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Perceiving driving speed in real world: A study on an expressway and a local road

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Abstract

Speed is the primary contributory factor in crashes around the world, thus it is consistently one of the most critical elements in traffic safety and operations. Correctly perceiving the travelling speed is essential for safety on the roads to ensure safer interactions with other drivers and to avoid violations of traffic regulations. Therefore, creating understanding of the pattern of speed perception of drivers and the influencing factors is important while studying any specific driving population. Forty drivers in the possession of a valid Qatari driving license were invited to participate in the study. The experiment was conducted using a test car equipped with high fidelity GPS. Data were collected on Doha expressway and on the adjacent local road for two settings (hidden versus revealed speedometer). For each setting, while driving on the local road the participants had to estimate a driving speed of 50kph and 70kph and while driving on the expressway a speed of 80kph and 100kph. Analysis of variance ANOVA was conducted along with separate t-tests and cumulative distributions for each speed independently. The results clearly show that there were significant differences in perceived speed between a hidden and revealed speedometer, between the first and second trial, and among all the requested speeds. Participants drove significantly faster for all the requested speeds during the second trial. Furthermore, females and Arab drivers drove significantly faster than males and non-Arab drivers respectively, in the setting with a revealed speedometer on the local road. For all the cases in the hidden speedometer setting, participants drove faster. This phenomenon shows that participants underestimated their driving speed. In case of complex situations, drivers may not be able to rely on speedometers and may cause a violation of law, unintentionally. Therefore, it is recommended to jurisdictions to consider these results while making decisions regarding speed management.

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Keywords: speed perception; speed estimation; Arab drivers; speedometer, State of Qatar

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1. Introduction

Speed is consistently one of the most critical elements in traffic safety and operations. Speed can be considered as key risk factor in crashes from a safety perspective: speed influences the likelihood of crash involvement as well as the severity of the crash [1-5]. Although drivers do not often travel at the speed limit [6], it has a strong relation with travel speed and speed perception. For instance, drivers with poor estimation of their travel speed will most probably drive at different travel speed if they are not looking at the speedometer intentionally or unintentionally.

Studies conducted in the State of Qatar showed that speeding was one of the main reasons, causing crashes among Qatari drivers [7-9]. An accurate perception of speed while driving is very important for safety, plays a crucial role in interactions with fellow drivers and helps to avoid unintentional violations of speed limits [10]. Therefore, creating understanding about the speed estimation of driver populations and the factors that influence speed perception is essential.

Most of the existing recent literature about speed perception is based on driving simulator studies or studies on other computer tasks. Culham [11] investigated the effect of fog on speed perception in a driving simulator study. The results from his study confirmed that fog influenced the drivers' speed perception and that drivers drove slower due to illusions produced by fog. Another simulator-based study by Charlton & Starkey [12] investigated the effects of traffic and roads with different characteristics on speed choices. In their study, drivers chose slower speeds when traffic was heavy. A video-based study on auditory feedback shows that participants perceive the same speeds as slower when noise was reduced. Hassan et al. [13] discovered speed perception in peripheral vision in their computer task based study. The results indicate that for increased eccentricity the subjects underestimated the speed.

Few studies can be found where researchers investigated the interaction of different factors on speed perception on real roads. Schmidt & Tiffin [14] studied the distortion of drivers' speed perception after driving at constant speed. Ten male students participated in their study and results show that speed was significantly underestimated for both the requested conditions (i.e. during acceleration and during deceleration). Another study investigated the relationship between speed and road width and found that drivers usually drive faster on the road they perceive to be wide [15]. Fildes et al. [16] explored that the interactions of driving experience, roadside development, road type and road width, travel speed and drivers' gender had an effect on the driver speed perception. Owens et al. [17] investigated the effects of reduced contrast on speed perception while driving in the real world. A plastic diffusing filter attached to the vehicle's window controlled the contrast in their study. Findings show that the speeds were slower under reduced contrast conditions.

