Evaluation of fixation and reaction gaze points near speed humps on urban roads in India

Satish Chandra, Ravi Sekhar Chalumuri*, Kamini Gupta and Neelima Chakrabarty

CSIR-Central Road Research Institute, Delhi–Mathura Road, New Delhi 110 025, India

Isolated speed humps are extensively used as speed-calming measures for motorized vehicles of different categories on urban roads. Most urban roads in India are provided with either a trapezoidal or circular speed hump based on the road category. The height of these humps influences the per cent reduction of speed at the crown of the hump. It has been observed that passenger motorized vehicles do not reduce their speeds before a speed hump, even when it is large. The objective of this study was to evaluate the driver perception and reaction distance near a speed hump and thereby examine the sensitivity of these parameters on the drivers of different age groups. For this, drivers of different ages (a total sample size of five subjects) were considered for real-time eye-tracking experiments. The experimental results of all subjects' eye tracking images were examined in this study. The visit duration or dwell time for an area of interest (AOI) was estimated and compared among various drivers. The speed data were also collected using a velocity-box along with eye-tracking data of each driver at the identified location. The collected eye-tracking experimental data were analysed using statistical techniques. Regression analysis between vehicular speed and fixation count was performed. It was observed that the power model was the best fit for the collected data. The visualization data helped to reveal the characteristics of fixation and reaction gaze points near the identified speed humps. The study results showed that driver attention was double when vehicle located between 0 and 20 m than 20 and 40 m from the speed hump. Drivers in the age group between 20 and 25 years had 48% AOI of visit duration, while for those in the age group between 30 and 40 years, it was 67%.

Keywords: Eye tracker, gaze plots, heat maps, regression analysis, speed hump, urban roads.

IN India, about half a million road accidents occurred killing around 0.15 million people and injuring over half a million. About 0.45 million road accidents occurred in India in 2019 resulting in 0.15 million deaths[1]. Out of 0.45 million road accidents 40% accidents occurred on urban roads and 60% accidents occurred on interurban and rural roads. Nearly 74.4% of road accidents in India are caused due to the driver's fault, including overspeeding, lack of lane discipline and driving under the influence of alcohol or drugs. Statistics revealed that the maximum fatalities were seen in the age group of 18–34 years (50%). India, as a signatory to the Brasilia declaration, intends to reduce road accidents and traffic fatalities by 50% by 2022. Therefore road safety must become an integral part of national security. The severity of road accidents can be reduced by decreasing the speed of vehicles[2]. Traffic-calming measures have played an important role in enhancing road safety by ensuring lower driving speeds.

Traffic-calming measures have emerged primarily as a societal requirement for road safety. Proper implementation of such measures reduces road accidents as well as pollution and makes the neighbourhood more livable. Isolated speed humps are extensively used for speed reduction of motorized vehicles on any urban road. In India, most urban roads have trapezoidal or circular speed humps based on the road category. The height of these humps influences the percentage reduction of the desired speed at the crown of the humps. Studies have shown that passenger motorized vehicles do not reduce their speeds before a speed hump, even when it is large[3].

Eye-tracking studies record human visual activity during a specific task. The main application of eye-tracking is studying driver behaviour in various real-world traffic situations. Eye-trackers have been successfully employed to compare driver behaviour using a car driving simulator (laboratory study) and real-world driving conditions. The most significant eye-tracking parameter in traffic studies is the eye fixation point, which shows the driver visual attention and behaviour in different driving scenarios. In the literature, eye movement indices are commonly used as a metric of the driver's mental workload[4]. The saccadic peak velocity is significantly associated with this mental workload in the dynamic and complex decision-making process, which can also substitute the pupil diameter index.

The objective of the present study was to evaluate the driver perception and reaction distance near a speed hump, study the sensitivity of these parameters at the hump and assign the right signage at proper distances to reduce the speed. Driver visual behaviour at different distances from the speed breaker was also studied in terms of gaze plots and heat maps. This study also examined the relationship between the number of fixation points and the speed of the vehicles.

