Statistical Assessment of the Glare Issue - Human and Natural Elements

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Abstract

Visibility is one of the basic requirements for safe driving; any type of obscurity in a driver's vision can interfere with the driving task and impose a threat to the roadway safety. Glare is known to be one of the significant factors causing vision obstruction. One would agree that headlamps are not the only source of glare. Sometimes, sunlight may also obstruct a driver's vision and contributing to a crash.

In this paper, the glare issue and some of its aspects are studied using statistical methods. Crash data are used in the analyses. Descriptive statistical and contingency analyses are employed with the objective of a preliminary investigation. The k-nearest neighbor approach is used to assess the potential of some factors in jointly contributing to the crash involvement of drivers who are exposed to glare. Configural frequency analysis is used for identifying the data segments in which glare, as a crash-contributing factor, is more predominant. Some results based on drivers' perceptions of glare, reported in a prior study, are discussed to compare perception with reality, i.e., how drivers perceive glare and how in real life their driving ability is affected by glare.

Keywords: glare, headlamps, sunlight, vision obstruction

1. Introduction

Drivers often confront vehicles in front, from behind, or from both directions that emit blinding glare. Although it has been a concern of drivers since electric headlamps replaced oil lamps, in recent years an increasing number of drivers have complained to the National Highway Traffic Safety Administration about glare from headlamps. Many drivers described being "blinded" for a few seconds after exposure to the glare and needed to slow down, while others mentioned their involvement in a crash or a near miss. Glare, especially due to increasing intensity, often causes discomfort to the driver as well as vision obstruction that may contribute to the occurrence of a crash.

At times, the sun's glare, too, may contribute to crash occurrence. According to Wells [1], who shared her experience in 'record online', "*The sun's nasty spectrum shone down on my windshield so brightly it could have signaled a 747 to land right there in front of my car. Sun glare causes accidents – multiple-car pile-ups, even.*" This driver could be one of the thousands who have had such an experience from glare coming from the natural source: Sun.

The effect of glare remains the same whether it comes from headlamps or sunlight; it obstructs the driver's vision and affects the driving performance. The challenge for vehicle manufacturers and regulators is to provide the driver with a reasonable level of protection from glare. Empirical research is necessary in order to address this issue. Using the crash data, the present study identifies factors that may contribute to the crash involvement of a driver who is exposed to glare.

Studies have shown that parameters, such as age, visual health, complexity of location, glare intensity, etc., affect the visual performance of a driver [2-6]. However, most of these studies look at the phenomenon by considering one factor at a time under controlled conditions. To consider what may actually happen on the roadways when glare is one of the elements in a crash scenario, this study makes a statistical assessment of the glare issue using the crash data. In the following section, the databases used for this purpose are briefly described. The objective of the study is mentioned in Section 3. Section 4 includes analysis for identification of some glare-relevant variables for subsequent analysis. Using descriptive analysis, Section 5 provides a broad picture of the glare issue with respect to the identified variables. A classification model is developed in Section 6 to identify variables related to driver, vehicle, and roadway that have the potential to describe a glare-related crash. Further analysis is done in Section 7 to identify the data segments in which glare in conjunction with driver age and sex seems to be a predominant factor. The study concludes with the summary and conclusions in Section 8. References used in this study are provided in Section 9.

2. Data

The crash data compiled in National Automotive Sampling System-General Estimates System (NASS-GES) [7], to be referred to as GES data in the subsequent discussion are used in the analyses conducted in this study. Some results from a previous study based on Omnibus Survey Data (OSD) [8] are also included in the discussion.

GES is a nationally representative probability sample selected from police-reported crashes that occur annually. These data provide information about drivers, vehicles, and other factors in crashes that result in fatalities, injuries, and major property damages. Four years of GES data (2000 to 2003) are used in this study. In order to segregate the effect of glare, these data are restricted to crashes that occurred in clear weather. The Omnibus Survey is a nationally representative telephone survey conducted by the Bureau of Transportation Statistics. This database is based on monthly surveys in which respondents are asked to express their opinion about different issues; the glare issue was on the questionnaire for the first six months of 2002.

