An Evaluation of Road Hump Markings in Riyadh: Detectability of the Shapes and Colors

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Abstract

Although there are several shapes and colors of road hump markings used around the world, there is no unified international standard for road hump markings. Road humps are causing a huge number of accidents and severe damage to cars in Riyadh, Saudi Arabia. This paper evaluates road humps in Riyadh in terms of detectability of road hump markings. The paper describes two experiments; the first experiment involves selecting the most three detectable shapes of road hump markings among six different shapes based on preferences of participants. The second experiment involves selecting the best combination of colors (White or Yellow) for the selected road hump marking shapes based on response time. The result of the second experiment was that the yellow colored road hump showed a faster response time compared to the white colored one. Regarding the shapes of road hump markings, the three shapes showed a similar response time as well as similar accuracies. These results suggest that color is a more important consideration than the type of shape when designing a road hump.

Keywords
Road hump, Markings, Detectability, Riyadh, Response time

1. Introduction

Traffic accidents are among the most serious problems in the world, resulting in serious injuries, deaths and disabilities for millions of people. One of the causes of traffic accidents in Saudi Arabia is road defects. The most common road defect is that related to the improper installation of road humps. Speed humps have gained acceptance as a traffic calming device by North American and international jurisdictions if they are installed properly [1]. A retroreflective road hump marking is used as a warning sign to attract driver attention to the hump. Increasing the detectability of road humps results in faster response times, which decreases accident rates and damage to cars.

1.1 Statistics Regarding Traffic Accidents in Saudi Arabia

Table 1 Statistics Regarding Traffic Accidents in Saudi Arabia during 2014 [2].

Region	No. of Casualties		No. of Accidents
	Injured	Dead	
Riyadh	2,803	858	147,568
Makkah	12,237	2,149	126,537
Madinah	4,177	716	19,058
Al-Qasim	1,497	395	24,273
Eastern	4,807	1,030	88,065
Aseer	2,409	881	32,163
Tabouk	1,875	451	20,638
Hael	949	346	8,415
Northern Boarders	732	156	13,076
Jazan	2,222	390	22,229
Najran	511	276	3,220
Al-Baaha	1,128	164	4,166
Al-Jouf	955	251	9,387
Total	36,302	8,063	51,8795

It is observed that the number of accidents is the highest in Riyadh, as shown in Table 1. Also, Table 2 shows that around 33.8% of accidents that occur inside the city in Saudi Arabia are in Riyadh. Moreover, it is observed from Figure 1, and Figure 2 that the most common type of death accidents are those occurring due to crashing with other moving cars, while the most reason for death accidents is that due to sudden deviations. One of the reasons of sudden deviation is road defects, which include improper road hump installation .Thus; the aim of this paper is to evaluate humps in Riyadh in order to improve their detectability by redesigning road hump markings. A report published by the Riyadh Municipality Emergency in 2014 showed that the number of complaints related to the operation and maintenance of roads were 2236 complaints reported that year, and most of these complaints were related to road humps [3].

Table 2 Traffic Accident Data by Region for 2014 [2].

Region	Total	Inside the City		Outside the City	
		No .of Accidents	Percentage	No .of Accidents	Percentage
Riyadh	14,7568	138,974	33.78%	8,594	8.00%
Makkah	126,537	102,607	24.94%	23,930	22.28%
Madinah	19,058	12,137	2.95%	6,921	6.44%
Al-Qasim	24,273	14,295	3.47%	9,978	9.29%
Eastern	88,065	68,280	16.60%	19,785	18.42%
Aseer	32,163	18,806	4.57%	13,357	12.44%
Tabouk	20,638	16,924	4.11%	3,714	3.46%
Hael	8,415	5,378	1.31%	3,037	2.83%
Northern Border	13,076	11,260	2.74%	1,816	1.69%
Jazan	22,229	9,700	2.36%	12,529	11.67%
Najran	3,220	1,989	0.48%	1,231	1.15%
Al-Baaha	4,166	3,079	0.75%	1,087	1.01%
Al-Jouf	9,387	7,968	1.94%	1,419	1.32%
Total	518,795	411,397	100%	107,398	100%

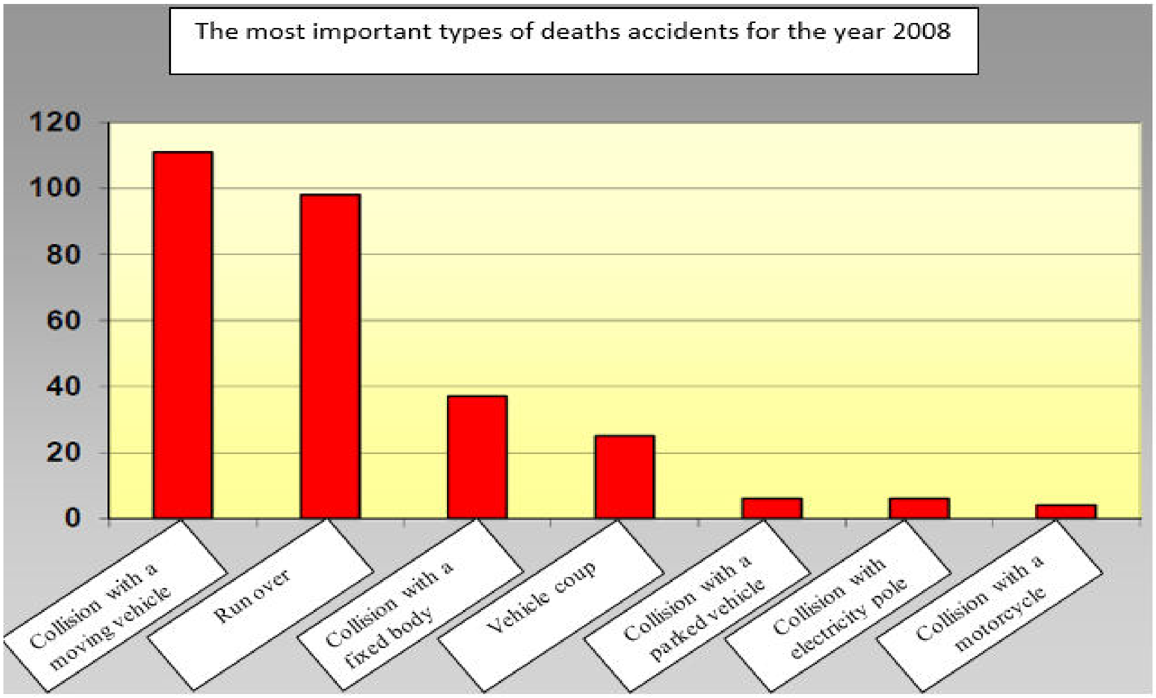

Figure 1 The Most Important Types of Death Accidents in 2008 [4].

