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Effects of planar and non-planar driver-side mirrors on age-related discomfort-glare responses

Thurmon E. Lockhart[a,*], **Bunji Atsumi**[b], **Arka Ghosh**[a], **Haruetai Mekaroonreung**[a], and **Jeremy Spaulding**[a]

[a]Department of Industrial and Systems Engineering, Virginia Tech Blacksburg, VA, USA

[b]Toyota Motor Corporation, Japan

Abstract

In this study, we evaluated subjective nighttime discomfort-glare responses on three different types of planar and non-planar driver-side mirrors on two age groups. Fifty-six individuals (28 young [18–35 years] and 28 old [65 years and over]) participated in this experiment. Subjective discomfort-glare rating scores on three different types of driver-side mirrors were assessed utilizing De Boer's rating scale in a controlled nighttime driving environment (laboratory ambient illuminant level—l lux with headlight turned off). Three driver-side mirrors included planar “flat mirror”: radius of curvature 242650.92 mm, reflectivity 0.60114, and surface reflectance 0.60568; “curved mirror”: radius of curvature 1433.3 mm, reflectivity 0.21652, and surface reflectance 0.58092; “blue mirror”: radius of curvature 1957.1 mm, reflectivity 0.25356, and surface reflectance 0.54585. The results indicated that with the same glare level (as measured by angle of incidence and illuminance in front of the eyes), older adults reported worse feelings of glare than their younger counterparts. Furthermore, the results indicated that both young and older adults reported worse feelings of glare for planar driver-side mirror than non-planar driver-side mirrors. These results suggest that older adults' criterion of discomfort-glare is more sensitive than their younger counterparts, and importantly, the non-planar driver-side mirrors can be beneficial in terms of reducing nighttime discomfort-glare for both the young and the elderly.

Keywords

Reflected headlamp glare; Elderly driver; Nighttime discomfort glare; De Boer's rating score; Non-planar driver side mirror

1. Introduction

Our population is undergoing a rapid and significant change worldwide. In the US, population of older adults who are over 65 year of age is increasing, and is believed to double and reach 70 million by the year 2030 (Stutts, 2001). It has been suggested that elderly individuals aged 65 and above use their cars 80% of the time for their daily routine activities (Kosnik et al., 1988). Thus, the inability of an elderly individual to drive independently can be detrimental for his/her overall well-being. The society has to bear substantial cost and effort to provide care for the elderly individuals who lose mobility.

*Corresponding author. Address: The Grado Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, 250 Durham Hall, Blacksburg, VA 24061, USA. Tel.: +1 540 231 9088/6656; fax: +1 540 231 3322. lockhart@vt.edu (T.E. Lockhart)..

Studies suggest that elderly individuals are involved in greater number of crashes than the young or middle aged drivers (Stamatiadis and Deacon, 1995). Moreover, there is a greater likelihood for the elderly individuals to get killed or injured than their younger counterparts (Evans, 1988; Barancik et al., 1986). According to the US Department of Transportation (2000), older adults are nine times more likely to be involved in fatal accidents than drivers aged 25–69 years old. For example, in 2000, older adults made of 9% of the resident population accounted for 13% of all traffic fatalities and 17% of all pedestrian fatalities (Department of Transportation, 2000). Furthermore, in two-vehicle fatal crashes 27% of these accidents were attributed to the older driver who was turning left (i.e. lane change accidents).

One of the reasons cited for high crash rates of the elderly drivers is visual impairment (Shinar and Schieber, 1991). Studies suggest that elderly drivers with visual impairments have greater inclination in avoiding adverse driving conditions than those without visual defects (Ball et al., 1998; Owsley et al., 1999). Thus, it becomes imperative to investigate the debilitating effects of visual impairment on driving performance.

Light, when traverses the eye in a certain way, interrupts vision temporarily leading to glare (Corso, 1981). Glare is often experienced by drivers during nighttime driving conditions (i.e. a passing car's headlights shining into driver's eyes), and daytime driving conditions (sunlight shining directly into driver's eyes). Reduced contrast sensitivity and increased glare has been reported to be one of the primary problems hindering the safety and comfort of elderly drivers (Schieber et al., 1992). Specifically, headlamp glare has been reported to deteriorate visual performance under driving conditions in contrast to conditions without glare (Mortimer, 1969; Ranney et al., 1999, 2000; Akashi and Rea, 2001), and glare has been reported to have greater impact on visual performance of elderly subjects.