3. Objective of the Study

While in OSD the term “glare” refers to glare from other vehicles, in GES, glare is one of the several elements of the variable called “Driver’s Vision Obscured By,” namely “Reflected Glare, Bright Sunlight, Headlights.” In the subsequent analysis and discussion, the term glare will be used to mean “driver’s vision obscured by reflected glare, bright sunlight, or headlights.”

To be specific, in GES data, a crash with value 2 recorded for the variable Driver’s Vision Obscured By refers to a crash in which the driver’s vision was obstructed by: (i) sunlight or headlamps’ light reflected from other objects, (ii) direct sunlight, or (iii) direct light from headlamps. The objective is to find out how glare might have contributed to a crash in combination with other factors related to driver, vehicle, and roadway.

4. Selection of Analysis Variables

Preliminarily, the variables age, sex, travel speed, maneuver, crash hour, trafficway flow, number of lanes, manner of collision, roadway profile, and vehicle role are considered. These variables are selected to consider the driver who is affected by the glare, the roadway scenarios under which the crash occurred, and the outcome of the crash. In order to study the extent to which glare from headlamps (human source) or sunlight (natural source) is likely to contribute to crash involvement of drivers, two groups of drivers were considered from GES 2000-2003 data: drivers whose crash involvement could be attributed to vision obstruction as a result of glare and those whose vision was not obstructed at all. The respective percentage representations of these two groups in the four years’ data are 1 percent and 58 percent of the total number of drivers involved in crashes in clear weather. In the subsequent discussion, the term glare-related be used to refer to a crash whose occurrence may be attributed to glare and the term glare-exposed for a class of drivers whose crash involvement may be attributed to glare.

Contingency analysis is conducted to test the hypothesis of no association between glare and some of the possible factors that might have contributed to crash involvement of drivers when their vision was obstructed due to glare. For the purpose of this analysis, the preliminarily selected variables are categorized as shown in Table 1. The statistical software SAS 8.2 and SUDAAN 9.0.1 are used for computing Chi-square values and the associated p-values for each variable listed in Table 1.

The results based on GES data are presented in Table 2. A Chi-square value with low p-value ($<<0.0001$) in this table shows significant association of the corresponding variable with glare. Specifically, the results show that driver’s age plays a significant role in conjunction with glare, while sex does not. The driver’s maneuvering is not associated with his/her crash involvement due to being exposed to glare. As regards the roadway, factors such as trafficway flow, roadway profile, and number of lanes are likely to contribute to crash involvement when a driver is exposed to glare. The vehicle-related factors, vehicle speed, crash hour, manner of collision, and vehicle role are also found significantly associated with glare.

The variables significantly associated with glare (as established in the above analysis) are subjected to further analysis for deeper insight into the glare phenomenon.

Table 1. Categorization of Analysis Variables

VARIABLE (CRASH CONTRIBUTING FACTOR)	CATEGORIES
Glare	1: No visual obstruction, 2: Vision obstructed by glare
Driver Age	19 and below, 20-24, 25-34, 35-44, 45-54, 55-64, 65-74, 75 and above
Sex	Male and Female
Maneuver	1: Driver did not maneuver to avoid, 2: Maneuver to avoid vehicle, 3: Avoidance maneuver for objects (no vehicle) in road
Manner of collision	Not collision, Rear-End, Angle, Head-On, Sideswipe
Travel speed	25 and below, 26-35, 36-45,46-55, 56-65, 66 and above
Vehicle role	Noncollision, Striking, Struck, Both
Trafficway flow	Not physically divided (two-way traffic), Divided trafficway (with or without barrier), One-way traffic
Roadway profile	Level, Grade, Hillcrest, Sag
Number of lanes	1, 2, 3, 4, 5, 6 and more
Crash hour*	Midnight- 3 am, 3 - 6 am, 6 - 9 am, 9 – 12 am, 12 - 3 pm , 3 - 6 pm, 6 - 9 pm, 9 - midnight