The objective of this study is to investigate Qatari drivers' speed perception in different conditions or influencing factors such as different speed limits, hidden versus revealed speedometer, age, ethnicity, gender and driving experience. To the best of our knowledge, a study on speed perception in a real world case has never been conducted in any Arab country. These results can help road-safety policy makers to understand the pattern of speed estimation of Qatari drivers.

2. Methodology

2.1. Participants

Forty subjects participated in this study under the condition that they were in the possession of a valid Qatari driving license. The data of six drivers were excluded from the analysis. Three of them were considered as outliers and for the other three drivers GPS data was incomplete. One of the outliers was detected by SPSS (i.e. drove the requested speeds slower than 1.5 interquartile range from the group's mean in more than 20% of the total requested speeds). The other two outliers exceeded the regulated speed limits of the road section and were therefore excluded from the data analysis. Consequently, the sample after exclusion was 34 participants of whom 28 male and 6 female drivers. The origins of the drivers was divided over 16 nationalities, with 23 drivers having an Arabic origin and 11 drivers were not Arabic. The mean age of the sample was 30.58 years ranging from 20 to 55 years (SD: 8.70 years). The driving experience was ranging from 1 to 31 years, with a mean driving experience of 8.91 years.

Fig. 1. The test car equipped with high fidelity GPS

Fig. 2. Google-earth image: Doha Expressway – Shamal Road, Doha, Qata

2.2. Apparatus

As visible from Fig. 1, a fully equipped Honda CR-V model 2016 was utilized as test car in this study. Build-in high fidelity GPS measured speed profiles and a NEXTBASE cam recorded all drives for all participants during the complete experiment. During the hidden speedometer setting, a non-transparent white cloth was used to cover the speedometer. To warn the participants of speeding over the limit in this setting the experimenter was additionally equipped with an external GPS.

2.3. Road segments selection

To measure the speed perception for four different speed limits two different types of road segments needed to be selected for data collection, as follows; a segment of the Doha expressway with 120kph as regulated speed limitation (Fig. 2) and a section of the local road that was located parallel to the expressway with 80kph as regulated speed limitation. To avoid conflict with other drivers (e.g. inappropriate to drive 50kph on a 120kph expressway) these two road segments with different regulated speed limitation were selected for the experiment. Data was collected at a

segment of the Doha expressway where participants were instructed to drive 80kph and 100kph and at a segment of a local road parallel to the expressway where participants were instructed to drive 50kph and 70kph.

2.4. Experiment procedure

Ethical approval was obtained from Qatar University's Institutional Review Board (QU-IRB) before the start of the experiment. At the start of the experiment the participants were requested to sign an informed consent form and complete a pre-test questionnaire consisting sociodemographic information alongside several questions related to driving experience. The participants were instructed about the study as follows; "This experiment examines speed perception of drivers and you will be driving on two different road sections, being the Doha Expressway with a speed limit of 120kph and a local road parallel to the expressway with a speed limit of 80kph. In one setting the speedometer will be covered, but in the other setting the speedometer is visible. In both trials, you will be asked to drive at a certain speed and as soon as you feel that you have reached the instructed speed please confirm with saying 'YES'."

After the instructions the participants were guided to drive to the area with the selected road stretches in the test car. Each participant was accompanied with two experimenters, with one experimenter instructing the participant to drive a certain speed, keep an eye on the driving speed via an external GPS and warn the participant when the road's regulated speed limit was exceeded. The second experimenter was responsible to note the precise time values displayed on the screen of the NEXTBASE camera, as soon as the participant said 'YES'.

The driving experiment took approximately one hour per individual participant. The participants speed perception was measured for 16 trials. Eight trails per road segment with four trials driving with the speedometer hidden and four with the speedometer visible. On the Doha expressway the participants were instructed to drive speeds of 80kph and 100kph and on the local road the requested speeds were 50kph and 70kph, in random order.

