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# BMJ Open

## A population-based case-control study of the effect of sun glare on pedestrian fatalities in Taiwan

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Manuscripts

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4 **1 A population-based case-control study of the effect of sun glare on pedestrian**  
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7 **2 fatalities in Taiwan**  
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10 Chih-Wei Pai<sup>a</sup> \*

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12  
13 <sup>a</sup> Graduate Institute of Injury Prevention and Control, College of Public Health, Taipei  
14  
15  
16 Medical University, Taiwan ROC  
17

18  
19 \* Corresponding author  
20

21  
22 Email: [cpai@tmu.edu.tw](mailto:cpai@tmu.edu.tw)  
23

24  
25 +886 02-27361661 ext.6575  
26

27  
28 Address: Graduate Institute of Injury Prevention and Control, College of Public  
29

30  
31 Health, Taipei Medical University, 250 Wuxing St, Taipei City, Taiwan 110.  
32  
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37 **Word count: 4416**  
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42  
43 **Abstract**  
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45  
46 **Introduction**  
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48  
49 Sun glare poses serious driving hazards and increases accident risks. Relatively few  
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52 studies, however, have been conducted to examine the effects of sun glare on  
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55 pedestrian fatalities, given that an accident has occurred.  
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57  
58 **Objectives**  
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4 20 The primary objective of this study was to investigate the effect of sun glare on  
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7 21 pedestrian fatalities.  
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## 10 22 **Methods**

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13 23 Using the Taiwan National Traffic Crash Data and sunrise and sunset data from the  
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15  
16 24 National Oceanic and Atmospheric Association (NOAA) for the period 2003–2016,  
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18  
19 25 this study investigated whether sun glare results in pedestrian fatalities resulting from  
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22 26 motor vehicle crashes. Pedestrian crashes were classified into glare-related (case) and  
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24  
25 27 nonglare-related crashes (control). To account for unobserved heterogeneity, mixed  
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27  
28 28 logit models were estimated to identify the determinants of pedestrian fatalities  
29  
30  
31 29 specifically in sun-glare-related crashes.  
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## 34 30 **Results**

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36  
37 31 Of the 100,411 pedestrians involved in crashes during 2003–2016, 13,355 and 87,056  
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39  
40 32 cases of glare-related and nonglare-related crashes, respectively, were reported.  
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42  
43 33 Pedestrians involved in glare crashes tended to be more fatally injured than those in  
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45  
46 34 nonglare crashes. Other contributory factors to fatal injuries among pedestrians were  
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48  
49 35 older pedestrians, male drivers, older drivers, intoxicated motorists, rural roadways,  
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51  
52 36 car overtaking manoeuvres, a heavy vehicle as the crash partner, and sunset hours.  
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55 37 Walking against traffic appeared to be beneficial in decreasing injury severity.  
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## 58 38 **Conclusions**

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4 39 Sun glare was associated with pedestrian fatalities. Older pedestrians, male drivers,  
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6  
7 40 older drivers, and intoxicated motorists were prevalent determinants of pedestrian  
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9  
10 41 fatalities in glare-related crashes.  
11  
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13 42 **Keywords:** Sun glare; Pedestrian fatalities; Crashes; Injury  
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16 43

#### 19 44 **Strengths and limitations of this study**

- 22 45 ● This is a comprehensive study using the linked data from the two datasets.
- 23  
24 46 ● Our results derived from the linked datasets can be more reliable than those  
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28 47 using a single database alone.
- 29  
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31 48 ● Limitations of this study include the data that are unavailable from the two  
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34 49 datasets such as geographic characteristics.  
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#### 43 52 **Introduction**

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49 54 Driving is a highly visual task that involves visual function and processing for  
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52 55 establishing the effective control over a vehicle.<sup>1</sup> Research<sup>2 3</sup> has suggested that bright  
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55 56 sunlight was ideal for driving because it increases the contrast, resolution, and  
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58 57 luminosity of the surrounding landscapes. As a result, drivers may misinterpret the  
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4 58 speed at which the surrounding landscape is approaching and gauge their travel  
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7 59 velocity to be illusively slow, which would in turn prompt drivers to compensate by  
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10 60 accelerating.<sup>4,5</sup>  
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13 61 Generally, bright sunlight causes temporary blindness when the sun is at a  
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16 62 relatively low altitude and its rays fall directly in an individual's line of sight (e.g.,  
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19 63 just after sunrise or before sunset when the sun is above the horizon). By using a  
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22 64 simulator, Gray and Regan<sup>6</sup> assessed the driving performance in both the absence and  
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25 65 presence of a simulated low sun. They reported that sun glare resulted in a significant  
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28 66 reduction in the safety margin accepted by drivers; the mean number of crashes was  
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31 67 significantly higher during conditions of glare than during those of without glare, and  
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34 68 older drivers exhibited a significantly greater reduction in the safety margin than did  
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37 69 younger drivers. Another simulation study was conducted by Theeuwes et al.<sup>7</sup>, who  
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40 70 reported that low glare sources resulted in participants (drivers) exhibiting a  
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43 71 significant drop in the ability to detect simulated pedestrians along the roadside.  
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45  
46 72 Theeuwes et al.<sup>7</sup> also pointed out that older participants reduced their driving speed  
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48  
49 73 the most and exhibited the largest drop in successful pedestrian detection.  
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52 74 Churchill et al.<sup>8</sup> employed a geometric model for examining whether sun glare  
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55 75 affects the speeds of drivers on roadways and concluded that changes in speed as a  
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58 76 result of sun glare was a factor in highway congestion. Jurado-Piña and Pardillo  
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4 77 Mayora<sup>9</sup>, in an attempt to investigate the maximum tolerable sun glare caused by the  
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7 78 angle between the sun and driving direction, pointed out that glare occurs when there  
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10 79 is a specific angular distance between the driver's line of sight and the sun; this  
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12  
13 80 angular distance is 19° for a 40-year-old driver and 25 ° for a 60-year-old driver.  
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15  
16 81 Anue<sup>10</sup> suggested that in general no sun glare occurs if the angular distance is greater  
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19 82 than 25°.

22 83 Several studies have investigated whether a direct relationship exists between sun  
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24  
25 84 glare and crashes by using data from police report or hospital. In a longitudinal study  
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28 85 of patients who had been hospitalised as a consequence of a motor-vehicle crash,  
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31 86 Redelmeier and Raza<sup>11</sup> concluded that bright sunlight was associated with an  
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34 87 increased risk of life-threatening motor-vehicle crashes in Canada. By analysing  
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37 88 police-reported crash data from Arizona, Mitra and Washington<sup>12</sup> indicated that sun  
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40 89 glare was a crucial omitted variable that could explain intersection crash occurrence  
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43 90 and that including this variable improved the explanatory power of statistical models.  
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45  
46 91 By linking police-reported crash data from Arizona with sunrise and sunset data from  
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48  
49 92 NOAA, Mitra<sup>3</sup> concluded that the odds of glare causing a crash were higher at  
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51  
52 93 intersections with roadways running eastbound and westbound than at those running  
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55 94 northbound and southbound. Mitra<sup>3</sup> further indicated that rear-end and angle crashes  
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58 95 at signalised intersections were affected by sun glare, and, furthermore, the severity of  
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4 96 motorist injury was unaffected by sun glare. A study that analysed traffic-accident  
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7 97 database of Chiba, Japan, Hagita and Mori<sup>13</sup> revealed a higher occurrence of crashes  
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9  
10 98 involving pedestrians or bicycles at intersections where the sun was below 45° above  
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12  
13 99 the horizon in the driving direction. Sun et al.<sup>14</sup>, who analysed police-reported crash  
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16 100 data in Edmonton, Canada, reported similar findings, concluding that sun glare  
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19 101 significantly contributed to crash occurrence, especially at intersections. Furthermore,  
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22 102 they also indicated that the effect of sun glare on crash occurrence during the  
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25 103 mornings on eastbound roads and evenings on westbound roads was significantly  
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28 104 greater during the spring and autumn months and that certain crash types (e.g., crashes  
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31 105 related to signal violation, failure to yield to pedestrians/cyclists, improper turning,  
32  
33  
34 106 and lane changing) were more likely to occur during periods of sun glare. By  
35  
36  
37 107 analysing police-reported crash data, Choi and Singh<sup>15</sup> pointed out that elderly  
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40 108 motorists tended to have a greater propensity for striking other vehicles in conditions  
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43 109 of sun glare, especially on roadways that were not physically divided.

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46 110 Based on our literature review, a significant gap remains in the comprehensive  
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49 111 understanding of the relationship between sun glare and pedestrian fatalities,  
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52 112 conditioned on that a pedestrian crash has occurred. The primary research hypothesis  
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55 113 of the present study is that pedestrian injury severity increases in accordance with  
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58 114 restricted visibility (i.e., sun glare). As a result, the primary aim of this study was to  
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4 115 investigate whether sun glare is associated with pedestrian fatalities. This study also  
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7 116 aimed to investigate the determinants of pedestrian fatalities specifically in crashes  
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10 117 related to sun glare.

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## 16 119 **Materials and Methods**

### 19 120 *Data source*

22 121 By using the Taiwan National Traffic Crash Data as well as sunrise and sunset data  
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25 122 from the National Oceanic and Atmospheric Association (NOAA) for the period from  
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28 123 2003 to 2016 (National Oceanic Earth System Research Laboratory and Atmospheric  
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31 124 Administration<sup>16</sup>. Accessed: 2018-08-22), the current study examined the effect of  
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34 125 sun glare on pedestrian fatalities, given that an accident involving a vehicle and  
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37 126 pedestrian has occurred. The Taiwan National Traffic Crash Data comprise two files:  
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40 127 an accident file and a vehicle and victim file. Accident files contain general  
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43 128 information on the times and dates of crashes; weather, road; and lighting conditions,  
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46 129 and road type. Vehicle and victim files contain vehicle-related information, such  
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49 130 vehicle type, manoeuvres, first point of impact, and orientation, as well as driver and  
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52 131 casualty characteristics, such as age, sex, and injury severity. Injury severity is  
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55 132 classified into two levels: fatality and injury. Victims who die within 24 h as a result  
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58 133 of an accident are classified as cases of fatality, whereas victims who sustain injuries,

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4 134 whether mild or severe, are classified as cases of injury.  
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7 135 Data on daily sunrise and sunset times and orientation are available from the  
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10 136 NOAA. The information on the sunrise and sunset orientation for Taiwan is presented  
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12  
13 137 in online supplementary appendix 1. By using the data on the temporal characteristics  
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15  
16 138 (i.e., time and date) and orientation of vehicle crashes from the Taiwan National  
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19 139 Traffic Crash Data, pedestrian crashes were matched with the sunrise and sunset data  
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22 140 of the NOAA and subsequently classified into glare-related or nonglare-related  
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25 141 crashes.  
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31 143 A glare-related crash is defined as a crash in which the following conditions are  
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34 144 satisfied: the car was travelling in a direction towards the sunrise or sunset, and the  
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37 145 angular distance between the driver's line of sight and the sun was between  $0^{\circ}$  and  
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40 146  $45^{\circ}$ . The angular distances were adjusted according to the time of the crash (available  
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42  
43 147 from the National Traffic Crash Dataset) and daily sunrise and sunset times daily  
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46 148 (available from the NOAA). For example, a crash in which a car driver headed  
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49 149 northeast collided with a pedestrian at 06:18 (A.M.) on 18 June, 2016, was classified  
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52 150 as a glare-related crash. Notably, the angular distances, ranging from  $0^{\circ}$  to  $45^{\circ}$ , were  
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55 151 reported<sup>13</sup> to cause sun glare and potentially affect on traffic safety. We therefore  
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58 152 adopted the angular distance, range of  $0-45^{\circ}$ , as the threshold for defining a  
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4 153 glare-related crash.  
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7 154 A flow-chart of the sample selection from the Taiwan Traffic Crash Dataset for the  
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10 155 period from 2003 to 2016 is presented in online supplementary Appendix 2. A total of  
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13 156 195,258 pedestrian casualties from traffic crashes were extracted from during this  
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16 157 period. This study focused on pedestrian crashes where the crash partner was a  
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19 158 motorcycle, car, taxi, heavy-goods vehicle, bus, or coach. Crashes that occurred  
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22 159 during adverse weather conditions, such as rain or fog, were excluded (n = 45,712). A  
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25 160 total of 917 cases had missing data with regard to accident date and time and vehicle  
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27  
28 161 orientation. Because these cases (adverse weather conditions and missing data) were  
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31 162 not mutually exclusive, the total number of cases excluded was 45,365, yielding a  
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33  
34 163 total of 149,839 valid cases for pedestrian casualties. These valid cases were matched  
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36  
37 164 with the NOAA sunrise and sunset data. After excluding crashes that had occurred  
38  
39  
40 165 before sunrise and after sunset (n = 49,428), 100,411 cases of pedestrian casualties  
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42  
43 166 remained. Of the 100,411 pedestrians that were matched with the sunrise and sunset  
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46 167 data from the NOAA, 13,355 were glare-related cases (treated as cases), and 87,056  
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49 168 were nonglare-related cases (treated as controls), respectively.

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4 175 *Definition of variables*  
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10 177 The following demographic data were collected for casualties: sex, age (four  
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13 178 groups: <18, 18–40, 41–64, and  $\geq 65$  years), alcohol use (yes: breathalyser test results  
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15  
16 179  $\geq 0.15$  mL/L or blood-alcohol consumption [BAC] level  $> 0.03\%$ ; no: breathalyser  
17  
18  
19 180 test results  $< 0.15$  mL/L or BAC level  $\leq 0.03\%$ ), licence status (licensed: with a valid  
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22 181 licence; or unlicensed: without a valid licence), and pedestrian crossing manner  
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25 182 (facing traffic: pedestrians walking towards traffic; back to traffic: pedestrians  
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28 183 walking back to the traffic; crossing: pedestrians crossing the street). In Taiwan, those  
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31 184 under the age 18 are identified as teenagers who are unable to legally ride motorcycles  
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34 185 or drive car. Those aged 65 years or older were identified as the elderly individual.  
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37 186 For individuals aged 18–40 and 41–64, we classified the remaining ages into two even  
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40 187 age intervals. BAC data were obtained by police who conducted breathalyser tests or  
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43 188 followed up for blood tests at hospitals. According to Taiwanese law, drivers with  
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46 189 either breathalyser test  $\geq 0.15$  mL/L or BAC level  $> 0.03\%$  were considered to be  
47  
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49 190 drunk-driving. Data from breathalyser tests or BAC levels were available only for  
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51  
52 191 motorists not for pedestrians because, by law, only motorists involved in crashes are  
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55 192 mandated to be tested for alcohol consumption.  
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58 193 The vehicle attribute considered was the crash partner (motorcycle, car, taxi, and  
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4 194 heavy vehicles such as buses and coaches). The following road factors were  
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7 195 considered: sun glare (yes: affected by sun glare; no: unaffected by sun glare) and  
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10 196 crash location (rural: roadways with speed limits of  $\geq 51$ km/h, and urban: roadways  
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13 197 with speed limits of  $\leq 50$ km/h). Two temporal factors, month of the crash  
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16 198 (spring/summer: March–August or autumn/winter: September–February) and days of  
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19 199 crash (weekday: Monday–Friday or weekend: Saturday–Sunday) were examined.  
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25 201 *Statistical analysis*  
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31 203 The distribution of pedestrian injury severity according to a set of variables (e.g.,  
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34 204 human attributes, environmental factors, and vehicle characteristics) is reported in this  
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37 205 study. Chi-square tests were conducted to examine the association between the  
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40 206 independent variables and pedestrian injury severity. Because the dependent variable  
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43 207 was binary (fatal vs. injury), the binary mixed logit models, which allow parameter  
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46 208 coefficients to have distribution rather than fixed across the individuals, were  
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49 209 estimated. Using the chi-square tests, the variables discovered to be significantly  
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52 210 associated with the outcome ( $p < 0.2$ ) were then incorporated into the multivariate  
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55 211 mixed logit models. To detect the multi-collinearity among the variables (all  
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58 212 categorical), a chi-square independent test was conducted and Cramer's  $V^{17}$  was  
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4 213 estimated. To determine whether sun glare was associated with pedestrian fatalities,  
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7 214 one overall model that includes sun glare as one of the variables was utilised. One  
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10 215 additional model was subsequently estimated to investigate the determinants of  
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13 216 pedestrian fatalities, specifically in sun-glare-related crashes.

16 217 Mixed logit models were estimated to account for unobserved heterogeneity that  
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19 218 may have arisen as a consequence of unmeasured variables, such as risk perception,  
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22 219 behavioural factors, and other socioeconomic factors not available in the crash data  
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25 220 from police reports. One example of a behavioural factor is distraction by phone use  
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28 221 that may result in risk-taking inclinations and consequently an increased risk of  
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31 222 injury.<sup>18 19</sup> Ignoring the effects of unobserved variables may lead to inconsistent  
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34 223 estimates in non-linear models.<sup>20</sup>

37 224 In the present study, the utility of the injury severity  $i$  for a crash  $n$  is defined as  
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40 225 follows:

43 226 
$$IS_{in} = \beta_n^i X_{in} + \varepsilon_{in} \quad \text{Eq. (1)}$$

46 227  
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48  
49 228 where  $IS_{in}$  is an injury-severity function determining the injury-severity category  $n$   
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51  
52 229 (fatal or injury) for an individual pedestrian  $i$ ,  $X_{in}$  is a vector of the observed  
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55 230 variables, such as pedestrian and driver attributes, vehicle characteristics, and  
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58 231 environmental or temporal variables,  $\beta_n$  is a vector of the parameters associated  
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4 232 with  $X_{in}$ , and  $\varepsilon_{in}$  is the error term. The mixed logit model uses  $\beta_n$  as a vector of  
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7 233 estimable parameters for the discrete outcome  $n$ , which varies across the observed  
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10 234 pedestrians. The variation is observed with density  $f(\beta|\theta)$ , where  $\theta$  is a vector of  
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13 235 the parameters of the density distribution. In most applications, mixed models specify  
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16 236 that the density  $f$  has a continuous distribution, such as a normal, lognormal,  
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19 237 triangular, or uniform distribution.