* time intervals are exclusive of endpoints

Table 2. Crash contributing factors and their association with glare

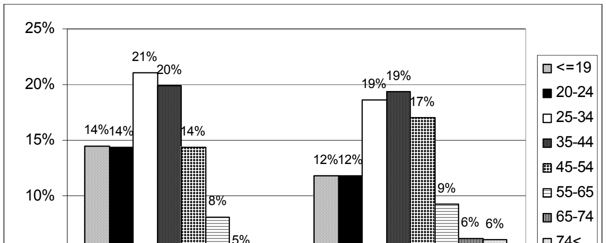
RESPONSE VARIABLE	VARIABLE TYPE	CRASH VARIABLE	ASSOCIATION Based on Chi-Square (95%)	P-Value
GLARE	Subjective	Age group	40.65	<< 0.0001
		Travel speed	221.36	<< 0.0001
		Sex	0.27	0.6066*
		Maneuver	1.92	0.3823*
	Circumstantial	Trafficway flow	105.94	<< 0.0001
		Roadway profile	29.05	<< 0.0001
		Number of lanes	79.98	<< 0.0001
		Crash hour	705.71	<< 0.0001
	Consequential	Manner of collision	180.41	<< 0.0001
		Vehicle role	546.53	<< 0.0001

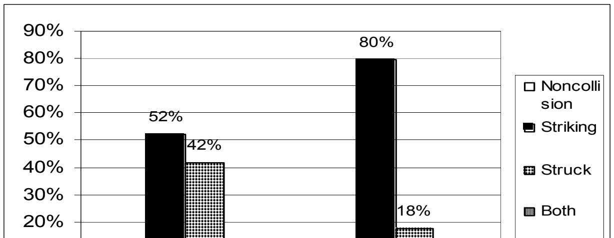
*Not significant

Data Source: GES 2000-2003

5. Broad picture

A broad picture is provided to show the extent to which glare may contribute to a crash in combination with each of the factors found to be significantly associated with glare. Percent frequency distributions over the defined categories of these factors are used for this purpose (Figure 1-8). The comparison of distributions for each variable in the presence or absence of glare enables an assessment of the difference glare can make in a driver's crash involvement. The results in Figure 1 show that 38.5 percent of the crash-involved drivers reported as exposed to glare were of age 45 years and older. This percentage is higher than the percentage (30 percent) of the drivers, involved in crashes without vision obstruction, who fell in the same age group. On the other hand, 61.5 percent of the glare-exposed drivers were below 45 years of age, which is lower than 70 percent of the drivers in the no-vision-obstruction category who were of the same age group. Also, when the crash occurred, most of the glare-exposed drivers (62 percent) were on roadways with two lanes as compared to 50 percent of those who were involved in crashes without vision obstruction when they were on the same type of roadway (Figure 4).





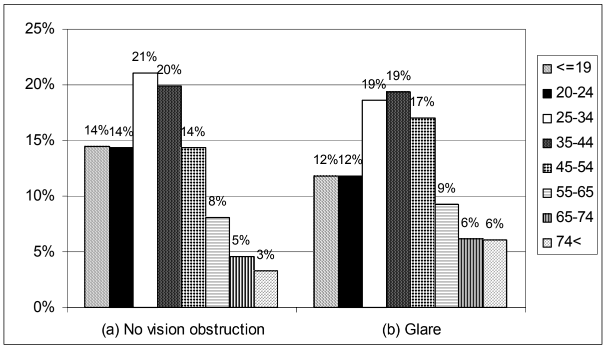


Figure1. Percent frequency distribution of drivers by Driver age: no vision obstruction group (b) in glare group.