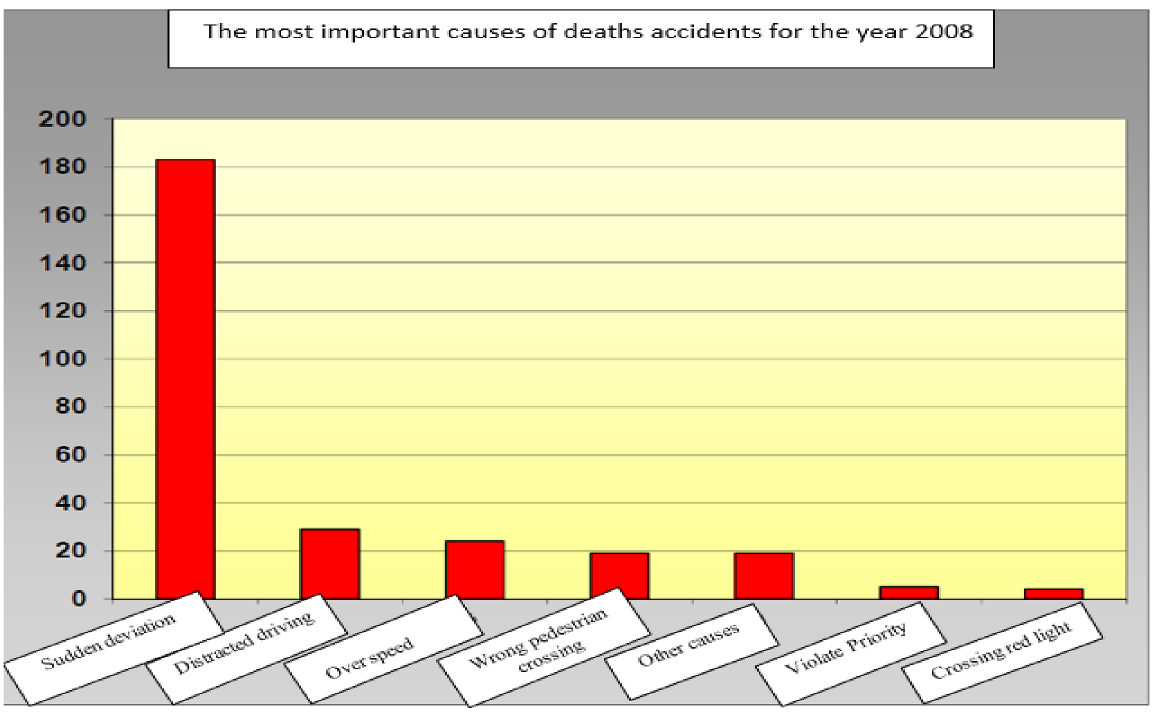

Figure 2 The Most Important Causes of Death Accidents in 2008 [4].

1.2 Statistics Regarding Accidents and Deaths Caused by Road Humps in India (2014)

In India, the number of crashes due to road humps in 2014 was 13,449 crashes, which are higher than the crashes due to potholes or speed breakers. As shown in Figure 3, 4,726 people died due to road humps, whereas 3,633 people died because of speed breakers and 3,039 persons because of potholes [5]. This means that road humps are more dangerous than potholes and speed breakers if not installed properly.

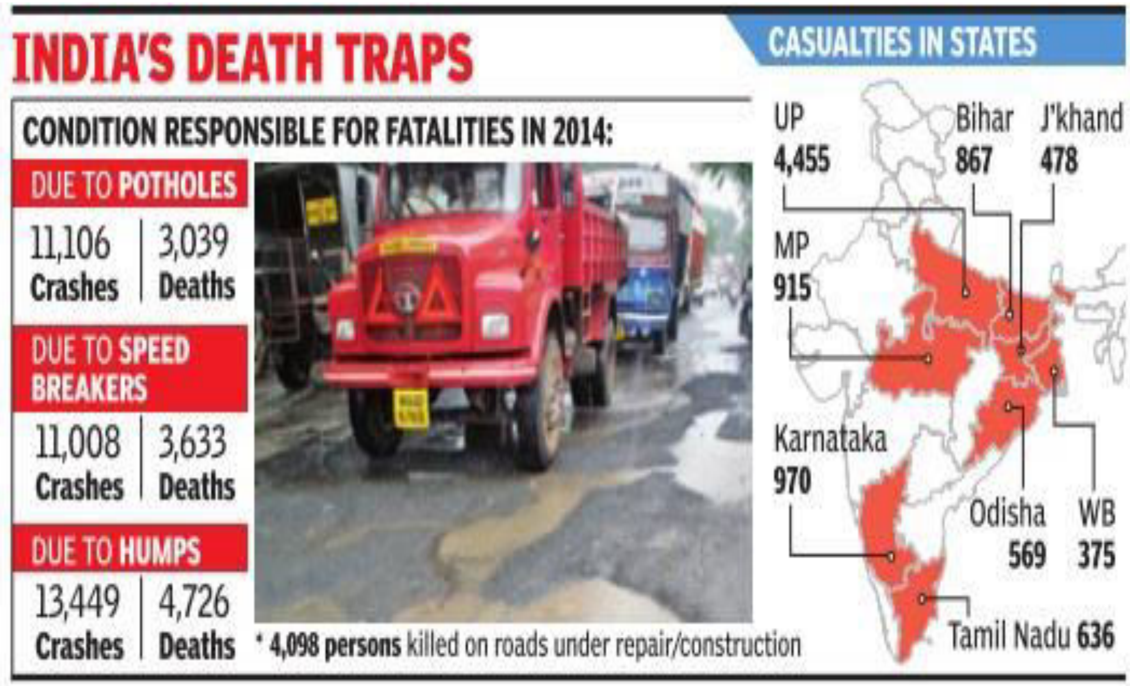

Figure 3 India's Death Traps [5].

