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16. Abstract

A Fuel Economy Driver Interface Concept (FEDIC) is a device that drivers can utilize to change driving behaviors that affect fuel economy. Three tasks were completed to evaluate and identify FEDIC components that result in behavior changes. The first task consisted of a hierarchical matrix evaluation that resulted in a list of FEDIC components that met user needs. The second task, a usability study, was conducted to evaluate user comprehension and effectiveness of the components. Results indicated that users benefited most from information about fuel economy or behavior when the information was presented in a horizontal bar format. Based on these findings, two FEDIC components were generated for a driving simulation evaluation; one displayed fuel economy information (FEDIC-FE) and the other displayed acceleration information (FEDIC-B). The driving simulator evaluation examined the utility of these FEDIC designs as they were used in typical driving situations where drivers could improve fuel economy. Participants completed a baseline drive and then an experimental drive in which participants were asked to drive as fuel efficiently as possible. During the experimental drive, one third of the participants drove with FEDIC-B, another third drove with FEDIC-FE, and the remainder did not drive with a FEDIC display. Results indicated that drivers were able to improve their fuel economy in all three conditions. Fuel economy for participants who drove with FEDIC-FE was greater compared to those who drove with FEDIC-B or without a FEDIC. The fuel economy for participants who drove with FEDIC-B was not significantly different compared to those who drove without a FEDIC. Collectively, results of Task 3 suggest that the FEDIC displays evaluated may have an influence on driver behaviors that impact fuel economy. A long-term on-road study is required to verify that the FEDICs have real-world value.

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Executive Summary

A Fuel Economy Driver Interface Concept (FEDIC) is a device that drivers can use to change their driving behavior to improve fuel economy. If drivers who utilize a FEDIC drive less aggressively (i.e., reduce maximum speed, accelerate and decelerate more gently) the risk and severity of crashes may be reduced. To date, there are no data to indicate the relationship between driving with a FEDIC and general driver safety. Limited research has been published to support the hypothesis that FEDIC use is associated with improvements in fuel economy. The overall goal of the current work was to develop two prototype FEDICs that would be associated with behavior changes that result in improved fuel economy. Although it is possible that some fuel-efficient behaviors might also have positive safety effects, this was not directly evaluated in this research.

Three tasks were completed for this project. The first was a concept development task that employed a hierarchical matrix rating activity to evaluate current FEDIC designs. The activity consisted of comparing FEDICs against a reference FEDIC to determine how each met user-needs and user interface design guidelines. FEDIC designs that presented multiple types of fuel economy information or information on relevant behaviors (e.g., acceleration) within a simple display met user needs. The results indicated that, in general, the designs were equivalent at a high-level but different at the component level. In light of this, the focus of subsequent usability testing was shifted from examining complete FEDIC designs to examining the components of those designs that may be associated with improvements in fuel economy.

The second task consisted of a usability evaluation that was employed to identify which components of the FEDIC designs evaluated within a hierarchical matrix activity would be most useful. Specifically, this task was employed to evaluate how well participants could understand the information presented on each FEDIC component; determine if users could accurately comprehend how changes in FEDIC component state related to fuel economy; and determine whether users found the FEDIC components to be usable and valuable for improving fuel economy. Participants scored the highest when presented with representative or symbolic forms of fuel economy information, such as horizontal bars or iconic images, as compared to text displays. Even so, text representation of fuel economy should still remain a viable consideration for FEDIC design because a display featuring representative information could easily include text to further improve comprehension. Participants performed well on a majority of usability tasks while they viewed a component that featured acceleration/deceleration behavior (in a horizontal bar format). Interestingly, data from a novel Perceived Safety and Effectiveness Inventory indicated that participants rated a few components as *difficult to figure out*, however these components scored well within the usability comprehension measures. This result indicated that contradictions can arise between user preference and user performance.

The third task consisted of a driving simulator study to examine the utility of two FEDIC designs. Participants drove through three typical driving scenarios that allowed them to modify behaviors related to fuel economy. Participants first completed a baseline drive before completing an experimental drive. The experimental drive required all participants to drive fuel efficiently, but one-third of the participants drove with a FEDIC that depicted fuel economy

information (FEDIC-FE), one-third drove with a FEDIC that depicted behavior information (FEDIC-B), while the remaining participants were not provided with any FEDIC. This experimental configuration was employed to answer three questions. Would FEDIC use improve fuel economy? Which FEDIC would be associated with changes in driving behavior that affect fuel economy? And how well would drivers be able to improve fuel economy without the use of a FEDIC? FEDIC-FE did not instruct participants how to modify their driving, yet participants made changes to their driving that led to greater fuel economy compared to those who drove with FEDIC-B or without a FEDIC. Participants who drove with FEDIC-FE attained significantly greater fuel economy (mpg) compared to the other two groups. Although the average fuel economy of participants who drove with FEDIC-B was similar to the participants who drove without a FEDIC, their driving was significantly smoother. However, participants who drove with FEDIC-B and participants who drove with FEDIC-FE made more glances away from the road than participants who did not drive with a FEDIC.

The findings from all three tasks suggest that effective FEDICs in this project:

- Presented fuel economy as horizontal bars and/or simple representations (i.e., pictures);
- Presented text representations of fuel economy along with graphical representations of fuel economy;
- Simultaneously presented instantaneous information with long-term information;
- Were visually simple (e.g., instantaneous and trip fuel economy that update periodically is visually simple, while multiple bins representing continually-updating 5 minute intervals spanning the last half hour is visually complex);
- Presented average fuel economy which facilitated fuel efficient driver behavior, especially during stop-and-go driving;
- Might ultimately have the same effect on fuel efficient driving behavior in a naturalistic setting if the ultimate production FEDIC systems adhere to standards and guidelines to reduce the effect of distraction (e.g., FMVSS Standard 101).

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1. Introduction

Smooth and non-aggressive driver behavior may improve fuel economy and reduce crash risk. Three examples of safe driver behavior that can reduce fuel consumption include observing the speed limit, avoiding rapid acceleration, and anticipating future events to avoid large changes in speed (The Alliance of Automobile Manufacturers, 2009). Such driving behavior can decrease fuel consumption by as much as 15% (Evans, 1979). Driver assistive systems can also assist drivers with implementing fuel efficient driving behavior (Voort, Dougherty, & Maarseveen, 2001). One such system is a Fuel Economy Driver Interface Concept (FEDIC; or “FEDI” as discussed in Jenness, Singer, Walrath, & Lubar, 2009) that conveys driving related information to drivers regarding the fuel economy[1] of their vehicle. This evidence suggests that drivers can develop fuel efficient driving behavior by utilizing a FEDIC.

Although fuel efficient driver behaviors have potential to reduce crash risk drivers do not always drive safely. For instance, if a driver chooses to draft (i.e., follow a vehicle closely to reduce wind resistance), roll through stop signs, or run red lights to increase fuel economy it would be at the expense of safety. Furthermore, given that other in-vehicle information systems have been shown to distract from driving (Jamson & Merat, 2005) and that driver distraction has been associated with increased crash risk (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005; Wang, Kipling, & Goodman, 1995) it is important to design FEDICs that maximize positive effects on driver behavior and minimize negative effects.