*For correspondence. (e-mail: chalumuri.ravisekhar@gmail.com)

Literature review

Zhao *et al.*[5] studied the effect of horizontal alignment on the driver's gaze pattern. The results showed that drivers focused on the middle region while driving. As the radius of the curve increased, the gazing points would move from the two sides of the road to the middle region. To evaluate the gaze behaviour pattern, straight and curved sections were used to evaluate the performance of drivers. Driver's gazing points tend to move to the centre line from two sides of the road with an increase of horizontal curve radius. Chen *et al.*[6] studied the impact of traffic conditions on the driver's visual behaviour under light, medium and heavy traffic. A driving simulator and eye-tracker were used to test the driver's visual behaviour. The authors concluded that with increasing traffic, the average fixation and standard deviation of horizontal search had an upward trend for roads with different traffic volumes. The saccadic behaviour of a driver generally had a small amplitude low-saccadic behaviour was more than high-speed saccadic behaviour for three types of traffic volumes (low, medium and heavy) on roads. The fixation and saccadic velocity were significantly different for the three different traffic conditions. This shows that traffic volume affects the driver's visual search range.

Qi *et al.*[7] studied the evolution trend of a driver's visual characteristics under traffic congestion and showed that increasing traffic congestion levels make the fixation points more dispersed and being transferred to the central main viewing area (short distance) under traffic congestion. This evolution trend can be interpreted based on changes in road information. Liu *et al.*[8] compared visual and cognitive distraction considering three different distraction conditions, viz. distraction, with visual distraction and with cognitive distraction. The results revealed that visual distraction led to higher speed variance and increased workload. Cognitive distraction made steering less smooth, but improved lane maintenance. Visual distraction was associated with more off-road glances, while increased blink frequency was observed during cognitive distraction. Both types of distraction resulted in gaze concentration and slow saccades when the drivers looked at the roadway.

Yeo *et al.*[9] studied the effectiveness of speed humps and speed tables. The study compared speed and acceleration at interrupted and non-interrupted humps. The differences in average speed were statistically significant at all sections of the speed humps. Drivers at both the speed humps and tables had similar speed patterns before reaching the devices. After passing the devices, the magnitude of speed differences between the speed humps and tables increased to 18% in the 50–60 m section. This study considered eye-track experiments to observe eye movement and fixation on speed control devices. Ren *et al.*[10] studied driver attention allocation under different driving behaviours. Right and left-turning behaviours, as well as right and left lane changes, were designed on a simulator test to study driver attention allocation under different driving behaviours. The distribution of fixation time on a driver's area of interest (AOI) and the searching range of visual information were used to express a driver's attention allocation. The authors concluded that drivers paid considerable attention to information far ahead, irrespective of driving behaviour. Under free driving, when a vehicle turns around on a curved section with large curvature or does a lane change, the driver's attention moves from the front area to the left-side in left-turning scenarios and from the front area to the right side in the right-turning scenarios.

The relationship between vision-related traits and their impacts on road safety was studied. It also performed a critical review on the role of various aspects of visual function in driving based on vision tests conducted on 625 heavy commercial vehicle drivers in four Indian metropolitan cities. The study highlighted that 22% of the subjects in the metropolitan cities had unacceptable 'far visual acuity', 25% had unacceptable 'stereopsis or depth perception' and 22% had unacceptable 'glare recovery'. Lijjarco *et al.*[11] assessed the visual health problems of various Spanish drivers and based on the study results, they formulated guidelines to enhance road safety features. Peregrina *et al.*[12] studied the impact of age-related vision change on drivers. They examined the relationship between simulated driving performance and the visual parameters tested. Various driver distraction methodologies, including qualitative and quantitative behaviour of drivers are summarized. They suggested that an eye-tracker is useful for capturing eye position and pupil diameter.

The oculomotor abilities of a driver play a distinctive role in improving driving-related abilities. The evaluation of visual strategies and processes of the drivers must determine their visual information management and predict their driving performance. Gené-Sampedro *et al.*[13] examined 302 physically fit drivers and non-drivers in the age group between 20 and 86 years. The study found that drivers performed better in the adult development eye movement (ADEM) test than non-drivers. This test consists of three sheets of numbers, two containing vertically aligned and one containing horizontally aligned numbers. The study also considered some important oculomotor parameters such as daytime and night-time difficulties while driving.

The eye-tracking approach was mainly used in the literature to study driver distraction and gaze patterns while driving on horizontal curves. This method can be adopted quantitatively and qualitatively to examine driver behaviour in the field as well as in experimental studies. In this study, the eye-tracker was used to examine driver behaviour in real-world driving conditions.

