A comparison of motivational and informational contexts for improving eco-driving performance

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ABSTRACT

Eco-driving, the practice of operating a vehicle with environmentally friendly objectives, has been the focus of an increasing number of driving studies over the past decade, as new forms of vehicle automation and more driver-centric feedback continually emerge. Common benefits range from reducing carbon footprints and emissions to better fuel economy. Studies have also examined the effectiveness of in-vehicle assistance devices and training or education programs for commercial and passenger vehicle operators. Eco-driving strategies in general show significantly smaller impacts in the field relative to their laboratory counterparts. This study further builds on this past work by comparing and disentangling the effects from motivational contexts, for example a competition with prizes, with the effects of informational context, such as tutorials for drivers. To investigate this comparison, laboratory experiments are conducted using a commercial vehicle simulator. The results suggest that motivational contexts are more effective at encouraging eco-driving relative to informational contexts. Furthermore, incentives within competitive contexts had similar positive impacts on reducing carbon dioxide emissions and improving fuel efficiency as experiencing a tutorial on eco-driving. One possible explanation is that drivers have gained knowledge on how to operate vehicles with an eco-driving objective through their driving experience. This result further suggests that with respect to effectively encouraging eco-driving, targeting experienced drivers through a competition is better than presenting information or a tutorial.

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1. Introduction and background

According to the Environmental Protection Agency (Environmental Protection Agency, 2015), more than 1750 million metric tons of carbon dioxide (CO₂) were released as a direct result of transportation activities in 2014, accounting for 26% of U.S. greenhouse gas (GHG) emissions. Eco-driving, the practice of operating vehicles with environmentally friendly objectives, has shown promise in reducing these emissions. Studies show reductions in CO₂ emissions and fuel consumption of between 2.7% and 18.4%, resulting from a combination of eco-driving aids and training programs (Barth & Boriboonsomsin 2009; Beusen et al., 2009; Kurani, Stillwater, Jones, & Caperello, 2013; Staubach, Schebitz, Koster, & Kuck, 2014; Zhao, Wu, Rong, & Zhang, 2015). Several studies have focused on the impacts of type, frequency, and mode (or form) of eco-driving information on vehicle performance from both an eco-driving and safety standpoint. Existing work suggests that motiva-
tional context may also play a significant role in encouraging eco-driving as studies show greater impacts in vehicle simulation studies versus longitudinal field studies of actual vehicle operations (Barth & Boriboonsomsin, 2009; Beusen et al., 2009; Kurani et al., 2013; Staubach et al., 2014). This paper builds on previous studies by comparing motivational and informational contexts through laboratory experiments using a commercial truck driving simulator. The hypothesis put forth is that the majority of drivers have existing knowledge on how to operate vehicles with an eco-driving objective, resulting in higher miles-per-gallon (MPG) of fuel and lower overall emissions. Consequently, informational contexts, which include tutorials and training programs, may only serve to reinforce existing knowledge, but not significantly improve operations by itself, relative to competitive motivation contexts.

The existing literature on eco-driving roughly fall into four categories regarding the effectiveness of the following: (i) driver assist devices and mechanisms; (ii) information presentation and feedback, including tutorials; (iii) motivational contexts, such as a competition; and (iv) longitudinal field studies over time.

Research on the effectiveness of driver assistive devices and mechanisms show that safety objectives are aligned well with eco-driving objectives, with improvement in safety in some cases (Birrell & Young, 2011; Mollenhauer, Lee, Cho, Hulse, & Dingus, 1994) accompanying improved eco-driving. These studies have examined the effects of frequency, modality and adaptability of information provided to drivers, with several focusing on safety. For example, Kircher, Fors, and Ahlstrom (2014) studied continuous versus intermittent feedback on human factors including eye glance frequency and dwell time, finding that intermittent feedback improves safety by reducing dwell time on the device. Rouzikhal, King, and Rakotonirainy (2013) compared three different device activities: (a) reading an eco-driving related text message; (b) changing a CD and (c) entering a 5-digit number into a PDA. Results indicate that an eco-driving related text has significantly less distraction than the other two tasks, but the messaging did slightly increase driver workload. For these two studies no eco-driving performance was measured, precluding a connection of these factors to eco-driving.