2.5. Analysis

Exact time values displayed on the NEXTBASE camera were recorded on data collection forms which were later converted in driving speed based on the extracted speed data stored by the GPS. Speed data was collected twice for each requested speed in both settings (revealed and hidden speedometer). Repeated measure analysis was applied for three factors being Requested speed ("R-speed": 50, 70, 80 or 100kph), "Setting" (hidden or revealed) and "Turn" (first drive or second drive). All participants drove each requested speed, so a within-subject design was used. An Analysis of Variance test (ANOVA) was conducted on "Speed" for 4 R-speed x 2 Settings x 2 Turns. Scatterplots and distribution charts were used as further analyses in case of a significant interaction effect. Furthermore, relationships were analyzed for additional driver attributes, like age, gender, driving experience and ethnicity. The significant level was set at a p-value of 0.05 for all analyses.

3. Results

The results from a univariate analysis for speed as a variable of interest are presented in Table 1. The results from ANOVA test shows that all the included factors are significant for main effects. This means that drivers' travelling speed is significantly different between "setting" (hidden and revealed speedometer), between "turn" (first trial and second trial) and between "R-speed" (50, 70, 80 and 100 kph). Besides, the two-way interaction effects of the factor Setting combined with the factors Turn and R-speed were also significantly influencing drivers' speed perception. In the hidden speedometer setting participants were driving significantly faster, in comparison to the revealed speedometer setting (Fig. 3a). In addition, participants drove significantly faster during the second drive compared to the first drive (Fig. 3b). It can be seen from Fig. 3 that the speed differences were higher for the lower requested speeds for both road segments (i.e. requested speed of 50 kph on the local road and 80 kph on the expressway).

Besides, separate paired t-tests were carried out to analyze each requested speed individually. Requested speeds (for each participant and for each speed) were plotted as series of coordinates (X=Hidden; Y=Revealed) on a scatter

Table 1. Analysis of variance for speed perception

Within-Subjects Effects (Greenhouse-Geisser)			
	F	*dfs*	*p*
Setting	15.7	1, 33	**<.001**
Turn	9.5	1, 33	**.004**
R-speed	1025.3	3, 99	**<.001**
Setting x Turn	4.7	1, 33	**.037**
Setting x R-speed	200.7	3, 99	**.004**
Turn x R-speed	<1	3, 99	.892
Setting x Turn x R-speed	<1	3, 99	.487

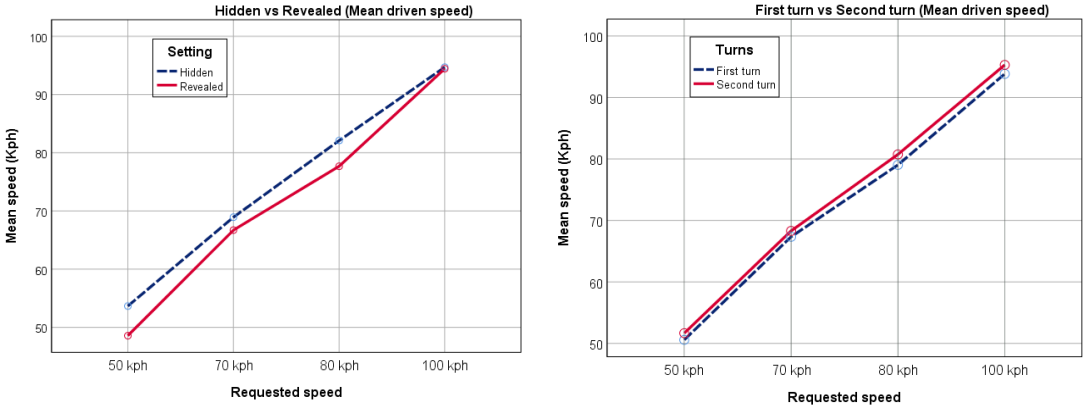

Fig. 3. (a) Mean driven speed for Settings by separate lines; (b) Mean driven speed for Turns by separate lines

