Do automotive window films affect drivers' safety by decreasing vision sensitivity? A Cross-sectional study

Películas automotivas e perda de acuidade visual? Estudo transversal

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ABSTRACT

Objective: To measure visual acuity in high contrast and low contrast sensitivities in different grades of visible light transmission films in three different positions (front, lateral and rear windows).

Methods: Forty-four healthy volunteers between 30-75 y-o, with BCVA better than 0,5, were tested in the 5 following vehicles with different grades of visible light transmission films. Vehicle 1: 75% in the front and 70% in the lateral and rear windows; Vehicle 2: 70% in the front and lateral windows and 28% in the rear; Vehicle 3: 70% in the front, 28% in the lateral and 15% rear; Vehicle 4: 35% in all 3 windows; Vehicle 5: 50% in the front, 20% in the lateral and 15% in the rear. Descriptive statistics were used and the average of the 3 measurements of VA was considered. Wilcoxon Test was applied to compare the average visual acuity in each vehicle and position. P value<0.05 was considered statistically significant.

Results: According to the Brazilian Traffic Regulations for driving in categories C/D/E, when low contrast was tested in the front window, all visible light transmissions were borderline, in the lateral window they were all outside the limit, while in the rear window for both low and high contrast, all visible light transmissions tested were outside the limit and also borderline for driving in categories A/B, with the exception of the vehicle with visible light transmission of 35%.

Conclusion: Visual acuity is affected, especially in the rear window, by the use of automotive films. The study is an alert that window films is a possible cause of accidents and may contribute to the revision of traffic regulations worldwide.

RESUMO

Objetivo: Medir a acuidade visual em alto e baixo contraste nas diversas graduações de transparência de filmes em três janelas de veículos: frontal, lateral e traseira.

Métodos: Foram avaliados 44 voluntários saudáveis entre 30 e 75 anos, com acuidade visual melhor corrigida acima de 0,5, em cinco veículos, sendo: veículo 1, com 75% de transparência frontal e 70% na lateral e traseira; veículo 2, com 70% na frontal e na lateral e 28% na traseira; veículo 3, com 70% na frontal, 28% na lateral e 15% na traseira; veículo 4, com 35% nas três janelas; e veículo 5, com 50% na frontal, 20% na lateral e 15% na traseira. Foi realizada estatística descritiva utilizando a média de três medidas consecutivas, com teste de Wilcoxon para comparar a média de acuidade visual em cada janela, e foi considerado estatisticamente significativo quando valor de p<0,05.

Resultados: Todas as transparências testadas nos vidros reduziram a acuidade visual em situação de baixo contraste para níveis limítrofes na janela frontal e níveis ilegais na lateral para conduzir veículos nas categorias C/D/E. Na janela traseira, tanto em alto quanto em baixo contraste, todas as transparências mostraram redução da acuidade visual para níveis ilegais para categorias C/D/E e limítrofes para as categorias A/B, exceto na transparência de 35%.

Conclusão: A acuidade visual é reduzida pelo uso dos filmes automotivos, especialmente na janela traseira. Condutores de veículos com filmes devem ser alertados pelo risco aumentado de acidentes. Esse dado científico propõe revisões nas regulações de tráfego mundiais.