Aging leads to an increase in light scatter in the eyes (Rea, 2000; Block and Rosenblum, 1987). Additionally, minor opacities of the lens (Anderson and Holliday, 1995) in presence of glare leads to reductions in threshold contrast and visual acuity. The detrimental effects of glare are probably increased when light traversing the eye gets reflected off the ocular structures causing a decrease in the image sharpness on the retina (i.e. decreased contrast) (Owsley and Ball, 1993). Glare recovery time for 65-year-olds has been reported to be 9 s in comparison to 2 s for 25-year-olds (Corso, 1981). Elderly individuals in comparison to the young, need objects to be significantly brighter after they have experienced glare (Wolf, 1960). Thus, drivers who are 65 years of age or older would have greater difficulty driving after having headlights (or sunlight) shined into their eyes and would take longer to recover from the glare than younger drivers. Thus, the debilitating effects of glare are more visible in the case of elderly individuals as compared to the young (LeClaire et al., 1982; Wolf, 1960).

As indicated earlier, large portion of two-vehicle fatal crashed were attributed to the older drivers. Conventional planar mirrors, due to their comparatively larger blind spot may be one of the reasons for lane change accidents. Non-planar mirrors on the other hand, present a larger field of view which increase detection of vehicles and consequently reduce the risk of accidents. However, a slight distortion of image leading to reduced image size was reported in the case of non-planar driver side mirrors (Walraven, 1974). A survey of the literature indicate that not much research has been undertaken in the paradigm of reflective glare associated with planar and non-planar mirrors especially with elderly drivers. As such, this study investigated age-related nighttime reflected glare effects on subjective discomfort-glare response utilizing three different types of planar and non-planar driver side mirrors. The overall aim of the study was to recommend design guidelines from the purview of the elderly drivers addressing their needs and limitations and ultimately enhancing their comfort and safety. It is hypothesized that elderly individuals would experience less discomfort glare with non-planar mirrors than with planar mirrors.

2. Methods

2.1. Experimental design

Independent variables, age group (2 levels) and mirrors (3 levels) were investigated with dependent measures being angle, illumination when glare was felt and associated rating scores of glare feeling (utilizing De Boer chart). The dependent measures were analyzed using 2 × 3 (age × mirror) two-way repeated measures of analysis of variance (ANOVA) with $\alpha \leq 0.05$. The *p*-values in the ANOVA were adjusted for violations of assumptions regarding the variance–covariance matrix using the Huynh–Feldt method to estimate ε adjusting the degree-of-freedom accordingly.

2.2. Participants

Fifty-six participants (28 young, 28 old) were tested for the study. Younger participants (14 male, 14 female) were recruited from Virginia Tech student population while the elderly were recruited from the local Blacksburg Community. The mean age of the elderly participants was 73 years while that of younger individuals was 23 years. The recruitment of elderly participants was facilitated with some assistance from the Center of Gerontology at Virginia Tech. All of the participants were initially tested (screened) for their static visual acuity, and instructed to fill out a driving questionnaire detailing their driving behavior and disabilities. Participants were excluded from the study based on these tests (must have static visual acuity of 20/50 or better—corrected vision, and no known eye pathologies). All subjects signed a release form approved by Virginia Tech IRB. All participants were compensated for their time and effort.

2.3. Apparatus

HID head lamp was utilized as a glare source to focus on three different door mirrors (Table 1). Reflectance ratio is defined as a ratio of the reflected light intensity to the incident light intensity. A reflectance ratio is calculated by dividing the total reflected light by the total transmitted light given a particular angle, and multiplied by 100. "Blue mirror" is a mirrored surface which has been seen to reduce surface glare and heat. It blocks blue light and enhances the contrast of colored objects (design by Toyota). As seen in Fig. 1, the door mirror was placed 60 cm away from participant's eyes (line of sight direction) and 55 cm perpendicular to the line of sight on the right side of the participant. The mirror height was set at sitting eye height. The HID headlamp was placed at a distance of 270 cm from the mirror behind the participant. The door mirror and head lamp was positioned in the same horizontal line (equal to mirror height). A De Boer chart was used to assess subjective rating of the glare. A 9 point De Boer chart (De Boer, 1967) consists of numerical ratings assigned to subjective visual responses (Table 2)—in order to objectively assess the discomfort or disability glare and most often used in the field of automotive and public lighting systems (Theeuwes et al., 2002).

A distance of 120 cm was kept between the chart and participant's eyes.

The walls of the experimental room were covered with black cloth to simulate nighttime conditions. The ambient illuminant level (head lamp turn off) was set at 1 lux (measured horizontally with the aid of a light meter). The De Boer chart was placed in front, while the mirror stand was placed to the right of the participant (Fig. 1).

