Feedback and its impact on driving behaviour of drivers in Delhi

Dinesh MOHAN [a], Rahul GOEL [b], Geetam TIWARI[c],

[a,b] *School of Engineering, Shiv Nadar University, Gautam Buddha Nagar, Uttar Pradesh – 201314, India*
[a] *E-mail: dineshmohan@outlook.com*
[b] *E-mail: rahul.goel@snu.edu.in*
[c] *TRIPP, Indian Institute of Technology Delhi, New Delhi 110017, India*
[c] *geetamt@gmail.com*

Abstract: The concept aims to reduce carbon footprint by influencing driver behaviour using ITS technologies and telematics. The objectives were to determine whether drivers in Delhi can 'improve' their driving using the Smartphone equipped with an app to record their driving characteristics and provide feedback. Ten drivers were provided with a Smartphone with a pre-installed software to record their driving characteristics and provide feedback. The Smartphone did not improve the overall eco-scores for the whole group for cruising and overall score significantly. The volunteers did not perceive the Smartphone to be very useful in making their driving eco-friendly.

Keywords: Eco-driving; Feedback; Smartphone

1. INTRODUCTION

Unending problems of traffic congestion, carbon dioxide (CO2) emission, road traffic injuries, and pollution in cities around the world are forcing us to re-evaluate both our favourite theories as well as our long-standing practices associated with road transport. A recent publication estimates that premature mortality related to PM2.5 and O3 was responsible for 3.3 (95 per cent confidence interval 1.61–4.81) million deaths per year worldwide in 2010 and likely on a business-as-usual emission scenario double by 2050 (Lelieveld, Evans, Fnais, Giannadaki, & Pozzer, 2015). The contribution of land traffic to this estimate of pre-mature mortality is estimated to be ~50 per cent. Professor Hermann Knoflacher of the Technical University in Vienna warns us that 'car traffic is cooling social relationships by heating up the atmosphere' (Knoflacher, 2007). Voices like his are not alone or new. Professor Banister argues that 'the belief that technology provides the solution is misplaced, as technological innovation can only get us part of the way to sustainable transport (Banister, 2005). Significant reductions of CO2 emissions in transport can only be achieved through behavioural change. There is little sign that people are aware of the scale of the challenge, or prepared to make the necessary changes' .

Solutions proposed include relative reduction in motorized travel and reducing emissions from vehicles (Banister, 2005; Graham-Rowe, Skippon, Gardner, & Abraham, 2011; Harrison & Shepherd, 2013; Santos, Behrendt, Maconi, Shirvani, & Teytelboym, 2010; Santos, Behrendt, & Teytelboym, 2010; Woodcock et al., 2009). While most of the efforts to reduce emissions from motor vehicles have been focused on reducing weights of vehicles, improving combustion efficiency, post combustion treatment of emissions (catalytic converters), and cleaner fuels (including hybrid and electric vehicles), efforts to make drivers improve their driving style continue in parallel. Most of these latter approaches can be clubbed as efforts to promote 'eco driving' by educational and technical means.

Rakotonirainy, Schroeter, and Soro (2014) suggest that vehicle to vehicle communication infrastructure and emerging human–machine interfaces could 'persuade drivers to (i) adopt better (e.g. greener) driving practices, (ii) reduce drivers aggressiveness towards pro-social driving behaviours, and (iii) reduce risk-taking behaviour in young, particularly male, adults…The use of self-efficacy, social norms, gamification theories and social cues could then increase the likelihood of a widespread adoption of such 'good' driving behaviours'. However, the results of various experiments around the world in influencing human behavior by different kinds of feedback to reduce fuel consumption have given mixed results.