Studies on information presentation and feedback have examined the type, frequency and modality of information provision (Brouwer et al., 2015). While Kircher et al. (2014) found that intermittent feedback increases driver safety by reducing device dwell time, a similar experiment by Jamson, Hibberd, and Jamson (2015) found that continuous real-time visual feedback was more effective than haptic feedback for eco-driving. In a separate study Hibberd, Jamson, and Jamson (2015) evaluated the effectiveness of haptic, auditory and visual displays, finding that haptic feedback was better at controlling over accelerations. While haptic and auditory/visual feedback showed similar eco-driving performance with respect to measured fuel economy, auditory/visual feedback showed a potential increase in driver workload. Dijkstra, Stuiver, Mulder, Brookhuis, and deWaard (2012) investigated the delivery of eco-driving feedback on a lane keeping task and found that intermittent feedback performed best, but only when necessary, for example when a driver makes hard accelerations. Similarly, Zhao et al. (2015) showed a 5% improvement in CO2 emissions and fuel economy when intermittent warnings were used alerting drivers of high accelerations or decelerations, high RPMs, unstable speeds and lengthy idling.

Motivational contexts for eco-driving have also been explored in past studies, though to a smaller degree relative to information. In a simulator study on multiple goals, such as minimizing travel time and eco-driving, the positive impacts on eco-driving declined as more goals were included (Dogan, Steg, & Delhomme, 2011). With respect to existing ability to eco-drive, one study showed that while drivers have an endogenous intention to drive eco-friendly, they are ineffective at translating these intentions into daily driving behaviors (Lauper, Moser, Fischer, Matthies, & Kaufmann-Hayoz, 2015). This study hypothesized that drivers possess eco-driving knowledge, but a gap exists between intention and performance that stems from lack of motivation. In a larger study of 118 drivers along the I-80 corridor in California over two months, examining three eco-driving aids which contained either numbers associated with eco-driving performance or random numbers, no significant improvement (only a 2.7% improvement in fuel economy) was associated with aids (Kurani et al., 2013). This study further suggests that future studies on motivational context are promising.

With respect to informational contexts, such as tutorials, one long-term study on the effectiveness of an eco-driving course examined the performance of ten drivers before and after the course (Beusen et al., 2009). Fuel consumption decreased by 5.8% after the course. Interestingly, leading up to the course, drivers showed a 40% decrease in fuel consumption, suggesting that drivers may already have eco-driving knowledge. Eco-driving performance was best directly after the training course, but these gains diminished over time. Finally, a bus driver study suggests that eco-driving training can have significant impacts on performance in real world driving; however, the experimental design does not allow distinguishing gains in driving performance between training or external motivating factors (Sullman, Dorn, & Niemi, 2015). Two cohorts of bus drivers were recruited, with each experiencing a training session. One cohort experienced a tutorial on eco-driving and the other on first aid. The cohort experiencing the eco-driving tutorial outperformed the other cohort in eco-driving measures. However, the authors of this study hypothesize that the first-aid cohort may have had similar performance if simply asked to drive eco-friendly.

This brief literature review underscores several dimensions of eco-driving that require further investigation. One of these dimensions is distinguishing between improvements in eco-driving from motivational versus informational contexts. Past studies have shown benefits from educational mechanisms, such as tutorials on eco-driving that simply present information on how to eco-drive. Other studies suggest their effectiveness is misleading as the majority of experienced drivers already know eco-driving, but require the proper motivational context. This study addresses this distinction, comparing the eco-driving effects of motivational relative to informational contexts. More specifically, this study compares a competitive context with prizes with one where information is presented through performance feedback post-trip and tutorials.
This paper is organized as follows: (i) the next section presents the overall methodological framework; (ii) the following section presents and discusses the sample characteristics and experimental procedure; (iii) the third section discusses the results of the experiments and analysis of participant performance; and (iv) the paper ends with conclusions.

2. Methodological approach and framework

The methodological approach and framework is presented in Fig. 1. This framework also serves to guide the experimental trials conducted. At the center of this methodological framework is a driver (the decision maker) who faces a series of driving tasks within a simulated driving situation. Eco-driving outcomes, such as lower emissions and improved fuel efficiency, are dependent on several factors including vehicle operations characterized through modal activities, such as accelerations and braking. Depending on the timing and intensity of these vehicle modal activities, the emissions and other environmental impacts will vary.

This study adopts a similar perspective to Fig. 1 where participants are presented a driving scenario which include a route and the “rules of the road,” such as requirements to come to a complete stop at all traffic lights, for completing the route. These driving scenarios are completed in a driving simulator which consists of (i) the hardware found in all commercial freight vehicles, such as a gas and brake pedals, steering wheel and driver’s seat and (ii) the virtual environment, which includes road network, traffic controls and other elements commonly found in a real world driving environment. As the driver operates vehicles within this environment, second-by-second route and vehicle operations data is collected for post-processing. Vehicle operations data include second-by-second modal activities and fuel rates. During post-processing, eco-driving performance metrics and emissions are determined. Emissions are estimated using the CMEM model (Barth, An, Younglove, Scora, & Levine, 2000).