Methodology and data collection

Methodology

The methodology adopted for this study included identification of the study section, collection of primary data using videography, processing of video data and their analysis, and evaluation of eye-tracking data near isolated speed humps. Drivers of different age groups (between 20 and 40 years) were considered for the study, which was limited to parabolic speed humps. A trap of 100 m length was considered in the approaching direction of the vehicle and it was divided into five sections of 20 m each to observe the speed profile of the approaching vehicles. Video data recorded in the field were run on a computer in the laboratory to extract the speed of individual vehicles at different intervals before the speed hump. The experimental results for image sequences of all subjects were examined using an eye-tracker. The subject sat in the driver's seat and wore a head-mounted eye-tracking device. The tracker had four camera sensors, with two sensors provided for each eye. These sensors helped obtain the eye images during extreme gaze angles acquiring accurate data on pupil size. The eye glasses with sensors produced the eye gaze data, which were mapped to coordinate the system along with the video data. The collected eye-tracking data were used to identify the driver reaction and eye fixation near isolated speed humps. The relationship between the speed of an approaching vehicle and the number of fixation points was determined using regression analysis techniques.

In this study, the Tobii eye tracker system was used for eye-tracking. This system has three components: head unit, recording unit and analysis software. The head unit is a wearable eye-tracker that integrates the illuminatory and eye camera into the lens (Figure 1). The video data related to the selected stretch were acquired with a sampling rate of 50–100 Hz. The technique of data extraction was based on corneal reflection, binocular and dark pupil tracking. The eye-tracker with four eye cameras having a resolution of 1920 × 1080 pixels at 25 fps was used for data collection. The recording unit collected the eye-tracking data and allowed the gaze data to be recorded. The recorded data were exported into the Tobil Pro Lab analytical software. This software is used as a mapping tool to generate map data from eye-tracing videos to snapshots. The snapshots were used for generating heat maps, gaze plots and areas of interest (AOIs). The automatic mapping was done with the help of Tobii Pro software.

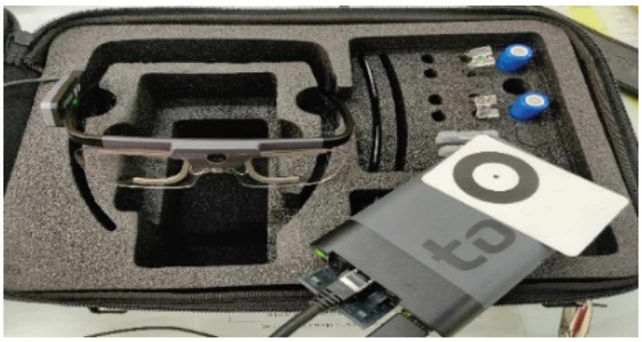

Figure 1. Wearable Tobii glass eye tracker.

Data collection

Five drivers of different age groups (20–40 years) with an average of 12 years of driving experience were considered for real-time eye-tracking. All the participants had valid driver's licenses and good visual acuity. The experimental results of eye-tracking for image sequences of all subjects were examined. The experiments were performed between 3.00 and 5.00 pm. The location of the study section was Maulana Mohammad Ali Jauhar Marg in South Delhi (four-lane divided carriageway). To observe driving pattern near the speed hump, experimental studies were conducted. The Participants drove a car equipped with velocity-box (V-box) apparatus, a GPS-logger and a wearable eye-tracker. Information from the eye-tracker and V-box apparatus enabled us to estimate eye-fixation and speed profile. The eye-tracker was calibrated before each test drive for each participant. Every participant completed three test drives for the selected route. During the task, V-box and eye-tracker were simultaneously commenced for the selected trap length (i.e. 100 m upstream and downstream of the speed hump). Figure 2 shows the set-up of the V-box and analysis using eye-tracker software with timeline data series.

The collected eye-tracking data were considered to identify the driver reaction and eye fixation near the isolated speed humps. The V-box and eye-tracker data were analysed using the software (Table 1). From the V-box data speed profile of different participants was plotted for a distance of 100 m upstream. The sections were divided into five categories, i.e. 0–20 m, 20–40 m, 40–60 m, 60–80 m and 80–100 m. The speed profile of each subject at different intervals was determined. From the eye-tracker data, gaze plots and heat maps were developed for the AOI. The video run from the V-box and eye-tracker data was analysed simultaneously for calibration. After running both video data, the time for each 20 m section was calculated from the speed data with distance and time extracted from the V-box data analysis software. Then, from the eye-tracker analysis software, a 20 m section up to 100 m distance from the speed hump was analysed, and gaze plots and heat maps were developed. The main parameters extracted from the eye-tracker data included fixation time, fixation count, total time of interest, AOI duration and AOI count. In this study, AOI was the speed hump location. Table 2 shows the eye-track metrics considered in this study.