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21  
22 238 Given error terms that are independent and identically Gumbel distributed<sup>21</sup>, the  
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25 239 unconditional probability of one alternative  $n$  (from the set of injury-severity  
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27  
28 240 categories  $I$ ) is the integral of the conditional probability with a multinomial logit  
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30  
31 241 form over the parameter  $\beta$  of density  $f$ :

$$242 \quad P_{in} = \int \left( \frac{\exp(\beta' X_{in})}{\sum_l \exp(\beta' X_{il})} \right) f(\beta|\theta) d\beta \quad \text{Eq. (2)}$$

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41 244 All parameters are first assumed to be random and then their estimated standard  
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44 245 deviations are evaluated using a zero-based (asymptotic)  $t$ -test for each parameter.  
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46  
47 246 One study<sup>20</sup> pointed out that a simulation-based maximum likelihood with 200 Halton  
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50 247 draws may provide a more efficient distribution of draws for numerical integration  
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52  
53 248 and requires fewer draws to achieve convergence. Attempts were made in the present  
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56 249 study to obtain more significant results by increasing the number of Halton draws, and  
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58  
59 250 the results appeared stable with the use of 1000 Halton draws.

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4 **251 Results**  
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10 **253** Table 1 lists the distribution of pedestrian injury severity according to a set of  
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13 **254** variables. Of the 13,355 glare-related cases, 329 pedestrians (2.46%) sustained fatal  
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16 **255** injuries, which is higher than those in nonglare-related crashes (1.83%). Additionally,  
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19 **256** the majority of pedestrian crashes involved motorists with valid licences (85.65%),  
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22 **257** sober motorists (85.97%), urban roadways (89.57%), pedestrians who were hit while  
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25 **258** crossing the street (65.85%), and nonglare conditions (86.70%) and occurred on  
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28 **259** weekdays (74.83%).  
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30 **260**

31 **261** Table 1: Distribution of pedestrian injury severity according to a set of variables for  
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33 **262** the period 2003–2016.  
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	N	Fatal n(%)	Injury n(%)	$\chi^2$ test p-value
Total	100411	1925(1.92)	98486(98.08)	
Sun glare				
Yes	13355(13.30)	329(2.46)	13026(97.54)	<0.01
No	87056(86.70)	1596(1.83)	85460(98.17)	
Pedestrian gender				
Male	50942(50.73)	1015(1.99)	49927(98.01)	0.08
Female	49469(49.27)	910(1.84)	48559(98.16)	
Driver gender				<0.01
Male	53351(53.13)	1132(2.12)	52219(97.88)	
Female	47060(46.87)	793(1.69)	46267(98.31)	
Pedestrian age				
<18	3644(3.63)	67(1.84)	3577(98.16)	<0.01
18-40	25851(25.75)	154(0.60)	25697(99.40)	
41-64	31283(31.15)	352(1.13)	30931(98.87)	
≥65	39633(39.47)	1352(3.41)	38281(96.59)	



	N	Fatal n(%)	Injury n(%)	$\chi^2$ test p-value
<b>Driver age</b>				
<18	4458(4.44)	103(2.31)	4355(97.69)	<0.01
18-40	25808(25.70)	295(1.14)	25513(98.86)	
41-64	32523(32.39)	474(1.46)	32049(98.54)	
$\geq 65$	37622(37.47)	1033(2.75)	36589(97.25)	
<b>Driver licence</b>				
Licensed	86007(85.65)	1609(1.87)	84398(98.13)	0.01
Unlicensed	14404(14.35)	316(2.19)	14088(97.81)	
<b>Alcohol use for driver</b>				
No	86322(85.97)	1512(1.75)	84810(98.25)	<0.01
Yes	14089(14.03)	413(2.93)	13676(97.07)	
<b>Months</b>				
Spring/summer	47671(47.48)	914(1.92)	46757(98.08)	0.99
Autumn/winter	52740(52.52)	1011(1.92)	51729(98.08)	
<b>Crash location</b>				
Rural	10475(10.43)	352(3.36)	10123(96.64)	<0.01
Urban	89936(89.57)	1573(1.75)	88363(98.25)	
<b>Crash partner</b>				
Motorcycle	33221(33.09)	643(1.94)	32578(98.06)	<0.01
Car	45963(45.77)	801(1.74)	45162(98.26)	
Taxi	9655(9.62)	208(2.15)	9447(97.85)	
Heavy vehicles	11572(11.52)	356(3.08)	11216(96.92)	
<b>Pedestrian's movement</b>				
Facing traffic	9704(9.66)	172(1.77)	9532(98.23)	<0.01
Back to traffic	24584(24.48)	623(2.53)	23961(97.47)	
Crossing	66123(65.85)	1130(1.71)	64993(98.29)	
<b>Car's manoeuvre</b>				
Straight	50836(50.63)	862(1.70)	49974(98.30)	<0.01
Changing lane	15625(15.56)	257(1.64)	15368(98.36)	
Overtaking	21339(21.25)	601(2.82)	20738(97.18)	
Turning	12611(12.56)	205(1.63)	12406(98.37)	
<b>Weekdays</b>				
Weekday	70366(70.08)	1267(1.80)	69099(98.20)	<0.01
Weekend	30045(29.92)	658(2.19)	29387(97.81)	

263

264 Using chi-square tests, the following variables were determined to be significantly

265 associated with the outcome: sun glare; pedestrian and driver sex and age; driver  
 266 license possession, alcohol consumption; crash month, location, and partner;  
 267 pedestrian movement; car manoeuvre; and day of the week. These factors were then  
 268 incorporated into the mixed logit models.

269 Table 2 presents the estimation results of the mixed logit model of pedestrian injury  
 270 severity. Parameters that were determined to be random were those that produced  
 271 statistically significant standard errors for the assumed distributions; in this study,  
 272 random parameters were male motorists and heavy vehicle as crash partners, with a  
 273 uniform distribution that appears to provide the best statistical fit.

274  
 275 Table 2: Mixed logit estimation results for pedestrian injury severity during the period  
 276 2003–2016<sup>a</sup> (n = 100,411).

Variable	Parameter	Standard error	<i>t</i> -value
Fatal injury			
Fixed parameter			
Constant	−0.531	0.215	−2.47
Sun-glare-related crash	0.527	0.164	3.21
Pedestrians facing traffic	−0.304	0.110	−2.76
Pedestrians aged 65+	0.553	0.237	2.33
Motorists aged 65+	0.218	0.102	2.14
Rural roadways	0.985	0.251	3.92
Intoxicated motorist	0.606	0.213	2.85
Weekend	0.134	0.053	2.53
Car overtaking manoeuvre	0.472	0.132	3.58
Random parameter			
Male motorists			
Standard deviation of distribution	0.360	0.116	3.10
Male motorists			

Standard deviation of distribution	0.467	0.173	2.70
Restricted log-likelihood (constant only): -8,116.7			
Log-likelihood at convergence: -5,867.2			
$\rho^2 = 0.277$			

277 <sup>a</sup> The outcome “injury” is the baseline case with its parameters set at zero.

278

279 Considering the results listed in Table 2, sun-glare-related crashes was found to be  
 280 significant, and the estimated parameter was fixed across the observed pedestrians  
 281 (the standard error for this parameter, when allowed to be random, was statistically  
 282 nonsignificant). The parameter implies that sun a sun-glared-related crash was more  
 283 likely to result in fatal injuries among pedestrians than a nonglare-related crash. Other  
 284 factors discovered to have fixed effects on observed pedestrians and increase the  
 285 likelihood of fatal injuries were pedestrians aged 65 or older, motorists aged 65 years  
 286 or older, rural roadways, intoxicated motorist, weekend, and car overtaking  
 287 manoeuvre.

288 The parameter for the variable of male motorist appeared to be random, with a  
 289 uniform distribution with a mean of 0 and standard deviation of 0.360 (see Table 2),  
 290 indicating that individual pedestrians being struck by male motorists had different  
 291 parameters. Given the estimates (a mean of 0 and standard deviation of 0.360),  
 292 approximately half of all pedestrians have a higher probability of sustaining fatal  
 293 injuries when all other variables remain constant. Another parameter found to have a  
 294 nonlinear effect across the sample of pedestrians was the variable of a heavy vehicle

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4 295 as the crash partner (with a uniform distribution). This parameter had a mean of 0 and  
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7 296 standard deviation of 0.467 (see Table 2), indicating that individual pedestrians struck  
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10 297 by heavy vehicles have different parameters, with half of the distributions resulting in  
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13 298 a positive parameter (increasing the likelihood of fatal injuries) and half resulting in  
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16 299 negative parameter (decreasing the likelihood of fatal injuries). The non-uniformity of  
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19 300 the effects of male motorists and heavy vehicles is likely a consequence of other  
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22 301 unmeasured factors, such as driver experiences; for some male drivers or more  
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25 302 experienced drivers operating heavy vehicles (factors would reduce the effect of sun  
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28 303 glare), injuries sustained by pedestrians were likely to be minor once a crash had  
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31 304 occurred.

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34 305 The movement of pedestrians towards traffic was also discovered to be  
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37 306 significantly affect pedestrian fatalities. This fixed parameter suggests that pedestrians  
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40 307 who faced traffic while walking were less likely to sustain fatal injuries than those  
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43 308 undertaking other movements, such as walking back to traffic or crossing the street.

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46 309 Table 3 presents the estimation results of the mixed logit model of pedestrian injury  
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49 310 severity specifically in sun-glare-related crashes. For this model, the only random  
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52 311 parameter (with a uniform distribution) was significant for the variable of heavy  
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55 312 vehicle as the crash partner. The heterogeneous effect indicates that certain crashes  
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58 313 involving heavy vehicles were associated with both higher and lower likelihoods of  
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4 314 pedestrians sustaining fatal injuries. We speculate that this heterogeneous effect may  
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7 315 be caused by variance in the experience level among certain driver groups, with more  
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10 316 experienced drivers exhibiting a decreased likelihood of causing fatal injuries. In  
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13 317 other words, heavy vehicles are normally operated by professional drivers, with the  
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16 318 majority of drivers in this group being men and middle-aged or older individuals. To  
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19 319 confirm this speculation, the interaction between the variable of heavy vehicle and  
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22 320 other variables, such as male and middle-aged or older motorists, were added to the  
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25 321 model specification, but were dropped from the model because all were determined to  
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28 322 be insignificantly different from zero at the 0.1 level. The heterogeneity identified for  
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31 323 the variable of heavy vehicle presented another argument in favour of estimating a  
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34 324 mixed logit model of pedestrian injury severity because such effects are difficult to  
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37 325 identify when using a logit framework with numerous interaction terms.  
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41 327 Table 3: Mixed logit estimation results for pedestrian injury severity specifically for  
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43 328 sun-glare-related crashes during the period 2003–2015<sup>a</sup> (n = 13,355).

Variable	Parameter	Standard error	<i>t</i> -value
Fatal injury			
Fixed parameter			
Constant	−0.262	0.127	−2.06
Sunset	0.336	0.090	3.73
Pedestrians facing traffic	−0.417	0.112	−3.72
Pedestrians aged 65+	0.510	0.183	2.79
Motorists aged 65+	0.468	0.137	3.42
Rural roadways	0.660	0.164	4.02
Car overtaking manoeuvre	0.367	0.107	3.43

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Random parameter

Heavy vehicle as crash partner

Standard deviation of distribution	0.396	0.154	2.57
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Restricted log-likelihood (constant only): -4,327.2

Log-likelihood at convergence: -3,286.5

$\rho^2 = 0.241$

329 <sup>a</sup> The outcome “injury” is constituted the baseline, with its parameters set at zero

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331 In this mixed logit model specifically for sun-glare-related crashes, the parameter

332 for the variable sunset was discovered to be significant and fixed across the observed

333 pedestrians. This parameter implies that injuries sustained by pedestrians were more

334 likely to be fatal under sunset conditions than under sunrise conditions. Other fixed

335 and significant factors that increased the likelihood of fatal injuries were pedestrians

336 aged 65 or older, motorists aged 65 or older, rural roadways, and car overtaking

337 manoeuvre. Similar to the overall mixed logit model of pedestrian injury severity,

338 facing traffic in a glare-related crash was determined to be a protective factor in

339 reducing pedestrian fatalities. This fixed parameter suggests that the effect of facing

340 traffic on pedestrian injury severity was uniform across the observed pedestrians.

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## 342 **Discussions**

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344 By using the National Traffic Crash Data and sunrise and sunset data from the

345 NOAA, the present study examined whether sun glare was associated with pedestrian

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4 346 fatalities involved in motor vehicle crashes. This research may constitute a valuable  
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7 347 contribution to the growing literature on pedestrian safety as well as fill a major  
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10 348 research gap regarding the effect of sun glare on pedestrian fatalities. Regarding  
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13 349 methodological contributions, the proposed models offer methodological flexibility  
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16 350 for identifying individual-specific heterogeneity that may arise as a result of other  
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19 351 unmeasured factors related to motorist experience, behaviour, and geometric  
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22 352 characteristics. When developing intervention strategies for improving pedestrian  
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25 353 safety in sun-glare conditions, the heterogeneous effects of certain variables (which  
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28 354 cannot be uncovered by using traditional logit models) should be considered.

31 355 The empirical contributions of this research comprise those research findings that  
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34 356 are related to the factors affecting pedestrian fatalities. The identification of these risk  
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37 357 factors may provide policy-makers with information for establishing suitable policies  
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40 358 and strategies that may further reduce the risk of crashes in general or severity in  
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43 359 particular. The following findings merit further discussion.

46 360 Most drivers commute during hours of extreme sun glare. It is therefore not  
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49 361 surprising that more crashes occurs on roadways where there is a significant portion  
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52 362 of traffic during peak morning (sunrise) and afternoon (sunset) hours. The adverse  
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55 363 effect of sun glare on crash occurrence has been well documented in relevant  
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58 364 literature.<sup>3 14</sup> Mitra<sup>3</sup> pointed out that motorist injury severity, however, was not  
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4 365 increased in glare conditions, possibly as a consequence of reduced travel speed.<sup>8</sup>  
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7 366 Such a protective effect of sun glare on the associated motorist injury severity does  
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10 367 not apply to pedestrians; our study concludes that glare conditions (as indicated in the  
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13 368 overall model) were associated with pedestrian fatalities. In our study, it is evident  
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16 369 that this adverse effect of sun glare was greater on rural roadways where collision  
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19 370 impacts can be higher and motorists may not expect to encounter a pedestrian as much  
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22 371 as they would on urban roadways. One commonly-adopted engineering measure is the  
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25 372 use of variable message signs to warn drivers of the risk of sun glare at the times  
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28 373 when and locations (i.e., rural roadways) where sun-glare conditions occur.<sup>9</sup>  
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31 374 Mitra<sup>3</sup> pointed out that the odds of glare causing crashes at intersections were  
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34 375 higher during the morning hours, and in autumn and winter months in Arizona,  
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37 376 United States. In our study, the effect of seasons on pedestrian fatalities was not  
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40 377 significant. Adding to the research conducted by Hagita and Mori<sup>22</sup>, who concluded  
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43 378 that the rate of pedestrian crashes shortly after sunset was higher than that of any  
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46 379 other time in Japan, our study revealed that compared with sunrise times, the adverse  
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49 380 effect of sun glare on pedestrian fatalities was greater during sunset hours in Taiwan.  
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52 381 It is therefore evident here that sun glare during the sunset hours may not only  
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55 382 increase pedestrian crashes, as indicated by Hagita and Mori<sup>22</sup>, but also the resulting  
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58 383 injury severity.  
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4 384 Studies have suggested that intoxicated motorists were more likely to leave  
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7 385 pedestrians unattended by leaving the crash scene, thereby increasing pedestrian  
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10 386 injury severity; and furthermore, alcohol use has been discovered to be a more  
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13 387 prevalent factor for hit-and-runs at nights and during the weekend.<sup>23 24</sup> Our study  
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16 388 revealed that the combined effects of alcohol consumption and sun glare were  
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19 389 associated with pedestrian fatalities. Similar to other studies<sup>23 24</sup>, our research  
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22 390 highlights, in particular, the effect of motorist alcohol consumption on fatal injuries  
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25 391 and on the weekends.