With respect to the two contexts, informational and motivational, examined in this study, drivers may receive (i) information on known vehicle operation strategies for eco-driving through tutorials and feedback on self-performance after completing a driving run or (ii) motivation in the form of a competition with prizes. In this study informational context is delivered in the form of post route eco-driving feedback and through an online tutorial. Competitive motivation is also created through feedback in the form of a leaderboard showing current ranking relative to other participants and carbon dioxide score based on total grams of carbon dioxide equivalent emitted.

The specific details of the experiment design are provided in Section 3 and include trial procedures, driving scenario completed at each driving run and eco-driving metrics determined.

3. Experimental design

Due to high costs and logistic challenges associated with field investigations of actual drivers during their daily commutes, the majority of eco-driving studies are laboratory-based using driving simulators as a means for testing hypotheses on vehicle operations under varying conditions. Past simulator studies show fuel efficiency and GHG emissions improvements between 5.3 and 18.4 percent (Barth & Boriboonsomsin, 2009; Staubach et al., 2014; Zhao et al., 2015). The main objective of the experiment in this study is to compare eco-driving performance when drivers experience a competitive motivational versus an informational context. Using a two factor full factorial experimental design, participants were allocated to one of four treatment groups or an additional control group for a total of five participant groups. The remainder of this section discusses the factor levels participants may experience, the driving scenario used, the characteristics of the subject population, and finally the participant trial procedure.

3.1. Experimental factors

This study has two main factors each with two factor levels: motivational context and informational context. Each of these factors and their respective levels are described here.

Motivational context factor: The two levels associated with the motivational context factor are competition (comp) and no competition (no comp). Participants experiencing the competition level of the motivational context factor were placed in a competition for a prize. For the competition, participants were informed that the driver with the best “eco-score” after three driving runs would receive a $25 gift card to a local establishment of their choice. Scores were based on the estimated total grams of carbon dioxide emission equivalents emitted for a single driving run. Upon completing each of the three competition driving runs, participants were shown their driving run score (total grams of equivalent carbon dioxide emissions) and a leaderboard which ranked their score against other competitors.

To provide the same exact motivational experience for each driver, the leaderboard they were shown contained simulated results for the other “competitors”; the purpose of the board was only to provide the perception of competition and consequently motivation. In this leaderboard, the subject would be shown that after their first eco-driving competition run they were currently in third place out of five participants. The leaderboard accurately represented the subject’s carbon dioxide emissions. The carbon dioxide emission scores for the first and second place fictional participants were set at 92% and 95% of the participant’s first competition trial run score. These fictional participants remained constant in the second and third trials. The artificial nature of the leaderboard allowed competitors to experience consistent competitive contexts inde-
dependent of trial participation order. Each participant perceived the opportunity to improve their score to take the lead, and then improve their score further and eventually win. An example leader board that would be seen after a participants first treatment run can be seen in Fig. 2.

Participants experience the no competition motivational factor level were asked to drive as eco-friendly as possible for each of three treatment runs. Participants were told that if they completed all required runs they would be entered into a raffle to win a $25 gift certificate. Therefore all study participants had a chance to win a $25 gift card, but only those subjects receiving the competitive motivational context could influence their chance of winning by trying to have the best score. Par-
Participants receiving the no competition motivational context factor level were not shown the leaderboard nor their emissions after each run.

**Informational context:** The two factor levels associated with the information context factor are training and feedback (training), and no training and feedback (no training). Subjects experiencing the training and feedback factor level were provided two forms of information: (i) educational materials on eco-driving and (ii) feedback on their individual driving performance. The education materials included a 10 min video tutorial on eco-driving, and additionally time was provided to review a website on eco-driving strategies. After each eco-driving run the participants were shown a set of maps, see Fig. 3, which provided a visualization of emissions, vehicle speed, braking and acceleration. The maps were used as a tool for conveying points of poor performance with respect to emissions. For example, in the set of maps shown in Fig. 3 one can observe that emissions are worst in a segment where gas pedal use (acceleration) is high.

Participants experiencing the no training and feedback level were not shown the eco-driving tutorial video and website, nor were the participants provided driving feedback after their driving runs in the form of maps and carbon dioxide emissions.

