Effect of Aftermarket Automobile Window Tinting Films on Driver Vision

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This study was conducted to determine the level of automobile window tint that causes a significant reduction of vision for automobile drivers. Contrast sensitivity was measured on 20 participants, of whom 10 were age 20 to 29 years and 10 were age 60 to 69 years, through a stock automobile window (control) and two windows darkened with plastic film. For the younger drivers, a car window with 37% transmittance did not significantly reduce contrast sensitivity, but a darker tint of 18% transmittance reduced contrast sensitivity at higher spatial frequencies. For the older drivers, a tint of 37% transmittance significantly reduced mid- to- high spatial frequency contrast sensitivity. The typical state standard (no tint with less than 35% transmittance) would thus seem to be appropriate for younger drivers; however, further examination of the standard may be necessary in regard to older drivers. Actual or potential applications of this research include guidelines and regulations regarding tinting of automobile windows.

INTRODUCTION

Factory-tinted automobile windshields and windows have been available for decades and are fairly standard on contemporary cars. Recently it has become possible and popular for automobile owners to further darken the tint (reduce transmittance of light) on car windows (side and rear). This is a result of two factors: Easily applied plastic films have been produced in various colors and tints, and numerous small, independent shops have arisen to apply these films.

Many automobile owners darken the windows of their vehicles with these aftermarket films to reduce interior heat in the summer and minimize fading and damage to interior components from the sun. These may be valid reasons to darken windows, but at what level is there a significant effect on the driver's vision to the side and rear?

Despite concern by law enforcement officials, it seems there are few current published studies of the effects of darkened windows on a driver's vision. A small cluster of publications occurred in the early 1950s (Haber, 1955), when tinted windshields first became an option on many new cars. Using calculations only, Haber (1955) predicted that drivers would experience a reduction of 9% to 15% in the distance to detect a target when an untinted windshield of 88% transmittance was compared with a tinted windshield of 73% transmittance. Heath and Finch (1953; cited in Haber, 1955) found that tinted windshields actually caused a 22% reduction in the distance at which drivers detected targets placed in the road. Both reports concluded that these tinted windshields are hazardous, especially at night, and called for a reconsideration of the 70% minimum transmittance requirement for windshields in the American Standard Safety Code.

Some substantiation of the concern voiced in these early papers was supplied in a recent study. Derkum (1993) used a target with a stripe pattern to determine the distance at which

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participants could recognize the orientation of the stripes through windshields with various transmission levels. The trials were conducted under mesopic light levels to simulate nighttime conditions, and Derkum concluded that windshields with transmittance levels below 70% could have a significant effect on a driver's vision.

Laws Regulating Tinting

In the United States, most states have considered the hazards of aftermarket tints applied to windshields and side or rear windows. It is almost universal, with the exception of the top 4 inches (10.2 cm), that no aftermarket tints are allowed to reduce the federally mandated 70% minimum transmittance of automobile windshields.

Possibly because the literature contains no studies on the effect of window tinting of side and back windows on a driver's vision, the laws vary greatly in regard to aftermarket tinting of this glass (LaMotte, Yeung, & Ridder, 1995). Most states (45 of 50) allow aftermarket tinting of side and rear windows, but the laws range from allowing tints as dark as desired to allowing no aftermarket tints at all. Of the states that allow tinting of side and rear windows, the most common standard (44% of states) allows no tint with less than 35% transmittance. The only rationale for establishment of this standard may be the ability of police officers to see into a car as they approach it.

Contrast Sensitivity

Because reduced visibility through side and rear windows may pose a hazard to automobile drivers, and considering the wide variability of standards relating to aftermarket tinting of this glass, we chose to determine the effect these tints have on a driver's vision and concluded that we needed a procedure that predicts the detection of real-world targets. Over the last decade, contrast sensitivity testing has been shown to be a much better measurement of visual capability in everyday life than has Snellen acuity (Evans & Ginsburg, 1985).