plot (see Fig. 4). The diagonal line shows the driven speeds with no difference between hidden and revealed settings. Below the diagonal line the points represent drivers with higher speeds in the hidden speedometer setting, but above the diagonal line the points represent drivers with higher speeds in the revealed speedometer. It can also be seen from the figure that most of the drivers drove with higher speeds than the requested speeds in the setting with hidden speedometer (points right to the vertical lines on respective requested-speeds) compared to the revealed speedometer while only few cases were observed where drivers drove faster than the requested speeds in the revealed speedometer setting (points above the horizontal lines on respective requested-speeds). The range of speed differences and mean difference in speed (dμ= hidden speed (Vh) – revealed speed (Vr)) are higher for a lower requested speed (i.e. 50 kph) compared to a higher requested speed (i.e. 100 kph). Moreover, significant results from separate t-tests show that for all requested speeds with the exception of 100kph (p=0.39), significantly higher speeds were driven by the participants in the hidden speedometer setting compared to the revealed speedometer setting.

However, to understand the individual effects between both settings for the requested speeds (i.e. interaction effect of Setting x R-speed) in detail, we examined each requested speed separately. Area and cumulative distribution diagrams were plotted for all the requested speeds separately within both settings. Additionally, descriptive analyses for factors such as gender, ethnicity, age and experience were done for each requested speed independently. These results are described in sections 3.1 to 3.3.

3.1. Local road – speed estimation for requested speeds of 50kph and 70kph

Participants estimated their speeds for 50 and 70 kph twice for both settings on the road section parallel to the expressway. Fig. 5 illustrates the perceived speeds area and cumulative distribution of both settings for the instructed speed of 50 kph. As it was expected, perceived speed is well distributed in the setting with revealed speedometer. The average (i.e. 48.57 kph) in this setting is closer to the requested speed with lower standard deviation of 2.5 kph