FEDICs are a standard feature in many vehicles and are available as aftermarket auto accessories. Currently FEDICs are not standardized and their design varies by manufacturer. Analog gauges have been employed within FEDICs to present instantaneous fuel economy. LCD displays have been employed to create a variety of forms (e.g., graphical gauges, dynamic bar charts, animations, simple text, and color changing meters) and fuel economy metrics (e.g., instantaneous economy, trip economy, lifetime economy, and fuel economy scores). It is currently unclear if drivers can improve their fuel economy with any of the existing forms and metrics that present fuel economy. Some FEDICs report fuel economy in miles per gallon or the vehicle’s fuel range as miles until empty. Other FEDICs have been designed to present measures of acceleration along with measures of fuel economy. FEDICs become visually complex when multiple types of information are presented simultaneously. The KIWI (PLX Devices Inc.) is a FEDIC that simultaneously presents trip-average fuel economy (i.e., fuel economy information that is averaged across the duration of each vehicle’s trip) along with instantaneous fuel economy (i.e., averaged over durations closer to 1 second). The KIWI is visually complex because it presents multiple pieces of information related to fuel economy that frequently change throughout a drive. A similar FEDIC is the Honda Eco Guide (American Honda Motor Co.) that

[1]Throughout the document, the terms “fuel economy” and “fuel efficiency” are both used when referring to fuel consumption. “Fuel economy” was the preferred term, however the term “fuel efficiency” was necessary when discussing actions relating to the maintenance of high fuel economy (e.g., We asked participants to drive fuel efficiently.)

presents instantaneous acceleration, a fuel economy score and an ambient meter that changes color according to the vehicle's current efficiency. There are more metrics presented within the Honda Eco Guide, thus it has greater visual complexity than the KIWI.

Increased visual complexity of in-vehicle displays has been shown to produce unsafe driving behavior such as slower driver reaction time to objects on the road, decreased minimum time-to-contact (TTC) and a greater frequency of steering corrections (Jamson & Marat, 2005). Large, unpredictable steering corrections occur more frequently when drivers become unable to monitor the driving environment effectively as a result of diverting their gaze to secondary tasks (e.g., talking on a cell phone, operating touch panel controls, scrolling through a map) within the vehicle instead of focusing on the primary task of driving (Nakayama, Futami, Nakamura, & Boer, 1999). Complex visual displays that present information related directly to driving, such as an in-vehicle navigational system, have been shown to decrease peripheral target detection rate (Harms & Patton, 2003) which suggests reduced detection of road hazards (e.g., pedestrians). Although complex visual displays may increase driver distraction, there may be safety benefits from presenting information in the vehicle that is directly related to achieving driving goals (e.g., navigation) when the information presentation method is an improvement upon alternative methods. For example, drivers were shown to demonstrate greater vehicle control while navigating using an in-vehicle navigation system rather than a paper map (Lee & Chen, 2008).

The extent to which visually complex information presented within a FEDIC affects driving is unknown. It is expected that drivers can obtain a comprehensive understanding of how their driving behavior is related to fuel economy by utilizing a FEDIC,. However there is the possibility that multiple information types within a FEDIC may result in greater driver distraction. Therefore, it is necessary to determine if a FEDIC can be designed to convey information that assists with fuel efficient driving without undermining safe driving. Voort et al. (2001) found that drivers who used a novel *fuel-efficiency support tool* reduced their fuel consumption by 16% compared to normal driving. These drivers also exhibited marginally longer TTC compared to drivers that did not use this fuel efficiency support tool. This result suggests that fuel economy information can facilitate driver behavior that decreases fuel consumption while simultaneously supporting safe driving practices. Voort et al. did not report the extent that the fuel efficiency support tool affected driver distraction.

In general, in-vehicle displays have been associated with increased driver distraction (Merit & Jamson, 2008; Rakauskas, Ward, Boer, Bernat, Cadwallader, & Patrick, 2008). Perhaps in light of this, Nissan Motor Co. developed the Nissan Eco Pedal that provides fuel consumption information via a counter-force delivered through the accelerator. The counter-force occurs whenever the driver's acceleration causes excessive fuel consumption. The benefit of a counterforce to control acceleration only reduces fuel consumption effectively during trips with multiple stops (Larsson & Ericsson, 2009). An alternative system that provides suggestions for fuel efficient driving is the Fiat eco:Drive. The eco:Drive is a computer application that drivers can use after completing a drive to learn fuel efficient driver behavior. The eco:Drive application uses data collected from a vehicle and presents the data such that drivers can observe their driving behavior (e.g., when they shifted, and how they accelerated) alongside the amount of fuel that their vehicle consumed during their last drive. The eco:Drive application helps drivers learn behaviors that can lead to decreased fuel consumption while driving on freeways, rural roads, and urban roads. The eco:Drive is unlikely to contribute to driver distraction because access to driving performance is only available after a trip is complete.

To date, it is not known if there is a FEDIC design that facilitates fuel efficient driving to an extent greater than other FEDIC designs (Jenness et al, 2009). The objective of this project was to identify two FEDIC designs from the array of existing designs that may result in changes in behavior that improve fuel economy. To accomplish this, Task 3 was divided into two primary tasks. The first task was *concept development*. The second task was *refinement and testing*. The refinement and testing task consisted of two phases: the first phase was a usability evaluation of FEDIC components and the second phase was a driving simulator evaluation of driver behavior associated with using a FEDIC.

The concept development task employed a hierarchical matrix procedure. The hierarchical matrix consisted of *selection criteria* that were used to rank order the FEDIC designs. The selection criteria were constructed from *user-needs* that were based on usability principles and were further developed using the findings from the exploratory examination of currently available FEDICs in Task 1 and the focus groups conducted in Task 2 of the overall project (Jenness et al., 2009). To systematically rank the FEDIC designs, an iterative process was used to prevent a bias toward one particular FEDIC design. The rankings indicated the degree to which the existing FEDIC designs conformed to the hierarchical matrix selection criteria, and therefore the user-needs. From this rank ordered set of FEDIC designs, *component-sets* (CS) were generated that spanned a range of representative component display types and a range of fuel economy information types.

The CS designs were evaluated for ease of comprehension within the usability evaluation. The usability evaluation consisted of three tests; the first was an *initial comprehension* test in which participants observed each CS during an imaginary drive. Following the imaginary drive, participants were asked to describe how the CS functioned. Following the initial comprehension test, participants completed a *fuel economy comprehension* test in which participants observed static images of the CS and were asked to respond “yes” if the display indicated high fuel economy and “no” if the display did not indicate high fuel economy. The purpose of this task was to determine which CS designs improved comprehension of fuel economy. This task was followed by a set of *general usability measures* to collect participants’ opinions about the CS.