In a theoretical paper Barkenbus (2010) estimates that if one-third of all USA drivers adopted eco-driving, it would save 33 million metric tons of CO2, and result in a societal savings of up to $15 billion in gasoline annually. Rutty, Matthews, Scott, and Matto (2013) used vehicle monitoring technology (VMT) and eco-driver training as a means to improve fuel efficiency and reduce CO2 emissions for a fleet of 14 vehicles at a ski resort in Ontario, Canada. They report that after eco-driver training, the fleet reduced its average daily speed by 14%, hard decelerations by 55%, hard accelerations by 44%, and idling time by 2%, resulting in decreased fuel costs by 8% and CO2 emissions by 8%. In another study the investigators studied the effects of feedback in an opt-in experiment with a total of 50 corporate car drivers, 25 in the control group and 25 in the treatment group, making over 800 journeys over eight weeks (Tulusan, Staake, & Fleisch, 2012a, 2012b). An eco-driving application called DriveGain, a product of DriveGain Ltd., UK, was used for the purpose of this study. The application provides feedback related to the ecodriving concepts, such as correct gear change during acceleration and braking, and most efficient average speed. The results of this study indicate that eco-driving can reduce fuel consumption by 10%, on average and over time, thereby reducing CO2 emissions from driving by an equivalent percentage. A study of sixty volunteers using an Eco-Driving System with driver feedback reports that the system showed minor benefits in gas mileage due to different driving behaviors and also increased task loads for the participants (Lee, Lee, & Lim, 2010).

A recent review of 69 studies dealing with eco-driving including those with driver feedback reports results ranging from no significant change in driver behaviour to about a maximum of 15 per cent reduction in fuel consumption (Kurani, Sanguinetti, & Park, 2015). A few of the studies indicated negative results and suggest that road environmental factors and load on the driving task may influence possible change in driving behaviour also. None of the studies reviewed by Kurani et al. (2015) included experiments in low and middle income countries.

This study reports the result of an evaluation of smartphone feedback on the eco-driving behaviour of drivers in the road environment of Delhi, the capital city of India. The objectives of the evaluation were: (a) to determine whether car drivers in Indian cities can 'improve' their driving behaviour when provided feedback; (b) to assess whether users 'perceive' an improvement in their fuel consumption due to use of the feedback from a smartphone; (c) to assess the extent to which users maintain their motivation for eco-driving over the course of the study using the smartphone.

2. METHOD

2.1 Driver Selection

8 drivers were selected and had the following characteristics:

- The drivers (6 male and 2 female) age ranged from 26-52 years.

- They had a regular route of commuting as well as the same time (approximately) of starting the trips, which allows for comparison of speed data and eco-driving performance without much variation in exogenous factors.
- The routes of drivers selected represent different types of roads - residential streets, major roads, and arterial roads.

2.2. Feedback Device (Smartphone)

A smartphone was provided to each driver which had a preinstalled software to record GPS based data of vehicle speed with latitude and longitude and time stamp at a frequency of 1 Hz. These data made it possible to record routes sued by the drivers and vehicle acceleration and deceleration values.

The preinstalled software on the smartphone was programmed to provide eco-scores (1-100, 100 being perfect) for each trip for acceleration, cruising, deceleration and overall trip. These phones did not have a SIM installed and the drivers could not use them for making telephone calls or texting.

2.3. Data Collection

The 8 volunteer drivers were asked to use the smartphone while driving along their regular commuting route for eight weeks. The study was conducted in two phases.

2.3.1 Phase 1

In the first phase of 4-5 weeks, the volunteers were instructed on the use of the smartphone, but were given no instructions regarding methods to improve or change their driving patterns. The volunteers were instructed to switch on the device for the commute to the workplace and back everyday. They submitted the smartphones for data download periodically. Data from the phone devices consisted of two types: (a) Eco-scores of trips for acceleration, deceleration, cruising and overall score. (b) For each trip GPS based data of speed with latitude and longitude and time stamp at a frequency of 1 Hz was recorded. Data analysis consisted of calculating chronological trend of scores in order to see if any improvement happened with the number of trips undertaken and the statistical analysis of raw speed and acceleration data points to detect differences in the driving behaviour between two phases. Eco-driving scores generated by the smartphone for acceleration, cruising, deceleration and the overall score were tabulated.