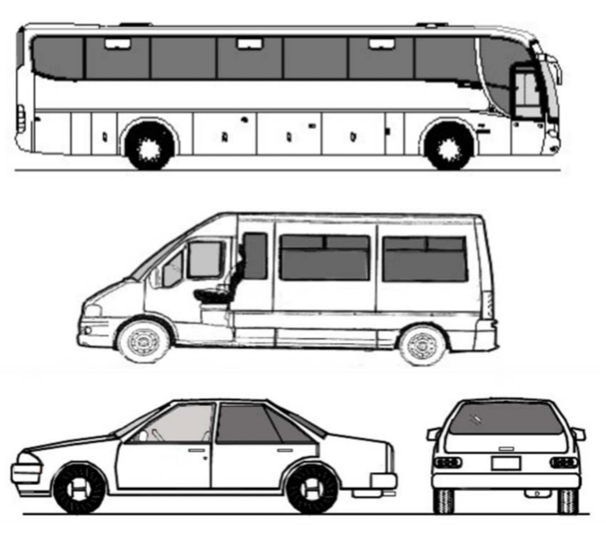
INTRODUCTION

Driving, and perhaps most human activities, are strongly dependent on vision. Most people would even agree that vision is the most important sense involved in driving, and for some authors it could involve 90% of all of the required skills.[1] From such a perspective, the 20/40 visual acuity (VA) criterion to obtain an unrestricted driver's license seems reasonable and well justified.

Automotive window tinting films have been developed to bring thermal comfort, Ultraviolet (UV) protection, privacy and security to drivers and passengers, but on the other hand it reduces the visible light transmission (VLT) through car windows and can decrease vision sensitivity, especially at night, or when drivers should be able to see through the windows of other vehicles in order to spot hazards. Therefore, in many jurisdictions, there are laws to restrict the darkness of tinting.

In the United States, each state has different limits of allowable tint measured on the front side window.[2] These range from a low VLT of 24% in Washington State,[3] to 70% in California,[4] with less stringent restriction being common for windows in the rear of the vehicles.

In Brazil, the traffic law regulates that the VLT cannot be less than 75% for front transparent windows and 70% for tinted windows. The same occurs for the lateral windows that are indispensable to conduct the vehicle (Figure 1). All other windows cannot have less than 28% of VLT.[5]



Source: Brazilian law.[5]

Figure 1. Front and lateral windows indispensable to conduct the vehicle with no less than 70% visible light transmission, other lateral and rear windows with no less than 28% visible light transmission.

In terms of VA, according to the Brazilian law, drivers are allowed to conduct vehicles with at least one eye if their BCVA is better than 20/40 (LogMar 0.3 in categories A – motorcycle –/B – car] and 20/30 (LogMar 0.17 in categories C – truck – /D –bus –/E –extra axial vehicles).[6]

Visual acuity is the measurement of the ability to discriminate two stimuli separated in space at high contrast relative to the background. Clinically, this is measured by asking the subject to discriminate letters of known visual angle. The VA is represented as the reciprocal of the minimal angle of resolution (the smallest letters resolved) at a given distance and at high contrast. Newer charts, such as the ETDRS chart, use letters of equal recognition difficulty and use the log of the minimal angle of resolution (LogMar). These charts have significant advantages over the old Snellen-type charts.[7]

However, the visibility of objects in our environment is often more limited by the lack of contrast than by their small size. Consider the pedestrian who misses a curb or step, or the driver who does not see a pedestrian on a dark road. In many surveys, contrast sensitivity (CS) is the visual parameter that is most closely related to problems experienced in activities of daily living (ADL).[8,9]

CS describes the ability to distinguish small differences in luminance.[10] Visual performance can be affected differently depending on lighting conditions.[8,9]

Taking all of this into consideration, this study was designed as a cross-sectional study to evaluate VA in two different circumstances, using high and low contrast charts in different grades of VLT.

OBJECTIVE

The purpose of this study is to measure visual acuity in high and low contrast sensitivities in different grades of visible light transmission films inside tinted window cars in three different positions (front, lateral and rear windows).

METHODS

Forty-four healthy volunteers between the ages of 30 to 75 years, with the mean age of 52 years old. There were 27 men and 17 women with BCVA of no less than 20/40 or 0,30 LogMar.

Exclusion criteria included the absence of ocular or systemic diseases as diabetes mellitus or hypertension, and the use of amiodarone or chloroquine.

The study was designed according to the Declaration of Helsinki and approved by the Ethic Committee of *Universidade Federal de São Paulo* (#1506/11) and did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Distance VA was assessed under photopic illumination conditions and scored on a letter-by-letter basis.