Contrast sensitivity is a measurement of the ability of the human visual system to distinguish patterns of different spatial frequencies at threshold visual levels (Comerford, 1983). This is often done by presenting the participant with a sine-wave pattern on an oscilloscope and altering the contrast of the pattern to determine the participant's threshold at a given spatial frequency (Figure 1). Typically, this is done with six different spatial frequencies (see Methods section), and the contrast at which the participant can detect the pattern is determined for each spatial frequency. Thus, contrast

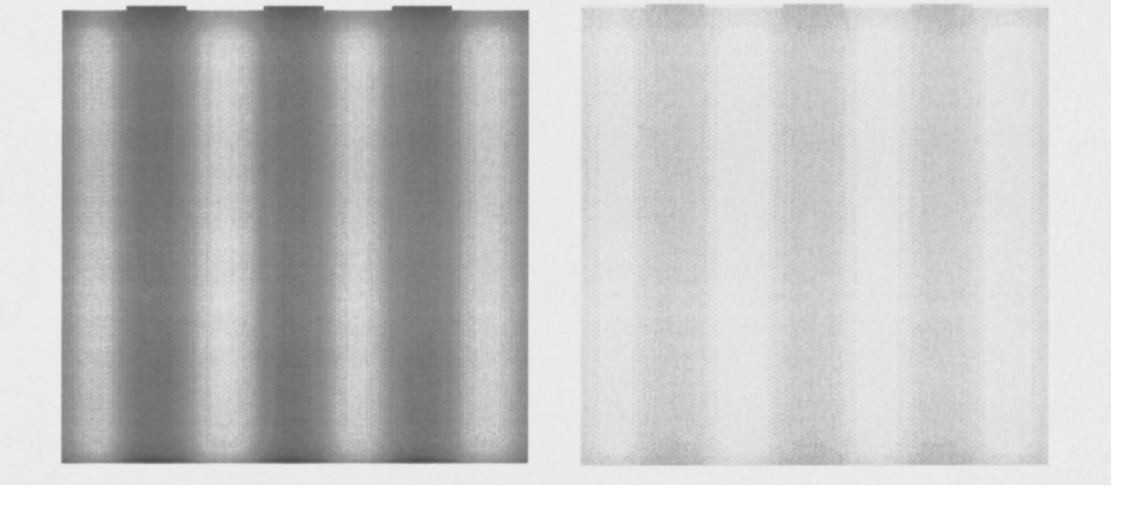

Figure 1. Sine wave patterns presented on the oscilloscope to measure contrast sensitivity. The pattern on the left is presented with greater contrast than the pattern on the right. The spatial frequency is the same for both patterns.

sensitivity not only measures the participant's ability to see small details in good lighting (high spatial frequency, high contrast), it also evaluates the ability to see larger details in less-than-optimum lighting conditions (low spatial frequency, low contrast).

The value of this measurement was shown in a study by Owsley and Sloane (1987) by comparing the contrast sensitivity of adults 20 to 77 years of age with the detection and identification of slides of real-world targets. Contrast thresholds were measured for both gratings of 0.5 to 22.8 cycles/° and real-world targets (faces, road signs, objects). Multiple regression techniques showed that contrast sensitivity at 3 to 6 cycles/° was a good predictor of thresholds for real-world targets. This study demonstrated that contrast sensitivity is an effective measurement of how well people see targets typical of driving and everyday life.

Measurement of contrast sensitivity has even been shown to be a useful tool to study visual performance related to the dynamic simulation of a jet fighter (Ginsburg, Evans, Sekuler, & Harp, 1982). In a task more related to driving an automobile, it was shown that the distance at which a participant could discriminate a highway sign correlated with contrast sensitivity thresholds for both an older group and a younger group (Evans & Ginsburg, 1985). Changes in the contrast of objects can have effects on other tasks involved in driving. The latency of the saccadic eye movements that are needed to recognize peripheral objects in road traffic increases with decreasing contrast of the target (Wacker, Buser, & Lachenmayr, 1993). Contrast sensitivity may even have a predictive value for the involvement of older drivers in accidents, as was shown in a study of 12 400 Pennsylvania drivers correlating crash involvement to contrast sensitivity criteria (Decina & Staplin, 1993).

In a pilot study using tinted side windows and the Vistech Contrast Test System (Vistech Consultants, Inc., Dayton, OH), we demonstrated a reduction in contrast sensitivity when participants were tested using tinted windows of decreasing transmittance (LaMotte, Floyd, & Sue, 1991). This method utilized printed contrast targets, and we found it lacked the precision and sophistication needed to determine important details about the reduction in contrast sensitivity caused by tinted windows.