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28 392 Other studies have consistently reported that elderly motorists were the group most  
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31 393 affected by sun glare. For example, two simulation studies conducted by Gray and  
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34 394 Regan<sup>6</sup> and Theeuwes et al.<sup>7</sup> reported that in conditions of sun glare, older drivers  
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37 395 executing a turning manoeuvre demonstrated a significantly greater reduction in  
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40 396 safety margin than did younger drivers; and older drivers demonstrated the most  
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43 397 significant decrease in the ability to successfully detect pedestrians. Studies analysing  
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46 398 real-life police-reported crash data<sup>15</sup> have indicated that in conditions of sun glare,  
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49 399 older drivers were more likely to strike other vehicles. Our study contributes to the  
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52 400 literature on pedestrian safety literature by concluding that older motorists, when  
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55 401 affected by sun glare, cause fatal injuries to pedestrians once a crash has occurred.  
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58 402 Advance warning signs or educational efforts to increase older driver's awareness of  
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4 403 sun-glare conditions may either temper the likelihood of vehicle crashes or reduce  
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7 404 pedestrian injury severity.  
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10 405 Considerable work has consistently concluded that older pedestrians were more  
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13 406 likely to be fatally or severely injured in crashes, both during daytime and night  
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16 407 conditions.<sup>25</sup> Our research has provided ample evidence to suggest that injuries  
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19 408 sustained by older pedestrians in crashes caused by sun glare are more fatal than those  
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22 409 sustained by younger pedestrians. It is unclear whether the reduced conspicuity of  
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25 410 pedestrians (particularly older pedestrians) under conditions of sun glare (twilight)  
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28 411 plays a role in this effect. However, enhancing the conspicuity of pedestrians through  
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31 412 the use of visibility aids, not only in night conditions<sup>26</sup> but also in twilight conditions,  
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34 413 may be beneficial for reducing crash risk or severity.  
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37 414 Adding to the research conducted by Sun et al.<sup>14</sup>, who reported that crashes related  
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40 415 to improper turning or lane changing were more likely to occur during periods of sun  
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43 416 glare, this present study concludes that an association exists between the execution of  
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46 417 overtaking manoeuvres during periods of sun glare and pedestrian fatalities. It is not  
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49 418 uncommon for injuries sustained in crashes caused by vehicle overtaking to be severe  
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52 419 because motorists must accelerate to overtake other vehicles. In Taiwan, it is common  
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55 420 that motorists execute overtaking manoeuvres by using roadway shoulders where  
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58 421 there are pedestrians. Motorists should be aware of the risk they pose to pedestrians  
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4 422 when overtaking other vehicles, particularly during periods of sun glare.  
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7 423 Studies have reported that facing traffic is beneficial for preventing pedestrian  
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10 424 crashes<sup>27</sup> and decreasing the severity of related injuries<sup>25</sup>. Our study complements  
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13 425 these two studies by concluding that walking against the traffic was associated with  
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16 426 decreased injury severity. Information expressing the necessity facing traffic while  
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19 427 walking along a street, particularly in conditions of sun glare, should be supplemented  
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22 428 with specific information regarding its safety benefits.  
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25 429 Although differing for observed pedestrians, being struck by heavy vehicles  
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28 430 increased the likelihood of fatal injuries. Although this finding agrees with those of  
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31 431 other studies<sup>28 29</sup> reporting the tendency of injuries sustained by pedestrians to be fatal  
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34 432 or more severe when struck by a heavy vehicle, we concluded that the effect of heavy  
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37 433 vehicles was greater in conditions of sun glare. Notably, drivers of heavy vehicles  
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40 434 tend to be professional. It is unclear whether drivers of this particular group, in  
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43 435 combination with undertaking longer hours of travel than those undertaken by a car  
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46 436 driver, are more susceptible to problems related to sun glare. Educational efforts can  
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49 437 be directed towards drivers of heavy vehicles regarding their susceptibility to sun  
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52 438 glare, and on roadways with pedestrians in particular.  
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55 439 This study had the following research limitations. First, our study did not consider  
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58 440 surrounding topography; it is possible that motorists travelling through some areas  
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4 441 with buildings or mountains, for example, are less susceptible to sun glare because the  
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7 442 sun is occluded. By analysing geographic data and data from police reports, likely  
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10 443 locations for sun glare can be predicted, and motorists can be well informed regarding  
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13 444 where to expect sun glare. Furthermore, we classified a crash as being glare-related  
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16 445 when the angular distance between the driver's line of sight and the sun was between  
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19 446 0° and 45°. Further investigations should be conducted concerning the angular  
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22 447 distances at which sun glare affects motorists, as well as the variance of this effect for  
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25 448 motorists of different ages, as indicated by Jurado-Piña and Pardillo Mayora<sup>9</sup>. Indeed,  
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28 449 sun glare is a combined spatial-temporal factor. To broaden our collective  
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31 450 understanding of factors in pedestrian safety, it is paramount that additional spatial  
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34 451 data and temporal data be collected and compared whenever possible. Finally, the  
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37 452 empirical results obtained in this study may be unique to Taiwan because of its unique  
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40 453 sunrise and sunset times and orientations. As a result, until additional analyses are  
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43 454 conducted using data from other jurisdictions to determine whether sun glare is a  
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46 455 salient factor to pedestrian fatalities, caution should be exercised in generalising our  
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49 456 findings for application in other settings.

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51 457

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57  
58  
59 460 drafting the manuscript and final approval of the version to be published.  
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9  
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12  
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16 465 and the NOAA.  
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20 467 **Reference**  
21

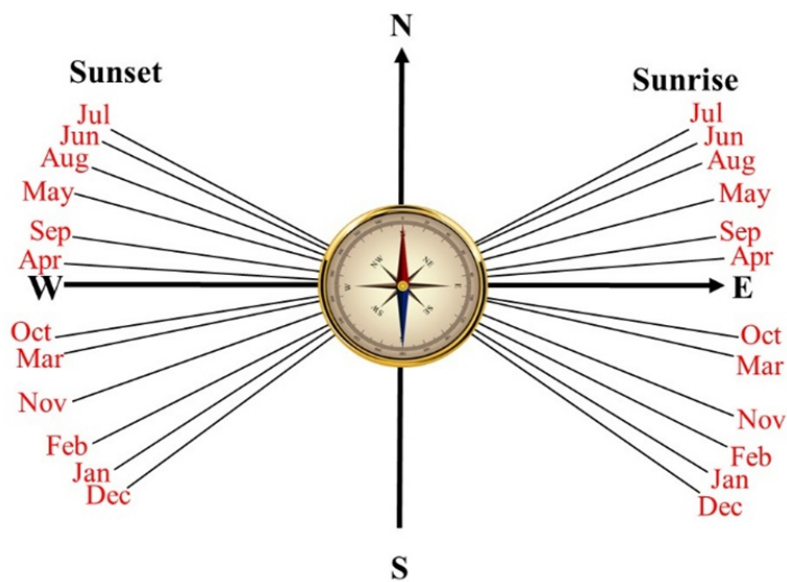
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Appendix 1: Directions of sunrise and sunset in Taiwan

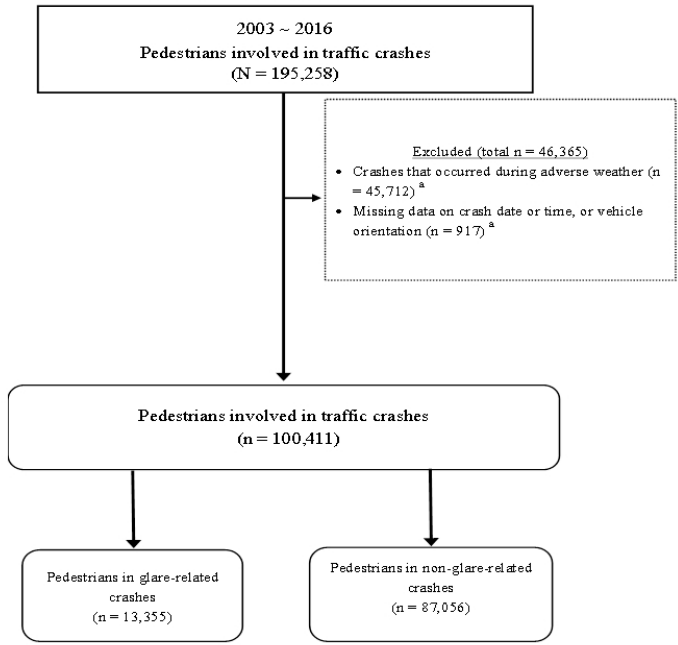


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Figure 2: Flow-chart of sample selection



<sup>a</sup> Because these cases were not mutually exclusive, the total number of cases excluded was 46,365.

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# BMJ Open

## A population-based case-control study of the effect of sun glare on pedestrian fatalities in Taiwan

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Keywords:	ACCIDENT & EMERGENCY MEDICINE, PUBLIC HEALTH, EPIDEMIOLOGY

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Manuscripts

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4 **1 A population-based case-control study of the effect of sun glare on pedestrian**  
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7 **2 fatalities in Taiwan**  
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10 3 Hon-Ping Ma <sup>a, b, c</sup>, Ping-Ling Chen <sup>a</sup>, Shang-Ku Chen <sup>a, b</sup>, Liang-Hao Chen <sup>a, d</sup>, Václav  
11  
12  
13 4 Linkov <sup>e</sup>, Chih-Wei Pai <sup>a, \*</sup>  
14  
15

16 5 <sup>a</sup> Graduate Institute of Injury Prevention and Control, College of Public Health, Taipei  
17  
18  
19 6 Medical University, Taiwan  
20  
21

22 7 <sup>b</sup> Department of Emergency Medicine, Shuang-Ho Hospital, Taipei Medical  
23  
24  
25 8 University, Taiwan  
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27

28 9 <sup>c</sup> Department of Emergency Medicine, School of Medicine, Taipei Medical  
29  
30  
31 10 University, Taiwan  
32  
33

34 11 <sup>d</sup> Department of Emergency Medicine, Wan-Fang Hospital, Taipei Medical  
35  
36  
37 12 University, Taiwan  
38  
39

40 13 <sup>e</sup> Department of Traffic Psychology, CDV-Transport Research Centre, Brno, Czech  
41  
42  
43 14 Republic  
44  
45

46 15 \* Corresponding author  
47  
48

49 16 Email: [cpai@tmu.edu.tw](mailto:cpai@tmu.edu.tw)  
50  
51

52 17 +886 02-27361661 ext.6575  
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54

55 18 Address: Graduate Institute of Injury Prevention and Control, College of Public  
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58 19 Health, Taipei Medical University, 250 Wuxing St, Taipei City, Taiwan 110.  
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4 20 **Word count: 4907**  
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10 22 **Abstract**  
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13 23 **Objectives** Sun glare poses serious driving hazards and increases accident risks.  
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16 24 Relatively few studies, however, have been conducted to examine the effects of sun  
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19 25 glare on pedestrian fatalities, given that an accident has occurred. The primary  
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22 26 objective of this study was to investigate the effect of sun glare on pedestrian  
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25 27 fatalities.  
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28 28 **Design** A population-based case-control study.  
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31 29 **Setting** Taiwan.  
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34 30 **Participants** Using the Taiwan National Traffic Crash Data and sunrise and sunset  
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36  
37 31 data from the National Oceanic and Atmospheric Association (NOAA) for the period  
38  
39  
40 32 2003–2016, 100,411 pedestrians involved in crashes were identified. Of these crashes,  
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42  
43 33 there were 13,355 and 87,056 cases of glare-related (case) and nonglare-related  
44  
45  
46 34 (control) crashes, respectively.  
47  
48

49 35 **Methods** To account for unobserved heterogeneity, mixed logit models were  
50  
51  
52 36 estimated to identify the determinants of pedestrian fatalities.  
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55 37 **Main outcome measures** Pedestrian fatalities.  
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58 38 **Results** Pedestrians involved in glare crashes were more likely to be fatally injured  
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4 39 than those in nonglare crashes. Other contributory factors to fatal injuries among  
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7 40 pedestrians were older pedestrians, male drivers, older drivers, intoxicated motorists,  
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10 41 rural roadways, car overtaking manoeuvres, a heavy vehicle as the crash partner, and  
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12  
13 42 sunset hours. Walking against traffic appeared to be beneficial in decreasing injury  
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16 43 severity.

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19 44 **Conclusions** Sun glare was associated with pedestrian fatalities. Older pedestrians,  
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22 45 male drivers, older drivers, and intoxicated motorists were prevalent determinants of  
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25 46 pedestrian fatalities in glare-related crashes.

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27  
28 47 **Keywords:** Sun glare; Pedestrian fatalities; Crashes; Injury  
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34 49 **Strengths and limitations of this study**

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36  
37 50 ● This is the first nationwide population-based case-control study to  
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40 51 investigate the associations between pedestrian fatalities and sun glare.  
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42  
43 52 ● The large population-based dataset minimises selection bias.  
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46 53 ● Glare-related crashes were defined by adjusting vehicle travel direction and  
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49 54 daily times and orientations of sunrise and sunset.  
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52 55 ● Limitations of this study include the data that are unavailable from the two  
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55 56 datasets such as geographic characteristics.  
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## 58 Introduction

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60 Driving is a highly visual task that involves visual function and processing for  
61 establishing the effective control over a vehicle.<sup>1</sup> Research<sup>2,3</sup> has suggested that bright  
62 sunlight was ideal for driving because it increases the contrast, resolution, and  
63 luminosity of the surrounding landscapes. As a result, drivers may misinterpret the  
64 speed at which the surrounding landscape is approaching and gauge their travel  
65 velocity to be illusively slow, which would in turn prompt drivers to compensate by  
66 accelerating.<sup>4,5</sup>

67 Generally, bright sunlight causes temporary blindness when the sun is at a  
68 relatively low altitude and its rays fall directly in an individual's line of sight (e.g.,  
69 just after sunrise or before sunset when the sun is above the horizon). By using a  
70 simulator, Gray and Regan<sup>6</sup> assessed the driving performance in both the absence and  
71 presence of a simulated low sun. They reported that sun glare resulted in a significant  
72 reduction in the safety margin accepted by drivers; the mean number of crashes was  
73 significantly higher during conditions of glare than during those of without glare, and  
74 older drivers exhibited a significantly greater reduction in the safety margin than did  
75 younger drivers. Another simulation study was conducted by Theeuwes et al.<sup>7</sup>, who  
76 reported that low glare sources resulted in participants (drivers) exhibiting a

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4 77 significant drop in the ability to detect simulated pedestrians along the roadside.  
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7 78 Theeuwes et al.<sup>7</sup> also pointed out that older participants reduced their driving speed  
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9  
10 79 the most and exhibited the largest drop in successful pedestrian detection.  
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12  
13 80 Churchill et al.<sup>8</sup> employed a geometric model for examining whether sun glare  
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16 81 affects the speeds of drivers on roadways and concluded that changes in speed as a  
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19 82 result of sun glare was a factor in highway congestion. Jurado-Piña and Pardillo  
20  
21  
22 83 Mayora<sup>9</sup>, in an attempt to investigate the maximum tolerable sun glare caused by the  
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24  
25 84 angle between the sun and driving direction, pointed out that glare occurs when there  
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27  
28 85 is a specific angular distance between the driver's line of sight and the sun; this  
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30  
31 86 angular distance is 19° for a 40-year-old driver and 25° for a 60-year-old driver.  
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33  
34 87 Anue<sup>10</sup> suggested that in general no sun glare occurs if the angular distance is greater  
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37 88 than 25°.  
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39  
40 89 Several studies have investigated whether a direct relationship exists between sun  
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43 90 glare and crashes by using data from police report or hospital. In a longitudinal study  
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45  
46 91 of patients who had been hospitalised as a consequence of a motor-vehicle crash,  
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48  
49 92 Redelmeier and Raza<sup>11</sup> concluded that bright sunlight was associated with an  
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52 93 increased risk of life-threatening motor-vehicle crashes in Canada. By analysing  
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55 94 police-reported crash data from Arizona, Mitra and Washington<sup>12</sup> indicated that sun  
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58 95 glare was a crucial omitted variable that could explain intersection crash occurrence  
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4 96 and that including this variable improved the explanatory power of statistical models.  
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7 97 By linking police-reported crash data from Arizona with sunrise and sunset data from  
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10 98 NOAA, Mitra<sup>3</sup> concluded that the odds of glare causing a crash were higher at  
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12  
13 99 intersections with roadways running eastbound and westbound than at those running  
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16 100 northbound and southbound. Mitra<sup>3</sup> further indicated that rear-end and angle crashes  
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19 101 at signalised intersections were affected by sun glare, and, furthermore, the severity of  
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22 102 motorist injury was unaffected by sun glare. A study that analysed traffic-accident  
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24  
25 103 database of Chiba, Japan, Hagita and Mori<sup>13</sup> revealed a higher occurrence of crashes  
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27  
28 104 involving pedestrians or bicycles at intersections where the sun was below 45° above  
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31 105 the horizon in the driving direction. Sun et al.<sup>14</sup>, who analysed police-reported crash  
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34 106 data in Edmonton, Canada, reported similar findings, concluding that sun glare  
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37 107 significantly contributed to crash occurrence, especially at intersections. Furthermore,  
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40 108 they also indicated that the effect of sun glare on crash occurrence during the  
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43 109 mornings on eastbound roads and evenings on westbound roads was significantly  
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46 110 greater during the spring and autumn months and that certain crash types (e.g., crashes  
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49 111 related to signal violation, failure to yield to pedestrians/cyclists, improper turning,  
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52 112 and lane changing) were more likely to occur during periods of sun glare. By  
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55 113 analysing police-reported crash data, Choi and Singh<sup>15</sup> pointed out that elderly  
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58 114 motorists tended to have a greater propensity for striking other vehicles in conditions  
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4 115 of sun glare, especially on roadways that were not physically divided.  
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7 116 Based on our literature review above, a significant gap remains in the  
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10 117 comprehensive understanding of the relationship between sun glare and pedestrian  
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13 118 fatalities, conditioned on that a pedestrian crash has occurred. The primary research  
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16 119 hypothesis of the present study is that pedestrian injury severity increases in  
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19 120 accordance with restricted visibility (i.e., sun glare). As a result, the primary aim of  
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22 121 this study was to investigate whether sun glare is associated with pedestrian fatalities.  
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25 122 This study also aimed to investigate the determinants of pedestrian fatalities  
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28 123 specifically in crashes related to sun glare.  
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## 32 33 34 125 **Materials and Methods**