1.3 Problem Statement and Objectives

Road humps are causing a huge number of accidents and a huge amount of damage to cars, as evidenced by previously stated of Riyadh Municipality Emergency statistics.

a) The primary objective of this paper is to increase the detectability of road humps by selecting the most detectable shapes among various proposed road hump marking shapes.

b) The secondary objective is to increase the detectability of road humps using a mixture of colors for the preferred road hump marking shapes (from among part a).

2. Background

Pavement markings can be a very cost-effective roadway improvement in terms of reducing crashes and providing guidance to drivers, especially at night [6]. Although pavement markings provide daytime longitudinal guidance to help keep drivers in their travel lanes, other aspects of the roadway environment, such as roadside alignment, also provide guidance. Drivers rely more on retroreflective pavement markings to provide guidance information during darkness than in daylight [7]. In addition, the pavement markings should be easily recognized and understood, well-maintained, and used only in consistent applications, including design, color, and placement location [6]. Chen et al. [8] assessed the effect of various safety countermeasures implemented in New York City. Simple before and after accident studies showed a reduction of fatal and injury accidents by approximately 33% on the sections where speed humps were placed. Rahman et al. [9] surveyed a number of North American, Australian, and European experts from Traffic Authorities concluding with the observation that speed humps are suitable for solving various types of street issues, such as speeding, high volume of cut through traffic, road accidents, and pedestrian safety issues due to the lack of sidewalks or narrow streets. Road hump markings have a high impact on detectability for drivers, so there is a need to enhance and improve the detectability of the road humps in order to satisfy neighborhoods preferences and to decrease the accidents and damages that happen in case of low detectability of speed humps.

2.1 Examples of Different Designs of Road Hump Markings

2.1.1 Design Details in the UK

The shape of road hump markings in the UK consists of two solid triangles in each direction of traffic [10]. The dimensions of road hump markings are shown in Figure 4. Note that all dimensions are in cm.

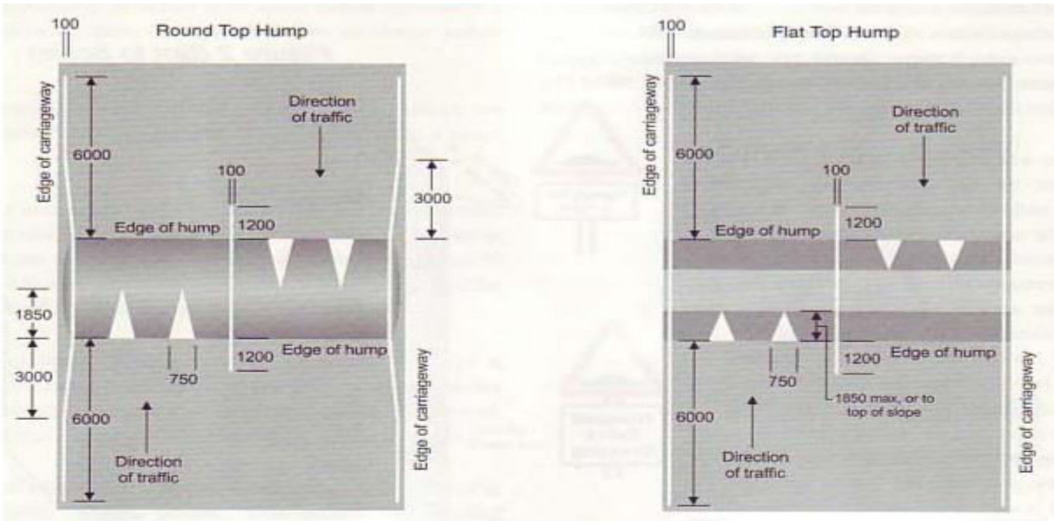

Figure 4 Hump Markings Specifications in the UK.

2.1.2 Design Details in Pennsylvania, USA

The pavement marking designs on the following pages are provided in the Manual on Uniform Traffic Control Devices (MUTCD). It is recommended that one of these sets of markings be used with speed hump designs. Speed hump markings shall be a series of white markings placed on a speed hump to identify its location [11]. The dimensions of road hump markings are shown in Figure 6.