**Control group:** In addition to the four treatment condition groups an additional study group was included to act as a control. While all treatment groups received instructions to drive eco-friendly, the control group performed all the driving trials under the impression that they were testing the driving simulator for realism. In lieu of being requested to drive in an eco-friendly manner, they were asked to drive as they normally would drive, while obeying all traffic and safety laws. Participants in the control group received no messages or information regarding eco-driving and served as a baseline to which treatment groups could be compared. The control group was also told they would receive a raffle entry to win a $25 gift card if they completed all required runs.

The two level full factorial design plus control group resulted in 5 possible group assignments for a study participant. These participant groups and the factor levels each received are outlined in Table 1 and the Group Ids provided will be used throughout the remainder of the paper.

### 3.2. Driving scenario and rules of the road

The main task all participants faced in the experiment required them to complete a given route in a simulated environment six times. The simulated environment was modeled after the City of Ann Arbor, Michigan. The given route was 2.3 miles in total length and contains a mix of arterials and highway segments. With respect to traffic control devices, the route contained three traffic signals. With respect to roadway geometrics the route contained two wide sweeping turns, one traffic circle and a highway on-ramp. The entire route, as shown to participants, is seen in Fig. 4. The simulated environment contained no other vehicle traffic.

All participants also faced the same set of driving rules for completing the route. Four rules were upheld across all driving runs. (1) All intersections with traffic lights were treated as four-way stops – although traffic lights were present, they were not functioning and always appeared red. (2) The speed limits on arterials and side streets was as posted ranging from 25 to 45 mph. (3) Highway speed limit was set at 50 mph to mimic urban highway speeds. (4) Drivers needed to obey all existing traffic laws in New York State. After the first three practice runs the drivers faced a fifth rule regarding a time limit: (5) The maximum time allowed for completing the route was 5 min and 30 s to prevent drivers from operating the vehicle extremely slowly in order to maximize fuel efficiency from coasting.

Fig. 2. Grams of carbon dioxide leaderboard shown to participants experiencing the competition level of the motivational context factor.
The experiment was performed on a box truck simulator manufactured by Mechanical Simulation using the TruckSim vehicle simulation software. The simulation platform provided a 160 degree field of view, and provided 3 degrees of freedom of realistic motion. The truck had an automatic transmission, and the control platform contained gauges for speed, RPM, fuel, an odometer, and a timer.

Table 1: Participant Groups.

<table>
<thead>
<tr>
<th>Group Id</th>
<th>Treatment messaging</th>
<th>Motivational context</th>
<th>Informational context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp_Train</td>
<td>Drive Eco Friendly</td>
<td>Competition</td>
<td>Training + Feedback</td>
</tr>
<tr>
<td>NoComp_Train</td>
<td>Drive Eco Friendly</td>
<td>No Competition</td>
<td>Training + Feedback</td>
</tr>
<tr>
<td>Comp_NoTrain</td>
<td>Drive Eco Friendly</td>
<td>Competition</td>
<td>No Training/Feedback</td>
</tr>
<tr>
<td>NoComp_NoTrain</td>
<td>Drive Eco Friendly</td>
<td>No Competition</td>
<td>No Training/Feedback</td>
</tr>
<tr>
<td>Control</td>
<td>Drive Normally</td>
<td>No Competition</td>
<td>No Training/Feedback</td>
</tr>
</tbody>
</table>

Fig. 3. Driving feedback maps shown to participants experiencing the training and feedback level of the informational context factor.

3.3. Simulator

The experiment was performed on a box truck simulator manufactured by Mechanical Simulation using the TruckSim vehicle simulation software. The simulation platform provided a 160 degree field of view, and provided 3 degrees of freedom of realistic motion. The truck had an automatic transmission, and the control platform contained gauges for speed, RPM, fuel, an odometer, and a timer.
3.4. Participants

A total of 36 subjects or participants were recruited for this study. A combination of participant drop-out (due to motion sickness, etc.), violation of scenario rules and errors in conducting the experiment, resulted in 29 subjects used in the final analysis. All subjects were students attending the Rochester Institute of Technology (RIT) and held a valid US driver’s license for a minimum of 2 years at the time of participation. Additional participation requirements included having no prior driving simulator experience within the past year, for example from an arcade video game, and having no experience driving a box truck in the past six months. The final requirements ensure that all participants were similar with regards to their familiarity with simulator and box truck driving. The sample was comprised of 18 males and 11 females, with an average age of 21.6 years and a standard deviation of 2.4 years. The average length of driving experience was 5.3 years with a standard deviation of 2.5 years, additional details per group can be seen in Table 2. Recruitment occurred through two mechanisms: (i) flyers placed around campus; (ii) visitor recruitment at the RIT Student Life Center. The distribution characteristics of the final sample of participants are shown in Table 2.