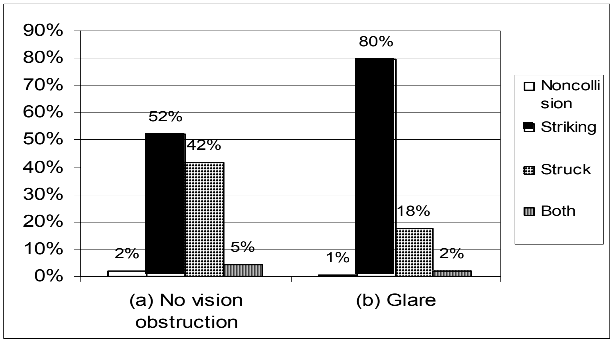


Figure2. Percent frequency distribution of drivers by Vehicle (a) in roles: (a) in no vision obstruction group (b) in glare group.

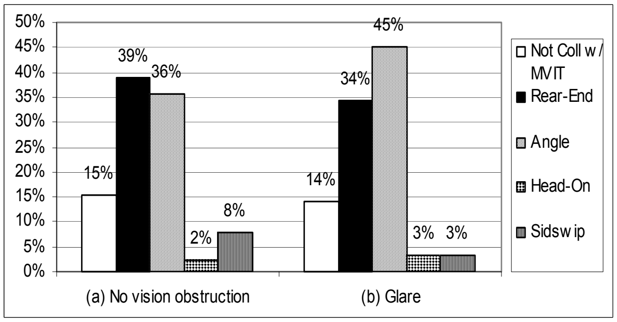


Figure3. Percent frequency distribution of drivers by Manner of collision: (a) in no vision obstruction group (b) in glare group.

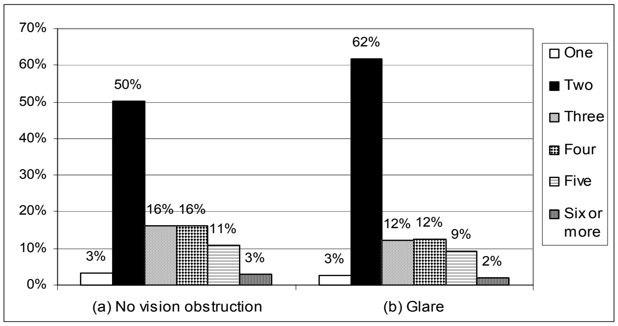


Figure4. Percent frequency distribution of drivers by Number of travel lanes: (a) in no vision obstruction group (b) in glare group.

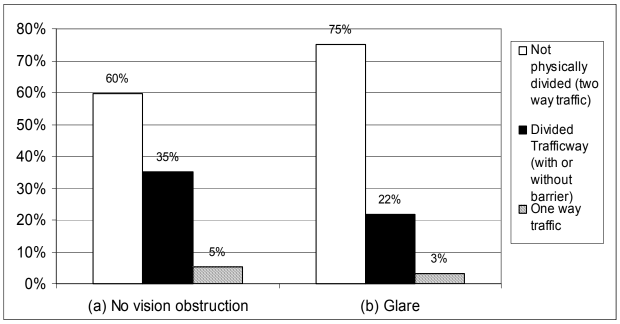


Figure5. Percent frequency distribution of drivers by Traffic flow: (a) in no vision obstruction group (b) in glare group.

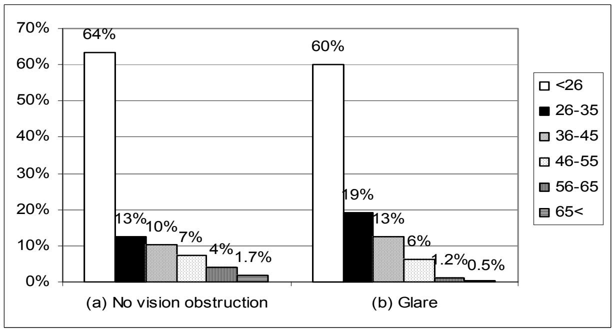


Figure6. Percent frequency distribution of drivers by Travel speed: (a) in no vision obstruction group (b) in glare group.