This current study was designed to determine the effect aftermarket window tinting has on the visual performance of two populations of drivers, using electronic measurement of contrast sensitivity to measure their performance when looking through car windows with aftermarket tints compared to a control window with no aftermarket tint. This electronic method allows precise measurements and permitted us to determine the level of these commercially available tints at which vision is significantly reduced for participants in their 20s or 60s.

METHODS

Participants

Testing was done on 10 participants 20 to 29 years old (average 24.6) and 10 participants 60 to 69 years old (average 62.2). These two groups were designed to represent both the lower and upper range of the driving population that commutes daily to school or work in Southern California. All participants had 20/20 corrected vision, and none had ocular pathology.

Visual Stimuli

The contrast sensitivity was determined electronically using an 80386 computer driving an image generator, which in turn produced vertically oriented sine-wave gratings on a Tektronix 608 monitor. Contrast sensitivity was measured for gratings at each of six different spatial frequencies (0.5, 1.0, 2.0, 4.0, 8.0, 12.0 cycles/°). The oscilloscope monitor subtended an angle of 6.3° by 8.0° at a viewing distance of 1.0 m. The screen luminance was 22.3 cd/m².

Procedure

Each participant viewed the stimulus under binocular conditions with his or her full visual correction. A timed, two-alternative, forced choice technique was used. Two periods (500 ms in duration separated by 500 ms) were demarcated by beeps from the computer. The stimulus was presented in one time interval, and the other interval contained an equiluminant gray field. The task for the participant was to determine which time interval contained the stimulus.

A modified staircase method based on the Bekesy audiometric method was used to determine the participant's contrast threshold at each spatial frequency (Sekuler & Tynan, 1977). Presentation of the spatial frequencies was randomized for each session. The stimulus contrast was increased 0.1 log unit if the participant chose the incorrect interval (no stimulus) but was decreased 0.1 log unit if the participant chose the correct interval (stimulus present) on two consecutive trials. With this technique, the stimulus contrast oscillated around the participant's threshold. A reversal was defined as an alteration in the direction the contrast changed from trial to trial (i.e., from increasing to decreasing contrast or vice versa). The computer program continued until 11 reversals of the staircase were tracked at each spatial frequency. The last 9 reversals were averaged to determine the mean and standard deviation of the contrast threshold.

Window Tints

Contrast sensitivity was tested through side windows removed from a Volkswagen automobile. One side window was left stock, with only the factory tint, and was used as a control. Two additional side windows were treated with aftermarket film described as "medium" and "dark" tints by a local installation shop. The control window had a factory tint with a light transmittance of 82%. Measured transmittance of the treated windows was 37% for the medium tint and 18% for the dark tint. The windows were placed 50 cm from the participants and presented in random order.

RESULTS

Contrast thresholds for each spatial frequency were converted to log sensitivity values (log of the reciprocal of contrast threshold), referred to as *contrast sensitivity.* These data are numerically and graphically summarized in Figure 2 for the 20s group and in Figure 3 for the 60s group. The table at the top of each figure provides the mean contrast sensitivity for each tint and spatial frequency along with the corresponding standard deviation. The plots in these figures demonstrate mean contrast sensitivity versus spatial frequency for each of the three viewing conditions (control, medium, and dark tints). This allows a graphical comparison of the contrast sensitivity functions obtained for each tint.

The 20s Group

The 20s group had comparable contrast sensitivity functions for the control and medium tints but showed a decline in contrast sensitivity through the dark tint, most noticeably at the higher spatial frequencies. These data were analyzed using a two-way repeated-measures analysis of variance (ANOVA) design in which tint and spatial frequency were within-group factors. The results are summarized in Table 1. Both of the main effects (tints and spatial frequency) were significant, and the Tint × Frequency interaction effect was not. Pairwise comparisons of the three tint levels using statistical contrasts were consistent with these observations on the 20s group. The overall mean difference in contrast sensitivity between the control tint and the dark tint was significant, mean = –0.14, $F(1, 9) = 9.26$, $p = .014$, as was the comparison of the medium and dark tints, mean = –0.12, $F(1, 9) = 14.42$, $p = .0042$. The statistical contrast comparing the control and medium tints was not significant, mean = –0.02, $F(1, 9) = 0.30$, $p = .60$.