2.4. Procedure

The head lamp was positioned sideways, away from the participant's line of sight. It was ascertained that the subject could see the predetermined target on the side of enclosure in the middle of the mirror. The center of glare source was adjusted to the same height as the center of the target chart (De Boer rating scale). Subsequently, the participant's height was adjusted so that the visual angle for center of chart and glare source was 0°. The illuminance at the participant's eye and in front of the mirror was measured and recorded. The head lamp was gradually rotated towards the middle of the participant's eyes (i.e. lamp focus moving towards the mirror). The participants were given detailed instructions of the definitions of discomfort glare. Discomfort glare was defined as a point in time when they started to feel glare. The participant was instructed to respond by saying “yes” when they started to feel glare. The movement of the glare source was halted at this point. Illuminance was measured and recorded for both in front of the mirror and at the participant's eyes (in this paper, illuminance in front of the eyes is reported). The angle of HID headlamp (center of enclosure) to mirror was measured and the participant was asked to provide his subjective rating of the glare using De Boer chart. Similar procedures were followed for mirror II (i.e. “curved” mirror) and mirror III (i.e. “blue” mirror). The participants were given time to recover from the glare effect and order of presentation of the mirrors were completely randomized to reduce trial effects.

3. Results

As seen in Fig. 2, the results for angle differences ($F_{1,54}$=0.4264, p=0.5140) and illumination differences ($F_{1,54}$=0.7211, p=0.3958) between the age groups were not statistically significant. However, statistically significant differences were observed ($F_{1,54}$=48.262, p<0.0001) between the age groups on glare subjective rating responses.

The results also show statistically significant angle differences ($F_{2,165}$=13.8121, p<0.0001) among mirror types (flat vs. curved vs. blue). Overall, the blue mirror allowed the largest angle of headlamp (Fig. 3). Additionally, the results indicated statistically significant illumination differences ($F_{2,165}$=5.9570, p=0.0027) between different type of mirrors. In general, the curved mirror resulted in highest illumination level. The blue mirror resulted in slightly less illumination, while the flat mirror resulted in the lowest illumination. However, there were no statistically significant differences found ($F_{2,165}$=2.1686, p=0.1152) among three mirror types on glare subjective rating responses. Overall, the blue mirror yielded slightly better glare feeling than the curved mirror and flat mirror.

4. Discussion

Annoyance and discomfort caused due to glare is a common problem experienced by nighttime drivers. The present study attempted to explore reflected headlamp glare effects on age and mirror types. Our results indicate that both elderly and younger age groups stopped the headlamp at similar angles. These similar angles correspond to similar illumination in front of the participant's eyes for both age groups as well. However, the results indicated that with the similar glare level (as measured by angle and illuminance in front of the eyes), elderly individuals reported lower glare rating scores (i.e. worse feelings of glare). These findings suggest that elderly individual's criterion of glare is more sensitive than their younger counterparts. An individual's subjective glare rating has been seen to be highly related to his/her perceived criterion of discomfort (Theeuwes et al., 2002), while his/her subjective glare tolerance depended on age. Thus, the Wndings that elderly individuals stopped the headlamp at similar angles and intensities as compared to their younger counterparts, but with low glare ratings, is plausible.

The illuminance of a reflected glare is greatly affected by the angle of incidence (i.e. reflectance ratio). According to our results, elderly and younger age groups halted the headlamp at significantly different angles (across different mirrors). Additionally, illuminations in front of the participant's eyes were also different for each mirror type across all participants. This difference is mainly due to the measurements from the flat mirror versus both the “curved” and the “blue” mirror. In general, the “blue” mirror accounted for the largest angle of the headlamp (suggesting better reflection), the “curved” mirror resulted in slightly less angle, while the “flat” mirror resulted in the smallest angle. However, possibly due to an effect from the difference in reflectivity, the illumination measured at the participant's eyes for “curved” mirror was found to be higher than the one from “blue” mirror, whereas the angle was smaller. Results indicate that although there were differences between mirrors (angles), individuals seem to have consistently stopped the headlamp at the similar level of discomfort among all trials, thus subjective response across mirror type was expected to be insignificant. This is supported by the fact that the participants stopped the headlamp at similar levels of discomfort for the different trials. In conclusion, the results indicate that with the similar glare level (as measured by angle of incidence and illuminance on the front of the eyes), elderly reported lower De Boer's rating scores (i.e. worse feelings of glare) than their younger counterparts.

