Visibility Through Tinted Automotive Glazing

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This study investigated the effect of tinted automotive glazing on the visibility of roadside targets. Modulation transfer characteristics and transmittance of five sample glazing were measured. These data were used to determine shifts in published contrast sensitivity functions for different age groups, display durations, luminances and retinal eccentricities. The visibility of typical roadside targets was evaluated within the spatial frequency domain by comparing their Fourier representations to resultant contrast sensitivity functions.

Introduction

Canadian motor vehicle safety standards require that automotive glazing meet a minimum luminous transmittance criteria of 70%. Standard tinted and heat absorbing glass (with visible light transmittance of 72-79%) offer a number of advantages over clear glass, including increased passenger comfort by reducing interior temperatures, increased fuel efficiency due to reduced solar load, reduced chlorofluorocarbon emissions from air conditioners, and reduced glare from oncoming headlamps. It has been suggested that more extensive tinting should be permitted to provide a greater degree of solar control. Although new technologies are available to selectively filter out infrared (IR) and ultraviolet components of the energy spectrum without altering the transmittance of visible light, the use of tinted plastic film is still the most prevalent technique for reducing IR penetration.

In light of current concerns for environmental protection and conservation, there is a need to determine whether Federal transmittance requirements for side and rear windows can be relaxed in order to permit the application of plastic films or other treatments that reduce solar heat penetration. Moreover, Provincial authorities are increasingly turning to the Federal government for advice on glazing specifications since the after-market application of tinted films is regulated and enforced by the Provinces. (Federal safety standards apply only to cars built in or imported into Canada with the result that there is no uniform standard for the after-market industry in Canada and the standards which do exist are very difficult to enforce.)

The present study was concerned with the effect of tinted plastic films on the performance of visual tasks involved in driving. The research literature is inconclusive and difficult to interpret due to the fact that none of the studies manipulated both contrast and size of target objects in a systematic fashion.

The study involved laboratory measurements of the optical characteristics of five representative sample films covering a wide range of transmittances. The effects on visual performance were derived from analytic predictions based on known human contrast sensitivity data.

Visual Performance Issues

The potential effects of tinted film on the performance of visual tasks of driving include (1) reduced object to background contrast due to increased veiling glare from reflections and imperfections in the glass/film medium, and (2) reduced background luminance (and therefore reduced levels of visual adaptation). These effects can reduce the visibility of objects, especially under low levels of illumination.

Modulation Transfer Function

A major factor in the ability of the eye to detect an object is the luminance contrast between the object and its background. Loss of contrast can occur as light is transmitted through an optical medium and may vary as a function of spatial frequency. The conventional measure of optical quality is the modulation transfer function (MTF). The MTF specifies the ratio of image modulation (contrast) to object modulation as a function of spatial frequency.

For flat glass of good quality, it can be shown that modulation transfer is not affected. But, automotive glass is not necessarily flat or of good quality. Curved glass will most certainly affect modulation transfer depending on the optical power introduced. Aberrations or imperfections can also reduce modulation transfer, as can scratches due to wear and tear. Modulation transfer can also be affected by large rake angles (which are not uncommon for rear windows) through increased distortions or reflections. Consideration of factors such as window curvature and rake angle and film durability were beyond the scope of the present study.

Contrast Sensitivity and Adaptive Luminance

After passing through space and glass, the light rays emanating from a given object impinge on the drivers' eyes, possibly distorted and/or attenuated. The ability of the eyes to detect the object depends on the contrast and spatial frequency characteristics of the image. The contrast sensitivity function (CSF) for human observers specifies the reciprocal of contrast threshold as a function of spatial frequency.

Contrast sensitivity is known to be affected by background luminance and other factors such as observer's age, stimulus presentation time, retinal eccentricity, accommodation, border gradients, masking, orientation, pupil size, size of viewing field, etc. (Boff and Lincoln, 1988). Tinted windows will have a direct effect on background luminance and, thereby, contrast sensitivity. It is well known that the darker the scene, the more contrast is required to detect an object (Van Nes and Bouman, 1967). Hence, while tinting may not alter the contrast of an object, a driver's ability to detect the object may be reduced under reduced luminance conditions.

Moreover, in cars with windows having different transmittance characteristics, the eyes cannot fully adapt to the background luminance (due to frequent shifts of visual attention). This may suppress contrast sensitivity further when looking through dark windows since the non-adapted eyes require more contrast than fully-adapted eyes.

Visibility Inside the Vehicle

The ability to see through the vehicle ahead and to make eye contact with the driver permits road users to anticipate road and traffic events. The use of tinted glass may remove this source of information, possibly contributing to increased judgmental errors or reaction times. This issue was beyond the scope of the present study.

Methodology

The approach used in the present study was to determine the modulation transfer functions and luminance transmittance levels of five samples of tinted films. The sample films had been applied to flat clear automotive glass. These data were then related to published data for human observers to determine shifts in contrast sensitivity that can be expected to result from reduced background luminance. Human contrast sensitivity data were derived from the published literature and delineated in terms of factors such as age, adaptation level and target eccentricity (i.e., foveal and peripheral contrast threshold) and exposure duration. This approach permitted estimating the nature and extent of visual losses that can occur through reduced transmittance glass. The effect on traffic safety was inferred from Fourier analyses of representative roadside objects.

Samples of Tinted Film

Five sample films were obtained from Ener-Gard Energy Products Inc., covering a wide range of transmittances. Sample transmittance levels are shown in Table 1.