The 60s Group

The 60s group showed a decline in contrast sensitivity with decreasing light transmittance of the tints (Figure 3). At each of the four highest spatial frequencies, there was an obvious decrease in mean contrast sensitivity with darker tint levels. The amount of decrease began with very small differences at 0.5 and 1 cycle/° and became more pronounced at higher spatial frequencies. The ANOVA results for these data are summarized in Table 2. The significant Tint × Spatial Frequency interaction effect reflects the observation that the effect of tint on contrast sensitivity varies with spatial frequency.

A summary of the results of a simple effects analysis is shown in Table 3. A one-way repeated-measures ANOVA (in which tint was

TINT	0.5	1	2	4	8	12
	SPATIAL FREQUENCY (CYL/DEG)					
CONTROL	1.87±0.13	2.38±0.10	2.43±0.15	2.33±0.26	1.79±0.32	1.55±0.28
MEDIUM	1.91±0.14	2.35±0.15	2.50±0.18	2.25±0.26	1.78±0.27	1.45±0.31
DARK	1.80±0.18	2.25±0.20	2.35±0.20	2.17±0.22	1.62±0.24	1.34±0.32

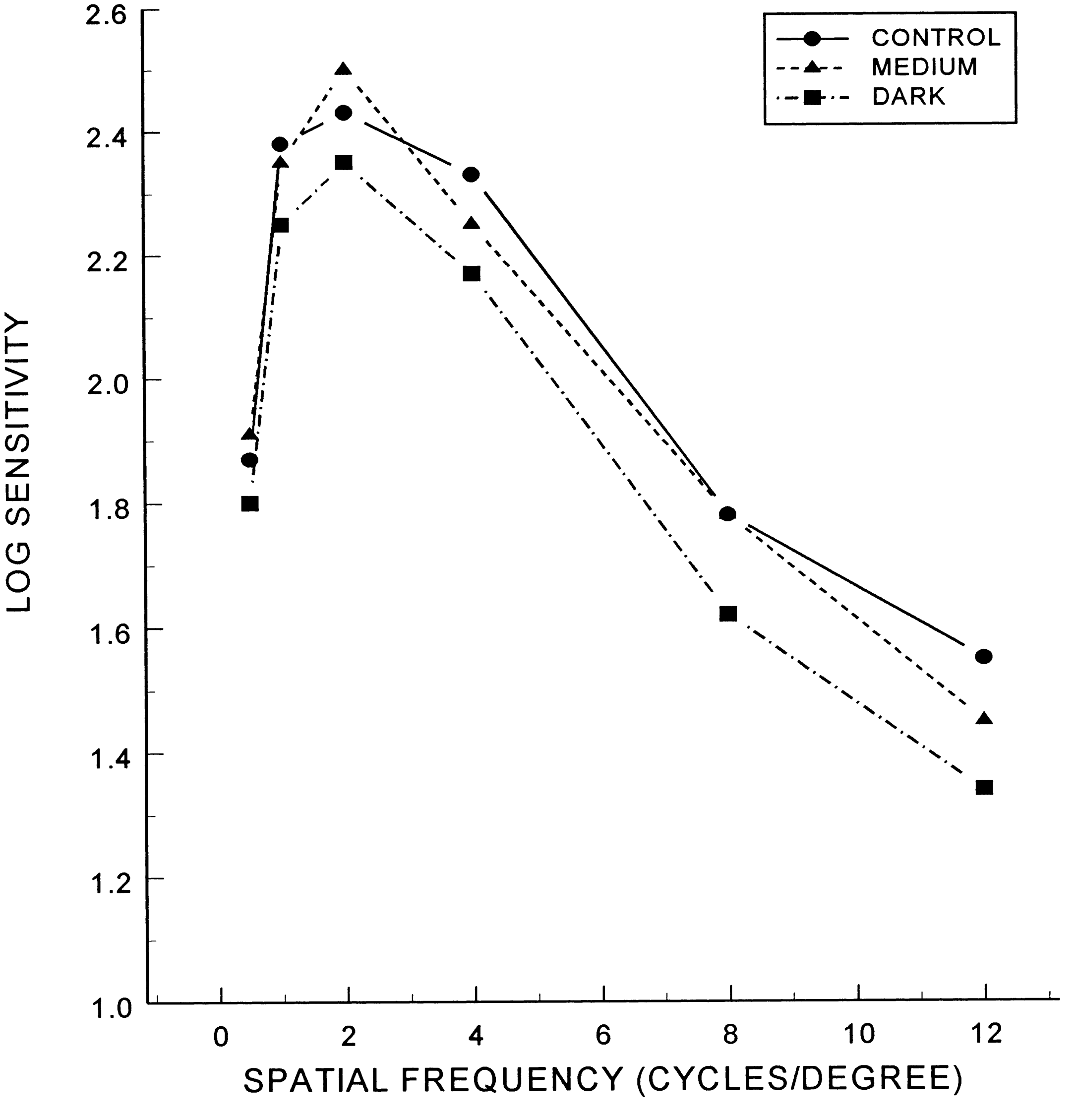

Figure 2. For the sample of participants in their 20s, the chart (top) gives the mean log sensitivity ±*SD* through each tint at each spatial frequency. For each windshield tint, the plot (bottom) of the means in the chart versus spatial frequency is shown.

SPATIAL FREQUENCY (CYCLES/DEG)

TINT	0.5	1	2	4	8	12
CONTROL	1.80±0.09	2.28±0.11	2.45±0.15	2.28±0.20	1.77±0.20	1.45±0.18
MEDIUM	1.77±0.14	2.20±0.17	2.31±0.21	2.14±0.26	1.61±0.15	1.31±0.18
DARK	1.75±0.16	2.18±0.21	2.25±0.25	1.99±0.20	1.44±0.16	1.08±0.28