CS designs that performed well on the usability evaluation tests were expected to provide users with the best experience in terms of information comprehension and usability of features. A ranked list of recommended CS designs was generated from the usability results that exemplified the CS that were expected to best improve fuel economy. Based on this list, the question that resulted from the usability evaluation was whether drivers would benefit more from information related directly to fuel economy or information related to behavior that they could use to improve their fuel economy. Therefore, the focus of the simulator study was to investigate how driver behavior was affected by a FEDIC that displayed information about acceleration behavior (FEDIC-B) and a FEDIC that displayed instantaneous fuel economy (FEDIC-FE).

The purpose of the driving simulator study was to investigate driver behavior while using a FEDIC display. Within the simulator evaluation, after participants completed a baseline drive

they were split into three groups and asked to drive fuel efficiently. One of the groups drove with a FEDIC that displayed instantaneous fuel economy (FEDIC-FE), the second group drove with a display that displayed acceleration behavior (FEDIC-B), and the third group drove without a FEDIC. Participants drove in 3 different simulated environments to determine the effect of driving with a FEDIC in an urban setting following a lead car, on an open highway, and on an open highway following a lead car. Driving behavior measures included celeration, coherence, modulus, delay, timed headway, time-to-collision, and time-to-accelerate. Steering entropy and pedal entropy were obtained to determine the amount of control participants devoted to steering and pedal position. Mental effort and eye glance frequency were also obtained to determine if the FEDIC distracted from driving. These behavioral measures, though not direct measures of safety, may be associated with crash risk. For instance, celeration, which is a measurement of absolute changes in speed, has been shown to be loosely related to crash likelihood. Wahlberg (2008) has reported correlations between celeration and crash frequency ranging from .38 to .51.
Fuel economy was also obtained to determine if changes in driver behavior decreased fuel consumption.

The results of the simulation evaluation answered three questions:

1. Does the presence of a FEDIC in the vehicle improve fuel economy? In particular, which FEDIC (FEDIC-B or FEDIC-FE) may influence driver behavior to the greatest degree?
2. Can a driver improve fuel economy without the assistance of a FEDIC display?
3. Does a FEDIC improve fuel economy beyond what a driver can accomplish without a FEDIC?

These results also recommended which FEDIC component-set (display type and information type) would be most useful to examine in terms of improving fuel economy in the context of future real-world driving evaluations.

2. Concept Development

As part of Task 1 of the overall project, Jenness et al. (2009) summarized the functionality of 22 existing FEDIC designs and 11 patents for FEDIC designs. This summary indicated that fuel consumption metrics appear in many quantitative forms (average trip fuel economy, tank average fuel economy, current fuel economy, fuel economy history, etc.) and many qualitative forms (animations, leaves that represent scores, ambient meters that indicate the degree fuel economy is good, average and poor, etc). There were a few FEDIC designs that provided direct feedback on driver behavior that appeared in this summary and it has been suggested that this is the best method to assist drivers with learning fuel efficient behaviors (Voort et al, 2001). In light of the diversity of existing FEDIC designs and to gain perspective on how drivers appreciate these designs, Jenness et al. (2009) conducted focus groups to evaluate nine FEDIC designs selected from their summary. Most members of the focus groups recognized the value of using a FEDIC to help conserve fuel, especially those who already drove a hybrid vehicle or had a FEDIC in their own vehicle. However, all drivers expressed a concern that these devices could distract drivers. They were also concerned about the extra expense of having the device, and they thought that some of the FEDICs were too complicated. There was no consensus regarding which of the existing FEDICs would be acceptable or most beneficial. However, they frequently mentioned suggestions for improving these FEDICS. One focus group member suggested presenting mpg and fuel range aurally instead of visually to decrease distraction, and another suggested that modal displays should not contain information such as outside temperature using the same screen that would otherwise contain fuel economy information. Focus group participants also mentioned that a FEDIC would be most useful if it provided guidance on how to improve fuel economy. They did not consider satisfactory the few FEDICs that provided feedback on driver behavior. The comments from the focus group suggested that there is room for improvement within the FEDICs that they reviewed.

During the focus groups, participants discussed fuel saving techniques that they have used to increase fuel economy. These can be divided into two categories. One category consisted of techniques that occur apart from driving (e.g., reducing unnecessary trips, carpooling, replacing fuel inefficient cars with fuel efficient cars, keeping tires properly inflated). The second category consisted of techniques that occur while driving (e.g., looking far ahead to synchronize speed with traffic signals to avoid stopping, maintain forward momentum to avoid having to accelerate from lower speeds, coasting, and "drive gently"). Coincidently the techniques within both categories are endorsed by The Alliance of Automobile Manufacturers (2009) and The United States Department of Energy, Office of Energy Efficiency and Renewable Energy (2009). The techniques within the second category are well suited to be incorporated within FEDIC designs. The information from the focus groups was combined with the design requirements outlined by Voort et al (2001) to generate guidelines for designing a FEDIC that could effectively assist with fuel efficient driving. The design requirements are:

- To provide the driver with clear, accurate, and non-contradictory information;
- To take into account the current context of the vehicle;
- To place no requirements on the driver which are too high to safely combine with the actual driving task;

- To work within both urban and non-urban environments.

Within the Concept Development task, the focus group information from Jenness et al. (2009) was combined with the requirements outlined by Voort et al. (2001), and synthesized into a set of *user-needs.* These user-needs were input into a hierarchical selection matrix (Ulrich & Eppinger, 2006) which was used to evaluate nine FEDICs . This systematic approach was used to determine how well each FEDIC complied with these user-needs. There were two iterations of the Hierarchical Matrix. During each iteration, each FEDIC was rated in comparison to a reference FEDIC. The results of this task provided a rank ordering of FEDIC designs from "most" to "least" likely to meet these user-needs. FEDICs that ranked high in the hierarchical matrix were considered to best help drivers improve their fuel economy and safety.

2.1 Methodology

The user-centered design methods outlined by Ulrich and Eppinger (2006) were employed for this task. What they term a "Pugh concept-selection matrix," is referred to in the present study as a "hierarchical matrix". The hierarchical matrix was employed to judge the degree to which an interface complied with user-needs. An interface with high compliance is more likely to result in a higher rate of use by drivers. To assess the utility of an interface, the hierarchical matrix employed user-needs as requirements for FEDIC designs.

User-needs statements and selection criteria were developed to make comparisons between the FEDIC designs that were evaluated within the concept selection exercise. Although useful for understanding the goals of the users, the user-needs statements could not be used directly to evaluate FEDIC designs. Instead, these user-needs were reworded into statements to allow raters to make judgments of tangible user interface elements. The *selection criteria* were based on user needs. Once these selection criteria were developed, two iterations of ratings were completed using the hierarchical matrix exercise, each time comparing the components of the FEDIC designs to each other. The result of both iterations was a list of the FEDIC designs presented in ranked order of compliance with the selection criteria. The result of this two-iteration rating procedure was a ranked list of FEDIC designs presenting a taxonomy of components that would be most useful to have as features within a FEDIC.