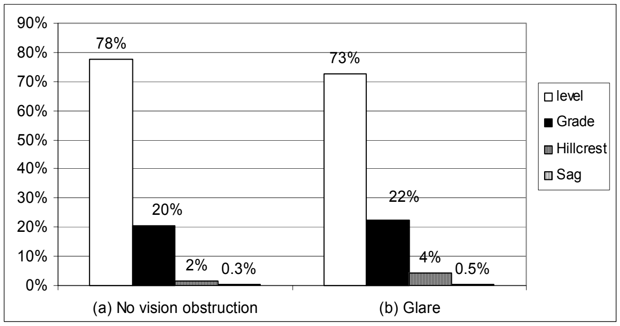


Figure7. Percent frequency distribution of drivers by Roadway profile: (a) in no vision obstruction group (b) in glare group.

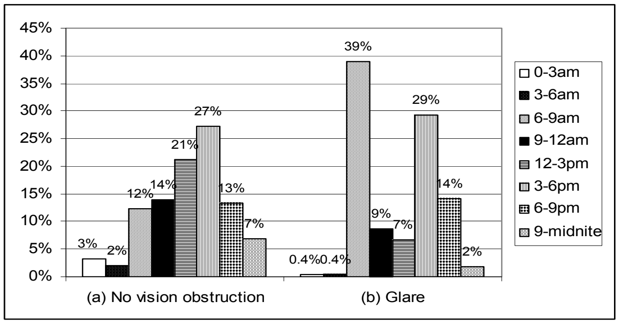


Figure8. Percent frequency distribution of drivers by Crash hour: (a) in no vision obstruction group (b) in glare group.

(Figure 1 – Figure8) Data Source: GES 2000-2003

Similarly, 80 percent of the glare-exposed drivers were in the striking role as compared to 52 percent of those who were in the same role even though their vision was not obstructed (Figure 2). Especially, if the trafficway is not physically divided, glare-exposed drivers has higher percentage (75 percent) as compared to no-vision-obstructed drivers (60 percent) (Figure 5). In angle and head-on collisions, the group disturbed by glare has higher percentages (45 percent and 3.1 percent, respectively) than the group without vision obstruction, for which the respective percentages for these manners of collision are 35.6 percent and 2.2 percent (Figure 3). Among the glare-exposed drivers, the percentage of drivers who were driving at a speed between 26 and 45 mph is higher (32 percent) than 23 percent from the no vision obstruction category who were driving in the same speed range (Figure 6). While the glare group has higher percentages than the group with no vision obstruction in grade (22.4 percent) and hillcrest (4.3 percent) roadway profiles, the group not visually obstructed has higher percentage (77.6 percent) in level roadway profile (Figure 7). 38.9 percent of the glare-exposed drivers were involved in crashes between 6:00 a.m. and 9:00 a. m. (Figure 8). On the other hand, only 12.2 percent of the drivers with no vision obstruction were involved in crashes during the same time interval. The crash involvement of glare-exposed drivers was more frequent (29.9 percent) during 5:00 p.m. to 8:00 p.m. as compared to 27.3 percent of those who were involved in crashes without vision obstruction during the same time period.