### 35 36 37 126 *Data source*

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40 127 By using the Taiwan National Traffic Crash Data as well as sunrise and sunset data  
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43 128 from the National Oceanic and Atmospheric Association (NOAA) for the period from  
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46 129 2003 to 2016 (National Oceanic Earth System Research Laboratory and Atmospheric  
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49 130 Administration<sup>16</sup>. Accessed: 2018-08-22), the current study examined the effect of sun  
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52 131 glare on pedestrian fatalities, given that an accident involving a vehicle and pedestrian  
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55 132 has occurred. The Taiwan National Traffic Crash Data comprise two files: an accident  
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58 133 file and a vehicle and victim file. Accident files contain general information on the  
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4 134 times and dates of crashes; weather, road; and lighting conditions, and road type.  
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7 135 Vehicle and victim files contain vehicle-related information, such vehicle type,  
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10 136 manoeuvres, first point of impact, and orientation, as well as driver and casualty  
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13 137 characteristics, such as age, sex, and injury severity. Injury severity is classified into  
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16 138 two levels: fatality and injury. Victims who die within 24 h as a result of an accident  
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19 139 are classified as cases of fatality, whereas victims who sustain injuries, whether mild  
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22 140 or severe, are classified as cases of injury.  
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25 141 Data on daily sunrise and sunset times and orientation are available from the  
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28 142 NOAA. The information on the sunrise and sunset orientation for Taiwan is presented  
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31 143 in online supplementary appendix 1. By using the data on the temporal characteristics  
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34 144 (i.e., time and date) and orientation of vehicle crashes from the Taiwan National  
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37 145 Traffic Crash Data, pedestrian crashes were matched with the sunrise and sunset data  
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40 146 of the NOAA and subsequently classified into glare-related or nonglare-related  
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43 147 crashes. The Institutional Review Board that is affiliated with Taipei Medical  
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46 148 University approved our study (IRB#: N201808071). Personal identification data such  
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49 149 as name or identification number are not available in the dataset.  
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52 150 A glare-related crash is defined as a crash in which the following conditions are  
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55 151 satisfied: the car was travelling in a direction towards the sunrise or sunset, and the  
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58 152 angular distance between the driver's line of sight and the sun was between 0° and  
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4 153 45°. Data on vehicle's travel path (north, south, east, or west) are available from the  
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7 154 National Traffic Crash Dataset; and data on sun directions are available from the  
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9  
10 155 NOAA. The angular distances were adjusted according to the time of the crash  
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12  
13 156 (available from the National Traffic Crash Dataset) and daily sunrise and sunset times  
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16 157 daily (available from the NOAA). For example, according to the Taiwan National  
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19 158 Traffic Crash Data, a car-pedestrian crash took place in Hsinchu City, where a car  
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22 159 heading to northeast collided with a pedestrian at 06:18 (A.M.) on 18 June, 2016. The  
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24  
25 160 angular distances, ranging from 0° to 45°, were reported<sup>13</sup> in Japan to cause sun glare  
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27  
28 161 and potentially affect traffic safety. We adopted the angular distance, range of 0–45°,  
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31 162 as the threshold for defining a glare-related crash. According to the NOAA website,  
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34 163 for this particular timing (18 June, 2016) and location (Hsinchu City with latitude of  
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37 164 24.778 and longitude of 120.988), the sun rose from northeast, and the apparent  
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40 165 sunrise and sunset times were at 05:07 and 18:47, respectively. The daytime length  
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43 166 for this particular day is 13 hours and 40 mins, which is equivalent to 820 mins. The  
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46 167 angular distances for sunrise and sunset are 0–180°; for this particular day, the sun  
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49 168 moved 0.2195° every min ( $180/820=0.2195$ ). The adopted angular distance of 45° is  
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52 169 equivalent to 205 mins ( $45/0.2195=205$ ); as such, the transformed angular distance of  
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55 170 0–45° for this particular crash is between 05:07 to 08:32 that has a difference of 205  
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58 171 mins. This particular crash was therefore classified as a glared-related crash because  
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4 172 the car headed to northeast (which was the direction of the sunrise) and the time of the  
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7 173 crash (06:18) falls into the angular distance of 0–45° (i.e., between 05:07 and 08:32).  
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10 174 A flow-chart of the sample selection from the Taiwan Traffic Crash Dataset for  
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13 175 the period from 2003 to 2016 is presented in online supplementary Appendix 2. A  
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16 176 total of 195,258 pedestrian casualties from traffic crashes were extracted from during  
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18  
19 177 this period. This study considered only pedestrian crashes where the crash partner was  
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21  
22 178 a motorcycle, car, taxi, heavy-goods vehicle, bus, or coach. Crashes that occurred  
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25 179 during adverse weather conditions, such as rain or fog, or when it was cloudy, were  
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27  
28 180 excluded (n = 45,712). A total of 917 cases had missing data with regard to accident  
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31 181 date and time and vehicle orientation. Because these cases (adverse weather  
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34 182 conditions and missing data) were not mutually exclusive, the total number of cases  
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37 183 excluded was 45,365, yielding a total of 149,839 valid cases for pedestrian casualties.  
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40 184 These valid cases were matched with the NOAA sunrise and sunset data. After  
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43 185 excluding crashes that had occurred after sunset and before sunrise (n = 49,428),  
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45  
46 186 100,411 cases of pedestrian casualties remained. Of the 100,411 pedestrians that  
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49 187 were matched with the sunrise and sunset data from the NOAA, 13,355 were  
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52 188 glare-related cases (treated as cases), and 87,056 were nonglare-related cases (treated  
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55 189 as controls), respectively.  
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4 191 *Definition of variables*  
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7 192 The following demographic data were collected for casualties: sex, age (four  
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10 193 groups: <18, 18–40, 41–64, and  $\geq 65$  years), alcohol use (yes: breathalyser test results  
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12  
13 194  $\geq 0.15$  mg/L or blood-alcohol concentration [BAC] level  $> 0.03\%$ ; no: breathalyser  
14  
15  
16 195 test results  $< 0.15$  mg/L or BAC level  $\leq 0.03\%$ ), licence status (licensed: with a valid  
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19 196 licence; or unlicensed: without a valid licence), and pedestrian crossing manner  
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22 197 (facing traffic: pedestrians walking towards traffic; back to traffic: pedestrians  
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24  
25 198 walking back to the traffic; crossing: pedestrians crossing the street). In Taiwan, those  
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28 199 under the age 18 are identified as teenagers who are unable to legally ride motorcycles  
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30  
31 200 or drive car. Those aged 65 years or older were identified as the elderly individual.  
32  
33  
34 201 For individuals aged 18–40 and 41–64, we classified the remaining ages into two even  
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36  
37 202 age intervals. BAC data were obtained by police who conducted breathalyser tests or  
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39  
40 203 followed up for blood tests at hospitals. According to Taiwanese law, drivers with  
41  
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43 204 either breathalyser test  $\geq 0.15$  mg/L or BAC level  $> 0.03\%$  were considered to be  
44  
45  
46 205 drunk-driving. Data from breathalyser tests or BAC levels were available only for  
47  
48  
49 206 motorists not for pedestrians because, by law, only motorists involved in crashes are  
50  
51  
52 207 mandated to be tested for alcohol consumption.  
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55 208 The vehicle attribute considered was the crash partner (motorcycle, car, taxi, and  
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58 209 heavy vehicles such as buses and coaches). The following road factors were  
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4 210 considered: sun glare (yes: affected by sun glare; no: unaffected by sun glare) and  
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7 211 crash location (rural: roadways with speed limits of  $\geq 51$ km/h, and urban: roadways  
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9  
10 212 with speed limits of  $\leq 50$ km/h). Two temporal factors, month of the crash  
11  
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13 213 (spring/summer: March–August or autumn/winter: September–February) and days of  
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16 214 crash (weekday: Monday–Friday or weekend: Saturday–Sunday) were examined.  
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### 22 216 *Patient and Public Involvement*

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25 217 The current research analysed national police-reported crash data as well as sunrise  
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28 218 and sunset data from the National Oceanic and Atmospheric Association, which are  
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30  
31 219 anonymised datasets. Patients and or public were not involved in this study.  
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### 37 221 *Statistical analysis*

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40 222 The distribution of pedestrian injury severity according to a set of variables (e.g.,  
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43 223 human attributes, environmental factors, and vehicle characteristics) is reported in this  
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46 224 study. Chi-square tests were conducted to examine the association between the  
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49 225 independent variables and pedestrian injury severity. Because the dependent variable  
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52 226 was binary (fatal vs. injury), the binary mixed logit models, which allow parameter  
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55 227 coefficients to have distribution rather than fixed across the individuals, were  
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58 228 estimated. Using the chi-square tests, the variables discovered to be significantly  
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4 229 associated with the outcome ( $p < 0.2$ ) were then incorporated into the multivariate  
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7 230 mixed logit models. To detect the multi-collinearity among the variables (all  
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10 231 categorical), a chi-square independent test was conducted and Cramer's  $V^{17}$  was  
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12  
13 232 estimated. To determine whether sun glare was associated with pedestrian fatalities,  
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15  
16 233 one overall model that includes sun glare as one of the variables was utilised. One  
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18  
19 234 additional model with interaction terms of sun-glare-related crashes with other  
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22 235 variables was subsequently estimated.

23 236 Mixed logit models were estimated to account for unobserved heterogeneity that  
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25  
26 237 may have arisen as a consequence of unmeasured variables, such as risk perception,  
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28  
29 238 behavioural factors, and other socioeconomic factors not available in the crash data  
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31  
32 239 from police reports. One example of a behavioural factor is distraction by phone use  
33  
34  
35 240 that may result in risk-taking inclinations and consequently an increased risk of  
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37  
38 241 injury.<sup>18 19</sup> Ignoring the effects of unobserved variables may lead to inconsistent  
39  
40  
41 242 estimates to all statistical models.<sup>20</sup>

42  
43  
44 243 In the present study, the utility of the injury severity  $i$  for a crash  $n$  is defined as  
45  
46  
47 244 follows:

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51 245  $IS_{in} = \beta_n^i X_{in} + \varepsilon_{in}$  Eq. (1)  
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54 246

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57 247 where  $IS_{in}$  is an injury-severity function determining the injury-severity category  $i$   
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4 248 (fatal or injury) for an individual pedestrian  $n$ ,  $X_{in}$  is a vector of the observed  
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7 249 variables, such as pedestrian and driver attributes, vehicle characteristics, and  
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9  
10 250 environmental or temporal variables,  $\beta_n$  is a vector of the parameters associated with  
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13 251  $X_{in}$ , and  $\varepsilon_{in}$  is the error term. The mixed logit model uses  $\beta_n$  as a vector of estimable  
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16 252 parameters, which varies across the observed pedestrians. The variation is observed  
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18  
19 253 with density  $f(\beta|\theta)$ , where  $\theta$  is a vector of the parameters of the density distribution. In  
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21  
22 254 most applications, mixed models specify that the density  $f$  has a continuous  
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25 255 distribution, such as a normal, lognormal, triangular, or uniform distribution.

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27  
28 256 Given error terms that are independent and identically Gumbel distributed<sup>21</sup>, the  
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31 257 unconditional probability of one alternative  $i$  (from the set of injury-severity  
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34 258 categories  $I$ ) is the integral of the conditional probability with a multinomial logit  
35  
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37 259 form over the parameter  $\beta$  of density  $f$ :

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41 260 
$$P_{in} = \int \left( \frac{\exp(\beta' X_{in})}{\sum_{j=1}^I 1 + \exp(\beta' X_{nj})} \right) f(\beta|\theta) d\beta \quad \text{Eq. (2)}$$
  
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49 262 All parameters are first assumed to be random and then their estimated standard  
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52 263 deviations are evaluated using a zero-based (asymptotic)  $t$ -test for each parameter.  
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55 264 One study<sup>20</sup> pointed out that a simulation-based maximum likelihood with 200 Halton  
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58 265 draws may provide a more efficient distribution of draws for numerical integration  
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266 and requires fewer draws to achieve convergence. Attempts were made in the present  
 267 study to obtain more significant results by increasing the number of Halton draws, and  
 268 the results appeared stable with the use of 1000 Halton draws.

269

## 270 Results

271

272 Table 1 lists the distribution of pedestrian injury severity according to a set of  
 273 variables. Of the 13,355 glare-related cases, 329 pedestrians (2.46%) sustained fatal  
 274 injuries, which is higher than those in nonglare-related crashes (1.83%). Additionally,  
 275 the majority of pedestrian crashes involved motorists with valid licences (85.65%),  
 276 sober motorists (85.97%), urban roadways (89.57%), pedestrians who were hit while  
 277 crossing the street (65.85%), and nonglare conditions (86.70%) and occurred on  
 278 weekdays (74.83%).

279

280 Table 1: Distribution of pedestrian injury severity according to a set of variables for  
 281 the period 2003–2016.

	N	Fatal n(%)	Injury n(%)	$\chi^2$ test p-value
Total	100411	1925(1.92)	98486(98.08)	
Sun glare				
Yes	13355(13.30)	329(2.46)	13026(97.54)	<0.01
No	87056(86.70)	1596(1.83)	85460(98.17)	
Pedestrian gender				
Male	50942(50.73)	1015(1.99)	49927(98.01)	0.08
Female	49469(49.27)	910(1.84)	48559(98.16)	

	N	Fatal n(%)	Injury n(%)	$\chi^2$ test p-value
<b>Driver gender</b>				
Male	53351(53.13)	1132(2.12)	52219(97.88)	<0.01
Female	47060(46.87)	793(1.69)	46267(98.31)	
<b>Pedestrian age</b>				
<18	3644(3.63)	67(1.84)	3577(98.16)	<0.01
18-40	25851(25.75)	154(0.60)	25697(99.40)	
41-64	31283(31.15)	352(1.13)	30931(98.87)	
$\geq 65$	39633(39.47)	1352(3.41)	38281(96.59)	
<b>Driver age</b>				
<18	4458(4.44)	103(2.31)	4355(97.69)	<0.01
18-40	25808(25.70)	295(1.14)	25513(98.86)	
41-64	32523(32.39)	474(1.46)	32049(98.54)	
$\geq 65$	37622(37.47)	1033(2.75)	36589(97.25)	
<b>Driver licence</b>				
Licensed	86007(85.65)	1609(1.87)	84398(98.13)	0.01
Unlicensed	14404(14.35)	316(2.19)	14088(97.81)	
<b>Alcohol use for driver</b>				
No	86322(85.97)	1512(1.75)	84810(98.25)	<0.01
Yes	14089(14.03)	413(2.93)	13676(97.07)	
<b>Months</b>				
Spring/summer	47671(47.48)	914(1.92)	46757(98.08)	0.99
Autumn/winter	52740(52.52)	1011(1.92)	51729(98.08)	
<b>Crash location</b>				
Rural	10475(10.43)	352(3.36)	10123(96.64)	<0.01
Urban	89936(89.57)	1573(1.75)	88363(98.25)	
<b>Crash partner</b>				
Motorcycle	33221(33.09)	643(1.94)	32578(98.06)	<0.01
Car	45963(45.77)	801(1.74)	45162(98.26)	
Taxi	9655(9.62)	208(2.15)	9447(97.85)	
Heavy vehicles	11572(11.52)	356(3.08)	11216(96.92)	
<b>Pedestrian's movement</b>				
Facing traffic	9704(9.66)	172(1.77)	9532(98.23)	<0.01
Back to traffic	24584(24.48)	623(2.53)	23961(97.47)	
Crossing	66123(65.85)	1130(1.71)	64993(98.29)	
<b>Car's manoeuvre</b>				
Straight	50836(50.63)	862(1.70)	49974(98.30)	<0.01

	N	Fatal n(%)	Injury n(%)	$\chi^2$ test p-value
Changing lane	15625(15.56)	257(1.64)	15368(98.36)	
Overtaking	21339(21.25)	601(2.82)	20738(97.18)	
Turning	12611(12.56)	205(1.63)	12406(98.37)	
Sunset				
Sunset	8325(8.29)	214(2.57)	8109(97.41)	<0.01
Other daytimes	87056(86.70)	1596(1.83)	85460(98.17)	
Sunrise	5030(5.01)	115(2.29)	4915(97.71)	
Weekdays				
Weekday	70366(70.08)	1267(1.80)	69099(98.20)	<0.01
Weekend	30045(29.92)	658(2.19)	29387(97.81)	

282

283 Using chi-square tests, the following variables were determined to be significantly  
 284 associated with the outcome: sun glare; pedestrian and driver sex and age; driver  
 285 license possession, alcohol consumption; crash month, location, and partner;  
 286 pedestrian movement; car manoeuvre; sunset hours; and day of the week. These  
 287 factors were then incorporated into the mixed logit models.

288 Table 2 presents the estimation results of the mixed logit model of pedestrian  
 289 injury severity. Parameters that were determined to be random were those that  
 290 produced statistically significant standard errors for the assumed distributions; in this  
 291 study, random parameters were male motorists and heavy vehicle as crash partners,  
 292 with a uniform distribution that appears to provide the best statistical fit.

293

294 Table 2: Mixed logit estimation results for pedestrian injury severity during the period  
 295 2003–2016<sup>a</sup> (n = 100,411).

Variable	Parameter	Standard error	t-value
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Fatal injury			
Fixed parameter			
Constant	-0.531	0.215	-2.47
Sun-glare-related crash	0.527	0.164	3.21
Pedestrians facing traffic	-0.304	0.110	-2.76
Pedestrians aged 65+	0.553	0.237	2.33
Motorists aged 65+	0.218	0.102	2.14
Rural roadways	0.985	0.251	3.92
Intoxicated motorist	0.606	0.213	2.85
Weekend	0.134	0.053	2.53
Car overtaking manoeuvre	0.472	0.132	3.58
Sunset	0.162	0.074	2.19
Random parameter			
Male motorists	0.324	0.139	2.33
Standard deviation of distribution	0.389	0.163	2.39
Heavy vehicles	0.274	0.110	2.49
Standard deviation of distribution	0.622	0.290	2.14
Restricted log-likelihood (constant only): -8,267.1			
Log-likelihood at convergence: -5,806.4			
$\rho^2=0.298$			

296 <sup>a</sup> The outcome “injury” is the baseline case with its parameters set at zero.

297

298 Considering the results listed in Table 2, sun-glare-related crashes was found to  
 299 be significant, and the estimated parameter was fixed across the observed pedestrians  
 300 (the standard error for this parameter, when allowed to be random, was statistically  
 301 nonsignificant). The parameter implies that sun a sun-glared-related crash was more  
 302 likely to result in fatal injuries among pedestrians than a nonglare-related crash. Other  
 303 factors discovered to have fixed effects on observed pedestrians and increase the  
 304 likelihood of fatal injuries were pedestrians aged 65 or older, motorists aged 65 years  
 305 or older, rural roadways, intoxicated motorist, weekend, car overtaking manoeuvre,

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4 306 and sunset hours.  
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7 307 The parameter for the variable of male motorist appeared to be random, with a  
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10 308 normal distribution with a mean of 0.324 and standard deviation of 0.389 (see Table  
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13 309 2), indicating that individual pedestrians being struck by male motorists had different  
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16 310 parameters. Given the estimates (a mean of 0.324 and standard deviation of 0.389),  
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19 311 approximately 79.8% of all pedestrians had a higher probability of sustaining fatal  
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22 312 injuries when all other variables remain constant. Another parameter found to have a  
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25 313 random effect across the sample of pedestrians was the variable of a heavy vehicle as  
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28 314 the crash partner (with a normal distribution). This parameter had a mean of 0.274 and  
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31 315 standard deviation of 0.622 (see Table 2), indicating that individual pedestrians struck  
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34 316 by heavy vehicles have different parameters, with 67.0% of the distributions resulting  
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37 317 in a positive parameter (increasing the likelihood of fatal injuries) and 33.0% resulting  
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40 318 in negative parameter (decreasing the likelihood of fatal injuries).  
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43 319 The direction of travel of pedestrians relative to vehicular traffic was also  
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46 320 discovered to significantly affect pedestrian fatalities. This fixed parameter suggests  
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49 321 that pedestrians who faced traffic while walking were less likely to sustain fatal  
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52 322 injuries than those undertaking other movements, such as walking back to traffic or  
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55 323 crossing the street.  
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58 324 Table 3 presents the estimation results of the mixed logit model of pedestrian  
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4 325 injury severity specifically in sun-glare-related crashes. For this model, the only  
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7 326 random parameter (with a uniform distribution) was significant for the variable of  
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10 327 heavy vehicle as the crash partner. The heterogeneous effect indicates that certain  
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13 328 crashes involving heavy vehicles were associated with both higher and lower  
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16 329 likelihoods of pedestrians sustaining fatal injuries. We speculate that this  
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19 330 heterogeneous effect may be caused by variance in the experience level among certain  
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22 331 driver groups, with more experienced drivers exhibiting a decreased likelihood of  
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25 332 causing fatal injuries. In other words, heavy vehicles are normally operated by  
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28 333 professional drivers, with the majority of drivers in this group being men and  
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31 334 middle-aged or older individuals. To confirm this speculation, the interaction between  
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34 335 the variable of heavy vehicle and other variables, such as male and middle-aged or  
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37 336 older motorists, were added to the model specification, but were dropped from the  
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40 337 model because all were determined to be insignificantly different from zero at the 0.1  
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43 338 level. The heterogeneity identified for the variable of heavy vehicle presented another  
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46 339 argument in favour of estimating a mixed logit model of pedestrian injury severity  
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49 340 because such effects are difficult to identify when using a logit framework with  
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52 341 numerous interaction terms.