2.3.2 Phase 2

At the beginning of the second phase of 4-5 weeks, drivers were requested to follow the tips given in the smartphone in order to improve their eco-driving scores. Instruction to the drivers for eco-driving is included in Appendix A. This was done in order to evaluate the effect that the use of smartphone might have on the driving behaviour of volunteers. At the end of Phase 2 the volunteers were requested to complete a questionnaire in order to get their feedback on the usage of the Smartphone and the eco-driving scores. The questionnaire details are included in Appendix B. The questionnaire has been designed in order to understand the attitude and opinion of users towards the NSA. The questionnaire was designed to understand the following:

- User opinion regarding the use of the application - appearance of human-machine interface, ease of navigating around smartphone options.
- Usefulness of driving tips - the users ‘perception’ of an improvement in their fuel consumption due to use of the smartphone.

- Usefulness of scoring and ranking system- whether the application was helpful in understanding the problems in their driving behaviour.

2.4. Data Analysis

Statistical analysis of eco-driving scores as well as the different phases of driving (cruising, acceleration and deceleration) was done in order to evaluate the following:

i) Whether the use of application could change (improve) the driving behaviour of the drivers before and after the use of application.
ii) Whether there is a temporal change in the driving behaviour due to the use of the Smartphone over the duration of trial period (8 weeks).
iii) Difference between the 'actual changes' in the driving behaviour (using the smartphone feedback) as well as the 'perceived' change in the driving behaviour mentioned in the questionnaire.

The difference in the driving behaviour of each participant was measured by statistical significance of difference in the distributions of values of speed, acceleration and deceleration as well as their duration belonging to different trial phases.
The smartphone provided the scores for three modes of driving, and raw speed data at a frequency of 1Hz. The raw data was downloaded from the phone devices. In order to compare the driving behaviour of volunteers for the two phases, speed data were analysed. Firstly, for each volunteer, all the trips in one phase were joined as a single dataset. Secondly, speed and acceleration (calculated by using speed and time difference between two points) data points were divided into three additional subsets based on the following driving modes and their respective speed and acceleration thresholds:

1. Cruise mode, defined as speed equal to or greater than 0.25m/s and acceleration between -0.1 to 0.1 m/s2,
2. Acceleration mode, defined as speed equal to or greater than 0.25m/s and acceleration equal to or greater than 0.1 m/s2
3. Deceleration mode, defined as speed equal to or greater than 0.25m/s and acceleration equal to or less than -0.1 m/s2.

Speed statistics (mean, minimum, maximum, 25th percentile (Q1), median and 75th percentile (Q2)) were calculated for 'all modes' (with all data points) and cruise mode. For acceleration and deceleration modes statistics of acceleration have been calculated instead of speed.
The two phases of data collection provide the volunteers' speed and acceleration distribution. To test whether the driving behaviour of volunteers changed during Phase 2, the non-parametric Mann-Whitney U test has been used in order to assess whether the Phase 1 samples of observations tends to have larger values than those in Phase 2.This test has been performed for the speed for all modes, cruise mode, and acceleration and deceleration mode.
The difference in the driving behaviour evaluated from the smartphone data is compared to the change perceived by the participants in their driving behaviour as mentioned in their response to questionnaires. By looking at the changing distribution of eco scores, it can be assessed whether the drivers could keep the motivation of improved driving over the entire duration of the trial period.

2.5. Problems in Data Retrieval and Analysis

There was problem faced in the retrieval of eco scores for Acceleration/Cruising/Deceleration for the trips carried out by volunteers. While the overall eco-score of the trip is shown as a number out of 100, ranking for acceleration, cruising, and deceleration is shown on a graphic scale from poor to good. In order to convert those graphical rankings to an absolute number, a paper scale was made with 10 subdivisions of the same size as the scale on the smartphone. The paper scale was superimposed on the graphic to obtain a numeric ranking for each trip for each type of score.