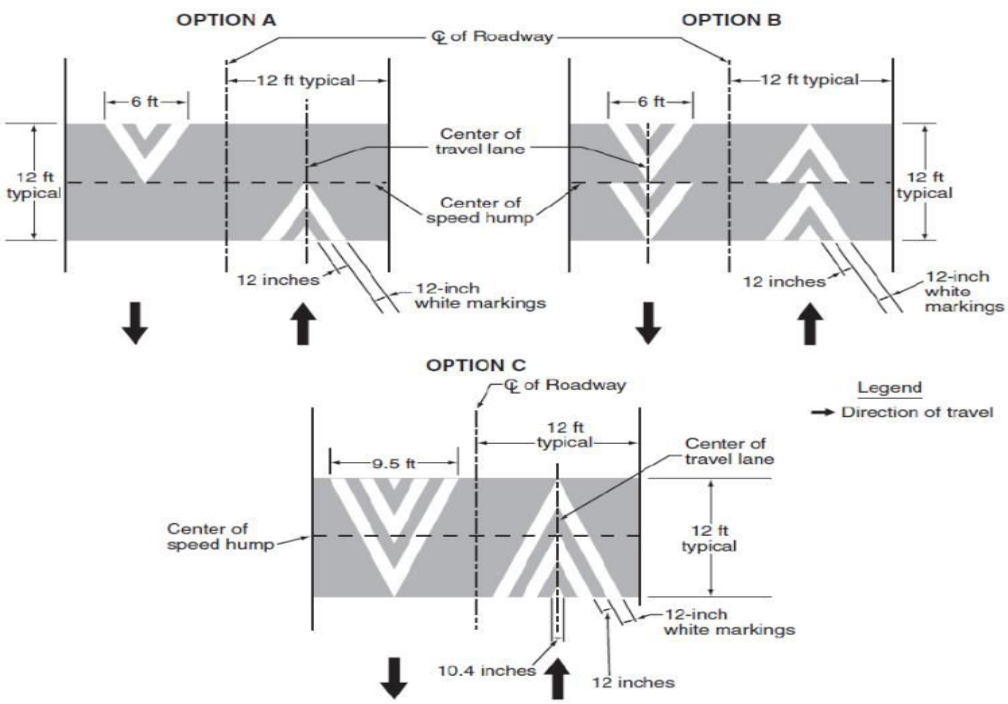

Figure 6 Marking Options in Pennsylvania, US [11].

2.1.3 Design Details of Hump Markings in Saudi Arabia

The lines should be yellow and thermoplastic reflective. The width of the line shall not be less than 30 cm [12]. The dimensions of road hump markings are shown in details in Figure 5.

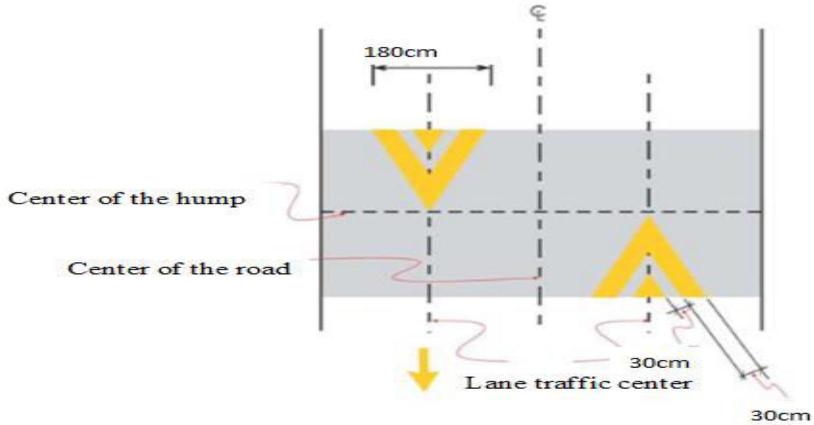

Figure 5 Hump Marking Specifications in Saudi Arabia [12].

3. Methodology

The paper includes two experiments. The first experiment was conducted to select the best three detectable shapes of road hump markings based on the preferences of the participants. The selected three shapes were used in the second experiment. The second experiment was conducted to select the best combination of shapes and colors based on the response time to detect the road hump. The two experiments will be described later in more detail.

3.1 The First Experiment

The objective of the first experiment was to select the best three detectable shapes of road hump markings among six different shapes based on the preferences of the participants. The details of the first experiment are illustrated below.

3.1.1 Subjects

The first experiment was applied to thirty male volunteers, aged 17 to 55 years old.

3.1.2 Experimental Design

The six shapes of road hump markings that were selected are the most used all over the world, and most of the other road hump markings shapes used in the world revolve around these six shapes. The participants were asked to rank the six shapes based on their preference. The first rank is the highest to detect (most preferred) whereas the sixth rank is the lowest to detect (least preferred). After that, we used the results of this experiment in the second experiment. The dependent variable of this experiment was the preference of participants regarding the shapes that are the easiest to detect. The independent variable was the shapes of the road hump markings, which were the six different shapes.

3.1.3 Road Hump Marking Shapes Examined in the First Experiment

There were six proposed types of road hump markings shapes, as shown in Figures 7-12.

Figure 7 Shape 1, Four Triangles in Each Direction of Road Hump (option B in MUTCD).

Figure 8 Shape 2, Triangles Shape of the Road Hump Marking.

Figure 9 Shape 3, Two Triangles in Each Direction of Road Hump (option A in MUTCD).

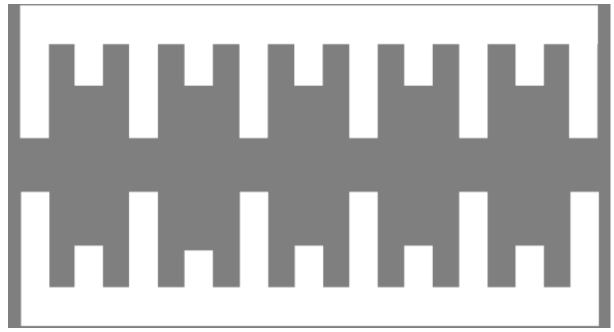

Figure 10 Shape 4, Piano Shape of the Road Hump Marking.

Figure 11 Shape 5, Solid Triangle Shape of the Road Hump Marking.

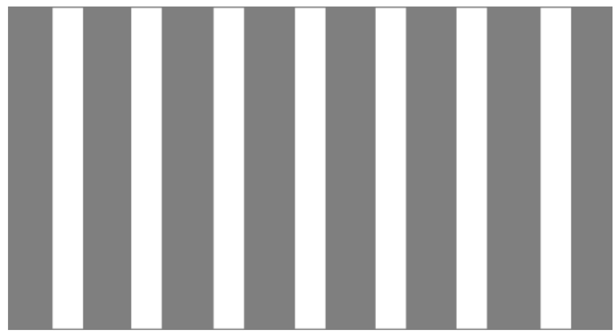

Figure 12 Shape 6, Bar Shape of the Road Hump Marking.

3.2 The Second Experiment

The aim of this experiment was to test the effect of the colors and shapes of road hump markings on the detectability of road humps.