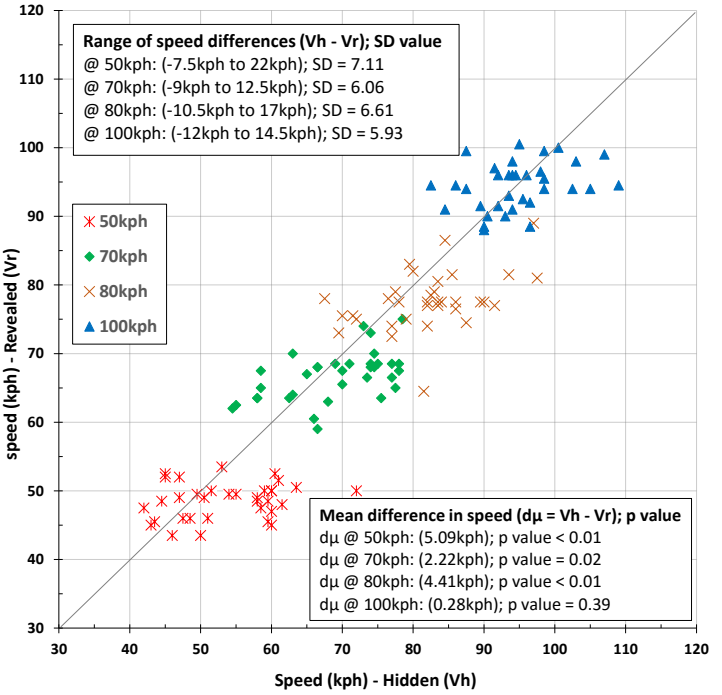

Fig. 4. Scatter plot with Hidden speed on X-axis and Revealed speed on Y-axis

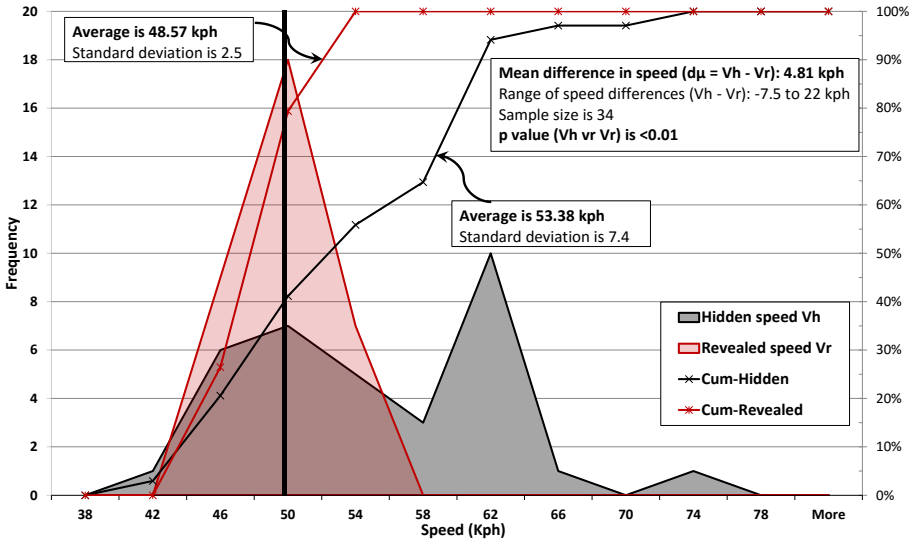

Fig. 5. Surface area and cumulative distribution for a requested speed of 50 kph

compared to the setting with hidden speedometer (i.e. Mean = 53.38; SD = 7.4). In the hidden speedometer setting, the surface area is more to the higher side of the median value, which means most of the drivers underestimated their speed and drove faster than 50 kph. The range of differences between hidden and revealed (Vh - Vr) was -7.5 to 22 kph with an average of 4.81 kph, which means most of the participants drove faster in the hidden speedometer setting.

Fig. 6 shows drivers' speed perceptions as a surface area and cumulative distribution for the 70 kph requested speed on the local road. Compared to the distribution for 50 kph, in this case the areas moved a little to the left for both settings, which indicates an inverse relationship of the requested speeds and perceived speeds on the local road. Moreover, average perceived speed with hidden speedometer was closer to the average requested speed than the other