3.5. Participant trial procedure

An overview of the participant trial procedure is shown in Fig. 5. All experiments consisted of one or more facilitators and one participant. Each participant was allowed to participate in only one group for the study. Each participant completed six
driving runs: three practice runs and three treatment runs. All participants (4 treatment groups plus the control group) faced the same procedure when beginning the experiment through finishing the three practice runs.

First, all participants were informed that the study goal was to evaluate the driving simulator and various driving aids, but no mention of an eco-friendly study was delivered. Participants were asked to sign a consent form, and then each was introduced to the simulator and allowed to drive freely until the subject felt comfortable with the simulator, up to a maximum of five minutes.

Second, after the warm up, drivers were explained and guided through the scenario route by being shown a map of the route (Fig. 4), and receiving verbal instructions from the facilitator as they were driving. Subjects practiced the route three times, and data was recorded for each route. This applies to all participants regardless of treatment. As they were guided through the route, all participants were informed of the rules for completing the route, described previously.

After the set of three practice driving runs, each group (see Table 2) experienced a set of treatments specific to their group. For example, group Comp_NoTrain participants were informed about the eco-driving competition, but were not provided with the eco-driving training materials and feedback. All groups except the control group were asked to “drive eco-friendly,” during the treatment runs, runs 4, 5 and 6. This allowed investigating the possibility that participants only need the framing of eco-driving in order to produce eco-driving benefits. Also prior to beginning their set of treatment driving runs, all participants were given a driving questionnaire to collect information of driving habits and attitudes. All groups received the same questionnaire, except for the control group which received a similar version without the mention of the study focus on eco-driving. The control group was not asked the eco-driving questions, so as not to influence their “natural driving” on the final three simulator rounds. The purpose of the questionnaire for non-control groups was to elicit any preconceived notions about eco-driving that the subjects may have had.

Informational context factor: For those experiencing the training and feedback level of the informational context factor, participants were shown a tutorial video and website online on eco-driving prior to the final three treatment driving runs. After each of the treatment driving runs, participants were shown a set of four maps that provide a visualization of emissions, vehicle speed, braking and acceleration (gas pedal) shown previously in Fig. 3. The facilitator(s) did not explain how best to use the information provided in the maps, subjects were left on their own to interpret the map information.

Motivational context factor: For those experiencing the competition level of the motivational context factor, prior to starting the final three treatment runs, participants were presented and explained a scenario where they are in a competition with other study participants to produce the best score for a driving run based on their carbon dioxide emissions. At the end of each of the treatment driving runs participants were shown a leaderboard with their emission score and rank relative to
fictional participants; while the leaderboard was fictional, participants were actually awarded the gift certificates based on their performance relative to their group peers.

For all participants, after the practice and each driving run participants were asked to complete the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993). To prevent possible severe cases of motion sickness, if during any of the SSQ administrations a participant cited the presence of a moderate or severe symptom, the participant was required to drop out of the study. Upon completing the final treatment run, all participants were debriefed and given a $5 gift certificate to a campus coffee shop.

3.6. Eco-driving performance measures

As drivers completed each driving run, vehicle operation data were collected, including speed, acceleration, gas pedal depression, and brake operation. The simulation provided data at a rate of 1 Hz which was used to determine emissions and vehicle operation throughout any given route. NOx, SOx, and CO emissions are also estimated with linear equations related to fuel usage. Vehicle operation data was mapped into vehicle emissions using the Comprehensive Modal Emissions Truck Model (CMEM) developed by Barth et al. (2000). The score used in the experiments is based on these emissions by converting them into carbon dioxide equivalents. For the route used, the score detailed the number of grams of carbon dioxide released and ranged from approximately 600 to 2300 g for the route based on preliminary trials before this study. The model calculated tailpipe emissions from the fuel rate generated during simulation and a fuel to carbon emissions ratio. While both fuel efficiency and emissions were presented to participants as feedback in the training and feedback level of the informational context factor, for the score in the competitive motivation context, only emissions was used; the reason for this is the strong relationship between fuel efficiency and preliminary truck emissions in the CMEM model (Barth et al., 2000). Each participant drove the same route 6 times, and carbon dioxide equivalent emissions were calculated for each run.