Furthermore, the results also show that both young and elderly individuals reported lower De Boer's rating scores (i.e. worse feelings of glare) for planar driver-side mirror (i.e. “flat” mirror) than non-planar driver-side mirrors (i.e. “curved” and “blue” mirrors). These findings suggest that elderly individuals' criterion of discomfort-glare is more sensitive than their younger counterparts, and importantly, the non-planar driver-side mirrors can be beneficial in terms of reducing nighttime discomfort-glare for both the young and the elderly. Although implicated, due to the high between-subject variations in subjective rating scores (Berman et al., 1994; Theeuwes et al., 2002), and rating score dependence on task difficulty, further studies exploring the effects of glare levels on light intensity utilizing objective performance measures (e.g., contrast sensitivity, and visual acuity at that intensity of the light, and electromyography [EMG]) are needed to elucidate this possibility.

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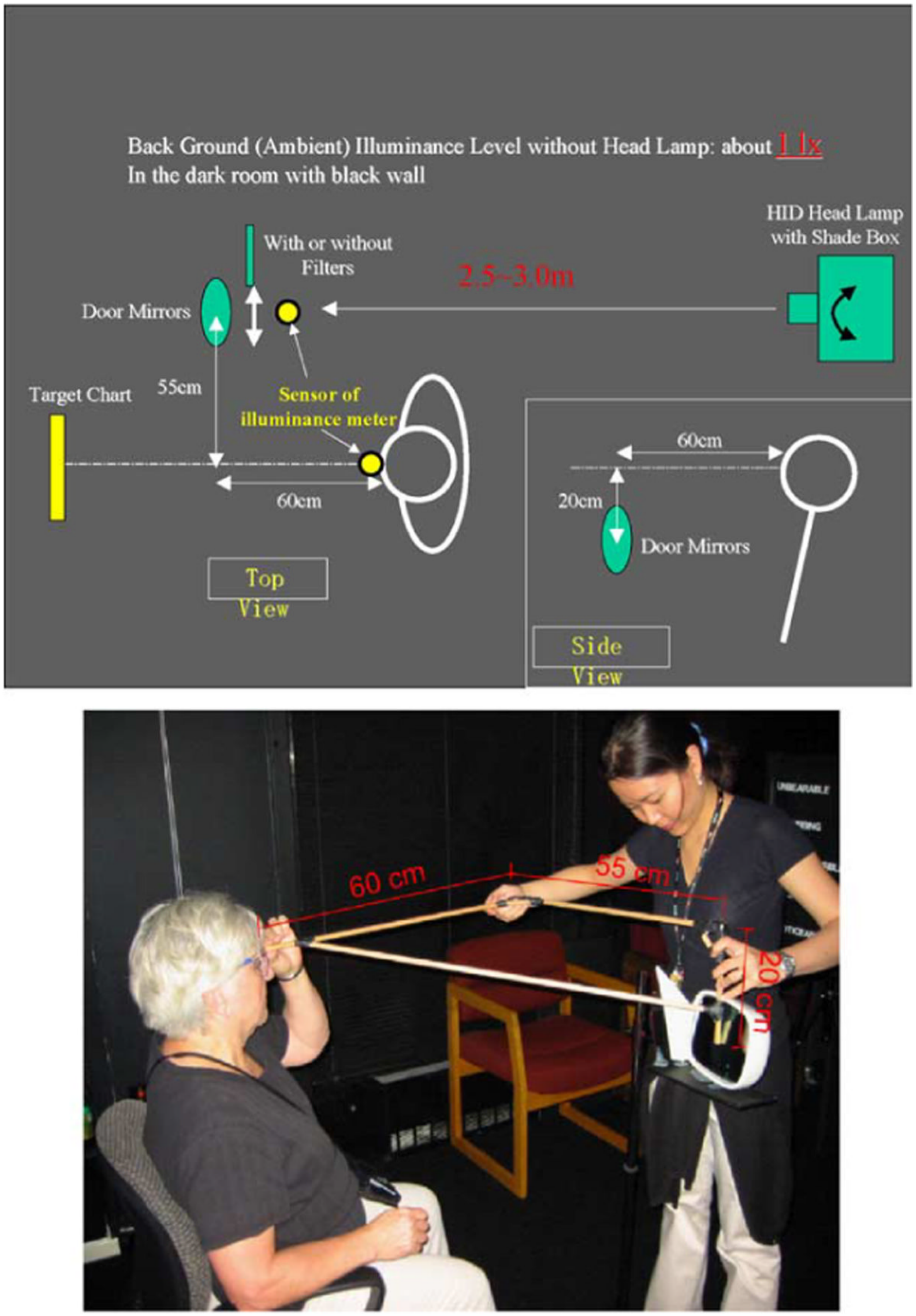

Fig. 1.
Experimental setup for the reflected glare study for nighttime condition.