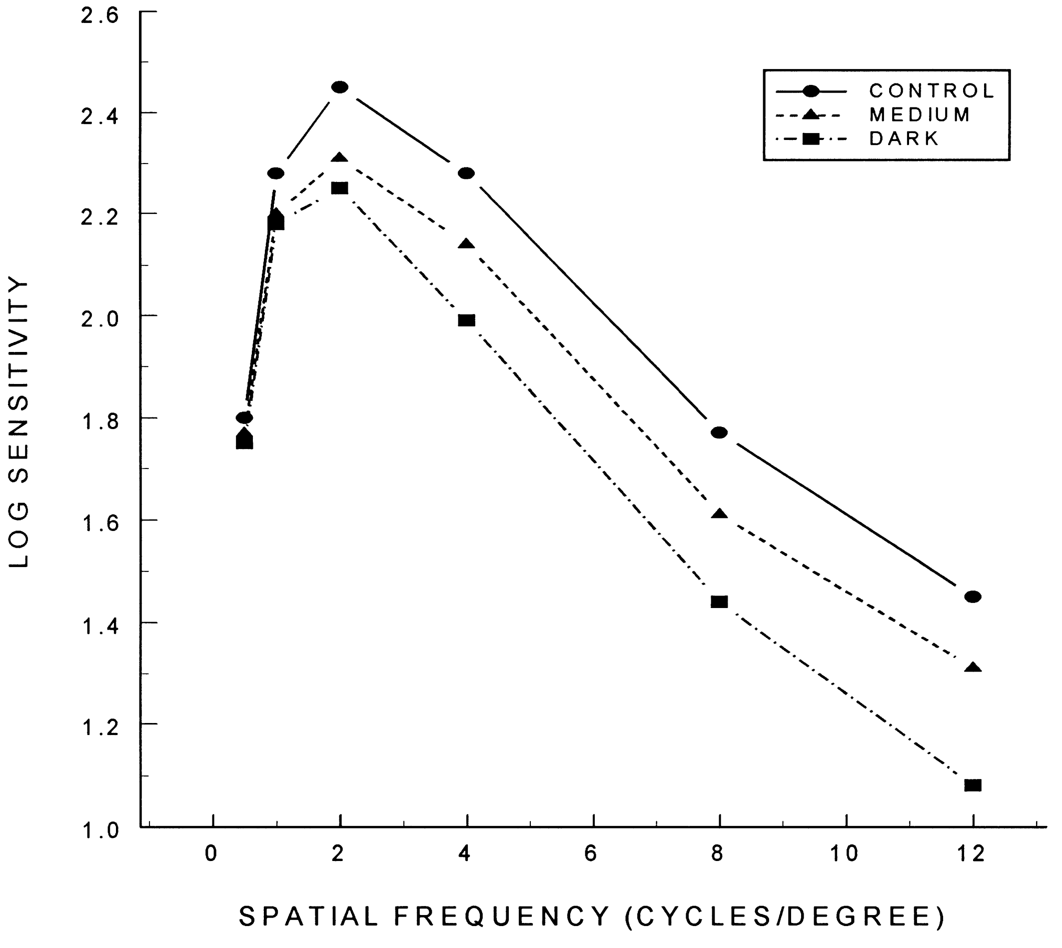

Figure 3. For the sample of 60-year-old participants, the chart (upper) gives the mean log sensitivity ±SD through each tint at each spatial frequency. For each windshield tint, a plot (lower) of the means in the chart versus spatial frequency is shown.

the within-group factor) was conducted for each spatial frequency. For the spatial frequencies 4, 8, and 12 cycles/° there is evidence that tint affected contrast sensitivity. For each of these three spatial frequencies, the tint effect was significant at the .05 level using a Bonferroni procedure in which the Type I error rate for each of the six spatial frequencies is 0.05/6 = 0.0083. The tint effects at 0.5 and 1 cycle/° were not significant, and at 2 cycles/° the results were marginal. Subsequent pairwise comparisons of the three tints at 4, 8, and 12 cycles/° were conducted. In comparing contrast sensitivity for the dark versus the control

TABLE 1: 20s Group ANOVA Table for Two-Way Repeated-Measures Design with Tint and Spatial Frequency as Within-Group Factors

Factor	*SS*	*df*	*MS*	*F*	*p*
Tint	0.670	2	0.335	8.50	.006*
Error 1	0.709	18	0.039		
SF	22.429	5	4.486	96.42	<.00005
Error 2	2.094	45	0.047		
Tint × SF	0.133	10	0.013	0.79	.53*
Error 3	1.508	90	0.017		

Note: SS = sum of squares, *df* = degrees of freedom, *MS* = mean square, SF = spatial frequency.
* This *p* value was determined using the Greenhous-Geisser degrees of freedom adjustment.

TABLE 2: 60s Group ANOVA Table for Two-Way Repeated-Measures Design with Tint and Spatial Frequency as Within-Group Factors

Factor	*SS*	*df*	*MS*	*F*	*p*
Tint	1.448	2	0.724	23.46	<.00005
Error 1	0.556	18	0.31		
SF	25.073	5	5.015	213.10	<.00005