Table 1. Characteristics of subjects considered for real-time eye-tracker data

Subject number	Age (yrs)	Type of driver	Driving experience (yrs)
1	37	Private	14
2	40	Commercial	20
3	29	Private	10
4	30	Private	11
5	23	Private	5

Figure 2. Set-up of V-box and eye-tracker software with timeline data series.

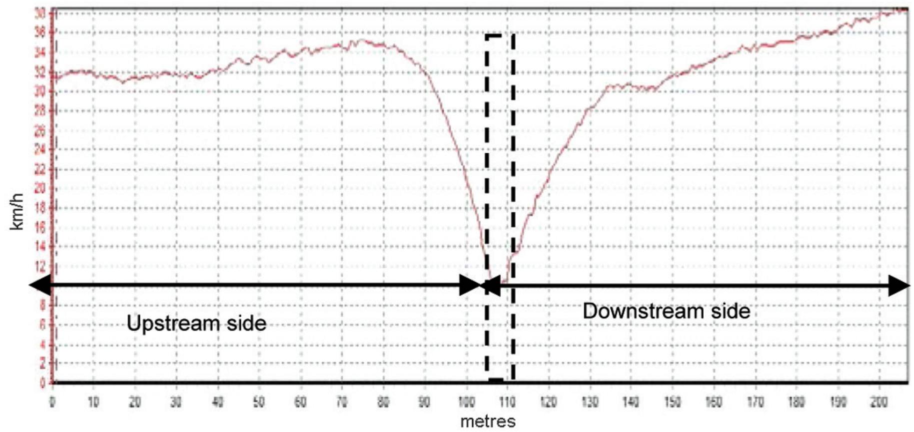

Figure 3. Speed profile of vehicles driven by the subjects at a speed hump.

Table 2. Eye-track measures considered for this study

Measure	Description
Fixation count	Number of times the eye was fixed on a particular region of interest.
Time of interest	Degree of analytical flexibility organizing the data according to intervals of time.
Area of interest (AOI)	Selected region of a displayed stimulus.
AOI total fixation duration	How long the fixation lasted.
AOI total fixation count	Total number of times the eye was fixed on a particular AOI.
AOI visiting count	Number of visits within an AOI.
AOI visiting duration	Total amount of time spent looking at a particular AOI.

Ethics and data processing

Ethical principles and data treatment details were adopted for the video-processing data and speed distribution of vehicle data collected by V-box. Personal and confidential data were not used and the voluntary particulars in the study were anonymous. Data processing was carried out using descriptive statistical methods, including the central tendency of the data (mean). Statistical regression techniques were adopted to determine the relationship between speed and fixation count. This model was developed by considering the 5% level of significance ($P < 0.05$), while for the statistical models, SPSS (version 24) was used. The goodness-of-fit measurement of the model included the coefficient of determination, sum of square error and root mean square error (RMSE) for validating it.

Analysis and results

Speed of vehicles approaching a speed hump

The logged data obtained from the probe vehicle were considered for the speed profile of various subjects. Figure 3 shows the speed profile of a vehicle driven by a typical subject obtained from the V-box at a speed hump. Figure 1 shows the speed profile with time and distance on the selected route, i.e. 100 m upstream and 100 m downstream from the speed hump. From Figure 3, it can be observed that there is a significant speed reduction between 0 and 20 m before the speed hump. After the speed hump, the driver retained the speed back to 30 km/h within 30 m from the speed hump. At the crown of the speed hump, the speed of the vehicle is reduced to 10 km/h. Figure 4 shows the speed variation of the five subjects. From this figure, it can be observed that all the drivers tend to follow normal speeds up to 20 m before the speed hump. Thereafter, they are forced to reduce their speed. Figure 4 shows the speed profiles of various drives at the identified speed humps.