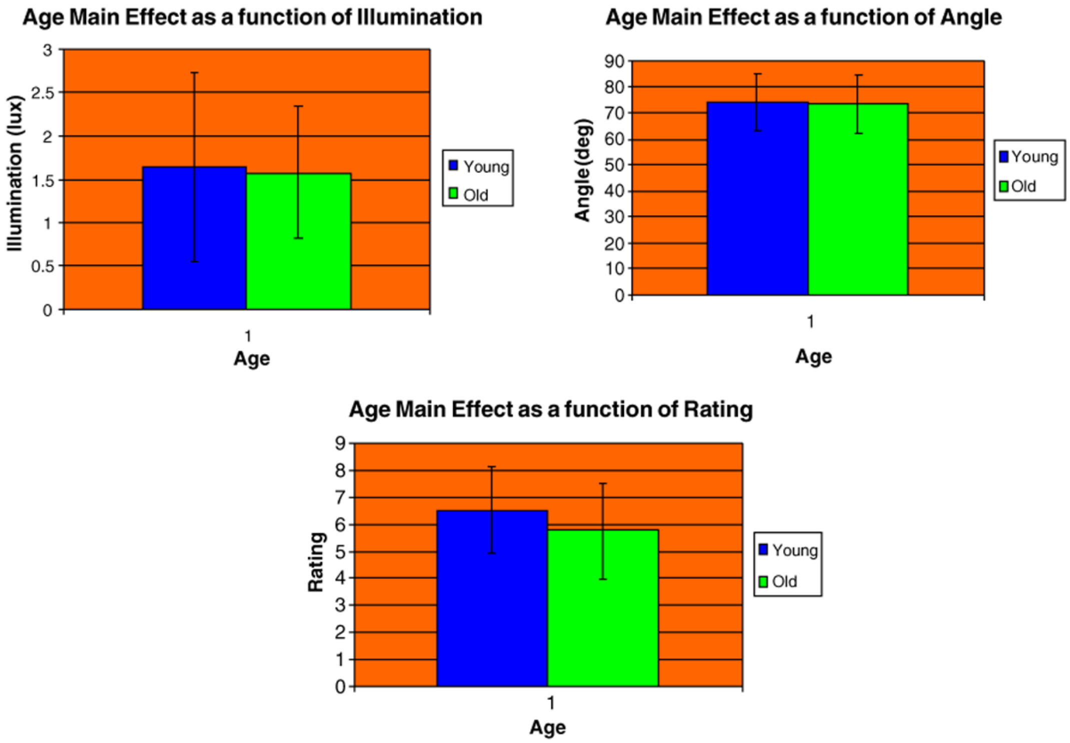

Fig. 2.
Age main effect as a function of illumination, angle and rating.

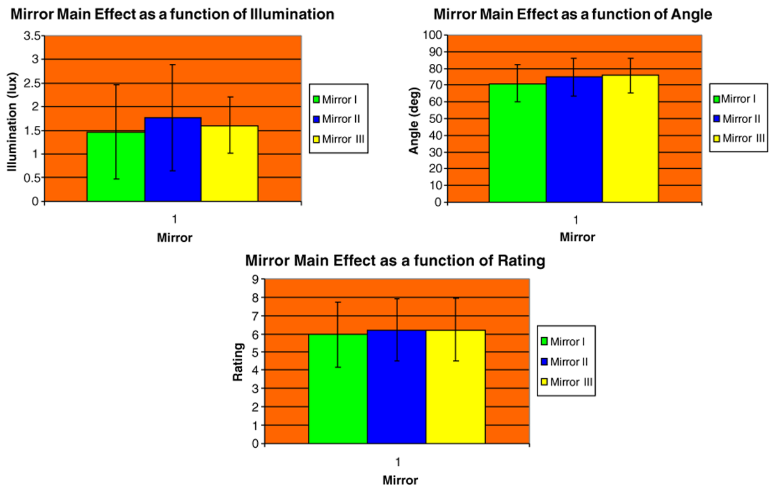

Fig. 3.
Mirror main effect as a function of illumination, angle and rating.

Table 1

Radius of curvature, reflectivity, and surface reflectance of three door mirrors tested in this experiment

Mirror	Types	Radius of curvature (mm)	Reflectivity	Surface reflectance
I	Flat	242650.92	0.60114	0.60568
II	Aspheric (Blue)	1433.3	0.21652	0.58092
III	Aspheric (Curved)	1957.1	0.25356	0.54585

Table 2

The De Boer rating scale

Visual response	Rating
Unnoticeable	9
	8
Satisfactory	7
	6
Just admissible	5
	4
Disturbing	3
	2
Unbearable	1