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56 343 Table 3: Mixed logit estimation results for pedestrian injury severity with interaction  
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58 344 terms of glare crashes and other variables <sup>a</sup> (n = 100,411)

Variable	Parameter	Standard error	t-value
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Fatal injury			
Fixed parameter			
Constant	-0.324	0.139	-2.33
Male motorist	0.193	0.069	2.80
Sunset	0.274	0.089	3.08
Pedestrians facing traffic × glare crashes	-0.439	0.126	-3.48
Pedestrians aged 65+	0.533	0.210	2.54
Motorists aged 65+ × glare crashes	0.432	0.143	3.02
Rural roadways × glare crashes	0.684	0.190	3.60
Intoxicated motorist	0.461	0.154	2.99
Weekend	0.157	0.075	2.09
Car overtaking manoeuvre	0.329	0.121	2.72
Random parameter			
Heavy vehicle as crash partner	0.248	0.089	2.78
Standard deviation of distribution	0.526	0.211	2.49

Restricted log-likelihood (constant only): -7,302.7

Log-likelihood at convergence: -5,054.6

$\rho^2=0.308$

345 <sup>a</sup> The outcome “injury” is constituted the baseline, with its parameters set at zero

346

347 This mixed logit model with the interaction term of glare crashes with other  
 348 variables highlight several crucial features of glare crashes. For example, several  
 349 interaction terms were discovered to be significant and fixed across the observed  
 350 pedestrians, including facing traffic × glare crashes, elderly motorists × glare crashes,  
 351 and rural roadways × glare crashes. It appears that facing traffic in a glare-related  
 352 crash was determined to be a protective factor in reducing pedestrian fatalities.  
 353 Injuries to pedestrians were more likely to be fatal in glare crashes in which the  
 354 drivers were elderly. Furthermore, in glare crashes that took place in rural setting,  
 355 injuries were more likely to be fatal than otherwise.

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4 356 **Discussions**  
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10 358 By using the National Traffic Crash Data and sunrise and sunset data from the  
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13 359 NOAA, the present study examined whether sun glare was associated with pedestrian  
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16 360 fatalities involved in motor vehicle crashes. This research may constitute a valuable  
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19 361 contribution to the growing literature on pedestrian safety as well as fill a major  
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22 362 research gap regarding the effect of sun glare on pedestrian fatalities. Regarding  
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25 363 methodological contributions, the proposed models offer methodological flexibility  
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28 364 for identifying individual-specific heterogeneity that may arise as a result of other  
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31 365 unmeasured factors related to motorist experience, behaviour, and geometric  
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34 366 characteristics. When developing intervention strategies for improving pedestrian  
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37 367 safety in sun-glare conditions, the heterogeneous effects of certain variables (which  
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40 368 cannot be uncovered by using traditional logit models) should be considered.  
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43 369 The empirical contributions of this research comprise those research findings that  
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46 370 are related to the factors affecting pedestrian fatalities. The identification of these risk  
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49 371 factors may provide policy-makers with information for establishing suitable policies  
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52 372 and strategies that may further reduce the risk of crashes in general or severity in  
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55 373 particular. The following findings merit further discussion.  
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58 374 Most drivers commute during hours of extreme sun glare. It is therefore not  
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4 375 surprising that more crashes occurs on roadways where there is a significant portion  
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7 376 of traffic during peak morning (sunrise) and afternoon (sunset) hours. The adverse  
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10 377 effect of sun glare on crash occurrence has been well documented in relevant  
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13 378 literature.<sup>3 14</sup> Mitra<sup>3</sup> pointed out that motorist injury severity, however, was not  
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16 379 increased in glare conditions, possibly as a consequence of reduced travel speed.<sup>8</sup>  
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19 380 Such a protective effect of sun glare on the associated motorist injury severity does  
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22 381 not apply to pedestrians; our study concludes that glare conditions (as indicated in the  
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25 382 overall model) were associated with pedestrian fatalities. In our study, it is evident  
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28 383 that this adverse effect of sun glare was greater on rural roadways where collision  
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31 384 impacts can be higher and motorists may not expect to encounter a pedestrian as much  
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34 385 as they would on urban roadways. One commonly-adopted engineering measure is the  
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37 386 use of variable message signs to warn drivers of the risk of sun glare at the times  
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40 387 when and locations (i.e., rural roadways) where sun-glare conditions occur.<sup>9</sup>

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43 388 Mitra<sup>3</sup> pointed out that the odds of glare causing crashes at intersections were  
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46 389 higher during the morning hours, and in autumn and winter months in Arizona,  
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49 390 United States. In our study, the effect of seasons on pedestrian fatalities was not  
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52 391 significant. Adding to the research conducted by Hagita and Mori<sup>22</sup>, who concluded  
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55 392 that the rate of pedestrian crashes shortly after sunset was higher than that of any  
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58 393 other time in Japan, our study revealed that compared with sunrise times, the adverse  
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4 394 effect of sun glare on pedestrian fatalities was greater during sunset hours in Taiwan.  
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7 395 It is therefore evident here that sun glare during the sunset hours may not only  
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10 396 increase pedestrian crashes, as indicated by Hagita and Mori<sup>22</sup>, but also the resulting  
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13 397 injury severity. Evening commute is often risky due to fatigue, distraction, or other  
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16 398 unrelated factors to sun glare. In our study, we have found that injuries sustained by  
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19 399 pedestrians were more likely to be fatal under sunset conditions than other daytime  
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22 400 conditions. Additional research is warranted to examine whether sun glare affects  
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25 401 pedestrian fatalities in evening commuting crashes.

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28 402 Studies have suggested that intoxicated motorists were more likely to leave  
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31 403 pedestrians unattended by leaving the crash scene, thereby increasing pedestrian  
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34 404 injury severity; and furthermore, alcohol use has been discovered to be a more  
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37 405 prevalent factor for hit-and-runs at nights and during the weekend.<sup>23 24</sup> Our study  
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40 406 revealed that the combined effects of alcohol consumption and sun glare were  
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43 407 associated with pedestrian fatalities. Similar to other studies<sup>23 24</sup>, our research  
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46 408 highlights, in particular, the effect of motorist alcohol consumption on fatal injuries  
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49 409 and on the weekends.

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52 410 Other studies have consistently reported that elderly motorists were the group  
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55 411 most affected by sun glare. For example, two simulation studies conducted by Gray  
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58 412 and Regan<sup>6</sup> and Theeuwes et al.<sup>7</sup> reported that in conditions of sun glare, older drivers  
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4 413 executing a turning manoeuvre demonstrated a significantly greater reduction in  
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7 414 safety margin than did younger drivers; and older drivers demonstrated the most  
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10 415 significant decrease in the ability to successfully detect pedestrians. Studies analysing  
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13 416 real-life police-reported crash data<sup>15</sup> have indicated that in conditions of sun glare,  
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16 417 older drivers were more likely to strike other vehicles. Our study contributes to the  
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19 418 literature on pedestrian safety literature by concluding that older motorists, when  
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22 419 affected by sun glare, cause fatal injuries to pedestrians once a crash has occurred.  
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25 420 Advance warning signs or educational efforts to increase older driver's awareness of  
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28 421 sun-glare conditions may either temper the likelihood of vehicle crashes or reduce  
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31 422 pedestrian injury severity.

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34 423 In our study, no discrepancy was found when comparing injuries in  
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37 424 spring/summer to autumn/winter. Such a result cannot be ascertained with any  
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40 425 certainty. However, we speculate that this is primarily because the anticipated effect  
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43 426 of sun glare in different seasons may be offset by, for example, tropical hurricanes  
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46 427 that strike Taiwan in summer and northeast monsoon in winter. Our result here seems  
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49 428 different to those in other studies conducted in large countries<sup>3</sup> where the adverse  
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52 429 effect of sun glare was found to be greater in autumn and winter months. These  
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55 430 studies were conducted in large countries such as the United States where climate  
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58 431 changes significantly across areas with different latitudes, whereas Taiwan is a small  
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4 432 country where climate does not change much across the small island.  
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7 433 Considerable work has consistently concluded that older pedestrians were more  
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10 434 likely to be fatally or severely injured in crashes, both during daytime and night  
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13 435 conditions.<sup>25</sup> Our research has provided ample evidence to suggest that injuries  
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16 436 sustained by older pedestrians in crashes caused by sun glare are more fatal than those  
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19 437 sustained by younger pedestrians. It is unclear whether the reduced conspicuity of  
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22 438 pedestrians (particularly older pedestrians) under conditions of sun glare (twilight)  
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25 439 plays a role in this effect. However, enhancing the conspicuity of pedestrians through  
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28 440 the use of visibility aids, not only in night conditions<sup>26</sup> but also in twilight conditions,  
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31 441 may be beneficial for reducing crash risk or severity.  
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34 442 Adding to the research conducted by Sun et al.<sup>14</sup>, who reported that crashes related  
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37 443 to improper turning or lane changing were more likely to occur during periods of sun  
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40 444 glare, this present study concludes that an association exists between the execution of  
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43 445 overtaking manoeuvres during periods of sun glare and pedestrian fatalities. It is not  
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46 446 uncommon for injuries sustained in crashes caused by vehicle overtaking to be severe  
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49 447 because motorists must accelerate to overtake other vehicles. In Taiwan, it is common  
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52 448 that motorists execute overtaking manoeuvres by using roadway shoulders where  
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55 449 there are pedestrians. Motorists should be aware of the risk they pose to pedestrians  
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58 450 when overtaking other vehicles, particularly during periods of sun glare.  
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4 451 Studies have reported that facing traffic is beneficial for preventing pedestrian  
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7 452 crashes<sup>27</sup> and decreasing the severity of related injuries<sup>25</sup>. Our study complements  
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10 453 these two studies by concluding that walking against the traffic was associated with  
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13 454 decreased injury severity. In these cases, it is possible that pedestrians' forward views  
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16 455 are strongly lit, which might be more favourable for them than other directions.  
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19 456 Information expressing the necessity facing traffic while walking along a street,  
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22 457 particularly in conditions of sun glare, should be supplemented with specific  
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25 458 information regarding its safety benefits.

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28 459 Although differing for observed pedestrians, being struck by heavy vehicles  
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31 460 increased the likelihood of fatal injuries. Although this finding agrees with those of  
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34 461 other studies<sup>28 29</sup> reporting the tendency of injuries sustained by pedestrians to be fatal  
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37 462 or more severe when struck by a heavy vehicle, we concluded that the effect of heavy  
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40 463 vehicles was greater in conditions of sun glare. Notably, drivers of heavy vehicles  
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43 464 tend to be professional. It is unclear whether drivers of this particular group, in  
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46 465 combination with undertaking longer hours of travel than those undertaken by a car  
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49 466 driver, are more susceptible to problems related to sun glare. Educational efforts can  
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52 467 be directed towards drivers of heavy vehicles regarding their susceptibility to sun  
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55 468 glare, and on roadways with pedestrians in particular.

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58 469 This study had the following research limitations. First, our study did not consider  
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4 470 surrounding topography; it is possible that motorists travelling through some areas  
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7 471 with buildings or mountains, for example, are less susceptible to sun glare because the  
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10 472 sun is occluded. By analysing geographic data and data from police reports, likely  
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13 473 locations for sun glare can be predicted, and motorists can be well informed regarding  
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16 474 where to expect sun glare. Furthermore, we classified a crash as being glare-related  
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19 475 when the angular distance between the driver's line of sight and the sun was between  
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22 476 0° and 45°, a threshold based on the research in Japan<sup>13</sup>. Further research may attempt  
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25 477 to compare our results to those adopting more stringent thresholds of 10, 20, or 30  
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27  
28 478 degrees, as well as the variance of this effect for motorists of different ages, as  
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30  
31 479 indicated by Jurado-Piña and Pardillo Mayora<sup>9</sup>. Due to restricted funds, we were just  
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33  
34 480 able to link the National Traffic Crash Dataset to the NOAA, but not to pre-hospital  
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37 481 triage system or hospital data (e.g., the National Health Insurance Research Dataset:  
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40 482 NHIRD). We recommend that future research should link our data to clinical datasets  
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43 483 that provide more details on injuries (e.g., injured body regions, hospitalisation) other  
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45  
46 484 than fatalities examined in the present paper.

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48  
49 485 Indeed, sun glare is a combined spatial-temporal factor. To broaden our collective  
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51  
52 486 understanding of factors in pedestrian safety, it is paramount that additional spatial  
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55 487 data and temporal data be collected and compared whenever possible. Finally, the  
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58 488 empirical results obtained in this study may be unique to Taiwan because of its unique  
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4 489 sunrise and sunset times and orientations. As a result, until additional analyses are  
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7 490 conducted using data from other jurisdictions to determine whether sun glare is a  
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10 491 salient factor to pedestrian fatalities, caution should be exercised in generalising our  
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12  
13 492 findings for application in other settings.

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15 493

16  
17 494 **Contributors:** HPM drafted and revised the manuscript and established the  
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19  
20 495 theoretical supports for data analyses; PLC re-analysed the data and interpreted the  
21  
22  
23 496 results; SKC reviewed relevant literature and analysed the data; LHC analysed the  
24  
25  
26 497 data; VL edited the manuscript and reviewed relevant literature; CWP was  
27  
28  
29 498 responsible for study design, contributed to the analyzing and interpretation of data,  
30  
31  
32 499 drafted the manuscript, and strengthened discussions and conclusions. The final  
33  
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35 500 version of the manuscript was read and approved by each contributing author.

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58  
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19 514 **Data sharing statement:** Only citizens of Taiwan who fulfill the requirements of  
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21  
22 515 conducting research projects are eligible to apply for the dataset. The use of dataset is  
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25 516 limited to research purposes only. The authors had no special access privileges that  
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27  
28 517 others would not have.  
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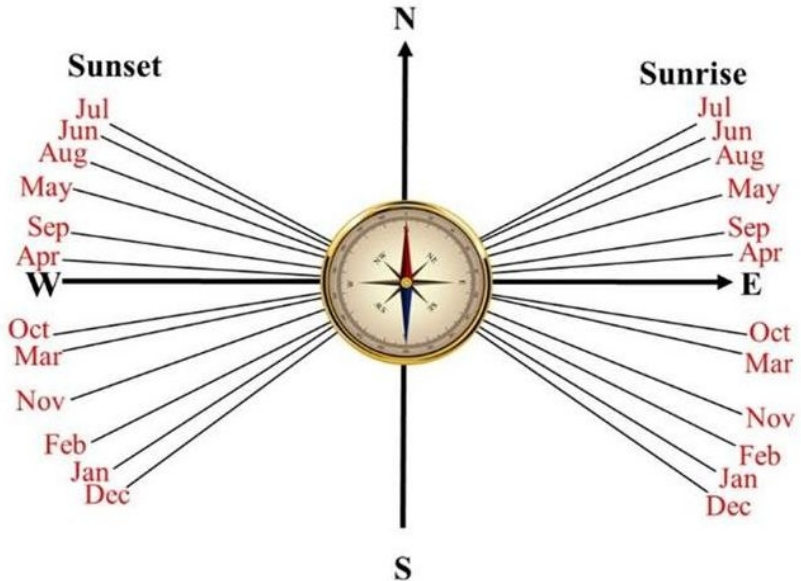


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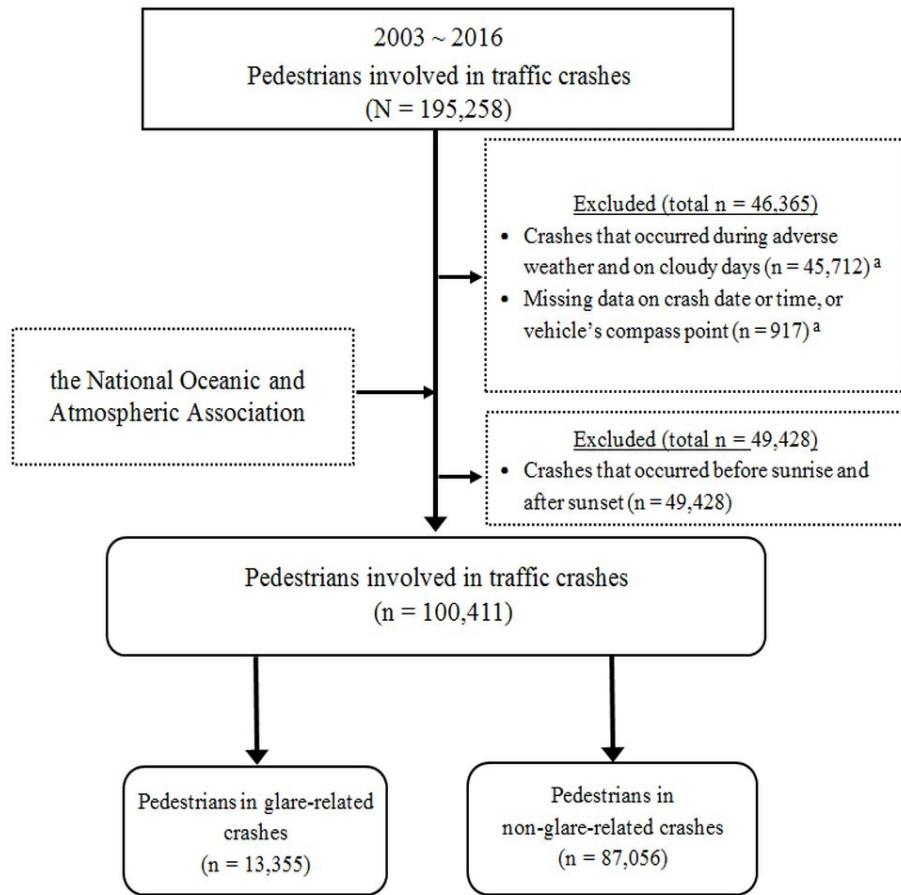
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Appendix 1: Directions of sunrise and sunset in Taiwan



66x49mm (300 x 300 DPI)

Figure 2: Study flow chart



<sup>a</sup> As these cases were not mutually exclusive, the total cases excluded were 45,365.