BCVA was measured three times and then the average was considered, first at a distance of 4m outside the car, with the high contrast ETDRS Chart, then at the driver's seat in five different vehicles. Each vehicle had one grade of VLT (Table 1), and the measures were taken in three positions (front, lateral left, and rear window) with high (100%) and low (20%) contrast ETDRS Charts (Precision Vision, LaSalle, Illinois, USA).

The light was controlled with 500 Lux for each chart. There were intervals of 5 minutes between each measure, and four different charts were used to avoid memorization. Both eyes were tested simultaneously. The charts were positioned 4m from the front window, 4m from the lateral left side of the driver and 4m in rear (from the mirror to the chart), as shown in figure 2.

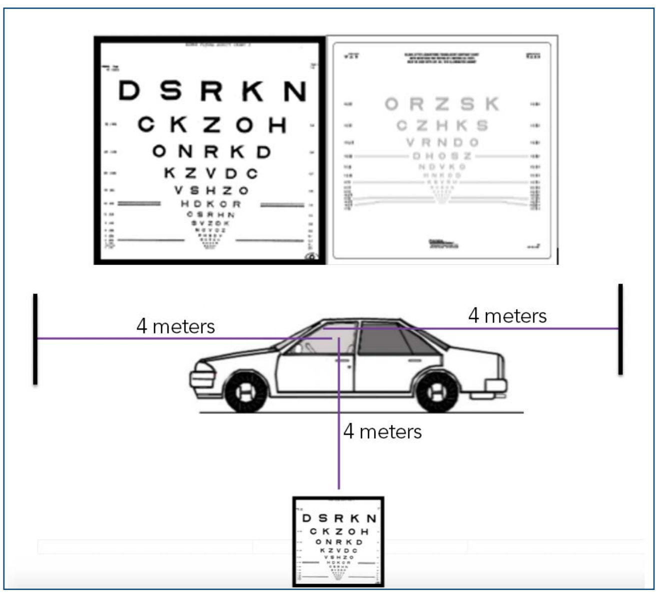


Figure 2. Positions of the charts at a distance of 4m from the volunteer to the charts in each window (front, lateral and rear).

Descriptive statistics was used and the average of the three measures of VA was considered. Wilcoxon test was used to compare the average VA in each vehicle and position. P-value<0.05 was considered statistically significant.

Visible light transmission in the three windows (front, lateral and rear), in the five vehicles. Visible light transmission in vehicles 3, 4 and 5 are considered illegal in the Brazilian Legislation. Vehicle 1 has default visible light transmission without tinting windows, vehicle 2 has the Brazilian regulation visible light transmission in all three windows, vehicle 3 has illegal visible light transmission for the lateral and rear windows, vehicle 4 has illegal visible light transmission for the front and lateral windows and vehicle 5 has illegal visible light transmission for all windows.

Table 1. Vehicles and visible light transmission

Windows	Visible Light Transmission (%)				
	V1	V2	V3	V4	V5
Front	75	70	70	35	50
Lateral	70	70	28	35	20
Rear	70	28	15	35	15

V: vehicles

RESULTS

For the front window, in all five vehicles, the BCVA remained good and achieved the limit (Table 2) required to obtain driver's license in Brazil in all categories for high contrast, but borderline for categories C/D/E with 70%, 50% and 35% when low contrast chart was tested (Table 3).

Table 2. BCVA in each vehicle in high contrast

Vehicle	1	2	3	4	5
Front	0.098±0.0149	0.082±0.101	0.073±0.093	0.100±0.106	0.099±0.102
Lateral	0.096±0.139	0.102±0.098	0.080±0.089	0.109±0.106	0.116±0.118
Rear	0.182±0.138	0.292±0.124	0.335±0.160	0.216±0.123	0.323±0.157

Average of BCVA measures (± standard deviation) with high contrast Chart (LogMAR) in each vehicle and each position.