The GPS did not always get activated on the phone for some trips. These trips were discarded from the sample. Since data from a large number of trips was obtained in this study, we have assumed that omission of these data has not had influence on the overall assessments.

3. RESULTS AND DISCUSSION

Table 1 gives a summary of the driver volunteers background, total time spent on the tests and the distance driven. Total distances driven by all drivers in Phase 1 and Phase 2 were 2,531 and 2,072 km respectively and time spent 6,038 and 5,410 minutes respectively. This shows that here was no significant difference in the two phases.

Table 1. Driver volunteers background, total time spent on the tests and the distances driven.

Driver No	Age	Sex	Total km driven		Total time driven, minutes	
			Phase 1	Phase 2	Phase 1	Phase 2
1	26	M	137	219	476	582
2	35	M	378	456	955	1,399
3	52	M	651	444	1,629	1,203
4	38	M	494	238	1,005	542
5	32	M	239	413	490	918
6	36	M	164	122	449	343
7	26	F	401	102	881	221
8	32	F	67	78	153	202

3.1. Eco-scores

Table 2 shows the average eco-scores for acceleration, cruising, deceleration and the overall trip for different volunteers for the two phases. Ranking for cruising as well as overall rank is consistently low for all the volunteers while acceleration and deceleration reach even double that of cruising scores. This could be partially because in the urban areas, cruising is hard to maintain in mixed stop and go traffic.

Acceleration mode has the best score followed by deceleration. Cruising and overall trip scores are consistently average for all volunteers. This order of scores is consistent among all the volunteers. These scores indicate that none of the volunteers were braking or accelerating erratically on most part of their trips.

Table 2 also gives the numerical values for the scores including means, standard deviations, maximum and minimum values for each of the seven volunteers for both the phases. When the

Table 2. Average numerical values for eco-scores for acceleration, cruising, deceleration and overall trip for drivers for Phase 1and 2.

Driver	Average Eco-Scores for drivers for different driving characteristics							
	Phase 1: Before specific driving instructions were given				Phase 2: After eco-driving instructions were given			
	Accelera-tion	Cruising	Decelera-tion	Overall	Accelera-tion	Cruising	Decelera-tion	Overall
1	99	50	87	66	94	51	78	61
2	96	52	94	63	99	54	96	65
3	95	53	93	60	96	54	96	63
4	80	47	82	50	82	44	87	49
5	94	45	82	55	94	47	85	56
6	96	39	81	54	94	36	79	49
8	97	52	96	60	99	55	98	68
Mean	93.9	48.3	87.9	58.3	94	48.7	88.4	58.7
STD Dev	5.8	4.7	5.9	5.1	5.3	6.4	7.7	7
Max	99	53	96	66	99	55	98	68
Min	80	39	81	50	82	36	78	49

seven volunteer means for acceleration, cruising, deceleration and overall trip for Phase 1 and Phase 2 were compared no statistical difference at the 95% confidence limit was detected for any of the variables. The variations in eco-scores for each volunteer within each variable did not exceed the 95% confidence limits.

3.2. Speed and Acceleration Analysis

Speed statistics (mean, minimum, maximum, 25th percentile (Q1), median and 75th percentile (Q2)) were calculated for 'all modes' (with all data points) and cruise mode.

Phases 1 and 2 of data collection provide speed and acceleration distribution before and after specific instructions were given to the volunteers. To test whether the driving behaviour of volunteers changed between Phases 1 and 2, the non-parametric Mann-Whitney U test has been used in order to see if there is a significance difference in the speed for all modes and cruise mode and in the acceleration for acceleration and deceleration mode. Mann-Whitney test performs a hypothesis test of the equality of two population medians and calculates the corresponding point estimate and confidence interval. The test provides the test statistic, U value as well as the asymptotic significance p-value. If the resulting p-value is small ($p<0.05$) then a statistically significant difference between the two samples can be accepted.