2.1.1 Developing User-Needs Statements

The first step in building the hierarchical matrix was to identify the types of information that users would want and need while using a FEDIC. These were considered to be requirements for FEDIC interface usability. Therefore the user-needs statements defined what features, components, and information were necessary for a FEDIC to successfully improve a driver's fuel economy. These needs statements were organized into three broad categories (Appendix A, column 1) relating to the *goals* (i.e., purpose) of the potential FEDIC designs, the *functions* of potential FEDIC designs, and the *behaviors* that the potential FEDIC designs were expected to promote, based on the needs development efforts.

To generate the user-needs statements, the research team first considered general principles of user-centered design suggested by Ulrich and Eppinger (2006). These principles were used as a starting point because they represented basic needs of any usable interface (e.g., the controls are accessible to the user, or the interface does not demand a great deal of attention of the user). These suggestions were supplemented by the project team's expertise and examination of FEDIC material relating to increasing driver fuel economy. This examination also included reviewing academic literature pertaining to FEDIC designs (e.g., requirements outlined by Voort et al., 2001) and other resources such as political action groups (e.g., the Alliance of Automobile Manufacturers website, Ecodrivingusa.com, 2009), car manufacturers (e.g., Fiat eco:Drive online resources), and private interest groups (e.g., fuel economy driving communities such as Ecomodder.com, 2009). The emphasis of this effort was to identify the information that drivers who were interested in conserving fuel would want or value in a FEDIC. In general, both instantaneous and average fuel economy information types appeared to be useful metrics to incorporate into FEDIC designs. The collected notes from this background examination are presented in column 4 of Appendix A. The results from Tasks 1 and 2 of the overall project (Jenness et al, 2009) were reviewed, with a focus on identifying the underlying concepts of these FEDIC designs. The results from Task 2 were also reviewed to identify how users perceived the FEDIC designs and how they currently use FEDIC information. This review identified FEDIC components and features that users would like to have in a FEDIC. These are presented in column 3 of Appendix A.

2.1.2 Establishing Specification Criteria

Although the needs statements are useful tools that describe high-level FEDIC system needs, they are not appropriate to make direct comparative judgments on FEDIC designs. Therefore, it was necessary to develop a set of selection criteria based on the user-needs statements and previous analyses. Table 1 presents the user needs statements (column 2), selection criteria based on those needs (column 3), and rationale for each selection criterion (column 4). Each needs statement is represented by at least one selection criterion except for the first two needs in the Function category that were collectively listed as "Ease of Comprehension." The reason for this was because it was not clear which fuel efficiency information type (e.g., mpg, miles-to-empty, cost) would be most appropriate, and so the actual type of information to be presented in any interface was discussed in general terms over these two criteria. Selection criteria were sequentially numbered for reference purposes only.

These selection criteria allowed for an objective scoring strategy in the hierarchical matrix exercise that facilitated comparisons between existing FEDICs identified during Tasks 1 and 2 of the overall project. In addition, the number of selection criteria for each need was qualitatively based on the notes from columns 3 and 4 of Appendix A. During the concept selection procedure, each selection criterion resulted in one equally-weighted rating for each CS. Therefore, a need that was recognized by multiple sources was represented by a larger number of selection criteria and ended up having an equivalently larger impact on the matrix net scores than another need that was represented by a smaller number of selection criteria.

Table 1. Needs statements, their resulting selection criteria, and supporting rationale, organized by category

Cat.	Need; "the FEDIC…"		Selection Criteria	Rationale
Goal of Display	is **effective…**	0	Effectiveness of delivering fuel economy information resulting in fuel efficiency and safe driving behavior	The effectiveness of all FEDIC concepts can be determined in a number of ways, including whether each interface accurately and clearly delivers information on fuel economy. It is also hoped that each FEDIC will also promote safe driving behavior. "Effectiveness" will ultimately be determined by how well each concept conforms to the user needs statements 1 through 23. Therefore, effectiveness is implied in the in hierarchical matrix net score and **this criterion was not rated during the exercise**.
	promotes **safe driving behaviors**	1	Does not change the driver's ability to maintain safe and consistent lateral driving performance	FEDIs are intended to promote behaviors that save fuel, but some of these behaviors may be at odds with safe driving. FEDIC designs should consider their effect on a driver's attention, cognitive limits, ability to maintain situational awareness for unexpected events, as well as their overall effect on driving behavior as it relates to safety. A complex FEDIC display that requires much time to comprehend will take the drivers attention away from the road environment. This will likely lead to worsened lateral driving performance (e.g., lanekeeping) which may lead to crossing into oncoming traffic or running off the road.
		2	Does not change the driver's ability to maintain safe and consistent longitudinal driving performance	Similarly to lateral driving performance, a complex FEDIC display may lead to worsened longitudinal performance (e.g., inappropriate speeds for conditions or the inability to see when vehicles or obstacles are stopped in the vehicle's path).
	is perceived as **affordable**	3	To purchase, accepted perceived value (benefit to cost ratio) (i.e., the system is worth the money spent)	Value (benefit in fuel economy relative to cost to purchase of FEDIC). Greater value may result in greater likelihood of purchase.
		4	To manufacture	Less expensive to manufacture is preferable, because it has a higher likelihood to be backed technologically, financially, and to be produced by OEMs
	keeps the driver's **interest** over time	5	Maintains user's interest, has value in recurring usage	Interest encompasses: user **engagement** in fuel efficient driving over a long period of time, increased **participation** in fuel economy saving behavior, and manifestation of the i**mportance** of fuel economy savings. There may need to be an **attractive** component to *interesting displays* because according to users the design seems to have an impact on if and how it would be used.

Table is continued on next page

Table 1. Needs statements and their resulting selection criteria, organized by category, continued

Cat.	Need; "the FEDIC…"		Selection Criteria	Rationale
Function	**Ease of Comprehension** provides instantaneous info in a metric that the user understands provides long-term or post-drive (higher-level) info in a metric that the user understands	6	Contains fuel economy information at both instantaneous & longer-term levels	Both instantaneous (e.g., dynamic mpg or gallons per mile provided in-vehicle) and long-term (e.g., reviewed by drivers post-drive or after longer intervals during a trip) information types were desired by users. Since it is unclear whether information from instantaneous or long-term interfaces will have the greatest influence on fuel economy or be most accepted by drivers, it is prudent to offer both information types to users. This level of configurability may also result in the greatest market penetration for FEDICs.
		7	Easy to understand meaning of information	Easy-to-understand interfaces are most often simple. For example, as concluded from Task 2, basic text and gauge displays were generally received favorably, most likely due to their simple designs.
		8	Contains fuel economy information in more than one metric (e.g., mpg, miles-to-empty) within each information level	Since it is unclear what type of metric will positively affect fuel economy, an interface that presents or allows the selection of at least two metrics (within either instantaneous of long-term information levels) is likely to appeal to drivers who prefer individually-selected metrics.
		9	Trust: information presented is believable	Information presented should be consistent over time, it should seem reasonable to the user, and it should be relevant to their driving experience. Failure to do so will result in decreased trust and potential system nonuse.
	information is easily visible/able to be **perceived**	10	Easy to detect information presented	Information must be easily detectable by the user (e.g., text must be large enough to be read; sounds must be loud enough to be heard; tactile sensation must be strong enough to be felt).
		11	Easy to perceive changes in information presented; information environment is not cluttered	Changes in information (e.g., mpg numbers change, pedal resistance changes) must be detectable by the user so the user can take advantage of that information. Clutter of any modality will mask this change detection.