Table 3. BCVA in each vehicle in low contrast

Vehicle	1	2	3	4	5
Front	0.169±0.124	0.176±0.113	0.189±0.138	0.198±0.113	0.183±0.113
Lateral	0/152±0.107	0.210±0.085	0.198±0.101	0.221±0.100	0.217±0.096
Rear	0.285±0.139	0.427±0.101	0.463±0.139	0.320±0.114	0.489±0.135

Average of BCVA measures (± standard deviation) with low contrast Chart (LogMAR) in each vehicle and each position.

There were statistically significant differences between all groups but without much variation of VA. Decreasing VLT from 75% or 70% to 50% or 35% does not show great interference in terms of VA using high or low contrasts charts, in the front window in normal subjects.

For the lateral window, when a high contrast chart was used, there was statistically significant difference only when VLT of 70% was compared to 20% (p-value: 0.004), but all measures achieved the required limits to obtain the Brazilian Driver's license. In low contrast chart, there were statistically significant differences for all the lower grades (35%, 28% and 20%) when compared to 70% that would be the recommended grade (with p-values: 0.001, 0.002, 0.001, respectively), and they showed decreased VA that were outside the limit for driving categories C/D/E (Table 4).

For the rear window, the decrease of VLT from 70% to 35%, 28% and 15% was tested on both high and low

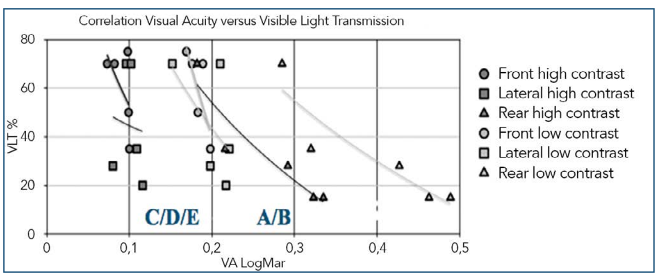
Table 4. Windows and contrasts

Contrast	Frontal (%)	p-value	Lateral (%)	p-value	Rear (%)	p-value
High	50	0.042	20	0.004	28	0.001
	35	0.021			25	0.001
Low	35	0.049	35	0.001	28	0.001
			28	0.002	15	0.001
			20	0.001		

The reduction of visible light transmission in the front, lateral and rear windows showing statistically significant differences compared to 75% and 70% of visible light transmission, especially in situations of low contrast.

contrast charts, and a significant decrease of VA in all grades below 35% was found, with statistically significant differences between VLT of 70% and 28% (p-value: 0.001) and to 15% (p-value: 0.001) but there were no differences when compared to VLT of 35% (p-value: 0.136).

Figure 3 shows VA decreases when VTL % decreases, in all the three windows (front, lateral and rear), the low contrast chart shows poorer VA compared to the high contrast chart, but in the front window less than in lateral and rear windows.



VA: visual acuity.

Figure 3. Correlation visual acuity versus visible light transmission

Figure 3 also shows the Brazilian traffic legislation categories and correspondent VA required to obtain the driver's license.

To drive in categories C, D and E, the minimum required is VA of 0,17 LogMar and for the categories A and B, the minimum is 0,30 LogMar.

In all five vehicles, the correspondent VA with the high contrast chart in all VLT tested were in accordance with the minimum VA required for the Brazilian license considering the front and lateral windows for categories A/B and C/D/E but not in the rear window, rear vision is outside the limit for all categories. When low contrast was used, there were decreased VA in all three windows for categories C/D/E and in the rear window for A/B.

When considering the Brazilian requirement to obtain the driver's license, with the high contrast chart, VLT of 15% was outside of the limit for categories A/B, and even the 70% showed sensible reduction in VA and was borderline to obtain driver's license in categories C/D/E. When the low contrast chart was applied, all grades were outside for C/D/E and only 70% was not for A/B.

Figure 4 show BCVA in high (blue) and low (green) contrasts in each vehicle. BCVA under 0,17 logMar is the limit required to obtain the Driver's license in categories C/D/E, and BCVA under 0,3 logMar is the limit required to obtain the Driver's license in categories A/B.