In three cases, there were significant differences for speed and acceleration between the two phases however the magnitude of difference for speed and acceleration was small. For three volunteers, there was no significant difference between the acceleration scores in the two-phases. The data for all the volunteers is summarised in table 3. The volunteers on an average had lower speeds in Phase 2 by 7.8 per cent and lower accelerations by 0.4 per cent. However, the difference in these means between Phase 1 & 2 was not significant at the 95% confidence level.

Table 3. Mean speed and acceleration data for all drivers.

Volunteer	Mean speed- all modes			Mean Acceleration- all acceleration modes		
	Phase I	Phase 2	Difference Phase 1&2 in per cent	Phase 1	Phase 2	Difference Phase 1&2 in per cent
1	17.4	20.1	15.5	0.47	0.43	-8.5
2	23.7	19.5	-17.7	0.51	0.52	2.0
3	22	16.7	-24.1	0.44	0.43	-2.3
4	28.4	26.5	-6.7	0.51	0.52	2.0
5	29.2	27.3	-6.5	0.52	0.51	-1.9
6	20.8	21.2	1.9	0.52	0.57	9.6
8	24.2	20.1	-16.9	0.46	0.47	2.2
Mean	23.7	21.6	-7.8	0.49	0.49	0.4
SD	3.85	3.58		0.030	0.048	

3.3. Responses to the Questionnaire

The results of the volunteers' response to the questionnaire given to them at the end of the experiment are shown in figures 1-9.

- Most volunteers did not know about eco-driving before using the smartphone.
- Most volunteers found the smartphone as useful or satisfactory.
- Only 2 drivers were certain that they could continue using the smartphone.
- Every volunteer had gone through the tips section in the smartphone (For phase 2 they were requested to do so).
- Three volunteers did not have a tachometer in their vehicles. Two did not ever look at the tachometer while changing gears. Only one volunteer mentioned looking at the tachometer while changing the gears, and two other mentioned using a few times. Clearly, it is not easy to keep looking at the tachometer.
- The respondents are divided equally among those who perceived no improvement in their driving and the ones who perceived some improvement.
- Only two volunteers perceived a noticeable reduction in their consumption of fuel after having used the smartphone.

All volunteers tried to improve their score at least a few times. This is in contrast to the question on rpm use while changing gears, mentioned previously. For that question, only three volunteers mentioned looking at rpm value to change gears appropriately as given in the tips.

Only one of the volunteers (volunteer 3) perceived having improved his driving significantly, while others perceived no improvement in their driving skills. The chronological trend of Volunteer 3 eco-score shows that the scores remained stable through all the trips and no improvement is seen. Also, average of eco-scores for two phases shows that his eco-scores increased very slightly.

The volunteers were also asked open-ended questions regarding their feedback after using the smartphone. Following are the findings from the feedback:

a. Almost all volunteers mentioned slow start-up of the device because of which the starting part of their trips doesn't get reported.

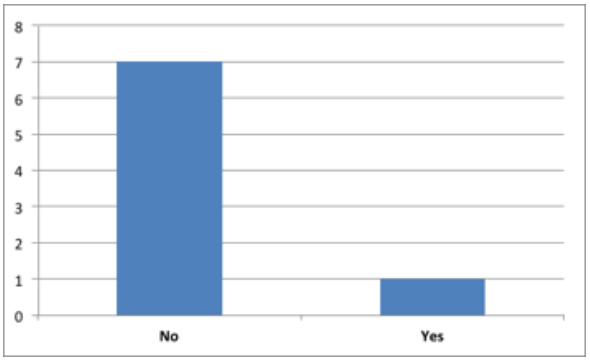

Figure 1. Response to the question "Before using the Smartphone, had you heard about Eco - Driving?"