Table 1: Measured luminous transmittance of samples

Sample	Transmittance (%)	Sample	Transmittance (%)
1	7	4	42
2	17	5	67
3	32	Clear glass	92

Measurement of MTF

Modulation transfer functions for these samples were measured using three different techniques (i.e., Line Spread Function measured using an EROS system, Point Spread Function measured using a CapCalc luminance and image analysis system, and measurements of luminance contrasts of sinusoidal gratings using the CapCalc system). All of these measurements indicated that the MTF's for these samples were effectively flat over the range of spatial frequencies of interest, indicating no loss in modulation. It should be pointed out, however, that the measurements were made on flat glass with light passing normal to the surface.

Contrast Sensitivity Functions

Having established that there was no loss in modulation through the sample glazing, it was possible to determine the expected effect of reduced transmittance on contrast sensitivity. The loss of contrast sensitivity with reduced luminance can be approximated by a square-root law (Van Nes and Bouman, 1967). This relationship, also known as the DeVries-Rose law, is valid for spatial frequencies above 3 cpd and for luminances below 100 cd/m^2.

A set of eight CSF's were derived from the literature corresponding to different levels of driver age (22 and 74 years), display duration (40 and 500 ms), retinal location (foveal and

30^{o} off axis) and mean adaptation luminance (0.1 and 107 cd/m^2). The DeVries-Rose law was used to determine losses in contrast sensitivity due to reduced luminous transmittance. Multiplying the original set of CSF's by the square-root of the luminous transmittance of each sample yielded a new set of CSF's. The resultant curves indicated significant shifts in cutoff frequency (the frequency above which visual stimuli are below threshold) towards lower spatial frequencies as mean luminance decreased. For example, the grating acuity for young observers was reduced from 45 to 30 cpd when transmittance levels decreased from 100% to 7%.

Dunn (1973) used a similar approach to estimate the probability of detection as a function of window transmittance for different twilight and night luminance levels. However, his analysis was based on published experimental data describing threshold contrasts for different background luminances. Dunn concluded that for optimum performance, transmittance levels should be above 0.79. What was missing from his study, however, was a link between threshold shifts and detectability of real objects.

Visibility of Roadside Targets

The visibility of objects in the real world as seen through a tinted window depends on a number of factors including object spatial characteristics and contrast. Real objects and backgrounds, however, are not of uniform luminance and they may contain different spatial frequency components. It has been demonstrated that the human visual system comprises feature analyzers which independently process information from the visual image, some of which are differentially sensitive to specific spatial frequencies (Ginsberg, and Easterly, 1983). When viewing real objects, the background itself may have spatial luminance variations which must be taken into account. Hence, in order to determine whether a particular object would be visible to a driver (discriminable from its background), it was necessary to transform the image into its spatial frequency components and relate these to discrimination thresholds which depend largely on the complexity of the background.

Studies have shown that discrimination threshold increases with background contrast. Based on previous studies (Nachmias and Sansbury 1973), the following equation was derived relating discrimination threshold, C_d, to detection threshold, C_{csf} (from the CSF's derived for different adaptation levels when viewed through the sample glazing),and background contrast, C_b:

$$C_d = 0.5(C_{csf})^{0.4}(C_b)^{0.6}$$

Target contrast levels were derived from Fast Fourier Transformations of recorded images after the objects were electronically separated from their background. The resultant contrasts were compared with the discrimination thresholds that had been derived for the different viewing conditions (using the equation above). If the contrast level of any component exceeded the discrimination threshold, the object would be considered to be visible.

Three real objects were digitized against their natural settings. The objects included a bicyclist at a distance of approximately 20 metres (e.g., as seen through the side window at an intersection), a small tricycle at about 15 metres (e.g., as seen through the rear window while reversing) and a car at 2 metres (e.g., as seen through the rear side window before lane change). The objects were selected to cover a wide range of sizes, contrasts and background complexity.

The results of this analysis indicated that target 3 (the target with lowest contrast) was completely invisible when viewed through the darkest film and marginally visible when viewed through the other samples for all observers (based on CSF data collected by Owsley et al., 1983 for a luminance level of 100 cd/m^2). The other targets were relatively more visible, though the cyclist was approaching the discrimination threshold. The maximum detection distance for a cyclist was reduced by a factor of 2 when viewed through sample 1. These results indicate that very dark films may adversely affect traffic safety.

A number of qualifications must be emphasized; (1) the assumption that any single suprathreshold component is sufficient for detection has not been verified in this context, (2) the CSF data used in calculating target detection thresholds are based on data collected under controlled conditions with healthy, attentive subjects, (3) the square-root law that was used to predict shifts in CSF is an approximation which holds under low light levels, (4) it was assumed that no optical scattering occurs in air over an optical path distance of 20 metres. The results, therefore, represent conservative predictions of the effects on visual performance of the sample glazing. Empirical verification of these results is warranted.

Conclusions

The results of the study indicate that reduced transmittance can have an adverse effect on night visibility. These data provide compelling reasons for retaining and extending existing standards.

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Dans cette étude, nous avons considéré les effets d'un vitrage automobile teinté sur la visibilité d'objets-cibles rencontrés sur route. La fonction de transfert de modulation et la transmittivité d'échantillons de vitres ont été mesurées. Un ensemble de fonctions de sensibilité au contraste de groupes d'âge, de temps d'exposition, de luminosités et de positions latérales de la rétine différentes a été sélectionné et analysé . La visibilité de cibles susceptibles d'être rencontrées sur route a été évaluée.