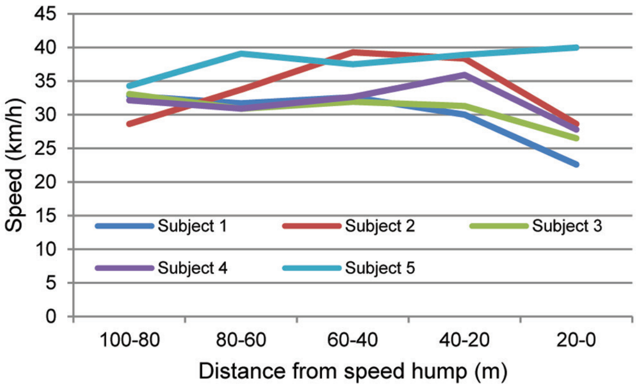

Figure 4. Speed profiles of different drivers at identified speed humps.

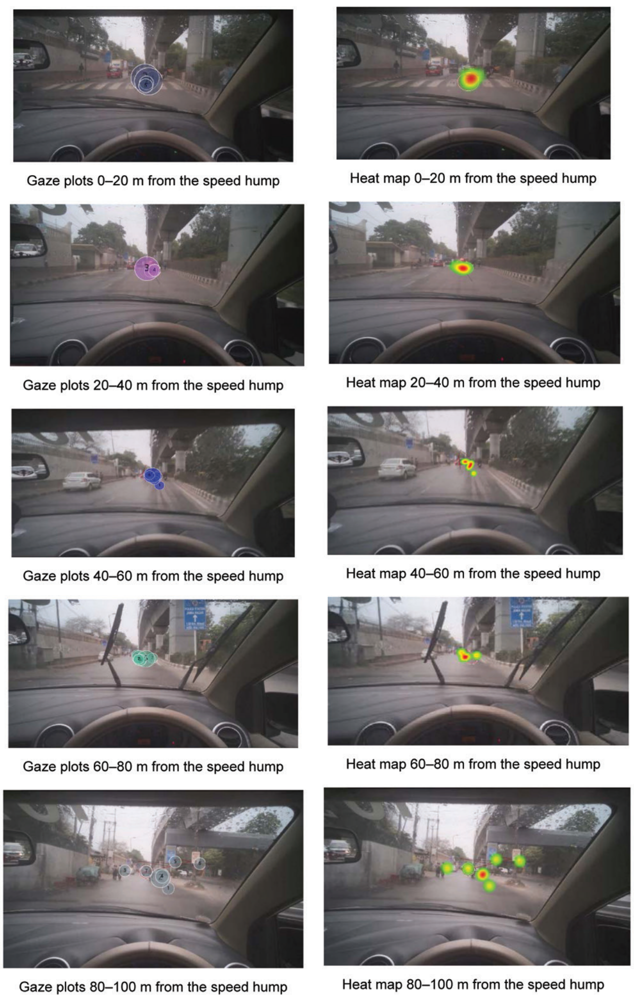

Figure 5. Gaze plots and heat map of a driver approaching a speed hump.

Eye-tracking behaviour of drivers approaching a speed hump

The eye-tracking behaviour of five identified subjects approaching a speed hump was determined in terms of fixation count, total time of interest duration, AOI of total fixation duration, AOI of total fixation count, AOI of visit count and AOI of visit duration. These data were extracted from the eye-tracker. Figure 5 shows the gaze plot and heat map of a typical driver behaviour on approaching a speed hump. The gaze points show whether the driver is looking at a static or moving object or subject. If a series of gaze points are very close, the gaze cluster constitutes a fixation-denoting period where the eyes are locked toward an object. This measures the visual attention of the driver approaching a speed hump. The heat map visualizes the viewed area data in a range of colours. This study considered three colour ranges, namely green, yellow and red for the heat map. Green shows the areas where the object spends less time, while red indicates the most viewed areas. From Figure 4 was observed that the gaze points are saccadic movements before 100 m from the speed hump, whereas no saccadic movement was observed from 40 m of the crown of the hump. It was also observed that focused fixed points were from 40 m before the speed hump, beyond which scattered fixation points were seen.

Similarly, heat maps presented in Figure 5 show the general distribution of gaze points and effectively reveal the focus of visual attention. They are typically displayed as a colour gradient overlay on the presented image or stimulus. In descending order the red, yellow and green colours represent the number of gaze points directed towards parts of the image. Heat maps can help understand how different groups might view a stimulus. The reduced and more broadly distributed heat over an image suggests reduced cognitive load, increased understandability, and deeper penetration. During recording, an eye-tracker collects raw eye-movement data points according to its sampling rate. To visualize and interpret the data, these raw data points are further processed into attentional eye movements such as fixation and are overlaid on the stimuli used in the test.