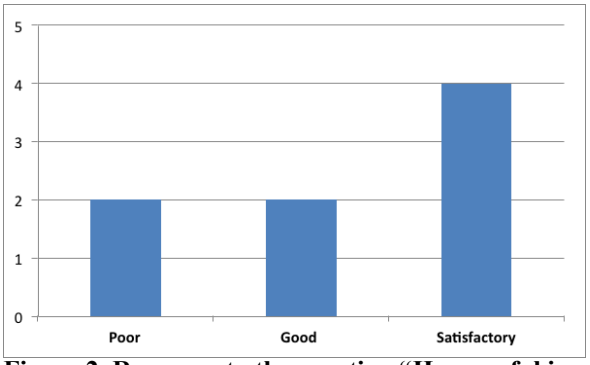

Figure 2. Response to the question "How useful is the Smartphone?"

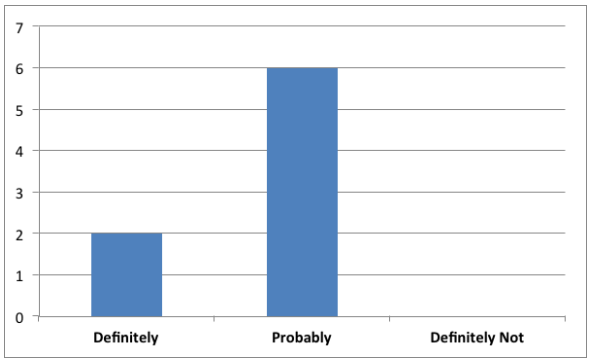

Figure 3. Response to the question "Would you find it useful to continue using the Smartphone?"

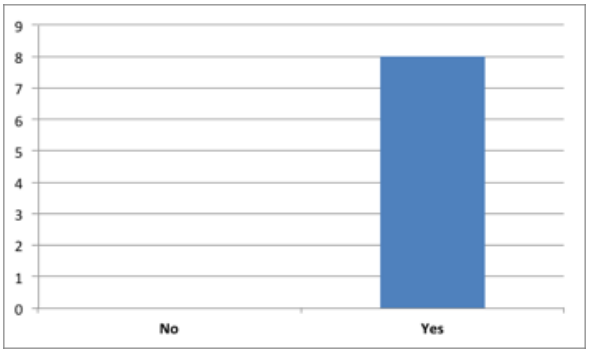

Figure 4. Response to the question "Have you looked at the tips give in the Smartphone?"

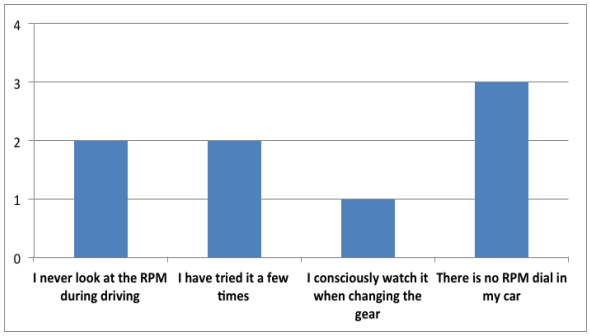

Figure 5. Response to the question "After using this Smartphone, when changing gears, do you try to keep the RPM around the 2000-2500 mark?"

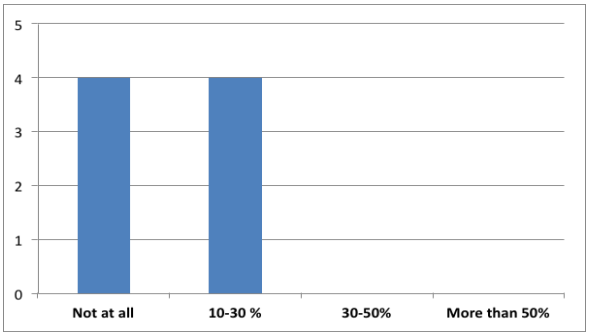

Figure 6. Response to the question "After using this Smartphone, how much has your driving improved?"