90x90mm (300 x 300 DPI)

**STROBE Statement**Checklist of items that should be included in reports of *case-control studies*

Section/Topic	Item No	Recommendation	Reported on Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2–3
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4–6
Objectives	3	State specific objectives, including any prespecified hypotheses	7
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	8–10
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	8–12
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	7–9
		<i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls	
		<i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	
Variables	7	(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed	11,12
		<i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	
Data sources/measurement	8*	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	11,12
Bias	9	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	9
Study size	10	Describe any efforts to address potential sources of bias	10
Quantitative variables	11	Explain how the study size was arrived at	10
		Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	11,12
		(a) Describe all statistical methods, including those used to control for confounding	12–15
		(b) Describe any methods used to examine subgroups and interactions	12–15
		(c) Explain how missing data were addressed	12–15
Statistical methods	12	(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed	12–15
		<i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed	
		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	
		(e) Describe any sensitivity analyses	N/A

Section/Topic	Item No	Recommendation	Reported on Page No
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	Appendix 2
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10
		(b) Indicate number of participants with missing data for each variable of interest	10
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	N/A
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	N/A
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	15
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	15–21
		(b) Report category boundaries when continuous variables were categorized	N/A
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	22–29
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	27–29
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	27–29
Generalisability	21	Discuss the generalisability (external validity) of the study results	28–29
<b>Other Information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	29

\*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).

# BMJ Open

## Population-based case-control study of the effect of sun glare on pedestrian fatalities in Taiwan

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2018-028350.R2
Article Type:	Research
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Complete List of Authors:	Ma, Hon-Ping; Shuang Ho Hospital - Taipei Medical University, Emergency medicine Chen, Ping-Ling; Graduate Institute of Injury Prevention and Control Chen, Shang-Ku; Shuang Ho Hospital - Taipei Medical University, Emergency Medicine; Taipei Medical University, Graduate Institute of Injury Prevention and Control Chen, Liang-Hao; Taipei Medical University, Graduate Institute of Injury Prevention and Control; Wan-Fang Hospital, Taipei Medical University, Department of Emergency Medicine Linkov, Vaclav; Department of Traffic Psychology, CDV, Transport Research Centre Pai, Chih-Wei; Taipei Medical University, Graduate Institute of Injury Prevention and Control
<b>Primary Subject Heading</b>:	Epidemiology
Secondary Subject Heading:	Epidemiology, Public health, Health policy
Keywords:	ACCIDENT & EMERGENCY MEDICINE, PUBLIC HEALTH, EPIDEMIOLOGY

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Manuscripts

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4 **1 Population-based case–control study of the effect of sun glare on pedestrian**  
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7 **2 fatalities in Taiwan**  
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10 3 Hon-Ping Ma <sup>a, b, c</sup>, Ping-Ling Chen <sup>a</sup>, Shang-Ku Chen <sup>a, b</sup>, Liang-Hao Chen <sup>a, d</sup>, Václav  
11  
12  
13 4 Linkov <sup>e</sup>, Chih-Wei Pai <sup>a, \*</sup>  
14  
15

16 5 <sup>a</sup> Graduate Institute of Injury Prevention and Control, College of Public Health, Taipei  
17  
18  
19 6 Medical University, Taiwan  
20  
21

22 7 <sup>b</sup> Department of Emergency Medicine, Shuang–Ho Hospital, Taipei Medical  
23  
24  
25 8 University, Taiwan  
26  
27

28 9 <sup>c</sup> Department of Emergency Medicine, School of Medicine, Taipei Medical  
29  
30  
31 10 University, Taiwan  
32  
33

34 11 <sup>d</sup> Department of Emergency Medicine, Wan–Fang Hospital, Taipei Medical  
35  
36  
37 12 University, Taiwan  
38  
39

40 13 <sup>e</sup> Department of Traffic Psychology, CDV–Transport Research Centre, Brno, Czech  
41  
42  
43 14 Republic  
44  
45

46 15 \* Corresponding author  
47  
48

49 16 Email: [cpai@tmu.edu.tw](mailto:cpai@tmu.edu.tw)  
50  
51

52 17 +886 02-27361661 ext.6575  
53  
54

55 18 Address: Graduate Institute of Injury Prevention and Control, College of Public  
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57  
58 19 Health, Taipei Medical University, 250 Wuxing St, Taipei City, Taiwan 110.  
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4 20 **Word count: 4712**  
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7 21  
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10 22 **Abstract**  
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13 23 **Objectives** Sun glare is a serious driving hazard and increases crash risks. Relatively  
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16 24 few studies have examined the effects of sun glare on pedestrian fatalities, given that  
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19 25 a crash has occurred. The primary objective of this study was to investigate the effect  
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22 26 of sun glare on pedestrian fatalities.  
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25 27 **Design** A population-based case-control study.  
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28 28 **Setting** Taiwan.  
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31 29 **Participants** Using the Taiwan National Traffic Crash Data and sunrise and sunset  
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34 30 data from the National Oceanic and Atmospheric Administration (NOAA) for the  
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37 31 period 2003–2016, 100,411 pedestrians involved in crashes were identified. Of these  
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40 32 crashes, 13,355 and 87,056 were glare-related (case) and non-glare-related (control)  
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43 33 crashes, respectively.  
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46 34 **Methods** To account for unobserved heterogeneity, mixed logit models were  
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49 35 estimated to identify the determinants of pedestrian fatalities.  
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52 36 **Main outcome measures** Pedestrian fatalities.  
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55 37 **Results** Pedestrians involved in glare-related crashes were more likely to be fatally  
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58 38 injured than those in non-glare-related crashes ( $\beta = 0.527$ ;  $t = 3.21$ ). Other  
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4 39 contributory factors to fatal injuries among pedestrians were older pedestrians ( $\beta =$   
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7 40 0.553;  $t = 2.33$ ), male drivers ( $\beta = 0.324$ ;  $t = 2.33$ ), older drivers ( $\beta = 0.218$ ;  $t = 2.14$ ),  
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10 41 intoxicated motorists ( $\beta = 0.606$ ;  $t = 2.85$ ), rural roadways ( $\beta = 0.985$ ;  $t = 3.92$ ),  
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13 42 overtaking manoeuvres ( $\beta = 0.472$ ;  $t = 3.58$ ), heavy vehicle crash partners ( $\beta = 0.248$ ;  $t$   
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16 43 = 2.78), and sunset hours ( $\beta = 0.274$ ;  $t = 3.08$ ). Walking against traffic appeared  
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19 44 beneficial for decreasing injury severity ( $\beta = -0.304$ ;  $t = -2.76$ ).

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22 45 **Conclusions** Sun glare is associated with pedestrian fatalities. Older pedestrians, male  
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25 46 drivers, older drivers, and intoxicated motorists are prevalent determinants of  
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28 47 pedestrian fatalities in glare-related crashes.

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31 48 **Keywords:** Sun glare; Pedestrian fatalities; Crashes; Injury  
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#### 50 **Strengths and limitations of this study**

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40 51 ● This is the first nationwide population-based case-control study of the  
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43 52 associations between pedestrian fatalities and sun glare.  
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46 53 ● Glare-related crashes were defined by adjusting vehicle travel direction and  
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49 54 orientations of sunrise and sunset.  
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52 55 ● Glare-related crashes were defined when the angular distance between the  
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55 56 driver's line of sight and the sun was between 0° and 45°.  
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58 57 ● Limitations of this study include data, such as geographic characteristics,  
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4 58 unavailable in the two datasets.  
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7 59 **INTRODUCTION**  
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13 61 Driving is a highly visual task that involves visual function and processing for  
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16 62 establishing effective control over a vehicle.<sup>1</sup> Research<sup>2 3</sup> has suggested that bright  
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19 63 sunlight is ideal for driving because it increases the contrast, resolution, and  
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22 64 luminosity of the surrounding landscape. As a result, however, drivers may  
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25 65 misinterpret the speed at which parts of the surrounding landscape are approaching  
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28 66 and underestimate their velocity, prompting them to compensate by accelerating.<sup>4 5</sup>  
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31 67 Generally, bright sunlight causes temporary blindness when the sun is at a  
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34 68 relatively low altitude (i.e., just after sunrise or before sunset when the sun is just  
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37 69 above the horizon) and its rays fall directly in an individual's line of sight. Using a  
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40 70 simulator, Gray and Regan<sup>6</sup> assessed driving performance in both the absence and  
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43 71 presence of a low sun. They reported that sun glare resulted in a significant reduction  
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46 72 in the safety margin accepted by drivers, the mean number of crashes was  
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49 73 significantly higher during conditions of glare than those without glare, and older  
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52 74 drivers exhibited significantly greater reductions in the safety margin than did  
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55 75 younger drivers. Another simulation study was conducted by Theeuwes et al.,<sup>7</sup> who  
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58 76 reported that low glare resulted in their participants (drivers) exhibiting a significant  
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4 77 decrease in the ability to detect simulated pedestrians along the roadside. Theeuwes et  
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7 78 al.<sup>7</sup> also revealed that older participants reduced their driving speed the most and  
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10 79 exhibited the largest decrease in successful pedestrian detection.  
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13 80 Churchill et al.<sup>8</sup> employed a geometric model to examine whether sun glare affects  
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16 81 the speeds of drivers on roadways and concluded that changes in speed as a result of  
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19 82 sun glare affected highway congestion. Jurado-Piña and Pardillo Mayora,<sup>9</sup> in an  
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22 83 investigation of the maximum tolerable sun glare determined that glare occurs when  
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25 84 at specific angular distances between a driver's line of sight and the sun; these angular  
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28 85 distances are 19° for a 40-year-old driver and 25° for a 60-year-old driver. Anue<sup>10</sup>  
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31 86 suggested that sun glare typically does not occur at angular distances greater than 25°.  
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34 87 Several studies have investigated whether a direct relationship exists between sun  
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37 88 glare and crashes by using data from police reports or hospitals. In a longitudinal  
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40 89 study of patients who had been hospitalised because of a motor-vehicle crash,  
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43 90 Redelmeier and Raza<sup>11</sup> concluded that bright sunlight was associated with an  
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46 91 increased risk of life-threatening crashes in Canada. By analysing police-reported  
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49 92 crash data from Arizona, Mitra and Washington<sup>12</sup> indicated that sun glare was a  
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52 93 crucial overlooked variable that could explain intersection crashes and that including  
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55 94 this variable improved the explanatory power of statistical models. By linking  
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58 95 police-reported crash data from Arizona with sunrise and sunset data from the  
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4 96 National Oceanic Atmospheric Administration (NOAA), Mitra<sup>3</sup> concluded that the  
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7 97 odds of glare causing a crash were higher on roadways running eastbound and  
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10 98 westbound than those running northbound and southbound. Mitra<sup>3</sup> further indicated  
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13 99 that rear-end and angle crashes at signalised intersections were affected by sun glare,  
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15  
16 100 but that the severity of motorist injury was unaffected by sun glare.

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19 101 By analysing the traffic-crash database of Chiba, Japan, Hagita and Mori<sup>13</sup> revealed  
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21  
22 102 that crashes involving pedestrians or bicycles at intersections were more likely when  
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24  
25 103 the sun was below 45° above the horizon in the driving direction. Sun et al.,<sup>14</sup>  
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27  
28 104 analysed police-reported crash data in Edmonton, Alberta, Canada, reported similar  
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31 105 findings, concluding that sun glare significantly contributed to crash occurrence,  
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33  
34 106 especially at intersections. Furthermore, they indicated that the effect of sun glare on  
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37 107 crash occurrence during mornings on eastbound roads and evenings on westbound  
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40 108 roads is significantly greater during the spring and autumn months and that certain  
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43 109 crash types (e.g., crashes related to signal violation, failure to yield to  
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46 110 pedestrians/cyclists, and improper turning and lane changing) are more likely during  
47  
48  
49 111 periods of sun glare. By analysing police-reported crash data, Choi and Singh<sup>15</sup>  
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51  
52 112 revealed that, when compared to other age groups, elderly motorists tend to have a  
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55 113 greater propensity for striking other vehicles in conditions of sun glare, especially on  
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58 114 roadways that are not physically divided.

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4 115 According to our literature review, a significant gap remains in the understanding  
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7 116 of the relationship between sun glare and pedestrian fatalities, conditional upon a  
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10 117 pedestrian occurring. The primary research hypothesis of the present study was that  
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13 118 pedestrian injury severity increases as visibility decreases (i.e., during sun glare). This  
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15  
16 119 study therefore investigated whether sun glare is associated with pedestrian fatalities.  
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18  
19 120 This study also examined the determinants of pedestrian fatalities in crashes related to  
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21  
22 121 sun glare.  
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25 122

## 28 123 **MATERIALS AND METHODS**

### 31 124 **Data source**

34 125 By using the Taiwan National Traffic Crash Dataset as well as sunrise and sunset  
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36  
37 126 data from the NOAA for the period from 2003 to 2016 (National Oceanic Earth  
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39  
40 127 System Research Laboratory and Atmospheric Administration,<sup>16</sup> accessed:  
41  
42  
43 128 2018-08-22), the current study examined the effect of sun glare on pedestrian  
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46 129 fatalities, given that a crash involving a vehicle and pedestrian has occurred. The  
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49 130 Taiwan National Traffic Crash Dataset comprises two types of file: crash files and  
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51  
52 131 vehicle and victim files. Crash files contain general information on the times and  
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55 132 dates of crashes, as well as weather, road conditions, lighting conditions, and road  
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57  
58 133 types. Vehicle and victim files contain vehicle-related information, such vehicle type,  
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4 134 manoeuvres, first point of impact, and orientation, as well as driver and casualty  
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7 135 information, such as age, sex, and injury severity. Injury severity is classified into one  
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9  
10 136 of two levels: fatality or injury. Victims who die within 24 h as a result of a crash are  
11  
12  
13 137 classified as fatalities, whereas victims who sustain injuries, whether mild or severe,  
14  
15  
16 138 are classified as cases of injury.

19 139 Daily sunrise and sunset times and orientation are available from the NOAA. The  
20  
21  
22 140 sunrise and sunset orientation data for Taiwan are presented in online supplementary  
23  
24  
25 141 Appendix 1. By using the data on the temporal characteristics (i.e., time and date) and  
26  
27  
28 142 orientation of vehicle crashes from the Taiwan National Traffic Crash Dataset,  
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30  
31 143 pedestrian crashes were matched with the sunrise and sunset data of the NOAA and  
32  
33  
34 144 subsequently classified into glare-related or non-glare-related crashes. The  
35  
36  
37 145 Institutional Review Board affiliated with Taipei Medical University approved our  
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39  
40 146 study (IRB#: N201808071). Personal identification data, such as name or  
41  
42  
43 147 identification number, are not available in the dataset.

46 148 A glare-related crash was defined as a crash in which the following two conditions  
47  
48  
49 149 were satisfied: the car was travelling in a direction towards the sunrise or sunset and  
50  
51  
52 150 the angular distance between the driver's line of sight and the sun was between 0° and  
53  
54  
55 151 45°. Data on a vehicle's travel orientation (north, south, east, or west) are available  
56  
57  
58 152 from the National Traffic Crash Dataset, and data on sun orientation are available  
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4 153 from the NOAA. The angular distances were adjusted according to the time of the  
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7 154 crash (available from the National Traffic Crash Dataset) and daily sunrise and sunset  
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9  
10 155 times (available from the NOAA).