Table is continued on next page

Table 1. Needs statements and their resulting selection criteria, organized by category, continued

Cat.	Need; "the FEDIC…"		Selection Criteria	Rationale
Function	**vehicle adaptation technology** gives appropriate level of control to user	12	Vehicle adaptation technology gives appropriate level of control to user (i.e., the ability to modify or turn it off)	If the FEDIC includes vehicle adaptation technology that impacts driving strategy (e.g., force feedback from throttle), the FEDIC should notify the user it is doing so and allow them to override this feature. Most drivers dislike systems that appear to take control from them. At a minimum, a FEDIC should let drivers know why their driving may seem different from normal driving. In addition, indications of when the FEDIC's adaptation technology is active may also help drivers learn fuel efficient driving strategies.
		13	Vehicle adaptation technology gives feedback so that user can improve fuel economy	If a vehicle adaptation technology that does not impact driving strategy (e.g., turning off power steering or all-wheel-drive) is activated to increase fuel economy, notification of this activation will help to instruct drivers on when their behavior results in higher fuel efficiency.
	provides **clear feedback** from user input or behavior	14	Control of interface is apparent from user's input	The display outputs appropriate and timely changes to the FEDIC system based on user input (e.g., input to FEDIC controls produces FEDIC changes).
Behaviors Promoted	provides **useful info** on ways/behaviors to make driver more fuel efficient	15	Information presentation indicates current behavior may increase fuel economy	Notifying the driver that they are exhibiting good fuel economy behavior will reinforce behaviors over time. Provide information so that drivers can determine what elements of a vehicle, combined with their own driving skills and preferences, will affect fuel economy costs (monetary, environmental, time-savings, or other). Drivers can use this information to change their driving behavior accordingly. These notifications will allow users to associate strategic and tactical behaviors with resultant fuel economy interventions.
		16	Provides suggestions for driving strategies that improve fuel economy.	Strategy information should promote the use of **known** fuel economy driving strategies. In addition, under this criterion, a FEDIC may also facilitate the development of novel fuel economy driving strategies.
		17	Alerts are timely	Alerts and feedback that are temporally linked to behavior are more likely to affect behavior because users can see the effects of their behavior on fuel economy.

Table is continued on next page

Table 1. Needs statements and their resulting selection criteria, organized by category, continued

Cat.	Need; "the FEDIC…"		Selection Criteria	Rationale
Behaviors Promoted	keeps drivers' **attention** on the road at most times	18	Information presentation does not draw a large amount of attention away from road	Information should not cause users to move their attention far from the road scene for prolonged periods (e.g., visually within 15 deg. of central FOV, presentation within reasonable/expected volume or tactile limits).
		19	Important information is salient; does not demand much attention to derive meaning from information	Important elements related to fuel economy should stand out in the FEDIC so that the user does not have to perform extensive interpretation that could lead to distraction from the road scene.
	is **intuitive** to set up and use	20	Easy to set up	An interface that is easy to set up will be desirable to a wider demographic of people, allow users to get fuel economy information faster, and will reduce frustration with the interface before even using it.
		21	Controls are easy to use	This will lead to more confidence in the interface, lower perceptions of frustration with the interface, and greater acceptance of the FEDIC.
	functionality is easily **accessible**	22	Does not interfere with perceiving information from other information sources	The interface should not present information that contradicts information from essential vehicle control interactions. FEDIC information should not interfere with using information present on other displays.
		23	Interface is manually / verbally accessible to driver	The interface should be accessible easily while driving, so that interacting with it does not interfere with normal vehicle control interactions.

2.1.3 Concept Selection Process

The results of Task 2 indicated that due to the diversity of current and prototype FEDICs, there is no driver-accepted or scientifically accepted best practice for FEDIC design (Jenness et al., 2009). Although none of the FEDIC designs discussed in the Jenness et al. (2009) focus groups stood out as a clear favorite, some concepts from these FEDIC designs appear to be especially promising for future consideration. These include:

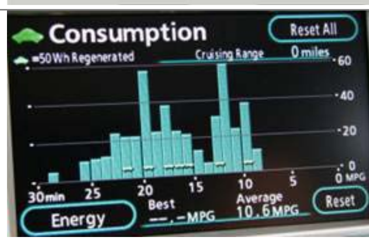
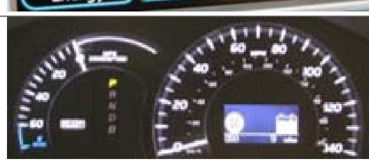
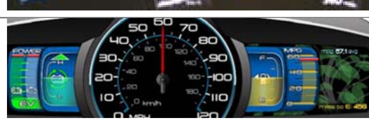
- A simple, qualitative, color-coded indication of current fuel economy;
- Post-drive reporting, feedback, and social comparisons;
- Potentially game-like displays; and
- Text and analog gauge displays.

We began by examining eight existing FEDIC designs that were available in the vehicle fleet and were tested during the Task 2 focus group evaluation (presented in Table 2). Each hierarchical matrix iteration began by listing the FEDIC designs in separate columns and listing the selection criteria in separate rows of a hierarchical matrix (see Table 3: the matrix from iteration one). When conducting a hierarchical matrix activity it was necessary to first select a reference FEDIC against which all other FEDIC designs were compared. The reference FEDIC design received a rating of 0 for all selection criteria. The FEDIC design being evaluated was then rated according to the extent that it was better (rating of +), worse (rating of –), or the same (rating of 0) compared to the reference FEDIC for each selection criteria. A rating of 0 was assigned in the event that the selection criterion did not apply to a FEDIC design. Each FEDIC design was rated on one criterion before being evaluated on the next criterion down the list, such that each row in the matrix was completed before proceeding to the next row down. When the entire hierarchical matrix was completed the count of "–" ratings was subtracted from the count of "+" for each FEDIC to produce a net score for each FEDIC design.

Two teams of two raters who were experienced in interface design principles rated each FEDIC against the selection criteria within the hierarchical matrix. To ensure a common understanding between all raters, the FEDIC designs and selection criteria (including the rationale for each criterion presented in Table 1) were reviewed by the raters as a group prior to splitting into teams and performing the rating exercise. To rule out rater-team bias, inter-rater reliability tests were conducted by calculating the correlation coefficient between each team's net scores. A high inter-rater reliability score indicated high rating consistency between rating teams thus permitting rating scores to be combined between both teams. For all instances where the two teams of raters disagreed on a rating, all four raters discussed the rationale for their rating and arrived at a consensus for the final rating used in the matrix. The resulting ratings within the hierarchical matrix were used to rank all of the FEDIC designs (see the bottom rows in Table 3) to indicate which ones would continue to the second iteration of the hierarchical matrix.