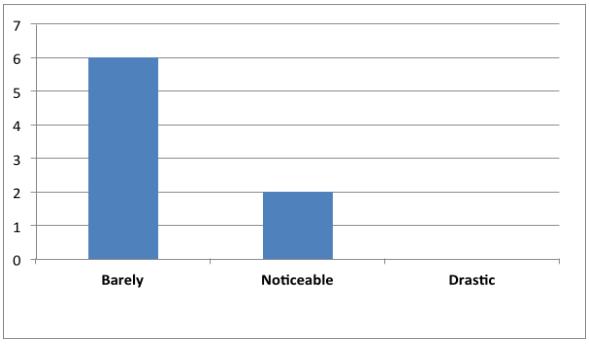

Figure 7. Response to the question "How much of an improvement is there in your fuel consumption?"

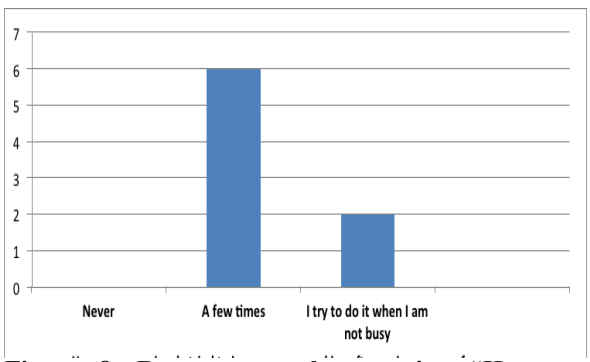

Figure 8. Response to the question "Have you consciously tried to improve your ranking after seeing your performance on the Smartphone?"

b. In some devices, the number of trips shown by raw GPS speed data was more than the number of trips shown in the history section of smartphone. Thus, some trips were made, however their eco-scores could not be retrieved.

c. The tips provided in the smartphone are not elaborate enough making it difficult to connect eco-scores with the driving behaviour.

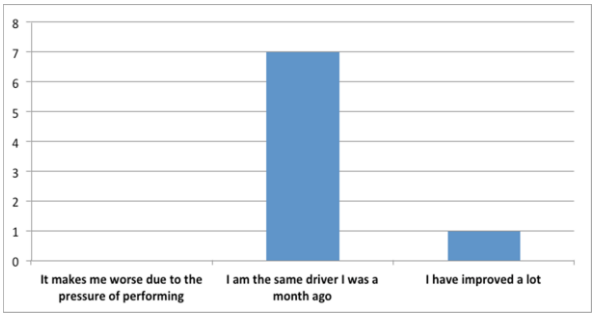

Figure 9. Response to the question "Do you feel you have become a better driver?

d. Higher deceleration and acceleration scoring and much lower scoring for cruising and overall are consistent for all the volunteers in almost all their trips. This was also, one of the major reasons mentioned by volunteers for their reduced motivation while using the smartphone - consistency in their eco-scores. For instance, volunteer 2 has the most consistent scores in all his trips. While his acceleration and deceleration scored above 90 in most cases, cruising score remained below 60 in all the cases. A very similar scoring result can be seen from the Volunteer 3 whose scoring remained very consistent (at least for acceleration and deceleration), while cruising remained below 60.

e. In contrast to these, some volunteers experienced high ups and downs in their scoring even though they claimed their driving conditions remained the same. For instance for volunteer 1 the scoring for deceleration varies from as low as 20 to as high as 100. This made it difficult for volunteers to analyse any association of their driving behaviour with the scoring.

f. According to a volunteer, it would be helpful to know the method by which scoring is given. That would help drivers to be able to relate their driving behaviour with the scoring.