4. Results

The final results show that the motivational context factor plays a significant role in determining eco-driving performance, while the informational context factor shows reduced benefits. The results supporting these findings are presented in this section. The main performance measure evaluated was the carbon dioxide emissions produced for each driving run. This section first analyzes results of carbon emissions looking across experiment treatment groups to identify if any statistical differences between treatment groups existed during any of the 6 runs. This section concludes by analyzing carbon emissions within each individual treatment group to understand if emissions significantly reduced once the eco-driving treatment runs began.

Figs. 6 and 7 summarize the results of emissions and compare different treatment groups for each of the six driving runs. Fig. 6 shows only mean emissions for each treatment group across the six driving runs, and Fig. 7 provides additional detail on the distribution of participant performance by displaying a box plot of the emissions data for each individual group for each of the six driving runs. Before continuing on with the analysis, it is important to note that all groups had statistically similar emissions across each of the 3 practice runs (runs 1, 2 and 3) of between 1000 and 1600 g of CO2. This was concluded based on a Tukey Test performed at a confidence level of 95%. The p-values and F-measures from these Tukey Tests can be seen on Fig. 7. The observation that all five groups are statistically similar during the first three runs is important because it demonstrates that all the treatment groups and control group started off the experiment on equal footing, no group had a pre-existing eco-driving advantage nor disadvantage.

Fig. 6 shows that on average, participants receiving at least one of the competition or the training and feedback factor levels, were better on average at eco-driving by the sixth run relative to the NoComp_NoTrain group which was only told to “drive eco-friendly,” but was offered no motivational incentive nor training to do so. Furthermore, the control group shows a relatively stable average level of emissions, with a slight increase in emissions during the treatment driving runs. The Comp_Train, NoComp_Train, and Comp_NoTrain groups showed a decrease in carbon emissions over the final three treatment runs, resulting in average carbon dioxide (CO2) emissions between 600 and 900 g. Interestingly, by the 6th run the NoComp_NoTrain group, performed similarly to the control group which had not been asked to eco-drive.

To provide a better visualization of the distribution of eco-driving performance scores (grams of carbon dioxide emissions) within different treatment groups a boxplot of the data was created. Fig. 7 shows a box plot of the grams of carbon dioxide emissions produced per driving run across participants within each treatment group and the control group. Groups that were similar statistically share shading elements, where similarity was based on a Tukey Test with a confidence interval of 95%. Treatment groups that share shading elements are statistically similar to one another. For example in Run 4 the NoComp_Train and the NoComp_NoTrain groups were statistically similar to both the control group and the Comp_Train, and Comp_NoTrain groups. For runs 1, 2, and 3, the practice runs, no statistical difference between groups was observed, meaning all groups had a similar baseline carbon dioxide emissions.

Two trends can be observed through evaluation of Fig. 7. First, Fig. 7 corroborates the reduction in average carbon dioxide emissions seen previously in Fig. 6. In driving runs 4, 5 and 6 some groups receiving treatments show a visually apparent reduction in both mean emissions and standard deviation of emissions. Second, in the final three treatment driving runs, groups Comp_Train, Comp_NoTrain, NoComp_Train show statistically lower emission relative to the Control Group and
the NoComp_NoTrain group. As treatment begins, statistically different clusters of groups begin to emerge indicating that treatments do lead to differences in eco-driving performance. In run 4, the first treatment run where groups were first asked to eco-drive statistically significant differences from the control group begin to appear. By driving run 6 the carbon dioxide emissions of groups Comp_Train, Comp_NoTrain, NoComp_NoTrain were statistically similar to one another, and more importantly, statistically significantly less than the NoComp_NoTrain group and the control group.

In the treatment driving runs, all groups except the control group were asked to “eco-drive to the best of their abilities.” One metric of interest is the whether or not those individuals asked to eco-drive actually reduced their emissions. To evaluate emissions reduction, a paired $t$-test was performed comparing each driver in runs 4, 5 and 6 to their emissions produced in run 3, their last practice run. Results of the paired $t$-tests are summarized in Table 3 and Fig. 8. Table 3 provides the 95% confidence interval on the mean difference in emissions as well as the corresponding p-value for the paired $t$-test. P-values lower than 0.05 indicate that there is a statistically significant difference in the emissions between the runs. Positive differences indicate a reduction in emissions. Between runs 3 and 4 drivers in the Comp_Train, Comp_NoTrain, and NoComp_NoTrain groups on average reduced their emissions, while drivers in the NoComp_Train and Control Groups did not show changes in their emissions. By the final run, however, all drivers receiving the training and/or experiencing the competition reduced their emissions while the control group and the NoComp_NoTrain showed no emissions reductions. As expected the control group did not show any difference in emissions between run 3 and any of the final three runs.