To verify the results of the first hierarchical matrix activity, a second iteration of the activity was conducted using the same methodology but using a different reference FEDIC. Consistency of results between the first and second iterations would support the conclusion that the results are reliable and valid. The procedures and results for each hierarchical matrix iteration are presented next.

Table 2. FEDIC designs that were evaluated during the hierarchical matrix exercise

Task 2 Number	FEDIC Designs		Information Display Components	
			Instantaneous	Long-Term
1		BMW fuel economy display	Analog (dial)	Text
2 & 3		Honda Ecological Drive Assist (Eco Assist) with "Eco Scores" concept for driver feedback	Color behind speedometer	Graphical
4		Kiwi PLX nomadic device	Text or graph	Text or graph
5		Nissan Eco Pedal	Pedal feedback, dashboard light	-
6		Toyota Prius consumption display & energy monitor	Energy diagram	Graphs
7		Toyota/Lexus gauge with small LCD display	Analog (dial), energy diagram	Text or graph
8		Ford/Ideo Smart Gauge with EcoGuide	Analog (vertical gauge)	Graphical or graph
9		Fiat eco:Drive	-	Text or graph

2.2 Hierarchical Matrix Iteration One

During hierarchical matrix iteration one, each rating team compared the BMW FEDIC design to the remaining seven designs. The BMW FEDIC (design 1 in Table 2) was chosen as the reference because it was the most representative of industry standards and likely to be most familiar to the raters. The inter-rater reliability score between teams was $r^2 = 0.97$ which indicated high consistency between the team's net scores. Due to the high consistency between team scores the matrix ratings were combined for both teams.

Results of the hierarchical matrix activity are presented in Table 3. The relative ranking of each FEDIC design is identified as a rank score at the bottom of the table. Results indicated that several FEDIC designs met the essential user-needs outlined by the selection criteria. The FEDIC design that received the highest net score received a "better than" ranking for 70% of the selection criteria (designs 2 and 3), and the FEDIC design that received the second highest net score received a "better than" rating for 65% of the selection criteria (design 5). It should be noted that the FEDIC designs receiving the highest net scores complied with the majority of selection criteria suggesting that little improvement could be made to the designs to improve usability and comprehension. In addition, each of the highest scoring FEDIC designs contained analogous information suggesting that the information appearing on the FEDIC contributed to this outcome. Because the highest scoring FEDIC designs already contain information essential to usability and comprehension, the rating teams came to a consensus that it was not necessary to revise any of the FEDIC designs for further evaluation. The top five ranked FEDIC designs were chosen for evaluation in the second hierarchical matrix iteration. These FEDIC designs were chosen because they complied with the selection criteria to a much greater extent than the reference FEDIC design, as shown by their net scores being above 0. The reference design (design 1) and design 7 (Toyota/Lexus gauge with small LCD display) were rated comparably and received the same net score. Because these two designs were comparable in component features and appeared to meet the selection criteria similarly, the research team decided to continue with only design 7 because the controls were superior to the controls in design 1.

Table 3. Hierarchical matrix iteration one results

Category	User-Needs	Selection Criteria No.	Selection Criteria	FEDIC Designs: BMW FEDIC [1] (reference)	Honda Ecological Drive Assist [2] w/ Eco Scores [3]	Kiwi PLX nomadic device [4]	Nissan Eco Pedal [5]	Toyota Prius consumption display & energy monitor [6]	Toyota/ Lexus gauge w/ small LCD display [7]	Ford/ Ideo Smart Gauge with EcoGuide [8]	Fiat eco:Drive [9]
Goal of Display	Effectiveness	0	Effectiveness of delivering FE information resulting in FE and safe driving behavior **(not rated)**								
	Safe Driving	1	Does not change the drivers ability to maintain safe and consistent lateral driving performance	0	0	0	0	0	0	0	+
		2	Does not change the drivers ability to maintain safe and consistent longitudinal driving performance	0	0	0	-	0	0	0	+
	Affordable	3	To purchase, accepted perceived value (benefit to cost ratio) (i.e., the system is worth the money spent, ability to train drivers adds value)	0	+	+	+	0	0	0	+
		4	To manufacture (including development)	0	-	0	-	0	0	0	+
	Interesting	5	Maintains users interest, has value in recurring usage	0	+	+	+	0	0	0	+
Function	Ease of Comprehension	6	Contains FE information at both instantaneous & delayed (longer-term) levels	0	+	+	-	+	0	+	-
		7	Easy to understand meaning of information (info. that tells you what you can do differently is easier to understand)	0	+	+	+	0	0	0	-
		8	Contains FE information in more than one metric (e.g., MPG, Miles to Empty) within each information level	0	+	+	-	0	0	0	+
		9	Trust: information presented is believable	0	+	0	+	0	0	0	+
	Information Perception	10	Easy to detect information presented	0	+	0	+	-	0	0	-
		11	Easy to perceive changes in information presented; information environment is not cluttered	0	+	0	+	-	0	-	-
	Vehicle Adaptation Technology	12	Vehicle adaptation technology gives appropriate level of control to user, i.e., the abiltiy to modify or turn it off	0	+	0	+	0	0	0	0
		13	Vehicle adaptation technology gives feedback so that user can improve FE	0	+	0	+	0	0	0	0
	Feedback	14	Control of interface is apparent from user's input	0	0	0	0	0	0	0	0
Behaviors Promoted	Useful Information	15	Information presentation indicates current behavior may increase FE	0	+	+	+	0	0	0	-
		16	Provides suggestions for driving strategies that improve FE.	0	+	+	+	0	0	0	+
		17	Alerts are timely	0	+	0	+	0	0	0	0
	Attention Demands	18	Information presentation does not draw a large amount of attention away from road (location)	0	+	0	+	-	0	0	0
		19	Important information is salient; does not demand a lot of attention to derive meaning from information (comprehension)	0	+	0	+	-	0	0	-
	Intuitive	20	Easy to set up	0	0	-	0	0	0	-	-
		21	Controls are easy to use	0	0	+	+	-	0	0	-
	Accessibility	22	Does not interfere with perceiving information from other information sources	0	0	0	0	-	0	0	0
		23	Interface is manually / verbally accessible to driver (controls on wheel & dash behind wheel are most accessible; on stalks moderately accessible; elsewhere least accessible)	0	+	-	+	-	+	+	-
			Sum +'s	0	16	8	15	1	1	2	8
			Sum 0's	23	6	13	4	15	22	19	6
			Sum -'s	0	1	2	4	7	0	2	9
			Net Score	0	15	6	11	-6	1	0	-1
			Rank	**5**	**1**	**3**	**2**	**8**	**4**	**5**	**7**
			Continue?	**No***	**Yes**	**Yes**	**Yes**	**No**	**Yes***	**Yes**	**No**

* The Toyota/Lexus FEDIC proceeded to the second Hierarchical Matrix because the display controls were superior to the display controls of the BMW FEDIC.