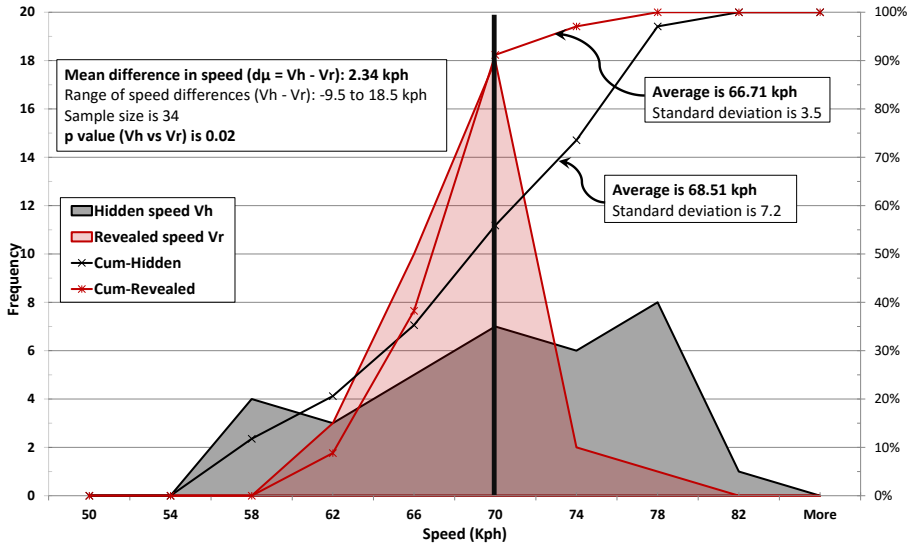

Fig. 6. Surface area and cumulative distribution for a requested speed of 70 kph

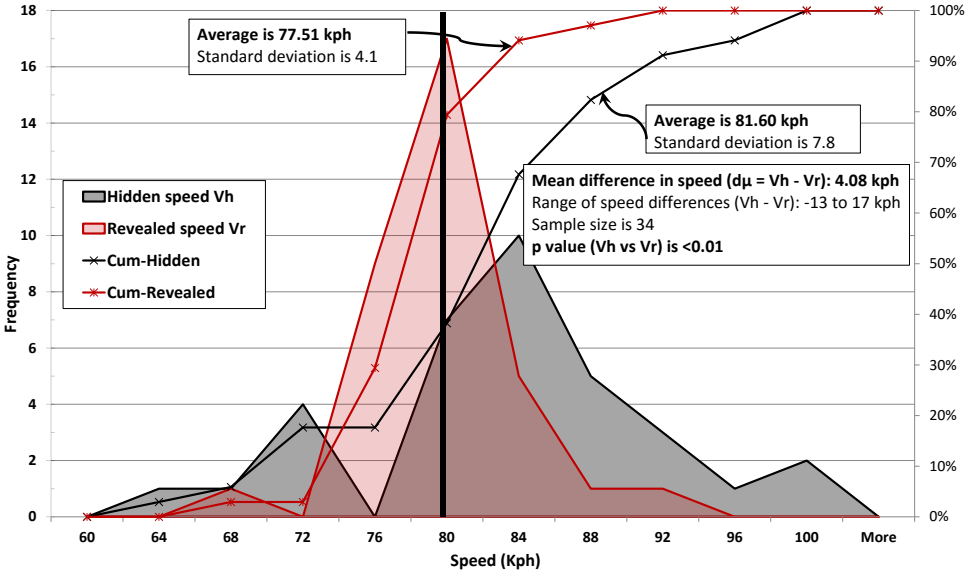

Fig. 7. Surface area and cumulative distribution for a requested speed of 80 kph

setting with revealed speedometer, but with higher variation among participants' speed values. The range of differences between hidden and revealed (Vh - Vr) was reduced to -9.5 to 18.5 kph with an average of 2.34 kph.

3.2. Doha expressway – Speed estimation for requested speeds of 80kph and 100kph

Participants were judged for 80 and 100 kph as target speeds on the Doha expressway. The surface area and cumulative distribution diagrams for "R-speeds" 80 and 100 kph on the expressway are presented in Fig. 7 & 8, respectively. Similar results can be observed for the expressway as compared to the results for the local road. In the setting with hidden speedometer, participants drove faster than the requested speed of 80 kph (i.e. 81.6 kph) while they drove slower than the requested speed of 100 kph (i.e. 94.2 kph). In addition, they drove slower for both requested

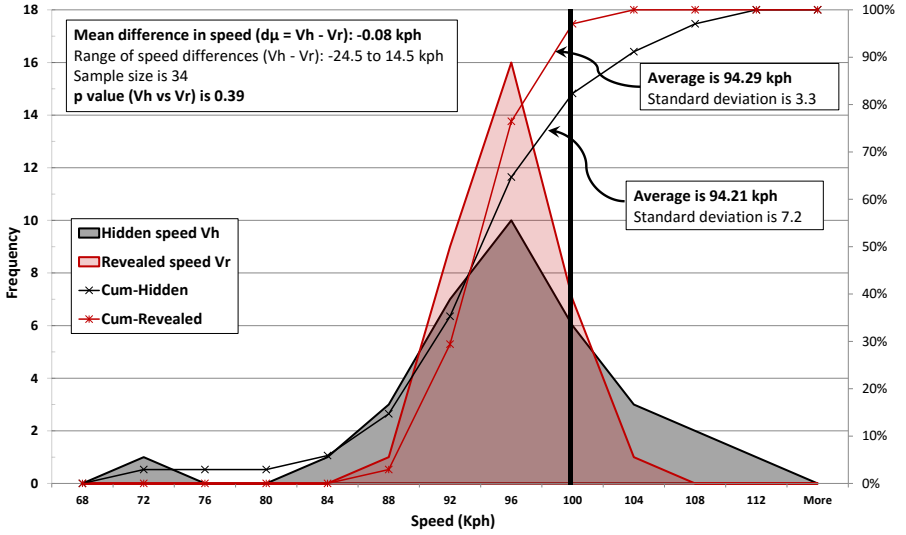

Fig. 8. Surface area and cumulative distribution for a requested speed of 100 kph

speeds on expressway in the setting with revealed speedometer. The mean differences between hidden and revealed settings were reduced from 4.08 kph (for 80 kph) to -0.08 kph (100 kph).