3.2.1 Subjects

Eighteen volunteers participated in this experiment. They were all males aged 20 to 25 years old.

3.2.2 Experimental Design

Each participant was asked to sit in front of the screen and press the 'L' or 'F' button as soon as an image was present on the screen. The 'L' button was pressed for a road hump image, while the 'F' button was pressed for an image not containing a road hump (examples of "road hump" and "no hump" images are shown in Figure 13 and Figure 14, respectively). After that, instructions regarding the experiment were described and shown to the participant before starting the experiment. Then, the participant performed one practice session before beginning the experiment. Thereafter, we ran the experiment and the participant responded by pressing either the 'L' or 'F' buttons based on the images. There were two sessions for each participant, and each session contained two runs, where each run consisted of twelve trials that are representative of the twelve different images (six images with road humps, plus six images without road humps, as a control). The twelve images appeared randomly twice in each session, hence the total images that appeared for each participant in the experiment were 48 (two sessions, each session containing 24 images). The time between the first and second session was fixed for all participants at half-a-minute. Finally, the results of each participant were recorded in an Excel file.

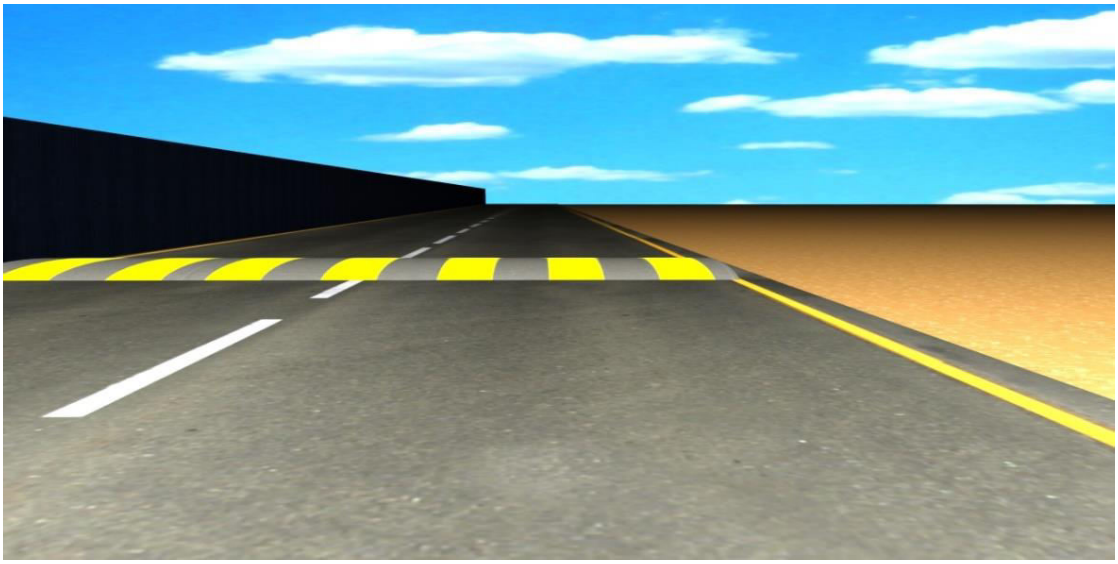

Figure 13 Example of an Image with "Hump".

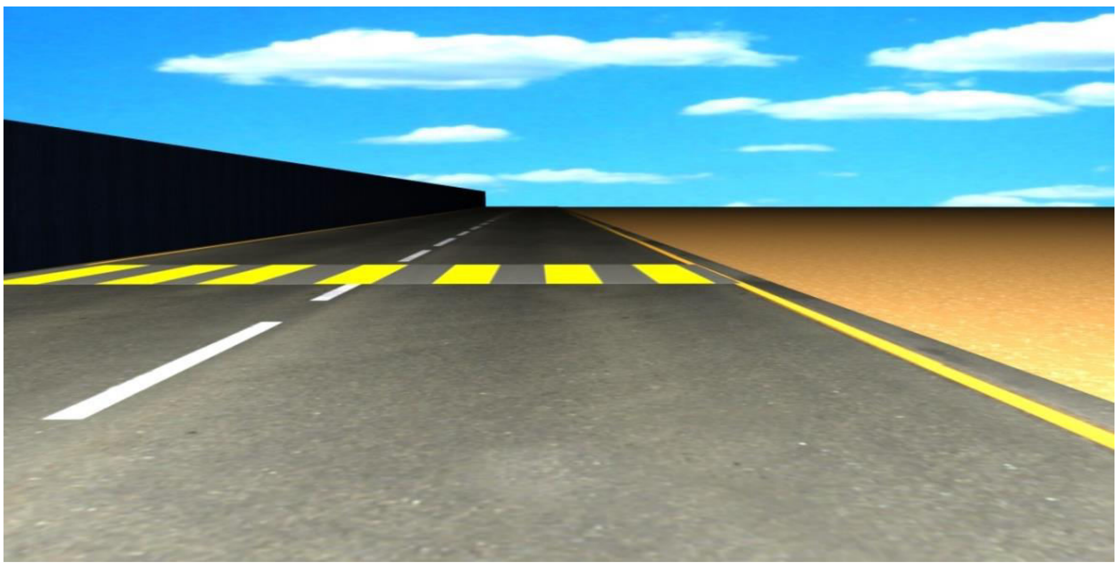

Figure 14 Example of an Image with "No Hump".

We used "3DS Max" software for designing the road, consisting of a two-way road and a road hump. Moreover, we designed a desert on the right side of road and a barrier to the left of it. We used a MATLAB program to simulate the experiment. In addition, all the participants used a laptop as the device for conducting the experiment.

The dependent variables for this experiment were the response time (RT) (in milliseconds) and the response accuracy. The independent variables of the experiment are the shapes of road hump markings, colors of road hump markings, and the existence or absence of road humps ("hump" or "no hump"); thus, the total number of independent variables is three. Three different road hump marking shapes were utilized from the first experiment and there were two colors, white and yellow.