Error 2	1.059	45	0.024		
Tint × SF	0.423	10	0.042	3.47	.014*
Error 3	1.097	90	0.012		

Note: SS = sum of squares, *df* = degrees of freedom, *MS* = mean square, SF = spatial frequency.
* This *p* value was determined using the Greenhous-Geisser degrees of freedom adjustment.

TABLE 3: 60s Group Summary of Simple Effects Analysis of Effect of Tint at Each Spatial Frequency

Spatial Frequency (cycles/°)	*F*	*p*
0.5	(2, 18) = 0.82	.46
1	(1.34, 12.08) = 1.87	.20*
2	(1.45, 13.02) = 5.48	.026*
4	(1.42, 12.77) = 8.71	.0070*
8	(1.17, 10.52) = 38.05	.0001*
12	(2, 18) = 16.75	.0001

* These *p* values were determined using the Greenhous-Geisser degrees of freedom adjustment.

tint, significance was obtained at 4, 8, and 12 cycles/°. For the medium tint versus dark tint, results were significant only at 8 and 12 cycles/°, and for the control versus the medium tint there was only marginal significance at 8 and 12 cycles/°.

CONCLUSIONS

Driving task analysis supports a model of driver information processing in which vision is the primary sensory channel, responsible for up to 95% of driving-related inputs (Shinar & Schieber, 1991). Indeed, "improper lookout" (driver either did not look, or did look, but did so inadequately) is cited often in detailed accident analyses (Treat et al., 1977). Vision difficulties have an effect on driving, as seen by the fact that improper lookout is three times more likely to be the accident cause when the driver has reduced vision (Shinar, McDonald, & Treat, 1978). Obviously, if a factor such as transmission of light through automobile windshields and side or rear windows reduces a driver's vision, it could contribute to unsafe driving.