3.3. Descriptive analyses – demographic factors

Table 2 presents the descriptive analyses for the factors gender, ethnicity, age and experience separately for the hidden and revealed settings, and for all the requested speeds. It can be seen from the table that in almost all the cases participants drove slower with a revealed speedometer. However, for investigation of statistically significant effects, each factor was split into two groups and two types of t-tests were performed: a) t-tests with two samples (i.e. between subjects) for each factor and each setting independently; b) t-tests with every single sample (i.e. within subjects) for hidden vs revealed.

The analyses for the hidden speedometer setting do not show any significant difference between the groups for the included factors. However, interesting results can be observed for the setting with revealed speedometer. On the local road, for both requested speeds (50 and 70 kph), female and Arab drivers drove at significantly higher speed and with higher accuracy (i.e. closer to the requested speed) than male and non-Arab drivers, respectively. On the expressway a significant difference was found only for the factor 'experience' for 100 kph only. Drivers with less than 10 years of driving experience (Mean: 4.8 years; SD: 2.5 years) drove significantly faster than those having 10 years or more experience (Mean: 15.2 years; SD: 5.9 years).

Separate paired t-tests for gender show that female drivers did not drive significantly different between the two settings (hidden vs revealed speedometer) while significant differences were found for male drivers for 50, 70 and 80 kph.

4. Discussion

The results from the ANOVA analysis showed that independent of any other parameter, the main effects of the factors Setting, Turn and R-speed were significant. As it was expected, drivers drove significantly different between the two settings i.e. hidden and revealed speedometer. In most of the cases, drivers drove faster than the requested speed with a hidden speedometer while opposite results were observed for a revealed speedometer. These results are consistent with several earlier studies [18-20], which reported that underestimation of speed is common among drivers, as they intend to drive faster than the requested speed if the speedometer is not visible. This might be because drivers' desired speed was higher due to the fact that they were asked to drive with comparable lower speeds (R-speeds) than

Table 2. Descriptive analysis of included factors for all requested speed and both settings

Setting	Factor	Sub-group	Requested speed (kph)							
			50 kph		70 kph		80 kph		100 kph	
			Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Hidden	*Gender*	Male *(n=28)*	53.46	7.6	68.80	7.4	81.80	7.3	94.35	6.0
		Female *(n=6)*	54.58	4.9	69.50	5.5	83.41	6.2	96.33	5.9
	Ethnicity	Arab *(n=23)*	54.02	6.4	69.76	6.9	81.32	5.6	94.39	5.6
		Non-Arab *(n=11)*	52.90	8.5	67.18	7.3	83.68	9.5	95.36	6.7
	Age	Under 30 *(n=21)*	54.45	7.4	69.52	7.4	81.83	7.6	93.50	5.6
		30 and over *(n=13)*	52.38	6.5	67.96	6.5	82.50	6.4	96.65	6.1
	Experience	Less than 10 *(n=20)*	54.37	7.3	68.25	7.2	81.97	7.7	94.37	5.5
		10 and more *(n=14)*	52.64	6.8	69.89	6.9	82.25	6.3	95.17	6.6
Revealed	*Gender*	Male *(n=28)*	48.21	2.6	66.12	3.3	77.53	3.1	94.25	3.3
		Female *(n=6)*	50.25	1.1	69.41	3.1	78.33	7.4	95.25	3.54
	Ethnicity	Arab *(n=23)*	49.15	2.5	67.63	3.5	77.63	3.9	94.52	3.5
		Non-Arab *(n=11)*	47.36	2.1	64.77	2.6	77.77	4.5	94.22	3.2
	Age	Under 30 *(n=21)*	48.73	2.3	48.73	2.3	78.57	3.1	94.92	2.7
		30 and over *(n=13)*	48.53	2.8	48.53	2.8	76.23	5.1	93.61	4.1
	Experience	Less than 10 *(n=20)*	48.32	2.5	65.92	2.6	78.42	3.3	95.55	2.5
		10 and more *(n=14)*	48.92	2.5	67.82	4.2	76.60	4.9	92.82	3.8