4. Results and Discussions

4.1 Results and Discussion of the First Experiment

After conducting the experiment, we obtained the raw data regarding the preferences of participants. The summary of the results of the first experiment is represented in Table 3. The columns of the table represent the six shapes while the rows represent the rank. For example, shape one was ranked first for eight times.

Table 3 Summary of Participant Preferences.

Rank	Shape 1	Shape 2	Shape 3	Shape 4	Shape 5	Shape 6
First	8	4	2	4	2	10
Second	4	6	7	3	4	6
Third	6	7	5	2	3	7
Fourth	4	5	6	7	6	2
Fifth	6	4	4	4	9	3
Sixth	2	4	6	10	6	2
SUM	30	30	30	30	30	30

We obtained the best three shapes by adjusting the participants' order of the shapes into two categories; if the shape is in the order from first to third, we classified it as "Good", and if the shape is in the order from fourth to sixth, we classified it as "Bad". For instance, shape one is ranked as first eight times, ranked as second four times, and ranked third six times as shown in Table 3. Thus, the total number of times that shape one appeared in the "good" classification is 18, as shown in Figure 15. The ranking of the six shapes is shown in Figure 15.

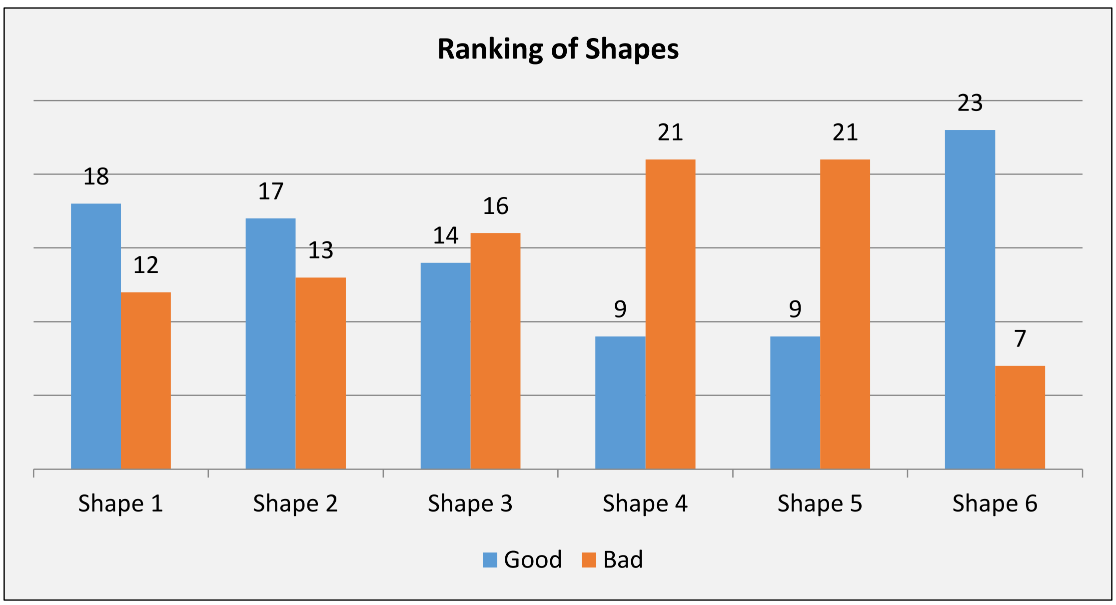

Figure 15 Ranking of Shapes.

It is clear that shape six is the highest preference compared to the rest based on the summation of the two columns of "Good" and "Bad" classifications, followed by shapes one and two. In addition, the lower preference shapes are four and five followed by shape three. Thus, the three shapes that were used in the second experiment were shape 6, shape 1 and shape 2.

4.2 Results and Discussion of the Second Experiment

4.2.1 Data Analysis

After collecting the data, we checked the integrity of the data by removing the outliers of data points based on the mean plus two standard deviations for each participant. In addition, we excluded the response times of wrong responses from the calculation and analysis of results. Moreover, we tested the normality of residuals for the response time by using Minitab and the result was that the residuals for the response time were approximately normally distributed. The residual plots for response time are shown in Figure 16.

The interval plot of response time in Figure 17 shows the mean and standard deviation for each treatment. We noticed from that Figure that the mean response times for the yellow color is lower than the white color whatever the shape was. Moreover, Table 4 shows the summary of the mean and standard deviation quantitatively for the response times, from which we can notice clearly that the yellow color for all the shapes had lower response times than the white color.

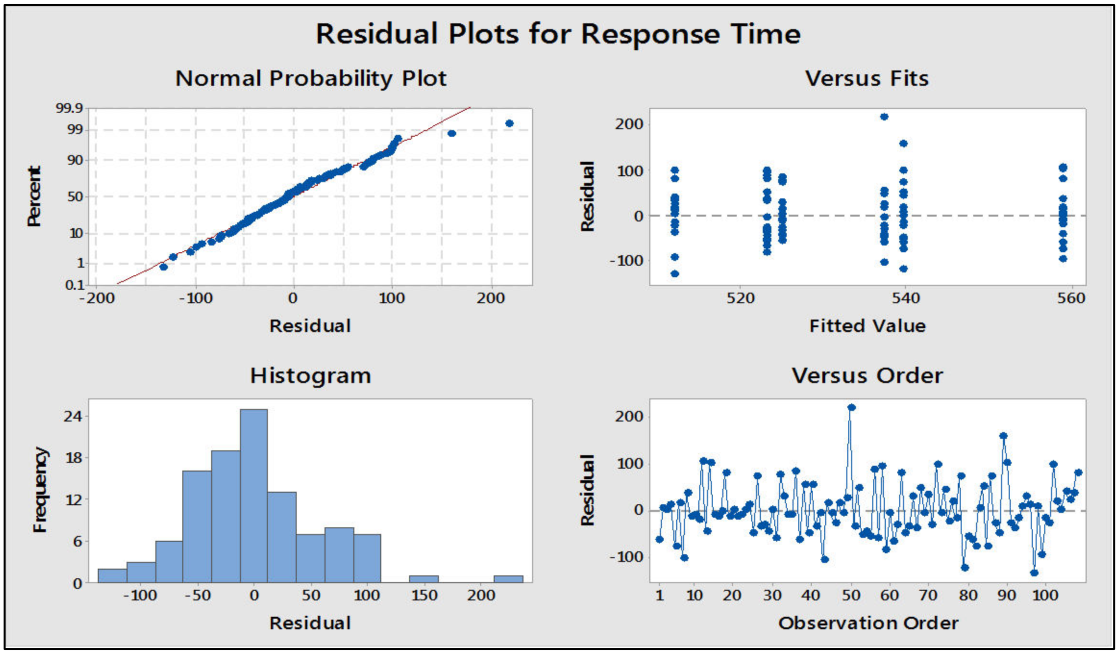

Figure 16 Residual Plots for Response Time.