6. Descriptive Potential of the Glare-Associated Variables

Using contingency analysis, some factors were tested for their individual associations with glare. These factors fall into three categories; namely the subjective (age, sex, travel speed, maneuver), circumstantial (crash hour, number of lanes, trafficway flow, roadway profile), and consequential (vehicle role, manner of collision). While consequential factors merely show what type of outcome is likely when a glare-exposed driver is involved in a crash, the circumstantial variables point out factors that are conducive to a glare-exposed driver's crash involvement. The subjective factors come into play when a driver confronts a glare scenario. From the crash occurrence point of view, it is important to know if these variables can jointly describe the occurrence of a crash following a glare-caused driving scenario. For this purpose, a statistical distance-based measure, to be referred to as a classifier, is developed using GES 2000-2002 data (training data for the classifier). Since the variable 'trafficway flow' is categorical and significantly associated with number of lanes ($\chi^2 = 208.02$ with $p - \text{value} << 0.0001$), it is excluded from the classifier. On the other hand, the variable 'roadway profile' being a categorical variable does not qualify for classification analysis. Thus, the classifier developed in this study is based on the variables, driver age, crash hour, travel speed, and number of lanes, found significantly associated with glare in an earlier section. If the resulting classifier has a significant classifying power to classify cases into two groups: glare and no vision obstruction, then the variables significantly jointly contribute to the crash involvement of drivers. Based on this argument, the developed classifier is used to cluster GES data of another year (2003) (test data) in two classes: 'glare' and 'no vision obstruction'. Squared distance function is used for developing the classifier [9]

$$D^2(\underline{X}_1, \underline{X}_2) = (\underline{X}_1 - \underline{X}_2)' \Sigma^{-1} (\underline{X}_1 - \underline{X}_2),$$

where $\underline{X}_1$ and $\underline{X}_2$ are two observation vectors of the glare-associated variables characterizing a crash and Σ is an estimated covariance matrix. The algorithm partitions the data space into subspaces through many stages using the distances of the observations in each subspace from the observation that is being assigned to a subspace. The prior probabilities of the subpopulations (subspaces) are used in calculating the posterior probability $\Pi(j/\underline{X})$ of membership in each class, which is updated at each stage, using the formula

$$\Pi(j/\underline{X}) = \frac{m_j(\underline{X})\,\pi_j}{\sum_k m_k(\underline{X})\,\pi_k},$$

where π_j is the prior probability of the j-th class and $m_j(\underline{X})$ is the proportion of observations in group j in 15-nearest neighbors of $\underline{x}$. The algorithm finally converges to distinct classes, glare and no vision obstruction, in the present case. The classification results for a sample of 1,000 cases selected randomly from GES 2003 data are presented in Table 3. The results show that 80 percent of the glare cases and 69 percent of no vision obstruction cases were classified correctly. This in turn shows that the variables used in the classifier have the potential to describe crash involvement of drivers who experienced glare. As an example, the efficiency of the classifier based on these variables is demonstrated by identifying ages of both groups of drivers and hours of their crash involvement (Figure 9). The identification results are presented in Figure 9(a) which shows driver age versus crash hour scatter plot of drivers who were involved in crashes possibly due to glare (□), those who were crash-involved without vision obstruction (•), and ties (*), i.e., the drivers who could not be classified into one of the above categories. The pattern of glare-exposed drivers over time periods 6:00 a.m. to 9:00 a.m. and 5:00 p.m. to 8:00 p.m. in this figure is in good agreement with the actual pattern of such drivers shown in Figure 9(b).

Table 3. Classification Summary using 15-Nearest Neighbors

Number of Observations and Percent Classified					
TO / **FROM**		Glare group	No vision obstruction group	Other (ties)	Total
Glare group		117	30	0	147
		80%	20%	0.00	100.00
No vision obstruction group		265	584	4	853
		31%	68.5%	0.5%	100.00
Total		382	614	4	1000
		38%	61.5%	0.5%	100.00