The 20s Group

From the results obtained in the 20s group it appears that the standard adopted by many states allowing no window tints with less than 35% transmittance is appropriate for younger drivers. This conclusion is based on our finding that the younger group did not show a statistically significant reduction in contrast sensitivity at 37% transmittance (medium tint) but did experience a significant loss with 18% transmittance (dark tint) when compared with their performance with the control window. The greatest losses with the dark tint occurred at 4, 8, and 12 cycles/°.

Clinical Significance

After an analysis of visual performance with soft contact lens and spectacle correction, Tomlinson and Mann (1985) utilized a change of 0.2 log units measured by contrast sensitivity as a definition of clinical significance. They felt this showed a difference in visual performance that was "manifest subjectively in a normal visual environment" (p. 56). If this standard is applied to our results, only the reduction at 12 cycles/° when comparing control with dark window tints demonstrates a clinically significant decrease for the 20s group.

The 60s Group

The group of participants in their 60s had a reduction of contrast sensitivity through both of the windows tinted with aftermarket film when compared with their performance with the control window. This group showed a statistically significant loss through the 18% transmittance window (dark tint) at medium to high spatial frequencies and also a significant drop in medium to high spatial frequencies through the 37% transmittance window (medium tint). Applying the 0.2 log unit definition (Tomlinson & Mann, 1985) to an examination of clinical significance, a drop of 0.2 log units occurred through the 18% transmittance window in the medium spatial frequencies and rose to 0.37 log units at 12 cycles/°. The dramatic drop in contrast sensitivity in this group strongly argues against allowing tints as dark as 18% transmittance, which may be sold as "dark" tints by shops that apply these plastic films.

Within the last decade four manufacturers of plastic window tinting film have petitioned (without success) the National Highway Traffic Safety Administration for a change in the regulation regarding light transmission through side and rear windows (Cunningham, 1993). The changes they were proposing would result in windows with transmission of light as low as 24.5%. Some of the authorities opposing the petition were concerned that the change would have potentially hazardous implications for all drivers, especially older drivers and those with ocular pathology. Our results for drivers in their 60s indicate that this is a legitimate concern.

Consideration of the 35% transmittance standard used in many states for window tinting in regards to the 60s group is problematic. In our study the younger group did not show a clinically or statistically significant reduction of contrast sensitivity with a 37% transmittance tint, but the older group demonstrated statistically significant decrements. A comparison of the 82% transmittance tint (control) with the

37% transmittance tint (medium) showed that these statistically significant reductions for the 60s group began in the middle spatial frequencies and continued through the higher spatial frequencies.

Studies have shown that an age-related decrease in contrast sensitivity occurs in older people with normal ocular health and is more pronounced in the middle to high spatial frequencies (Owsley & Sloane, 1987). A significant portion of this loss can be attributed to a decrease in retinal illuminance caused by the age-related reduction in pupil size and the loss of lens transparency (Owsley, Sekuler, & Siemsen, 1983; Sloane, Owsley, & Alvarez, 1988). Further illustrating this change in contrast sensitivity with decreased retinal illuminance, a large study on the vision of older individuals found that decreasing the light levels on a contrast sensitivity target caused the contrast sensitivity function curve to shift downward, indicating lowered contrast sensitivity (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999). Our results are consistent with these studies, as we found that our 60s group had a significant reduction when contrast sensitivity through the medium tint was compared with contrast sensitivity through the control tint. It seems the 37% transmittance (medium) tint (which is a reduction of 45% in transmittance from the control window) exacerbated the retinal illuminance reduction that already existed in these older participants and caused the decreased contrast sensitivity we observed at middle to high spatial frequencies. Thus even the 35% transmittance tint, which is currently legal in most states, could significantly reduce the vision of older drivers but not have a significant effect on younger drivers.

Our study shows that tints as dark as 18% transmittance, which are applied by many shops as "dark" tints, can have a detrimental effect on a driver's vision regardless of age. Additionally, our results support a position against any effort to allow side and rear window tints darker than the 35% transmittance standard that is currently the law in many states. We suggest that further examination is warranted of the effect a tint of 35% transmittance has on the vision of older drivers.

ACKNOWLEDGMENTS

This research was supported by a grant from the Bausch and Lomb InVision Institute.

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Date received: November 6, 1997
Date accepted: December 2, 1999