4. CONCLUSIONS

1. The use of the smartphone with feedback did not improve the overall average eco-scores for the whole group for cruising, acceleration, deceleration, overall score, at statistically significant level.
2. The mean speed values changed significantly between Phase 1 and Phase 2 for all volunteers – reducing for 5 and increasing for 2. Both decreases and increases were for a maximum of ~ 3 km/h. However, the change was not significant at the 95% confidence level for the whole group.
3. The mean acceleration did not change significantly during the experimental period for the whole group.
4. Overall, the volunteers have not expressed a strong preference for the use of the smartphone, nor did they perceive it to be very useful in making their driving more eco-friendly.
5. The drivers did not find it easy to monitor the tachometer as a constant endeavour.
6. It is possible that gear change indicators informing the drivers when to shift into a higher or lower gear may be more effective than monitoring the tachometer or referring to their eco-scores on a smartphone all the time. Such indicators are already available on some car models.
7. It may be more efficient to inform drivers regarding the range of speeds at which combustion is most efficient for each gear for petrol and diesel engines.
8. It may be useful for the drivers to get average fuel consumption data over pre-set time intervals.

Our results showing that eco-driving feedback did not change driver behaviour significantly could be because urban driving situation in mixed traffic in Delhi makes it more difficult for

drivers to follow idealistic driving instructions. It is also possible that our sample was not large enough and we the experiment was not carried out for a sufficient long period of time. However, Harvey, Thorpe, and Fairchild (2013) also caution us that "There is little evidence here that any people other than those who perceive themselves as very 'green' care much about what driving does to the environment. Although respondents expressed concern for sustainability in the survey, the focus groups largely, apart from the few who were from 'green' organisations, did not even mention the issue until it was raised by the researchers".

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APPENDIX A. ECO-DRIVE INSTRUCTIONS

- Please make sure you drive carefully, adhere to all speed limits and traffic regulations of your respective country and come to a safe standstill before you check your measurements.
- Do not check the display while driving.
- Values may vary and are subject to change depending on different conditions.

TIPS

Acceleration

- Accelerate gently.
- Accelerate gradually and drive smoothly.
- Change gear as soon as possible without labouring the engine – try changing up at an engine speed of around 2,000 rpm in a diesel car or around 2,500 rpm in a petrol car.

Cruising

- Reduce and maintain constant speeds.
- The higher the speed the greater the fuel consumption and pollution.
- Driving at 110 km/h uses up to 9% more fuel than 95 km/h and up to 15% more than at 80 km/h.
- Anticipate road conditions so that you drive smoothly and avoid sharp acceleration and heavy braking, this improves fuel consumption.

Deceleration

- Lift off the accelerator early.
- Release your foot from the accelerator early when slowing down or stopping the vehicle. This reduces the fuel used by the engine to almost zero.
- Anticipate road and traffic condition and decelerate early when needed.

APPENDIX B. DRIVER QUESTIONNAIRE

1. Before this experiment, had you heard about " Eco - Driving"?
2. How useful is the smartphone App? - a) Poor b) Satisfactory c) Good
3. Would you find it useful to continue using this smartphone App? – a) Definitely b) Probably c) Definitely Not
4. Have you looked at the tips give in the smartphone App? – Yes / No
5. Do you follow the tips given in the smartphone App? – a) I am good enough driver to worry about these tips b) I follow these tips everyday c) I follow these tips occasionally
6. After using this smartphone App, when changing gears, do you try to keep the RPM around the 2000-2500 mark?
    a) I never look at the RPM during driving. b) I have tried it a few times. c) I consciously watch it when changing the gear. d) There is no RPM dial in my car.
7. After using this smartphone App, how much has your driving improved? a) Not at all b) 10-30% c) 30-50% d) more than 50%.
8. How much of an improvement is there in your fuel consumption? a) Barely b) Noticeable c) Drastic
9. Have you consciously tried to improve your ranking after seeing your performance on the smartphone App? a) Never b) a few times c) I try to do it when I am not busy
10. Do you feel you have become a better driver? a) It makes me worse due to the pressure of performing b) I am the same driver I was a month ago c) I have improved a lot
11. What were the major positive driving behaviors that were affected after using this smartphone App?
12. Anything you want to share about the experience…
13. Please mention origin address for your commuting / work trip
14. Please mention destination address for your commuting / work trip
15. Age
16. Sex
17. How many years of driving experience do you have?