the speed limits designed for those roads. A real-world example could be reducing temporary speed limits due to hazardous conditions such as work zones. Previous studies showed that drivers do reduce driving speeds in work zones but not to the posted levels [21-23]. Moreover, there were higher variations when the speedometer was hidden. This reflects wider range of speed behaviors, which may contribute to more conflicts on the roads and more safety threats [24]. In essence, the verification of actual speed visible on the speedometer is important for drivers to maintain consistency of speed behaviors and safety on the road.

Results also showed that participants drove the same speeds significantly faster in the second time. Comparable results were noted in a study done by Matson et al. [25] who stated that after driving at a constant speed, drivers often perceive their speed to be lower than it was at the beginning and hence drive faster than the previous speed.

For the lower speeds on both types of road (i.e. 80 kph on expressway and 50 kph on local road) participants drove faster than the requested speed while for higher speeds (i.e. 100 kph on expressway and 70 kph on local road) they drove slower than the requested speed, in the hidden speedometer setting. A possible explanation could be that after participants were informed about the speed limits on both roads, they were more conservative when were requested to drive in a speed closer to the speed limit to avoid violating it. In other words, in this setting they overestimated their actual travel speeds. This indicates that maybe in complex situations when drivers do not have enough time to reach out to the speedometer, they will perceive they are traveling faster. For instance, a driver in the yellow light dilemma zone, accelerating to cross the intersection safely before it turns to red, will probably overestimate his/her travel speed due to caution for a speed ticket at the intersection.

In several earlier studies, significant differences in driving speed were observed for different factors [26-29]. Probably, gender of the drivers is one of the crucial factors that has to be considered in this regard. In all studies,

females were more likely to drive slower than male drivers. However, in our study females drove faster than males in both settings for all the requested speeds. These differences were significant only on the local road in the setting with revealed speedometer. One of the reasons could be the skewed distribution of males and females in the present study. The sample included only six female drivers (out of total 34 drivers), of which five were Arab and one non-Arab. So, probably the results can be attributed to the small sample size of female drivers or the higher ratio of Arab drivers in the female sample, as Arab drivers were also driving significantly faster than non-Arab drivers on local road for setting with revealed speedometer.

Certain limitations for this study should be taken into consideration. The sample size used in this study was rather small with little ratio of female drivers. However, previous studies included smaller samples than the present study did, ranging from 10 to 18 drivers [14-17]. Another limitation could be the use of a single test car. Some of the participants confirmed during the test that they might estimate travel speed more accurately in their own car. Moreover, the presence of two experimenters inside the test car during the experiment could have influenced the driving behavior of the participants due to peer pressure. Finally, GPS for speed measurements has always been questioned in terms of its accuracy and therefore can be a limitation to be considered in this regard.

5. Conclusion

This paper investigated speed estimation of Qatari residents on two different types of roads in two settings, with a covered and revealed speedometer while driving. The study results clearly show that there were significant differences in perceived speed between hidden and revealed speedometer, between first and second trials, and among all the requested speeds. Participants underestimated the lower requested speeds and drove faster on both the local road for 50 kph (i.e. 53.38 kph) and on the expressway for 80 kph (i.e. 81.6 kph). Arab and female drivers drove significantly faster than males and non-Arab drivers respectively, in the setting with revealed speedometer on the local road. The latter result however needs confirmation from further research with larger sample size of non-Arab female drivers.

In the setting with hidden speedometer, participants drove faster in all the cases. This phenomenon indicates the drivers' pattern of underestimation of their travel speed. In the case of complex situations, drivers may not be able to read their speedometers and may commit a speeding violation, unintentionally. Therefore, it is important for policy makers to take this into account while making decisions regarding speed management.

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