Data Source: GES 2000-2003

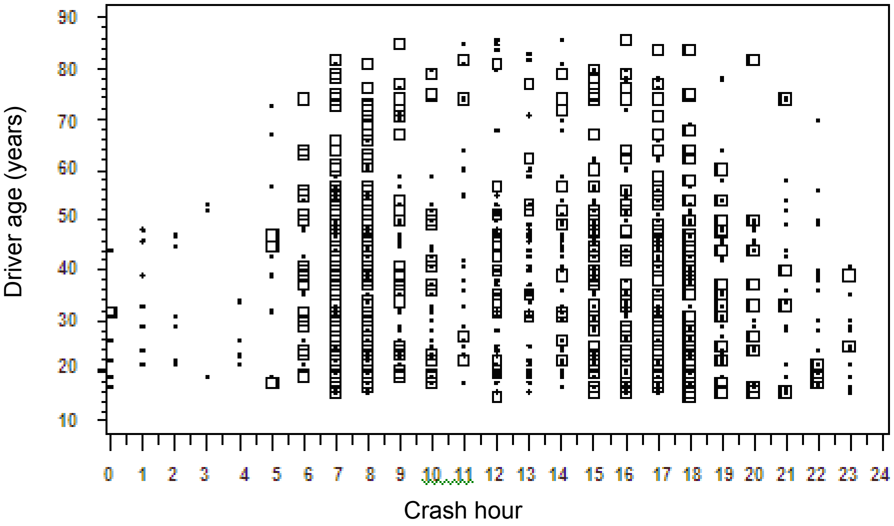


Figure 9 (a). 1,000 cases originally falling into glare (□) and no vision obstruction (•) groups.

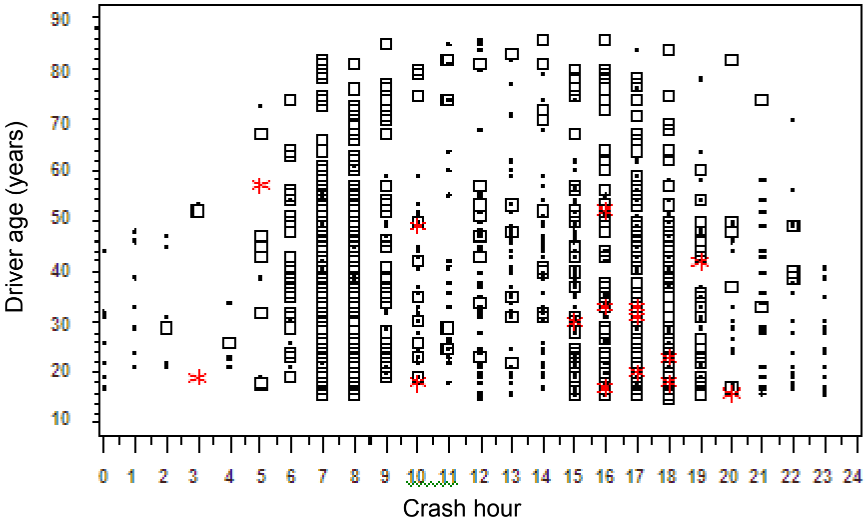


Figure 9 (b). 1,000 cases classified by classifier into glare (□) no vision obstruction (•) groups, and ties (*).

Figure 9. Comparison of original scatter of crash involved drivers as described by Driver age and Crash hour and the classification plot using15-nearest neighbors classifier based on Driver age, Crash hour, Travel speed, and Number of lanes.

7. Data Segmentation Based on Age and Sex in the Presence and Absence of Glare

In a crash system with its elements drivers, vehicles, and roadway, it is the driver who is affected first and directly by the glare resulting in the emergence of a crash scenario. The following analysis explores the driver attributes in conjunction with glare. Although contingency analysis of the crash data show that sex of the driver may not be a contributing factor in crash-involvement of drivers who are exposed to glare, an earlier study, by Singh and Perel [10] on glare perception of drivers based on the OSD opinion survey data, shows that the driver's perception of glare depends on both age and sex. Configural Frequency Analysis (CFA) is used to explore the crash data subspaces in which these factors have significant influence. The results are presented in Table 4, where the highlighted groups indicate the corresponding sex versus age groups for which the observed frequencies are significantly higher than the expected frequencies. These differences are significant at 99 percent level of confidence (after the a priori determined confidence level 95 percent is adjusted using Bonferroni adjustment [11]). These are the groups for which more-than-expected drivers are observed to have been involved in crashes.