An analysis of variance (ANOVA) with a significance level of 0.05 was completed to determine the statistical significance of improvements in emissions observed between the two factors considered, motivational and informational contexts. The ANOVA test was performed twice, looking first at the differences observed between run 3 and run 4, and secondly looking at the differences observed between run 3 and the last run of each driver. When looking at the results of differences between
run 3 and run 4 the educational context factor shows a mild significance, indicating that those receiving eco-driving training had a different emissions reduction than those who did not. In fact those receiving eco-driving training had a smaller reduction than those participants who did not receive training. This result is in line with the observations from the paired t-tests. After the first driving run the motivational factor did not show any significance, meaning that after the first run, those drivers placed in a competition did not drive any better than drivers merely asked to eco-drive. The results of the ANOVA test for the difference between run 3 and run 6 tell a very different story. At this point the motivational factor becomes very significant while the informational factor is no longer significant. P-values for the results of these ANOVA tests are summarized in Table 4.

5. Discussion

The results support the hypothesis that eco-driving performance is more effectively encouraged through a motivational context than an informational context which consists of training and feedback on performance. Departing from past studies which compare eco-driving training and informational feedback with a control group, this study included an additional group (NoComp_NoTrain) that was simply asked to eco-drive, but did not receive any motivational context nor training and informational feedback. This experiment design allowed analyzing the effects of motivational contexts, more specifically competition, separately from informational contexts, such as training and other feedback tools. The results illustrated that the motivational context to eco-drive is a more effective means of encouraging eco-driving relative to tutorials and information feedback. The results further suggest that experienced drivers have already acquired knowledge of eco-driving techniques as the performance of the groups that received training could also be achieved by motivating the un-trained drivers with a competition involving prizes. These conclusions are supported by examining the evaluation of the average and distribution of total carbon dioxide emissions across the treatment runs and the improvement between Run 3 and Run 6 (the last treatment run), where in both cases the control group and the NoComp_NoTrain (those only asked to eco-drive) performed statistically worse than the remaining three treatment groups.

Interestingly at the fourth driving run, when all groups receiving treatments were asked to "drive eco-friendly" average emissions dropped across all treatment groups. This initial drop can be seen in Fig. 6 as the slope of treatment groups is negative between runs three and four. In contrast the control group showed a relatively constant level of emissions across driving runs. However, a paired t-test revealed that the mean difference for the NoComp_Train group was not statistically different from zero. These results suggest that there is some learning curve with executing eco-driving training. During

### Table 3

Results of the difference in emissions from the last practice run (run 3) and each of the three treatment runs (runs 4, 5, 6). The 95% Confidence Interval on the mean difference is presented as well as the p-value of the corresponding paired t-test. Significant differences are highlighted with an *.

<table>
<thead>
<tr>
<th>Group Id</th>
<th>Difference Run 3 to 4</th>
<th>Difference Run 3 to 5</th>
<th>Difference Run 3 to 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95% CI on Mean</td>
<td>P-value</td>
<td>95% CI on Mean</td>
</tr>
<tr>
<td>Comp_Train</td>
<td>(173, 505)</td>
<td>.003*</td>
<td>(159, 676)</td>
</tr>
<tr>
<td>NoComp_Train</td>
<td>(−8, 421)</td>
<td>.056</td>
<td>(32, 451)</td>
</tr>
<tr>
<td>Comp_NoTrain</td>
<td>(353, 780)</td>
<td>.001*</td>
<td>(389, 878)</td>
</tr>
<tr>
<td>NoComp_NoTrain</td>
<td>(46, 670)</td>
<td>.032*</td>
<td>(−279, 800)</td>
</tr>
<tr>
<td>Control</td>
<td>(−263, 133)</td>
<td>.439</td>
<td>(−266, 107)</td>
</tr>
</tbody>
</table>

Fig. 8. Boxplot of carbon emissions per run, grouped by experiment groups. A paired t-test was conducted between Run 3 and each of Runs 4, 5 and 6. Those runs whose mean difference was statistically different from 0 at a confidence of 95% are indicated with diagonal line fill.
The NoComp_Train group performed as expected. When they were initially asked to eco-drive, they were able to significantly reduce their emissions as indicated by the pair t-test with p-value of 0.032 for the difference between run 3 and run 4. However, without any motivation, training nor feedback they were not able to sustain this reduction, and by their 6th run they had returned to their practice run level of emissions. By run 6 they were also statistically similar to the control group which had not been asked to eco-drive. The performance of the NoComp_NoTrain group is important because it illustrates that drivers do possess the skills needed to operate their vehicles in an environmentally friendly manner, but without significant motivation these skills will not be used.