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12  
13 156 For example, according to the Taiwan National Traffic Crash Dataset, a car–  
14  
15  
16 157 pedestrian crash occurred in Hsinchu City, where a car heading northeast collided  
17  
18  
19 158 with a pedestrian at 06:18 on 18 June, 2016. Angular distances from 0° to 45° were  
20  
21  
22 159 reported<sup>13</sup> to cause sun glare and potentially affect traffic safety in Japan. We adopted  
23  
24  
25 160 these same angular distances as the threshold for defining a glare-related crash.  
26  
27  
28 161 According to the NOAA website, for this particular (18 June, 2016) and location  
29  
30  
31 162 (Hsinchu City with latitude of 24.778°N and longitude of 120.988°E), the sun rose  
32  
33  
34 163 from northeast, and the sunrise and sunset times were at 05:07 and 18:47,  
35  
36  
37 164 respectively. The daytime length for this particular day was 13 h and 40 min,  
38  
39  
40 165 equivalent to 820 min. The angular distances for sunrise and sunset are 0–180°,  
41  
42  
43 166 respectively; on this particular day, the sun moved 0.2195° every minute ( $180/820 =$   
44  
45  
46 167  $0.2195$ ). The adopted angular distance of 45° is equivalent to 205 min ( $45/0.2195 =$   
47  
48  
49 168  $205$ ); therefore, the glare times transformed from the angular distances of 0°–45° for  
50  
51  
52 169 this particular crash can be between 05:07 and 08:32 (range of 205 min). This  
53  
54  
55 170 particular crash was therefore classified as a glare-related crash because the car was  
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58 171 headed northeast (which was the direction of the sunrise) and the time of the crash  
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4 172 (06:18) was associated with an angular distance within  $0^{\circ}$ – $45^{\circ}$  (i.e. times between  
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6  
7 173 05:07 and 08:32).  
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10 174 A flow-chart of the sample selection from the Taiwan Traffic Crash Dataset for  
11  
12  
13 175 the period from 2003 to 2016 is presented in online supplementary Appendix 2. A  
14  
15  
16 176 total of 195,258 pedestrian casualties from traffic crashes during this period were  
17  
18  
19 177 selected from the dataset. In our sample, each pedestrian was counted. Only crashes  
20  
21  
22 178 involving a single pedestrian were considered in this study; crashes involving two or  
23  
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25 179 more pedestrians (accounting for 0.12% of all pedestrian crashes) were excluded. This  
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27  
28 180 study also considered only pedestrian crashes in which the crash partner was a  
29  
30  
31 181 motorcycle, car, taxi, or heavy vehicle (e.g. bus or coach). Crashes that occurred  
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33  
34 182 during adverse weather conditions, such as rain, fog, or clouds, were excluded (n =  
35  
36  
37 183 45,712). A total of 917 cases had missing data with regard to date, time, or vehicle  
38  
39  
40 184 orientation. Because these cases (adverse weather conditions and missing data) were  
41  
42  
43 185 not mutually exclusive, the total number of cases excluded was 45,365, yielding a  
44  
45  
46 186 total of 149,839 valid cases of pedestrian casualties. These valid cases were matched  
47  
48  
49 187 with the NOAA sunrise and sunset data.

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52 188 After crashes that had occurred after sunset or before sunrise (n = 49,428) were  
53  
54  
55 189 excluded, 100,411 cases of pedestrian casualties remained. Of the 100,411 pedestrians  
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58 190 that were matched with the sunrise and sunset data from the NOAA, 13,355 were  
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4 191 glare-related cases (treated as cases), and 87,056 were non-glare-related cases (treated  
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7 192 as controls).  
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10 193

#### 13 194 **Definition of variables**

16 195 The following demographic data were collected regarding the pedestrians in cases  
17  
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19 196 of casualties: sex, age (four groups: <18, 18–40, 41–64, and  $\geq 65$  years), alcohol use  
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21  
22 197 (yes: breathalyser test results of  $\geq 0.15$  mg/L or blood-alcohol concentration [BAC]  
23  
24  
25 198 level  $> 0.03\%$ ; no: breathalyser test results  $< 0.15$  mg/L or BAC level  $\leq 0.03\%$ ),  
26  
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28 199 licence status (licensed: with a valid licence; unlicensed: without a valid licence), and  
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31 200 pedestrian crossing manner (facing traffic: pedestrians walking towards traffic; back  
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34 201 to traffic: pedestrians walking with their backs to traffic; crossing: pedestrians  
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37 202 crossing the street).  
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40 203 In Taiwan, those under the age of 18 are identified as teenagers who are unable to  
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43 204 legally ride motorcycles or drive cars. Those aged 65 years or older were identified as  
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46 205 elderly individuals. The remaining individuals aged 18–64 were classified into two  
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48  
49 206 even age intervals: 18–40 and 41–64 years. BAC data were obtained by police who  
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51  
52 207 conducted breathalyser tests or who ordered follow-up blood tests at hospitals.  
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54  
55 208 According to Taiwanese law, drivers with either breathalyser test  $\geq 0.15$  mg/L or  
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58 209 BAC level  $> 0.03\%$  are considered to be drink driving. Data from breathalyser tests or  
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4 210 BAC levels were available only for motorists and not for pedestrians because, by law,  
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7 211 only motorists involved in crashes are required to be tested for alcohol consumption.  
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10 212 The vehicle attribute considered was the crash partner (motorcycle, car, taxi, or  
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13 213 heavy vehicle, such as a bus or coach). The following road factors were considered:  
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16 214 sun glare (yes: affected by sun glare; no: unaffected by sun glare) and crash location  
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19 215 (rural: roadways with speed limits of  $\geq 51$ km/h; urban: roadways with speed limits of  
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21  
22 216  $\leq 50$ km/h). Two temporal factors, the month of the crash (spring/summer: March–  
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25 217 August; autumn/winter: September–February) and days of the crash (weekday:  
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27  
28 218 Monday–Friday; weekend: Saturday or Sunday), were examined.  
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### 32 33 34 220 **Patient and public involvement**

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37 221 The current research analysed national police-reported crash data as well as sunrise  
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40 222 and sunset data from the NOAA, which are anonymised datasets. Neither patients nor  
41  
42  
43 223 the public were involved in this study.  
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### 47 48 49 225 **Statistical analysis**

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52 226 The distribution of pedestrian injury severity according to a set of variables (i.e.  
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55 227 human attributes, environmental factors, and vehicle characteristics) is reported in this  
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58 228 study. Chi-square tests were conducted to examine the association between the  
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4 229 independent variables and pedestrian injury severity. Because the dependent variable  
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7 230 was binary (fatality vs. injury), binary mixed logit models, which allow parameter  
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10 231 coefficients to have distributions rather than be fixed across individuals, were  
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13 232 estimated. The variables discovered through chi-squared testing to be associated with  
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16 233 the outcome ( $p < 0.2$ ) were then incorporated into multivariate mixed logit models. To  
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19 234 detect multi-collinearity among the variables (all categorical), a chi-square  
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21  
22 235 independent test was conducted, and Cramer's  $V^{17}$  was estimated. To determine  
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25 236 whether sun glare was associated with pedestrian fatalities, one overall model that  
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27  
28 237 included sun glare as one of the variables was utilised. One additional model with  
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31 238 interaction terms of sun glare with other variables was subsequently estimated.

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34 239 Mixed logit models were estimated to account for unobserved heterogeneity that  
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37 240 may have arisen because of unmeasured variables, such as risk perception,  
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40 241 behavioural factors, and other socioeconomic factors not available in the  
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43 242 police-reported crash data. One example of a behavioural factor is distraction by  
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46 243 phone use that may result in risk-taking inclinations and consequently an increased  
47  
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49 244 risk of injury.<sup>18 19</sup> Ignoring the effects of unobserved variables may lead to  
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51  
52 245 inconsistent estimates in all statistical models.<sup>20</sup>

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55 246 In the present study, the utility of the injury severity  $i$  for a crash  $n$  was defined as  
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58 247 follows:

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4 248  $IS_{in} = \beta_n X_{in} + \varepsilon_{in}$  Eq. (1)  
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250 where  $IS_{in}$  is an injury-severity function determining the injury-severity category  $i$   
251 (fatal or injury) for an individual pedestrian  $n$ ;  $X_{in}$  is a vector of the observed  
252 variables, such as pedestrian and driver attributes, vehicle characteristics, and  
253 environmental or temporal variables,  $\beta_n$  is a vector of the parameters associated with  
254  $X_{in}$ ; and  $\varepsilon_{in}$  is the error term. The mixed logit model uses  $\beta_n$  as a vector of estimable  
255 parameters, which vary among pedestrians. The variation is observed with density  
256  $f(\beta/\theta)$ , where  $\theta$  is a vector of the parameters of the density distribution. In most  
257 applications, mixed models specify that the density  $f$  has a continuous distribution,  
258 such as a normal, lognormal, triangular, or uniform distribution.

259 Given error terms that are independent and identically Gumbel distributed<sup>21</sup>, the  
260 unconditional probability of one alternative  $i$  (from the set of injury-severity  
261 categories  $I$ ) is the integral of the conditional probability with a multinomial logit  
262 form over the parameter  $\beta$  of density  $f$ :

263

264 
$$P_{in} = \left( \frac{\exp(\beta' X_{in})}{\sum_{j=1}^I 1 + \exp(\beta' X_{nj})} \right) f(\beta|\theta) d\beta$$
 Eq. (2)  
265  
266

267 All parameters are initially assumed to be random; then, their estimated standard

268 deviations are evaluated using a zero-based (asymptotic) *t* test for each parameter.

269 One study<sup>20</sup> pointed out that a simulation-based maximum likelihood with 200 Halton

270 draws may provide a more efficient distribution of draws for numerical integration

271 and requires fewer draws to achieve convergence. We attempted to increase the

272 number of Halton draws, and the results appeared stable with the use of 1000 Halton

273 draws.

274

## 275 RESULTS

276

277 Table 1 lists the distribution of pedestrian injury severity according to a set of

278 variables. Of the 13,355 glare-related cases, 329 pedestrians (2.46%) sustained fatal

279 injuries, which is higher than those in non-glare-related crashes (1.83%). Majority of

280 pedestrian crashes involved motorists with valid licences (85.65%), sober motorists

281 (85.97%), urban roadways (89.57%), pedestrians who were hit while crossing the

282 street (65.85%), or non-glare conditions (86.70%) or occurred on weekdays (74.83%).

283

284 Table 1: Distribution of pedestrian injury severity according to a set of variables for

285 the period 2003–2016.

	N	Fatality n(%)	Injury n(%)	$\chi^2$ test p-value
Total	100411	1925(1.92)	98486(98.08)	
Sun glare				
Yes	13355(13.30)	329(2.46)	13026(97.54)	<0.01

	N	Fatality n(%)	Injury n(%)	$\chi^2$ test p-value
No	87056(86.70)	1596(1.83)	85460(98.17)	
Pedestrian gender				
Male	50942(50.73)	1015(1.99)	49927(98.01)	0.08
Female	49469(49.27)	910(1.84)	48559(98.16)	
Driver gender				
Male	53351(53.13)	1132(2.12)	52219(97.88)	<0.01
Female	47060(46.87)	793(1.69)	46267(98.31)	
Pedestrian age (years)				
<18	3644(3.63)	67(1.84)	3577(98.16)	<0.01
18-40	25851(25.75)	154(0.60)	25697(99.40)	
41-64	31283(31.15)	352(1.13)	30931(98.87)	
$\geq 65$	39633(39.47)	1352(3.41)	38281(96.59)	
Driver age (years)				
<18	4458(4.44)	103(2.31)	4355(97.69)	<0.01
18-40	25808(25.70)	295(1.14)	25513(98.86)	
41-64	32523(32.39)	474(1.46)	32049(98.54)	
$\geq 65$	37622(37.47)	1033(2.75)	36589(97.25)	
Driver licence				
Licensed	86007(85.65)	1609(1.87)	84398(98.13)	0.01
Unlicensed	14404(14.35)	316(2.19)	14088(97.81)	
Alcohol use for driver				
No	86322(85.97)	1512(1.75)	84810(98.25)	<0.01
Yes	14089(14.03)	413(2.93)	13676(97.07)	
Seasons				
Spring/summer	47671(47.48)	914(1.92)	46757(98.08)	0.99
Autumn/winter	52740(52.52)	1011(1.92)	51729(98.08)	
Crash location				
Rural	10475(10.43)	352(3.36)	10123(96.64)	<0.01
Urban	89936(89.57)	1573(1.75)	88363(98.25)	
Crash partner				
Motorcycle	33221(33.09)	643(1.94)	32578(98.06)	<0.01
Car	45963(45.77)	801(1.74)	45162(98.26)	
Taxi	9655(9.62)	208(2.15)	9447(97.85)	
Heavy vehicle	11572(11.52)	356(3.08)	11216(96.92)	
Pedestrian movement				
Facing traffic	9704(9.66)	172(1.77)	9532(98.23)	<0.01

	N	Fatality n(%)	Injury n(%)	$\chi^2$ test p-value
Back to traffic	24584(24.48)	623(2.53)	23961(97.47)	
Crossing	66123(65.85)	1130(1.71)	64993(98.29)	
Car manoeuvre				
Straight	50836(50.63)	862(1.70)	49974(98.30)	<0.01
Changing lane	15625(15.56)	257(1.64)	15368(98.36)	
Overtaking	21339(21.25)	601(2.82)	20738(97.18)	
Turning	12611(12.56)	205(1.63)	12406(98.37)	
Sunset				
Sunset	8325(8.29)	214(2.57)	8109(97.41)	<0.01
Other times	87056(86.70)	1596(1.83)	85460(98.17)	
Sunrise	5030(5.01)	115(2.29)	4915(97.71)	
Weekdays				
Weekday	70366(70.08)	1267(1.80)	69099(98.20)	<0.01
Weekend	30045(29.92)	658(2.19)	29387(97.81)	

286

287 Through chi-square testing, the following variables were determined to be  
 288 associated with the outcome: sun glare; pedestrian and driver sex and age; driver  
 289 license possession and alcohol consumption; crash month, location, and partner;  
 290 pedestrian movement; car manoeuvre; sunset hours; and day of the week. These  
 291 factors were then incorporated into the mixed logit models.

292 Table 2 presents the estimation results of the mixed logit model of pedestrian  
 293 injury severity. We compared the Akaike Information Criterion (AIC) of the models  
 294 when determining the optimal distribution and determining whether parameters were  
 295 fixed or random; male motorists and heavy vehicles as crash partners were determined  
 296 to be random parameters, with a uniform distribution that appears to provide the best  
 297 statistical fit.



298

299 Table 2: Mixed logit model estimation results for pedestrian injury severity during the  
 300 period 2003–2016<sup>a</sup> (n = 100,411).

Variable	Parameter	Standard error	<i>t</i> -value
Fatal injury			
Fixed parameters			
Constant	−0.531	0.215	−2.47
Glare-related crash	0.527	0.164	3.21
Pedestrian facing traffic	−0.304	0.110	−2.76
Pedestrian aged 65+ years	0.553	0.237	2.33
Motorist aged 65+ years	0.218	0.102	2.14
Rural roadway	0.985	0.251	3.92
Intoxicated motorist	0.606	0.213	2.85
Weekend	0.134	0.053	2.53
Overtaking manoeuvre	0.472	0.132	3.58
Sunset	0.162	0.074	2.19
Random parameters			
Male motorist	0.324	0.139	2.33
Standard deviation of distribution	0.389	0.163	2.39
Heavy vehicle partner	0.274	0.110	2.49
Standard deviation of distribution	0.622	0.290	2.14
Restricted log-likelihood (constant only): −8,267.1			
Log-likelihood at convergence: −5,806.4			
$\rho^2 = 0.298$			

301 <sup>a</sup> The outcome ‘injury’ is the baseline case with its parameters set at zero.

302

303 According to the results listed in Table 2, glare-related crashes contributed to  
 304 fatalities ( $t = 3.21$ ), and the estimated parameter was fixed across all observed  
 305 pedestrians (the AIC, when fixed, was smaller than when allowed to be random). The  
 306 parameter implies that glared-related crash was more likely to result in fatal injuries  
 307 among pedestrians than a non-glare-related crash. Other factors discovered to have  
 308 fixed effects on observed pedestrians and increase the likelihood of fatal injuries were

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4 309 pedestrians aged 65 years or older, motorists aged 65 years or older, rural roadways,  
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7 310 intoxicated motorists, weekend days, overtaking manoeuvres, and sunset hours.  
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10 311 The parameter for the parameter of male motorist appeared to be random, having a  
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13 312 normal distribution with a mean of 0.324 and standard deviation of 0.389 (see Table  
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16 313 2), indicating that individual pedestrians being struck by male motorists had different  
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18  
19 314 parameters. Given the estimates (mean = 0.324, standard deviation = 0.389),  
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21  
22 315 approximately 79.8% of pedestrians had a higher probability of sustaining fatal  
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25 316 injuries when all other variables remained constant. Another parameter found to have  
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27  
28 317 a random effect across the sample of pedestrians was the variable of a heavy vehicle  
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31 318 as the crash partner (with a normal distribution). This parameter had a mean of 0.274  
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33  
34 319 and standard deviation of 0.622 (see Table 2), indicating that individual pedestrians  
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37 320 struck by heavy vehicles have different parameters, with 67.0% of the distributions  
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40 321 resulting in a positive parameter (increasing the likelihood of fatal injuries) and 33.0%  
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43 322 resulting in negative parameter (decreasing the likelihood of fatal injuries).  
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46 323 The direction of travel of pedestrians relative to vehicular traffic was also  
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49 324 discovered to affect pedestrian fatalities ( $t = -2.76$ ). This fixed parameter suggests  
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52 325 that pedestrians who faced traffic while walking were less likely to sustain fatal  
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55 326 injuries than were those making other movements, such as walking with their backs to  
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58 327 traffic or crossing the street.  
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4 328 Table 3 presents the estimation results of the mixed logit model of pedestrian  
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7 329 injury severity specifically in glare-related crashes. For this model, the only random  
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10 330 parameter (with a uniform distribution) was the variable of a heavy vehicle as the  
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13 331 crash partner. The heterogeneous effect indicates that crashes involving heavy  
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16 332 vehicles were associated with both higher and lower likelihoods of pedestrians  
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19 333 sustaining fatal injuries. We speculate that this heterogeneous effect is caused by  
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22 334 variance in the experience level among certain driver groups, with more experienced  
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25 335 drivers exhibiting a decreased likelihood of causing fatal injuries. In other words,  
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28 336 heavy vehicles are normally operated by professional drivers, with the majority of  
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31 337 drivers in this group being men and middle-aged or older individuals. The  
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34 338 heterogeneity of the heavy vehicle partner variable presented supporting estimating a  
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37 339 mixed logit model of pedestrian injury severity because such effects are difficult to  
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40 340 identify when using a logit framework with numerous interaction terms.