Table 4. Observed and expected frequencies for data segments based on driver age and sex

VISION OBSTRUCTION	SEX	AGE GROUP	OBSERVED	EXPECTED	OBSRVD -EXPCTD	Z-VALUE
NO	MALE	**Below 19**	28793	26962	1831	11.15*
		19 - 24	32770	28229	4541	27.03*
		25 - 34	44536	42139	2397	11.67*
		35 - 44	40495	39415	1080	5.44*
		45 - 54	29515	32729	-3214	17.77
		55 - 64	19830	19542	288	2.06*
		65 - 74	10348	12746	-2398	21.24
		Above 74	9297	10652	-1354	13.12
	FEMALE	**Below 19**	22841	20846	1995	13.81*
		19 - 24	26592	23747	2845	18.46*
		25 - 34	33012	31258	1754	9.92*
		35 - 44	31290	32136	-846	4.72
		45 - 54	20003	23093	-3090	20.34
		55 - 64	8880	11674	-2794	25.86
		65 - 74	5324	6225	-901	11.42
		Above 74	5532	7665	-2133	24.37
GLARE	MALE	**Below 19**	21931	23762	-1831	11.88
		19 - 24	20337	24878	-4541	28.79
		25 - 34	34742	37138	-2396	12.43
		35 - 44	33657	34737	-1080	5.79
		45 - 54	32059	28845	3214	18.93*
		55 - 64	16935	17222	-287	2.19
		65 - 74	13630	11233	2397	22.62*
		Above 74	10742	9388	1354	13.98*
	FEMALE	**Below 19**	16377	18372	-1995	14.72
		19 - 24	18084	20929	-2845	19.67
		25 - 34	25794	27548	-1754	10.57
		35 - 44	29168	28322	846	5.03*
		45 - 54	23443	20352	3091	21.66*
		55 - 64	13083	10289	2794	27.55*
		65 - 74	6387	5486	901	12.16*
		Above 74	8889	6756	2133	25.96*

* significant at 99 percent confidence level
Data Source: GES 2000-2003

Specifically, the results show that more-than-expected male drivers of age below 45 years and female drivers below 35 years were involved in crashes due to factors other than glare. In contrast, older drivers in both sexes (males 45 and older and females 35 and older) were observed in crashes significantly more than expected when exposed to glare.

Based on these results, one may infer that male drivers 45 and older and female drivers 35 and older are more likely to be affected by glare. This finding is in agreement with the findings by McGwin et al. [2] based on experiments conducted to study the effect of glare on older drivers.

8. Summary and Conclusions

The results of this study based on the GES data indicate that glare from headlamps as well as sunlight is a contributing factor in crashes. These crashes show particular patterns with respect to driver, vehicle, and roadway. For example, in general, older drivers are more likely to get involved in crashes if glare obstructs their vision. Similarly, most of such drivers end up striking other vehicles, especially if the trafficway is not physically divided. Roadway profile plays a significant role in the occurrence of a glare-related crash, as does the number of lanes. The classifier based on driver age, crash hour, travel speed, and number of lanes could correctly classify 80 percent of the glare-related crashes. This shows that these variables have the potential to describe a glare-related crash, which in turn suggests how they may jointly contribute to the occurrence of a crash in a glare-caused driving scenario. However, the list of variables considered in this study is not exhaustive, and more research is required. Obviously, the intensity of light from headlamps can somehow be controlled, but not from the sun. So far as crash avoidance is concerned, when looking at the overall phenomenon and the distribution of crashes over a period of 24 hours in a day, it becomes clear that future efforts concerning glare should include both headlamps and sunlight. What is needed is a common approach to both headlamp and sunlight glare and develop counter measures to reduce glare before it strikes drivers' eyes.

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