It was observed from the data that the average fixation duration before the 20 m speed hump was 1.1 sec and between 20 and 40 m it was 0.5 sec. The average fixation count before 20 m of the speed hump was 4 and between 20 and 40 m, it was 2. This indicates that the driver's attention between 0 and 20 m is double that between 20 and 40 m. Beyond 40 m, the AOI fixation duration and AOI fixation count are zero. This emphasizes that the drivers react to reduce the speed from 40 m of the crown of the speed hump. Figure 5 shows that as the participants drove towards the speed hump with low traffic, fixation became approximately equal or no distraction was shown, as we conclude from the gaze plot map. When the traffic volume increased, the driver became distracted and the fall on both sides of the fixation location also increased. The driver only started fixating on reaching a distance of 40 m from the speed hump.

Figure 6 shows the heat map for drivers of different ages approaching the speed hump, i.e. 0 to 20 m and 80 to 100 m from the hump. The visit duration or dwell time for AOI was estimated. AOI of total visit duration is the total time spent by each participant on the AOI. This metric deal examines the participant's interest or ease of understanding. From the results, it could be inferred that for drivers in the age group between 20 and 25 years, the average total AOI visit duration was 48%, while for those in the age group between 35 and 40 years, it was 67%. This shows that with the increase in age, participant interest or visual understanding also increases while approaching a speed hump. It can also be observed from Figure 6 that for drivers aged 23 years, the fixation points are focused (20 m before the speed hump), whereas with an increase in age, more clusters of fixed points are observed before the speed hump.

Individual fixation has interpretable functional roles. A driver never focuses on fixates at any particular location or object for an extended time. On a straight path, the drivers have more time to explore the environment, as shown in Figure 5, than curves. Driver's near and far path fixation difference due to the cognitive load. In Figure 5, for the same stretch the driver had different representations of stimuli in front of them. The mapping of the fixation in the form of a heat map shows that the driver responds significantly different. Various studies on cognitive load for driver performance show these variations[14,15]. The driver's lateral and longitudinal control efficiency also helps interpret his/her visual search[16]. Eye movement has important significance in visual search, as suggested by Wilkie and Waan[17]. The cognitive load results in shorter look-ahead lead distances. Also, look-ahead lead time is shorter, which indicates that the drivers do not essentially compensate for the cognitive load by slightly reducing their speed. This effect is consistent with the gaze concentration effect of cognitive load[18,19].

Relationship between the speed and fixation counts

This study considered linear and non-linear regression analysis to describe the relationship between speed and fixation count. Statistical validation of the developed model was performed through RMSE. The regression model was fitted using SPSS (version 24.0). The regression analysis between vehicular speed (V) and fixation count (FC) was carried out using data from five subjects to determine the functional relationship between these two variables. For this, four different models, i.e. linear, quadratic, exponential and power, were considered to describe the appropriate relationship between the dependent parameter (FC) and independent parameter (speed). Table 3 summarizes the model coefficients and goodness-of-fit values for eye-track data collected before the speed hump. Three goodness-of-fit parameters, viz. coefficient of determination (R^2), standard error of estimate (SEE) and RMSE, were considered to identify the best-fit model for the data. It was observed that R^2 values were comparatively higher in the case of the exponential and power models. SEE and RMSE values suggest that the exponential and power models are better than the other models (Figure 7).

From Figure 7, it can be observed that with the increase in speed, the fixation count reduces. Similarly, the duration of the fixation decreases and the driver is more focused. As the speed decreases, the drivers information needs should significantly affect visual search strategy when people who are uncertain about the surrounding environment will be more actively searching for information. The relation is suggested when the driver is at a higher speed and reduces the uncertainty of the visual search during the run. This implies that for greater speed, the driver pays less attention to the surrounding objects during the driving task.

Figure 6. Heat map of drivers of different age groups approaching a speed hump.