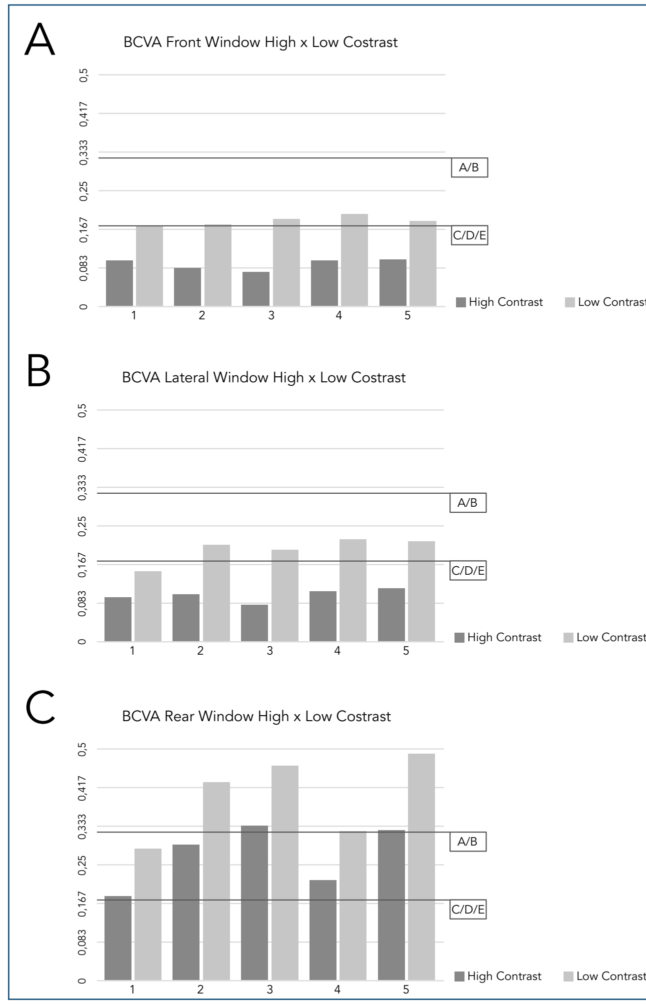


Figure 4. Graphs of visual acuity in high and low contrast in the 3 windows.

Figure 4A shows the measures of the front window, and in low contrast all the VLT tested were borderline for categories C/D/E. Figure 4B: shows the measures from the lateral window; likewise, in low contrast slightly above the limit for categories C/D/E. And figure 4C shows the measures from rear window shows all measures in high and low contrasts above the limit for C/D/E and most of them borderline or above the limit for categories A/B, except for vehicle 4, that had VLT of 35%.

DISCUSSION

Visual acuity and CS are important measures of visual function, although the latter, despite being a better predictor of traffic incidents, is often neglected in clinical testing.[8,9]

Other studies have already demonstrated the relation between CS and the ability to perform routine daily activities. When CS is affected in the middle to low spatial frequencies, targets of everyday life like faces, road signs and objects are difficult to be discriminated. Spatial CS can effectively predict how well patients see targets typical of everyday life.[9]

Higgings et al.[11] evaluated 24 young licensed drivers (15 men and 9 women) with normal vision. Driving performance was measured while the participants wore modified swimmer's goggles to which blurring lenses were affixed in amounts necessary to produce binocular VA levels of 20/20, 20/40 (the prevalent acuity standard for driving), 20/100, and 20/200. Driving performance was measured using the closed-road method of Wood and Troutbeck.[12] Acuity degradation produced significant decrements in road sign recognition and road hazard avoidance, as well as significant increments in total driving time.[11]

Even considered more important than VA, there are no regulations for CS stablished and standardized for driving.

Contrast sensitivity is not currently used as a licensing requirement in any state in the United States,[13] , Europe[14] or Brazil.