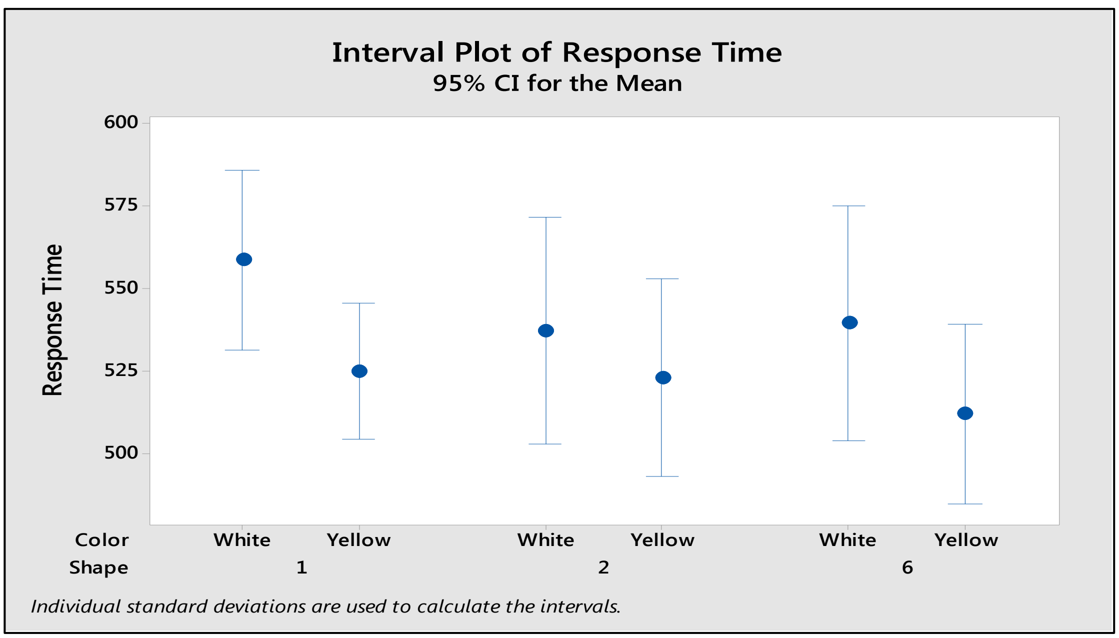

Figure 17 Interval Plot of Response Time.

Table 4 Summary of Response Time Data.

Color		Response Time (ms)			Mean of Each Color
		Shape 1	Shape 2	Shape 6	
White	Mean	558	537	539	545
	STD	55	69	71	
Yellow	Mean	525	523	511	520
	STD	41	60	54	
Mean of Each Shape		542	530	526	

The interval plot of response accuracy in Figure 18 shows the mean and standard deviation for each treatment. We observed from the figure that the mean accuracy for Shape 1 (regardless the type of color) is higher than the others. Also, Table 5 shows the summary of the mean and standard deviation quantitatively for the response accuracy, from which we can notice clearly that shape 1 had a higher level of accuracy than the others.

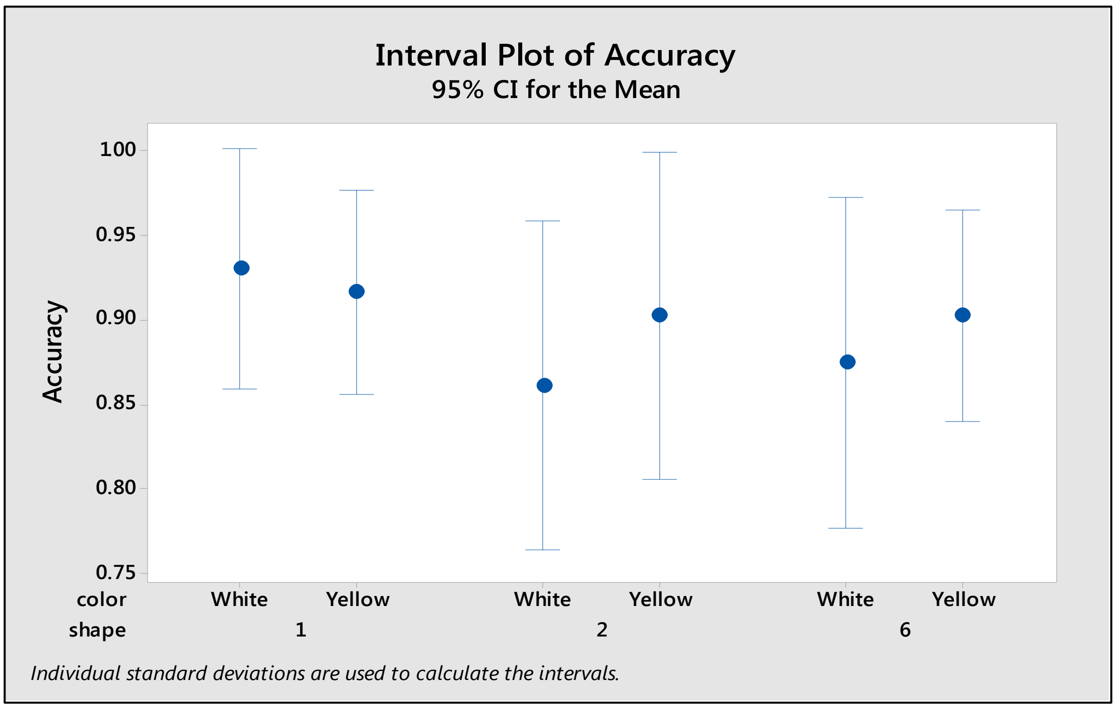

Figure 18 Interval Plot of Accuracy.

