tinted spectacles (TCL = CCL <TSP) $X^2(2) = 20.36$, $p = 0.000$. No significant difference was found between the lens modalities in the amount of perceived image ghosting $X^2(2) = 0.29$, $p = 0.867$.

Discussion

Research has clearly shown the advantages of performance tinted CL wear with regard to various measures of objective and subjective responses under various lighting conditions. The current study expanded upon these results. Objective data included distance stereoacuity and texture gradient recognition. Stereoacuity results showed no statistically significant difference in stereolocalization when subjects were wearing clear CLs, SportSight CLs, or tinted spectacles. Texture gradient results were assessed using timed and tachistoscopic presentations. Both of these testing conditions demonstrated that it was more difficult for subjects to correctly identify the seam orientation at farther distances than nearer distances, and that subjects took more time to try to identify distant target orientation versus near target orientation. On average, subjects required approximately 0.5 sec less to attempt to identify texture gradient with tinted spectacles compared to either CL condition. However, this time difference did not translate into any significant difference in the correctness of responses. In fact, we surmise that the longer time required when using CLs was due to the unfamiliarity of the emmetropic subjects with this modality. In addition, tachistoscopic presentations were not found to be significant with regard to correctness of responses at any distance with any lens modality.

Subjective data indicated that even though the test subjects were not habitual CL wearers, a general trend suggested more physical comfort with either CL modality instead of tinted spectacles. The tinted spectacles were designed to be one size fits all. SportSight CLs were also found to be the most visually comfortable modality, followed by tinted spectacles and then clear CLs. Furthermore, a general trend indicated that subjects felt they were able to perform best while wearing the SportSight CLs. This may partially be due to the fact that subjects noted fewer perceptions of stray light with SportSight CLs than with the other modalities. Likewise, subjects reported an equal number of perceived reflections while wearing SportSight CLs and clear CLs but significantly more while wearing tinted spectacles.

In summary, objective findings of the current study demonstrate that SportSight CLs provide similar performance with regard to distance depth perception and texture gradient recognition to tinted spectacles. Subjective data indicate that visual comfort of the SportSight CLs was superior to tinted spectacles and clear CLs. Additionally, a trend in subjective data demonstrated that the subjects perceived improved performance on the tests while wearing the SportSight CLs. This trend might have translated into significance if the number of subjects had been greater. The combination of consistent visual performance with improved visual comfort through the SportSight technology has applications in a wide variety of outdoor activities from leisure and recreation to competitive athletics. Future studies should assess the impact of SportSight technology on performance during specific activities, such as baseball, golf, waterskiing, etc. Standardized visual measures to be assessed objectively during such studies may include color perception and figure-ground discrimination.

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Appendix A
Howard-Dolman Protocol

I need you to stand up as straight as possible. Do you see the two rods in the instrument in front of you? You need to position your head by moving it left or right so that an equal amount of space lies between the two rods and the sides of the rectangular opening. Have you done this? Okay, the rod to the right is fixed and the one you see to your left moves (Move the rod to both extremes to show this). Do you see this? All right, the goal of this test is to compare the position of the left right rod to the in each of the presentations we will give you. Each presentation will last two seconds and, at the end of which, you must give a response of "in front" (move the rod position to the front position), "even" (move the rod to the even position), or "behind" (move the rod to the behind position). You may have many types of each response, as we may not even decide to move the rod for some of the presentations. But the direction of movement will always be the same for each set of presentations. We will either start the rod in "in front" position and randomly move it backward or start in it in the "behind" position and move it randomly forward. You will occlude both your eyes with some lenses between presentations and, when the operator opens the instrument you will look at the two rods and tell me the position of the left rod when compared to the right. Do you understand these instructions? Then let's begin.

Appendix B
Texture Gradient Recognition Protocol

<u>Tachistoscopic Presentation</u>

(Show ball seam orientation while patient looking at ground). You are going to be looking at the ground with the goggles in front of your eyes. When we say go, look up and remove the goggles. Begin at the (nearestlfarthest) pole and call out the orientation of the seams on the balls from the top of the pole to the bottom. Only look at the pole we tell you to. When we call time (you will only have 2 seconds), replace the goggles over your eyes and look at the ground. You must provide an answer for each ball on the pole, even if you must guess.

<u>Timed Presentation</u>

Once again, you will start the test by looking at the ground with the goggles in front of your eyes. When we say go, look up and remove the goggles. Begin at the (nearest/farthest) pole and call out the orientation of the seams on the balls starting at the top of the pole and going down. Only look at the pole we tell you to. For this test you will be timed. Perform the test as quickly but as accurately as possible. Your first response will be taken as your final answer so you cannot change any response. You must provide an answer, even if you have to guess. When you are finished, look at the ground and replace the goggles.