Wood and Carberry[15,16] also demonstrated that, for older drivers with cataract, cataract surgery improves driving performance, an effect that is mediated by improvement in CS following surgery.[13]

Spreng et al.[14], in a Cross-Sectional Study with elderly population in Switzerland, showed that 21% of his sample of 162 patients had CS decreased in at least one eye and 6.8% of all drivers aged 70+ started experiencing difficulties in low illumination without their VA being affected in normal light conditions (VA ≥0.5decimal).

Owsley[17] and Higgings[18] demonstrated that severe CS impairment due to cataract elevates at-fault crash risk among older drivers, even when present in only one eye.

In the United States and Canada, older adults (65 years of age or older) are overrepresented in fatal motor vehicle collisions. In fact, in 2015, older adults were almost 18% or approximately 245,000 of the drivers involved in fatal collisions or injuries in the United States.[19] Similarly, in 2014, older adults were approximately 20% of the 149,900 collisions seen in Canada.[20,21]

Age-related declines in physical, cognitive, and neurological functions may occur and affect a person's fitness to drive, which is the ability to control a motor vehicle smoothly and cautiously, with or without technology, to keep up with the flow of traffic.[22]

Based on these factors, The Fitness-to-Drive Screening Measure© (FTDS), a web-based tool developed to help caregivers identify at-risk older drivers, equipping with strategies and resources for decision making related to continued driving, referral to rehabilitation, or driving cessation, was developed. This questionnaire analyzes normal driving tasks such changing lanes, entering or leaving a highway, target road signs, driving in fog, driving at night, etc. Most of the tasks are dependent of a good vision sensitivity and the use of mirrors and lateral windows. Conversely, the VLT of the windows for the elderly drivers was not considered in this questionnaire.

Another important study was performed by Classen et al.[23] when comparing 30 young Multiple Sclerosis patients with Visual-cognitive impairments and a group of 145 older volunteer drivers. MS patients were found to make significantly more total and critical driving errors. Furthermore, these critical driving errors were related to slower visual processing speed and poorer visual sensitivity, and it's known that CS is very compromised in MS.

In a cross-sectional study, Wood et al.[24] demonstrated that drivers with AMD self-report more difficulties with driving, particularly night driving, even in the early stages of the disease, and that these difficulties in night driving in AMD could be linked to reductions in scotopic (rod-mediated) sensitivity.

Simulator studies of small numbers of drivers with AMD suggest impairments in some aspects of driving ability, including delayed braking times, slower speeds, and more lane crossings, compared with age-matched controls.[25] This study also hypothesized that central CS would have the strongest association with driving ability, given that reduced CS was identified as the strongest correlate with other measures of functional performance, including impaired balance, gait, and increased fall risk in older adults with AMD in other studies. But this perhaps was not demonstrated by the study because of the small size of sample.[26,27]

A recent report highlights the use of anti-VEGF therapy as a major long-term treatment for neovascular AMD, with 50% of eyes having VA 20/40 or better after 5 years of treatment. Thus, many would meet driving license requirements and could continue to drive in non-safe conditions, specially under tinted window car.[28]

Another group of population at risk of crash are the novice driver's and findings suggest that older drivers with impaired CS in the worse eye and far peripheral vision in both eyes have significantly higher rates of crash involvement than those without these impairments. This data was provided by a new model called Naturalistic driving data that generates by participants driving their own vehicles during the course of their everyday life over long observation periods. Vehicles are unobtrusively equipped with sensors and video cameras, which record vehicle kinematics, Global Positioning System (GPS), presence of nearby objects, and the roadway environment. These studies are innovative because they can provide an unprecedented level of detail on the occurrence of safety critical events such as crashes and near-crashes.[29,30]

There are few current published studies about the effects of darkened windows itself on a driver's vision. A small cluster of publications occurred in the early 1950s, when tinted windshields first became an option on many new cars. Using calculations only, Haber[31] 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)[31] 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.[32]

LaMotte et al.[32] measured CS on 20 participants, of whom ten were 20 to 29 years old and ten were 60 to 69 years old, through a stock automobile window (control) and two windows darkened with plastic film. The authors showed that in the group of the younger drivers, a car window with 37% transmittance did not significantly reduce CS, but a darker tint of 18% transmittance reduced CS at higher spatial frequencies. But, for the older drivers, a tint of 37% transmittance significantly reduced mid-to- high spatial frequency CS, and the present study confirmed this statement. When measuring VA in high and low contrast charts, our study showed decrease of BCVA in about one line of ETDRS in low contrast in all the three windows, but this was seriously compromised in the rear window, compared to high contrast chart.