Table 5 Summary of Response Accuracy Data.

Color		Response Accuracy (%)			Mean of Each Color
		Shape 1	Shape 2	Shape 6	
White	Mean	93	86	88	89
	STD	14	19	19	
Yellow	Mean	92	90	90	91
	STD	12	19	13	
Mean of Each Shape		92	88	89	

4.2.2 Statistical Methods

We used a two-way repeated measures ANOVA test as a statistical method performed using Minitab. The reason for using this type of test is because each participant in the experiment was subject to both conditions. We used a 95% confidence level (alpha= 0.05). The first factor was the shape of road hump markings, which had three levels (shape 1, shape 2 and shape 6). The second factor was the color of road hump markings, which had two levels (white and yellow). The dependent variable (response) is the response time (RT) which is measured in milliseconds. Regarding the response accuracy, we used the Mood's Median Test which is a non-parametric test.

4.2.3 Results of Second Experiment

For the response time data, a two-way repeated measures ANOVA showed that the color of road hump markings has a statistically significant effect on the response time (P=0.03) as shown in Table 6, meaning that the yellow color of road hump markings is better than the white color based on the mean response time. The shape of road hump markings did not show any statistically significant difference with respect to the response time; thus, the color of road hump markings is a more significant variable than the shape, because the color had an impact on the response time of road humps. In the ANOVA, the interaction between the colors and shapes of road hump markings did not show any statistically significant effect on the response time.

Table 6 ANOVA Result for the Response Time.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Shape	2	5038	2518.9	0.71	0.494
Color	1	17165	17164.8	4.84	**0.030**
Shape*Color	2	1819	909.5	0.26	0.774
Error	102	361980	3548.8		
Total	107	386002			

For the response accuracy data, we tested the median for the shape and color by using Mood's Median Test Method with a 95% confidence level. We found that the shape and color had no significant effect on the response accuracy.

4.2.4 Discussion of Second Experiment

The result of the second experiment indicates that the color of road hump markings has a statistically significant effect on the response time, which means that the type of color has an impact on the response time of drivers to detect the road hump. The yellow color of road hump markings has a faster response time compared to the white color, which indicates that the white color shouldn't be used for coloring road hump markings. The yellow color is statistically recommended to use rather than the white color, because it will reduce the response time of drivers, and hence increasing the detectability of road humps. On the other hand, the shape of road hump markings has no statistically significant effect on the response time, which means that either of the three shapes used in the experiment has a similar effect on the response time. Moreover, the interaction between shape and color has no statistically significant effect on the response time, which indicates that no combination of shape and color is statistically preferred. We recommend using the yellow color (which is statistically preferred) with shape 6. Although shape 6 is not statistically significant, it has the fastest mean response time among the other three shapes.

The response accuracy result shows that there is no statistically significant effect on the response accuracy for either shape, color or the interaction between them. Thus, we can't recommend a specific shape, color or a combination of them to be used in the road hump marking. However, when we are looking at the mean of response accuracy in Table 5, we observed that shape 1 has the highest mean accuracy among the three shapes, whereas the yellow color has the highest mean accuracy among the two colors.

5. Conclusions and Recommendations

In conclusion, road hump marking color has a statistically significant effect on the response time, hence it should have an effect on the detectability of road humps. The white color has a slower response time than the yellow color, so the white color shouldn't be used for road hump markings. On the other hand, the yellow color is more detectable than the white color based on the response time. The road hump marking shape and the interaction between the shape and color do not have any statistically significant effect on the response time. Shape 6 (which consists of several bars) has the fastest mean response time compared to the other shapes of road hump markings. Moreover, the bar shapes are easy to install and maintain which will save a lot of time and cost.

The recommended design (shape and color) of road hump marking is shape 6 with a yellow color. Shape 6 consists of several bars, where each bar has a width of 30 cm and a length extending to the edge of the road hump. The distance between each two bars should be 40 cm. Moreover, we recommend that this paper be the base for more investigation regarding the road hump markings especially for the colors of road hump markings. In addition, we recommend that the white color should be no longer be used for road hump markings.

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Biography

Ahmed M. El-Sherbeeny is an assistant professor at the Industrial Engineering department (since 2010) and head of the Alumni and Employment Unit (since 2013) at the College of Engineering, King Saud University. He completed both his PhD (2006) and Master's (2001) degrees in Mechanical Engineering from West Virginia University (WVU), where he was a graduate teaching and research assistant. He holds a BSME from the American

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Mohammed A. Alghufaili is a fresh graduate engineer. He completed his Bachelor degree (2018) in industrial engineering from the King Saud University. He graduated with Second Class Honors. He participated in various competitions locally and abroad. He was a member of the gasoline team that participated in Shell eco-marathon (2017) in Singapore. He received the practical training at Riyadh Metro Project (RMP) with Siemens Company in system safety department. He interested in some topics that related to industrial engineer such as: Manufacturing Processes, Quality Engineering, Operations Management, Safety Engineering, Supply Chain Management and Project Management. He aspired to be one of the most successful people in his field.

Abdulrahman I. Alhusseini is a Motivated and focused junior industrial engineer. He completed his Bachelor in industrial engineering from King Saud University (2018). He trained in the Saudi Academy of Languages and Training for 6 months. He completed two training courses, Six Sigma green belt and Risk Management Professional. He interested in Manufacturing Processes, Safety Engineering Supply Chain Management, Operation Management, Human Factors Engineering, Project Management and Quality Engineering.