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44 342 Table 3: Mixed logit estimation results for pedestrian injury severity with interaction  
45 343 terms of glare-related crashes and other variables <sup>a</sup> (n = 100,411)

Variable	Parameter	Standard error	t-value
Fatal injury			
Fixed parameters			
Constant	-0.324	0.139	-2.33
Male motorist	0.193	0.069	2.80
Sunset	0.274	0.089	3.08
Pedestrian facing traffic × glare crash	-0.439	0.126	-3.48
Pedestrians aged 65+ years	0.533	0.210	2.54
Motorists aged 65+ years × glare crash	0.432	0.143	3.02

Rural roadways × glare crash	0.684	0.190	3.60
Intoxicated motorist	0.461	0.154	2.99
Weekend	0.157	0.075	2.09
Overtaking manoeuvre	0.329	0.121	2.72
Random parameter			
Heavy vehicle as crash partner	0.248	0.089	2.78
Standard deviation of distribution	0.526	0.211	2.49

Restricted log-likelihood (constant only): -7,302.7

Log-likelihood at convergence: -5,054.6

$\rho^2=0.308$

344 <sup>a</sup> The outcome ‘injury’ constituted the baseline, with its parameters set at zero

345

346 This mixed logit model with interaction terms of glare crashes with other variables

347 highlights several crucial features of glare crashes. For example, several interaction

348 terms were discovered to affect fatalities and fixed across the observed pedestrians:

349 facing traffic × glare crash, elderly motorist × glare crash, and rural roadway × glare

350 crash. It appears that facing traffic in a glare-related crash is a protective factor

351 against pedestrian fatalities. Injuries to pedestrians were more likely to be fatal in

352 glare crashes in which the drivers were elderly. Furthermore, in glare crashes that

353 took place in a rural setting, injuries were more likely to be fatal than otherwise.

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## 355 **DISCUSSIONS**

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357 By using the National Traffic Crash Dataset and sunrise and sunset data from the

358 NOAA, the present study examined whether sun glare was associated with pedestrian

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4 359 fatalities involved in motor vehicle crashes. This research contributes to the growing  
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7 360 literature on pedestrian safety as well as fills a major research gap regarding the effect  
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10 361 of sun glare on pedestrian fatalities. Regarding methodological contributions, the  
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13 362 proposed models offer methodological flexibility to identify individual-specific  
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16 363 heterogeneity that may arise as a result of other unmeasured factors related to motorist  
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19 364 experience or behaviour or geographic characteristics. When developing intervention  
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22 365 strategies for improving pedestrian safety in sun-glare conditions, the heterogeneous  
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25 366 effects of certain variables (which cannot be determined with traditional logit models)  
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28 367 should be considered.

31 368 The empirical contributions of this research are those findings related to the  
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34 369 factors affecting pedestrian fatalities. The identification of these risk factors may  
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37 370 provide policy-makers with information crucial to establishing suitable policies and  
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40 371 strategies that may reduce the risk of crashes or severity. The following findings merit  
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43 372 further discussion.

46 373 Most drivers commute during hours of extreme sun glare. It is therefore not  
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49 374 surprising that more crashes occur on roadways that experience a significant portion  
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52 375 of traffic during peak morning (sunrise) and afternoon (sunset) hours. The adverse  
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55 376 effect of sun glare on crash occurrence has been well documented in relevant  
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58 377 literature.<sup>3 14</sup> However, Mitra<sup>3</sup> discovered that motorist injury severity was not  
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4 378 increased in glare conditions, possibly as a consequence of reduced travel speed.<sup>8</sup>  
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7 379 Such a protective effect of sun glare against associated motorist injury severity does  
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10 380 not apply to pedestrians; our study concludes that glare conditions (as indicated in the  
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13 381 overall model) are associated with pedestrian fatalities.  
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16 382 In our study, the adverse effect of sun glare was greater on rural roadways where  
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19 383 crashes occur at higher speeds and motorists may not expect to encounter pedestrians  
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22 384 as often as they would on urban roadways. One commonly-adopted engineering  
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25 385 measure is the use of adjust message signs to warn drivers of the risk of sun glare at  
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28 386 times and locations (i.e. rural roadways) prone to sun glare.<sup>9</sup>  
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31 387 Mitra<sup>3</sup> noted that the odds of glare causing crashes at intersections were higher  
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34 388 during the morning hours and in autumn and winter months in Arizona, United States.  
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37 389 In our study, seasons had a negligible effect on pedestrian fatalities. Adding to the  
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40 390 research conducted by Hagita and Mori,<sup>22</sup> who concluded that the rate of pedestrian  
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43 391 crashes shortly after sunset was higher than that at any other time in Japan, our study  
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46 392 revealed that compared with sunrise, the adverse effect of sun glare on pedestrian  
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49 393 fatalities was greater during sunset in Taiwan. Therefore, sun glare during sunset  
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52 394 hours may not only increase pedestrian crashes, as indicated by Hagita and Mori<sup>22</sup>,  
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55 395 but also affect the resulting injury severity. Evening commutes are often risky due to  
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58 396 fatigue, distraction, or other factors unrelated to sun glare. In our study, injuries  
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4 397 sustained by pedestrians were more likely to be fatal at sunset than any other daytime  
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7 398 of day. Additional research is warranted to examine whether sun glare affects  
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10 399 pedestrian fatalities in evening commuting crashes.

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13 400 Studies have suggested that compared to sober motorists, intoxicated motorists are  
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16 401 more likely to leave pedestrians unattended by leaving the crash scene, thereby  
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19 402 increasing pedestrian injury severity. Furthermore, alcohol use has been discovered to  
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22 403 lead to hit-and-runs at night and during the weekend.<sup>23 24</sup> Our study revealed that the  
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25 404 combined effects of alcohol consumption and sun glare were associated with  
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28 405 pedestrian fatalities. Similar to other studies,<sup>23 24</sup> our research highlights, in particular,  
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31 406 the effect of motorist alcohol consumption on the likelihood of fatality and on the  
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34 407 weekends.

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37 408 Studies have consistently reported that elderly motorists are the group most  
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40 409 affected by sun glare. For example, two simulation studies conducted by Gray and  
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43 410 Regan<sup>6</sup> and Theeuwes et al.<sup>7</sup> reported that in conditions of sun glare, older drivers  
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46 411 executing a turning manoeuvre demonstrated significantly greater reductions in safety  
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49 412 margin than did younger drivers, and older drivers demonstrated the most significant  
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52 413 decrease in the ability to successfully detect pedestrians. Studies analysing real-life  
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55 414 police-reported crash data<sup>15</sup> have indicated that in conditions of sun glare, older  
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58 415 drivers are more likely to strike other vehicles. Our study contributes to the literature  
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4 416 on pedestrian safety by concluding that older motorists, when affected by sun glare,  
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7 417 are likely to cause fatal injuries to pedestrians when crashes occur. Advance-warning  
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10 418 signs or educational efforts to increase older drivers' awareness of sun-glare  
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13 419 conditions may reduce the likelihood of vehicle crashes or pedestrian injury severity.  
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16 420 In our study, no discrepancy was found between injuries in spring/summer and  
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19 421 autumn/winter. We speculate that this is primarily because the anticipated effect of  
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22 422 sun glare in different seasons may be offset by, for example, typhoons that strike  
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25 423 Taiwan in summer and northeast monsoon in winter. Our result differs from those  
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28 424 from large country,<sup>3</sup> where the adverse effect of sun glare was found to be greater in  
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31 425 autumn and winter months. Such studies have been conducted in large countries such  
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34 426 as the United States, where the climate changes substantially across latitudes, whereas  
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37 427 Taiwan is a small island where climate changes little throughout the country.  
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40 428 Considerable work has concluded that older pedestrians are more likely to be  
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43 429 fatally or severely injured in crashes, both during daytime and night conditions.<sup>25</sup> Our  
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46 430 research provides ample evidence to suggest that injuries sustained by older  
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49 431 pedestrians in crashes caused by sun glare are more likely to be fatal than those  
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52 432 sustained by younger pedestrians. Whether the reduced conspicuity of pedestrians  
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55 433 (particularly older pedestrians) under conditions of sun glare (twilight) plays a role in  
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58 434 this effect is uncertain. However, enhancing the conspicuity of pedestrians with the  
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4 435 use of visibility aids, not only in night conditions<sup>26</sup> but also in twilight conditions,  
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7 436 may be beneficial for reducing crash risk or severity.  
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10 437 Adding to the research conducted by Sun et al.,<sup>14</sup> who reported that crashes related  
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13 438 to improper turning or lane changing were more likely to occur during periods of sun  
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16 439 glare, the present study reveals an association between the execution of overtaking  
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19 440 manoeuvres during periods of sun glare and pedestrian fatalities. Injuries sustained in  
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22 441 crashes caused by vehicles executing overtaking manoeuvres are commonly severe  
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25 442 because motorists must accelerate to overtake other vehicles. In Taiwan, it is common  
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28 443 for motorists to execute overtaking manoeuvres by using roadway shoulders, where  
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31 444 pedestrians walk. Motorists should be aware of the risk they pose to pedestrians when  
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34 445 overtaking other vehicles, particularly during periods of sun glare.  
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37 446 Studies have reported that facing traffic is beneficial for preventing pedestrian  
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40 447 crashes<sup>27</sup> and reducing the severity of related injuries.<sup>25</sup> Our study complements these  
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43 448 studies by concluding that walking against traffic is associated with decreased injury  
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46 449 severity. In these cases, pedestrians' forward views may be well lit and thus be more  
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49 450 favourable for pedestrians than walking in other directions. Expressing the necessity  
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52 451 of facing traffic while walking along a street, particularly in conditions of sun glare,  
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55 452 should be supplemented with information regarding the related safety benefits.  
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58 453 Although it varied among the study pedestrians, being struck by heavy vehicles  
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4 454 increased the likelihood of fatal injuries. Although this finding agrees with those of  
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7 455 other studies,<sup>28 29</sup> we additionally concluded that the effect of heavy vehicles was  
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10 456 greater in conditions of sun glare. Notably, drivers of heavy vehicles tend to be  
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13 457 professional. It is unclear whether driving this particular group of vehicles, in  
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16 458 combination with undertaking longer hours of travel compared with those undertaken  
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19 459 by a car driver, makes such drivers more susceptible to problems related to sun glare  
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22 460 than other drivers are. Educational efforts can be directed towards drivers of heavy  
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25 461 vehicles regarding driver susceptibility to sun glare, particularly on roadways with  
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28 462 pedestrians.

31 463 This study had the following research limitations. First, it did not consider the  
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34 464 surrounding topography; motorists travelling through areas with buildings or  
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37 465 mountains, may be less susceptible to sun glare because the sun is occluded. By  
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40 466 analysing geographic and police report data, likely times and locations for sun glare  
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43 467 can be predicted, and motorists can be well informed regarding where and when to  
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46 468 expect sun glare. Furthermore, we classified crashes as being related to glare when the  
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49 469 angular distance between the driver's line of sight and the sun was between 0° and  
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52 470 45°, a threshold based on research in Japan.<sup>13</sup> Further research adopting more  
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55 471 stringent thresholds of 10°, 20°, or 30° degrees or analysing the changes in this effect  
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58 472 for motorists of different ages may attempt to compare their results with ours, as  
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4 473 indicated by Jurado-Piña and Pardillo Mayora.<sup>9</sup>  
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7 474 Due to limited funding, we could link only the National Traffic Crash Dataset and  
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10 475 NOAA data but not prehospital triage system or hospital data (e.g. the National  
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13 476 Health Insurance Research Dataset: NHIRD). We recommend that future research  
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16 477 link our data to clinical datasets that provide details on injuries (e.g. injured body  
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19 478 regions, hospitalisation) other than the condition of fatalities examined in this study.  
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22 479 Sun glare is a combined spatiotemporal factor. To broaden our collective  
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25 480 understanding of factors of pedestrian safety, collecting spatial and temporal data  
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28 481 whenever possible is paramount. The empirical results obtained in this study may be  
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31 482 unique to Taiwan because of its unique sunrise and sunset times and orientations. As a  
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34 483 result, until additional analyses are conducted using data from other countries to  
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37 484 determine whether sun glare is a salient factor of pedestrian fatalities, caution should  
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40 485 be exercised in generalising our findings for application in other settings.  
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43  
44 487 **Contributors:** HPM drafted and revised the manuscript and established the  
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46  
47 488 theoretical support for data analyses. PLC re-analysed the data and interpreted the  
48  
49  
50 489 results. SKC reviewed relevant literature and analysed the data. LHC analysed the  
51  
52  
53 490 data. VL edited the manuscript and reviewed relevant literature. CWP was responsible  
54  
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56 491 for study design, contributed to the analysing and interpretation of data, drafted the  
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58  
59 492 manuscript, and strengthened discussion and conclusion. The final version of the  
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4 493 manuscript was read and approved by all contributing authors.  
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18  
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21  
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23  
24  
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26  
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28 501 data, or preparation of the manuscript. Václav Linkov was supported by the Ministry  
29  
30  
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32  
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34 503 of Transport R&D Centre (LO1610), on a research grant acquired from the  
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37 504 Operational Programme Research and Development for Innovations  
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40 505 (CZ.1.05/2.1.00/03.0064).  
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46 507 **Data sharing statement:** Only citizens of Taiwan who fulfil the requirements of  
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49 508 conducting research projects are eligible to apply to use the dataset. The use of dataset  
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52 509 is limited to research purposes only. The authors had no special access privileges that  
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55 510 others would not have.  
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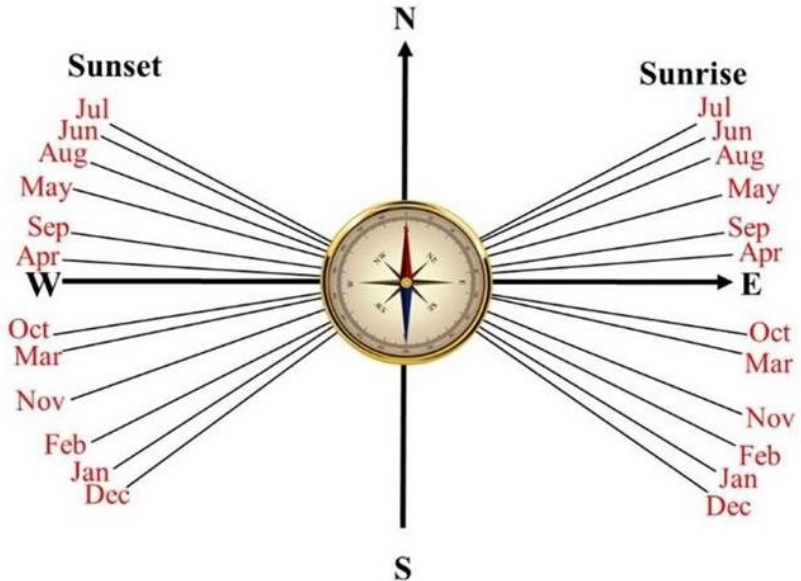
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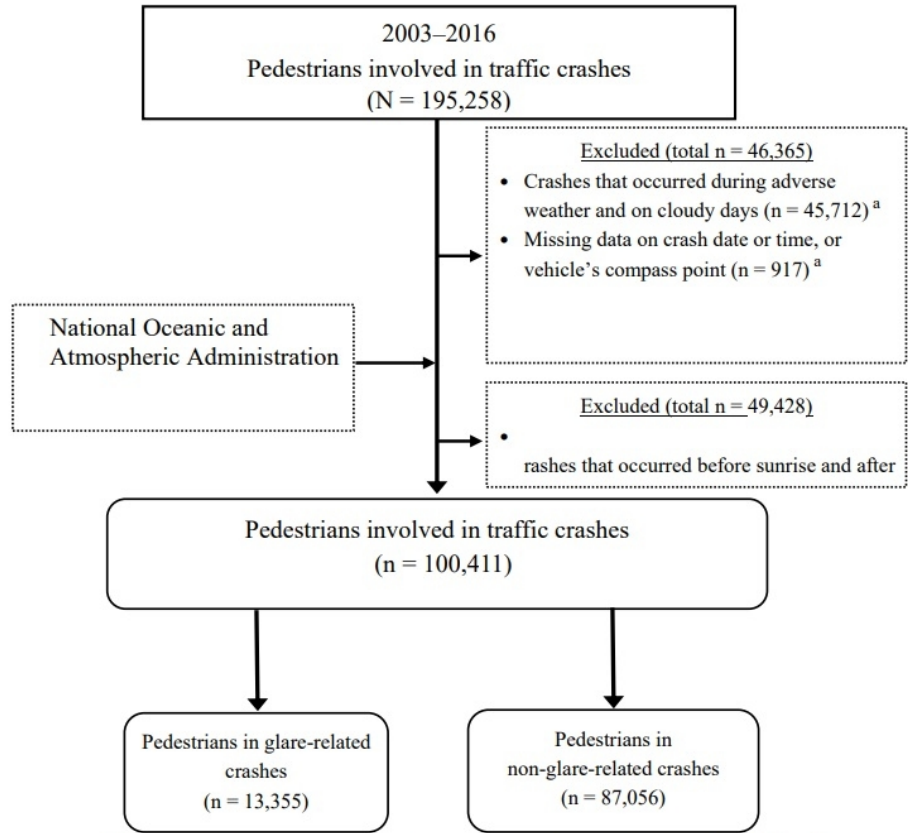
Appendix 1: Directions of sunrise and sunset in Taiwan



66x49mm (300 x 300 DPI)



Appendix 2: Study flow chart



<sup>a</sup> Because these cases were not mutually exclusive, the total number of cases excluded was 45,365.

209x204mm (96 x 96 DPI)

**STROBE Statement**Checklist of items that should be included in reports of *case-control studies*

Section/Topic	Item No	Recommendation	Reported on Page No
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2–3
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4–6
Objectives	3	State specific objectives, including any prespecified hypotheses	7
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	8–10
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	8–12
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	7–9
		<i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls	
		<i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	
Variables	7	(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed	11,12
		<i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	
Data sources/measurement	8*	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	11,12
Bias	9	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	9
Study size	10	Describe any efforts to address potential sources of bias	10
Quantitative variables	11	Explain how the study size was arrived at	10
Statistical methods	12	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	11,12
		(a) Describe all statistical methods, including those used to control for confounding	12–15
		(b) Describe any methods used to examine subgroups and interactions	12–15
		(c) Explain how missing data were addressed	12–15
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed	12–15
<i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed			
		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	
		(e) Describe any sensitivity analyses	N/A

Section/Topic	Item No	Recommendation	Reported on Page No
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	Appendix 2
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10
		(b) Indicate number of participants with missing data for each variable of interest	10
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	N/A
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	N/A
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	15
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	15–21
		(b) Report category boundaries when continuous variables were categorized	N/A
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	22–29
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	27–29
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	27–29
Generalisability	21	Discuss the generalisability (external validity) of the study results	28–29
<b>Other Information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	29

\*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).