Another study demonstrated that visibility is seriously degraded during night driving and that the problem is greater for older drivers based on testing relevant targets, including road signs, large low-contrast road obstacles, and pedestrians who wore retroreflective markings on either the torso or the limb joints (creating "biological motion"). Real-world recognition performance was measured as a percentage of correct recognition and, in the case of low-contrast road obstacles, it was avoided. Clinical vision tests included high-contrast VA and Pelli-Robson letter CS measured at four luminance levels, showing the impact of this reduction in driving performance.[33]

In our study, we did not stratify by age group and the great majority were around 50 y-o. As in the study mentioned above, we could demonstrate that there was significant reduction of vision sensitivity when VLT was bellow 35%, especially in the rear window. Moreover, the VLT lower than 40% in the Low contrast chart and 20% in High contrast chart measures showed that VA dropped significantly to levels that are beyond the threshold allowed by the Brazilian Traffic Regulation, which could lead also to decrease driving performance and safety. For lateral windows that are indispensable for driving, maybe lowering VLT under 20% would bring sensible reduction in visual sensitivity, and the Brazilian Regulation established 28% as the lowest limit for the other windows, but not for the lateral window on the driver's or passenger's side. These two windows should be 70% of VLT.

The comparison of different VLT films showed that there are statistically significant differences in vision sensitivity when, in the front window, we compare VLT of 75% or 70% to 50% in high contrast and from 75% to 35% in low contrast. However, even statistically significant differences did not show in the graph of correlation too much variability in terms of VA necessary to obtain the driver's license in Brazil for the categories A/B, as well as in the lateral window, where even reducing VLT, all the volunteers achieved VA under what is allowed by the law to drive, but not for categories C/D/E. On the other hand, the rear window shows worse Visual Acuities than the other windows even in the VLT around 70%, and when VLT decreases, the drop of VA goes to levels that are far from the minimum required by law to obtain the Brazilian driver's license also for categories A/B.

In rear windows, all groups showed marked reduction of VA, except for 70% and 35%.

Lowering VLT to 28% or 15% seems to decrease too much vision sensitivity, but 35% VA is considered similar to 70%. It is also interesting to point out that the increase of the VLT in the rear window from 28% (which is the accepted by the Brazilian law) to 35% could bring a sensible increase in vision sensitivity, providing a positive impact in traffic and accident prevention.

To our knowledge, it was the first study in literature that has tested window films in different positions and VLTs and demonstrated how much of vision in affected by them, specially in the lateral and rear windows, even when being under governmental regulations. We can also conclude from this study that, for older people or in case of diseases that affect CS, it is presumable that under lower contrast situations as night and foggy drive there is an enormous prejudice of using window films in terms of safety.

Research using naturalistic driving methods is relatively new and could be useful to understand the veridical relationship between vision and driving safety in this special condition of tinted windows.

CONCLUSION

The present study demonstrates that vision acuity is tremendously affected by the use of window films, especially in situations of low contrast. The decrease of vision is worse in the rear window, even with visible light transmission of 28%, which is allowed by the law in the Brazilian traffic regulation. Moreover, the results show a considerable increase of vision sensitivity in the rear window when visible light transmission is over 35%, and consequently could increase safety to drivers specially in situations of decrease of contrast sensitivity. The study is an alert that window films, by reducing VA and contrast sensitivity, can be an important risk factor for car accidents and also brings contribution to the revision of traffic regulations worldwide.

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