2.3 Hierarchical Matrix Iteration Two

The second iteration of the hierarchical matrix evaluation contained the same selection criteria as the first iteration but employed the Kiwi PLX nomadic device as the reference FEDIC (design 4 in Table 2). The Kiwi PLX was chosen as the reference because it was one of the top three ranked FEDIC designs from the first iteration, it was a nomadic device (i.e., not factory-installed), it would allow for a much different set of comparisons using the same selection criteria than were performed during iteration one, and it was the only display that contained training components and fuel economy information components. Within the second iteration of the hierarchical matrix, two members of the HumanFIRST group rated the FEDIC designs individually. Inter-rater reliability scores between the two raters' net scores was $r^2 = 0.95$ which indicated high consistency between the raters' scores. As a result, the ratings were combined. As was the practice for the first iteration of the hierarchical matrix, any differences in net score between the raters were resolved by reaching consensus on individual selection criteria ratings.

The net scores were tabulated in the same manner as the first iteration and the FEDIC designs were rank ordered according to their net score. Results of the hierarchical matrix activity are presented in Table 4. The FEDIC design with the highest net score, the Honda Ecological Drive Assist, was ranked number 1. Results indicated that the same three FEDIC designs that met the essential user-needs outlined by the selection criteria during iteration one also met these needs when design 4 was used as a reference. The FEDIC design that received the highest net score received a "better than" ranking for 35% of the selection criteria (designs 2 and 3), and the FEDIC design that received the second highest net score received a "better than" rating for 39% of the selection criteria (design 5). Compared to the percentages for the same FEDIC designs during iteration one, the percentages during iteration two were lower suggesting that the new reference was successful in creating a separate set of ratings based on the same set of selection criteria. During this iteration, a large proportion of the ratings were "0" suggesting that the components within these designs (especially the top three ranked designs) were comparable with each other. The FEDIC designs presented in table 4 were chosen because they complied with the selection criteria to a much greater extent than the reference FEDIC design, as shown by their net scores being above (or equal to) 0.

Table 4. Hierarchical matrix iteration two results

Category	User-Needs	Selection Criteria No.	Selection Criteria	FEDIC Designs: Kiwi PLX nomadic device [4] (reference)	Honda Ecological Drive Assist [2] w/ Eco Scores [3]	Nissan Eco Pedal [5]	Toyota/ Lexus gauge w/ small LCD display [7]	Ford/ Ideo Smart Gauge with EcoGuide [8]
Goal of Display	Effectiveness	0	Effectiveness of delivering FE information resulting in FE and safe driving behavior **(not rated)**					
	Safe Driving	1	Does not change the drivers ability to maintain safe and consistent lateral driving performance	0	+	+	+	0
		2	Does not change the drivers ability to maintain safe and consistent longitudinal driving performance	0	0	-	0	0
	Affordable	3	To purchase, accepted perceived value (benefit to cost ratio) (i.e., the system is worth the money spent, ability to train drivers adds value)	0	0	0	-	-
		4	To manufacture (including development)	0	-	-	+	+
	Interesting	5	Maintains users interest, has value in recurring usage	0	0	0	-	-
Function	Ease of Comprehension	6	Contains FE information at both instantaneous & delayed (longer-term) levels	0	0	0	0	0
		7	Easy to understand meaning of information (info. that tells you what you can do differently is easier to understand)	0	0	0	-	-
		8	Contains FE information in more than one metric (e.g., MPG, Miles to Empty) within each information level	0	0	-	0	0
		9	Trust: information presented is believable	0	0	0	0	0
	Information Perception	10	Easy to detect information presented	0	+	+	0	0
		11	Easy to perceive changes in information presented; information environment is not cluttered	0	+	+	0	0
	Vehicle Adaptation Technology	12	Vehicle adaptation technology gives appropriate level of control to user, i.e., the abiltiy to modify or turn it off	0	+	+	0	0
		13	Vehicle adaptation technology gives feedback so that user can improve FE	0	+	+	0	0
	Feedback	14	Control of interface is apparent from user's input	0	0	-	0	0
Behaviors Promoted	Useful Information	15	Information presentation indicates current behavior may increase FE	0	0	-	-	0
		16	Provides suggestions for driving strategies that improve FE.	0	0	0	-	-
		17	Alerts are timely	0	0	0	-	-
	Attention Demands	18	Information presentation does not draw a large amount of attention away from road (location)	0	+	+	+	+
		19	Important information is salient; does not demand a lot of attention to derive meaning from information (comprehension)	0	+	+	0	0
	Intuitive	20	Easy to set up	0	+	+	+	+
		21	Controls are easy to use	0	0	+	0	0
	Accessibility	22	Does not interfere with perceiving information from other information sources	0	0	-	0	0
		23	Interface is manually / verbally accessible to driver (controls on wheel & dash behind wheel are most accessible; on stalks moderately accessible; elsewhere least accessible)	0	0	0	0	0
			Sum +'s	0	8	9	4	3
			Sum 0's	23	14	8	13	15
			Sum -'s	0	1	6	6	5
			Net Score	0	7	3	-2	-2
			Rank	**3**	**1**	**2**	**4**	**4**

2.4 Hierarchical Matrix Results and Recommendations

The overall result of the hierarchical matrix was a rank order of FEDIC designs according to the degree to which FEDIC designs met user-needs. Presumably, the highest-ranking FEDICs would be usable and potentially influence driver behaviors such that fuel economy is increased. During both iterations of the hierarchical matrix exercise, the same rank order was produced for the FEDIC designs that were evaluated during both iterations. Therefore, the final rank order presented in Table 5 begins with these designs in that same ranked order. The remaining FEDIC designs that were evaluated only during iteration one are ranked underneath these designs because they were rated less favorably on the selection criteria (during iteration one). Table 5 also presents a taxonomy of the components that compose each FEDIC design. The final rank order was agreed-upon by group consensus between HumanFIRST, NHTSA, and Westat.

While these results provide an initial indication for the utility of several FEDIC designs, they should be considered tentative because the evaluation represents only one method by which FEDIC design was evaluated. In addition, the hierarchical matrix activity was an evaluation of each FEDIC design as a whole; the contributions of individual information components that may influence usability and comprehension were not examined. In light of these considerations, NHTSA, Westat, and the HumanFIRST program recognized the need to conduct a second major evaluation activity (Usability Evaluation, identified in Section 3) to examine FEDIC design *components* that convey information to a driver. The results of the hierarchical matrix evaluation activity and FEDIC design components that were evaluated within the usability evaluation are outlined in the following section. On the next page is a summary of each FEDIC design in the taxonomy rank-order (Table 5) with a description of the specific FEDIC design components that were evaluated within the usability test.