Table 3. Summary of model coefficients and goodness-of-fit values

Model	Equation	Goodness-of-fit		
		Coefficient of regression (R^2)	Standard error (SSE)	RMSE
Linear	FC = – 0.493 * V = 21.02	0.914	7.58	0.9739
Quadratic	FC = –0.255 * V^2–1.97 * V = 41.68	0.977	2.065	0.5432
Exponential	FC = $60.38e^{-0.0794V}$	0.978	1.973	0.4966
Power	FC = 6838 * $V^{-2.098}$	0.987	1.141	0.3777

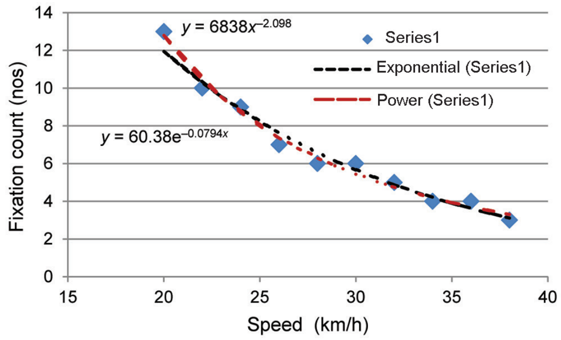

Figure 7. Relation between speed versus fixation count.

Discussion

In this study, we developed a relationship between the speed of vehicles approaching a speed hump and the fixation count. This study considered five subjects and their eye-track movements while approaching a speed hump. From the results, it was observed that the speed of the vehicles drastically reduced from more than 40 km/h to less than 20 km/h while approaching a speed hump. At the same time, the fixation count increased from 3 to 13, with vehicular speed decreasing from 40 to 20 km/h. Qin *et al.*[20] studied the influence of vehicle speed on the characteristics of driver eye movements at a highway tunnel entrance. The study revealed that the average number of fixations negatively correlated with vehicle speed. The results indicated that the drivers were more concerned before reaching a speed hump. A limitation of current study is the sample size; it considered five subjects in the age group between 23 and 40 years.

A preventive measure to reduce risk at speed humps is to introduce effective traffic-calming measures, driving-related factors such as driver oculomotor abilities and transport environment. The use of intelligent transportation systems and artificial intelligence applications in traffic information, as well as public and passenger transportation information, will help improve the mobility of traffic on urban roads[21]. Driving-related cues such as road signs and markings should be accessible to road users to reduce the risk of accidents at speed humps.

Policy implications

This study evaluated factors such as the driver's attention to the distance of a speed hump and the related speed of a vehicle, and driver's fixation distribution. The findings of this study demonstrate that driver behaviour will change with the deployment of speed humps. The outcome of this study is useful for recommending appropriate location of visual warnings or pre-warnings to ensure that drivers become aware of speed humps. The Indian Roads Congress has published guidelines on traffic-calming measures in urban and rural areas, in which visual warnings are discussed[22]. The present study demonstrates the application of an eye-tracker as a quantitative measure and recommends examining suitable positions for placing traffic signs and other traffic control devices to help the approaching vehicles. The results of this study will also help provide recommendations for distracted drivers at speed humps, which ultimately adds to road safety and will aid the planning and implementation authorities.

Conclusion

This study examined the general characteristics of fixation counts through the statistics of visual parameters using the eye-tracking device. From the driver observation and study results, it can be concluded that the driver behaviour approaching speed humps under different traffic conditions, changes the driver's fixation pattern. The following significant findings can be drawn from this study.

- The horizontal search span of a driver is wider and the fixation area is scattered as shown in the gaze plots for 100–80 m from a speed hump, whereas the gaze plots are not so much scattered when the vehicle is approaching the speed hump (0–20 m). From the speed profile data, it has been observed that the driver changes speed immediately on reaching speed humps. The average AOI of the fixation duration 20 m before the speed hump was 1.1 sec and that between 20 and 40 m was 0.5 sec. This indicates that the driver's attention between 0 and 20 m is double compared to that between 20 and 40 m.
- From the relationship between speed and fixation count, it was observed that the average fixation count decreases with an increase in vehicle speed. The distribution of driver fixation points in the AOI was more concentrated under smooth traffic, while under high-volume traffic, the fixation points were more divergent. From the results, it can also be concluded that when the driving load increases, the difficulty of processing information increases

for driver's in the age group between 20 and 25 years the average total AOI of visit duration is 48% and for the age group between 35 and 40 years, the age group is 67%. This shows that with the increase of age, participant interest or visual understanding increases while approaching a speed hump.
- The relationship between the speed and fixation count suggests that the drivers are likely to focus more on fixation at a speed of 25–30 kmph and distance of 40–50 m from the speed hump.

Due to the restriction of experimental conditions, only the index of driver fixation count, fixation duration, AOI of fixation count, AOI of fixation duration and AOI of visit count were selected. Further studies are required to examine the variation of drivers' parameters under different traffic conditions, age groups and behaviour towards speed humps of different shapes.

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