The treatment groups experiencing the competition had the most immediate and sustained emissions reduction across the treatment runs. Both the Comp_Train and Comp_NoTrain reduced their emissions from their last practice run on each of the three treatment runs. The competition served to negate the lag in eco-driving performance observed in the NoComp_Train group.

The results of this experiment suggest that experienced drivers, in general, have acquired eco-driving skills through regular motor vehicle operation, and given the appropriate motivational context, they can reduce their carbon dioxide emissions to meet eco-driving goals. Furthermore, the results can be further extended to suggest that future efforts should also focus on setting the correct motivational context, either through gaming or another set of mechanisms. While drivers have knowledge of eco-driving, information feedback may serve to reinforce any uncertainties they have regarding these driving skills. The improved relative effectiveness of motivational context versus informational feedback in terms of a tutorial is further underscored in looking at the results of the ANOVA tests where the motivational context factor was statistically significant for reducing emissions in run 6 while the informational context was not significant.

The slight increase in emissions for the control group across all six driving runs was initially surprising, but several factors could plausibly result in this increase. One plausible explanation is that drivers became more familiar with the vehicle dynamics as they had more time in the simulator. This familiarity allowed them to negotiate portions of the route more quickly, without hesitation during practice, leading to more vehicle emissions as higher speeds were maintained for longer periods of time. A second plausible explanation is that the control group may have experienced boredom, and felt incentivized to finish the driving task as fast as possible, leading to more emissions as vehicles were accelerated more quickly and operated at higher speeds in order to complete the route faster. A third explanation could be that without any goals pertaining to eco-driving the goal of reaching the end of the course in under 5 min 30 s became the primary motivating factor, leading drivers to speed up to finish the course on time even though the time limit was significantly higher than required to finish the course under normal vehicle operations.

While this study demonstrates the importance of considering motivational factors when designing eco-driving tools the study population needs to be taken into account when considering these results. The study population consisted of relatively young drivers who were on average 21.7 years old. While young drivers may be a limitation in some studies, particularly those studies involving driver safety, we believe the young driver population was a valuable asset to this study. Having young drivers illustrated that even young drivers have developed eco-driving skills that can be taken advantage of. The fact that the drivers were all college students played a more significant role than their age in the study. The offer of a $25 prize for the competition winners acted as a significant motivation for the college students. This $25 prize may not have been as universally motivating had we used a more diverse group of study participants from a range of economic backgrounds. Further work needs to be completed to identify and evaluate motivational factors for drivers of different social and economic backgrounds.

Another concern with the study may be the relatively small sample size consisting of 5–6 participants per group. While the sample size was small, the differences in performance between those experiencing the competition and/or training and those that did not (NoComp_NoTrain and Control Groups) were so striking that even the small sample size was able to pick up the difference.

### 6. Conclusion

The study results underscore the effectiveness of motivational context in encouraging eco-driving performance, which may compliment any informational mechanisms such as training programs drivers may have experienced. This result...
departs from previous research which has emphasized eco-driving aids and training as means for reducing emissions and improving fuel efficiency. Along this line of thought, the experiment results also show that asking drivers to eco-drive or framing the exercise as a competition sets the motivational context and leads to improved eco-driving performance. These results suggest that future research should focus on creating the most effective motivational context, in addition to work on information feedback which may also serve to reinforce motivational effects. Experienced drivers may already possess knowledge of eco-driving vehicle operations, but require a motivational context to help solidify or bring them forward and translate them into actual vehicle operations.

There are many fruitful directions for future work related to constructing contexts that motivate and engage drivers to eco-drive. First, motivation is a product of several dimensions and components, ranging from the feedback information presented and mechanisms for acquiring experiences and feedback, such as social networks and endogenous self-imposed goals. For example, given the proper context, drivers could be motivated to acquire information on personal performance and improve based on a history of performance indicators. Related to this is a literature on gaming which could be incorporated in experiments to test different motivational contexts, with varying levels of competition. Secondly, future research could more thoroughly examine incentives and incentive structures to engage with eco-driving for the long term. Finally, there is the question of how to fairly compare drivers in real world driving settings taking into consideration the different makes and models of vehicles, different routes and terrain, and different environmental conditions that each vehicle may be operated in.

References