Table 5. FEDIC design ranking and taxonomy of components

Ranking	Task 2 Number	FEDIC Design	Concept Components: Intensity-Changing Light	Representative Pictures	Graph	Single Dial	Single Bar	Text	Other Modality
1	2 & 3	Honda Ecological Drive Assist (Eco Assist) with "Eco Scores" concept for driver feedback	"Ambient Meter" behind speedometer (TA)	"Eco Scores" (TA & OA)	MPG over last 3 drives (OA)	-	Acceleration/Brake indicator "MID" bar (I)	Range (MTE)	-
2	5	Nissan Eco Pedal	"Eco-driving indicator" light (I)	-	-	-	-	-	Pedal counter-pressure
3	4	Kiwi PLX nomadic device	-	Growing plants "animation" (OA)	-	-	Acceleration, Brake, Speed, etc. "game" comparisons (I & TA)	MPG (I & TA), Gas used (g), $ saved/used, "Kiwi Score"	-
4	7	Toyota/Lexus gauge with small LCD display	Arc behind speedometer (TA)	-	MPG "Eco Drive Level" (OA)	Leftward pointing, higher MPG = bottom-left (I)	-	Tank MPG (OA), Range (MTE)	-
5	8	Ford/Ideo Smart Gauge with EcoGuide	-	Growing leaves (TA)	MPG over last 10 minutes (TA)	-	MPG (TA)	MPG (OA), Range (MTE)	-
6	1	BMW fuel economy display	-	-	-	Downward pointing, higher MPG = left (I)	-	MPG (OA), Range (MTE)	-
7	9	Fiat eco:Drive	-	Gearbox diagram	eco:Index score by drive (TA)	-	-	Overall eco:Index score (OA), Projected CO2 saving (kg) Projected Euro Savings	post-drive analysis
8	6	Toyota Prius consumption display & energy monitor	-	-	MPG over last 30 minutes, 1 or 5 minute intervals (TA)	-	MPG (I)	MPG (OA), Best MPG (TA)	-

Note: (I) = Instantaneous fuel economy; (TA) Trip Average fuel economy; (OA) = Overall Average fuel economy; MTE = Miles to Empty

1. Honda Ecological Drive Assist with Eco Scores. The top ranking FEDIC design was the Honda Ecological Drive Assist that presented fuel economy information in several formats including instantaneous, trip-average, lifetime-average, a fuel economy scoring metric (proprietary to Honda), tank range, and a history of fuel economy. In addition, the display provided acceleration information with the intent to notify the driver when acceleration rates reduced fuel economy. A strength of the Honda Ecological Drive Assist interface components is that they could be adapted to both hybrid and traditional vehicles. From this FEDIC, the following components were tested within the usability study:
    a. "Eco Scores," representative pictures present short-term or trip average fuel economy information. This type of representation is advantageous in that it may require less viewing time for the driver to obtain the relevant information. In addition, it may allow the driver to make faster judgments of scale, just as a fuel gauge showing a needle pointing towards the "E" side of a scale may be interpreted more easily than a text display that reads "1.0 gallon remaining."
    b. Behavioral display featuring information on acceleration/deceleration will be displayed. This horizontal bar grows from a central pole towards the right when accelerating and to the left when decelerating. Hatched regions on the screen are placed at the far right and left. When a bar grows into one of these regions it indicates fuel inefficient driving behavior. In this way, this display also serves as a teaching mechanism for drivers.
2. The Nissan Eco Pedal. The Nissan Eco Pedal achieved the second highest ranking because it presented fuel economy information to a driver through a change in force in the accelerator pedal. Specifically, when the driver instigated excessive acceleration that resulted in poor fuel economy, the accelerator pedal provided a counterforce that informed the driver they were driving fuel inefficiently. A significant benefit of this FEDIC was that it did not require the driver to visually attend to the interface to receive fuel economy information. This eliminated any visual distraction due to FEDIC use. The Eco Pedal would have scored markedly lower in both iterations of the hierarchical matrix had it delivered fuel economy information via a traditional visual display. A significant drawback to the Eco Pedal is that it is only available in Japan. Given that its effectiveness may be limited to traffic conditions with frequent stops and starts, and its poor reception during the focus groups during Task 2 (see Jenness et al., 2009), this FEDIC design was not considered for testing in the usability study.
3. The Kiwi PLX nomadic device (Kiwi). Although the small display size of the Kiwi was judged to contribute to potential driver distraction, there were two components that were considered for the usability test. The instantaneous fuel economy and trip average fuel economy information were presented simultaneously such that a driver could observe current fuel consumption along with trip fuel consumption. The instantaneous and trip fuel economy consisted of horizontal bars that increased in length from left to right when fuel economy increased. The Kiwi *fuel efficient driver* training module was another progressive component feature that benefitted drivers by instructing them how to drive more fuel efficiently. This component was also presented in the same easy-to-

comprehend format as the instantaneous and trip fuel economy averages. Thus, the following components were tested within the usability study:

a. Average fuel economy and instantaneous fuel economy bars present fuel economy information on horizontal bars. By viewing this information in a bar, users will be able to see how fuel efficient they are driving relative to the whole range of the bar. This provides feedback that they are driving fuel efficiently or that they could do better. The bars also display a numerical readout of the exact mpg for each bar.

b. The Fuel Efficient driver training component serves as a training mechanism for drivers to improve their driving behavior. The display is similar to the horizontal average and instantaneous fuel economy bars described above, but instead of continually displaying information, the program sets goals for the driver to accomplish during a three-minute time period. This gives drivers the chance to attempt to master specific changes in behavior (e.g., acceleration) that result in improved fuel economy.

4. Toyota/Lexus (T/L) fuel economy gauge with small LCD display. The T/L design contained an instantaneous fuel economy meter that was presented simultaneously with a display of tank average fuel economy. The T/L design also presented trip average fuel economy information via a light-arc that changed intensity and was located above the speedometer. From this FEDIC, the following components were selected for further evaluation in the usability study:

    a. The light-arc above the speedometer provided a unique and subtle indication of fuel economy over the course of a trip. The brightness of this arc changed depending on the driver's fuel economy over a moderate period of time (i.e., longer than instantaneous fuel economy, but shorter than trip average fuel economy). If noticed by the driver, this may provide information on how well they are maintaining good fuel economy over intermediate periods of time within a trip.

    b. The leftward pointing fuel economy meter is a simple gauge that points to the number for instantaneous fuel economy in mpg. This gauge will change rapidly with changes in mpg to give the driver immediate feedback on their instantaneous fuel economy.

    c. The tank average in text (mpg) is a ubiquitous display which is often used to give drivers an indication of how fuel efficiently they have been driving over long periods of time, such as over the course of an entire tank of gas. This component presents a direct representation of fuel economy. This component requires the driver to judge whether they are driving fuel efficiently or not.

5. Components of the Ford/Ideo Smart Gauge with EcoGuide were not tested within the usability study because similar components within this design exist within other displays considered for testing. Examining components within the Ford/Ideo Smart Gauge would have been redundant with components there were already to be examined from the Kiwi (average fuel economy in bar form), Honda Ecological Drive Assist (representative pictures) and T/L displays (tank average in text).

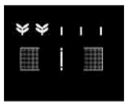
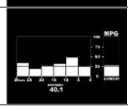
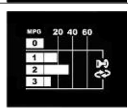
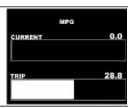
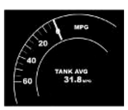
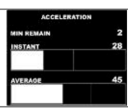
6. BMW fuel economy display. This FEDIC was eliminated after the first iteration of the hierarchical matrix because both this design and the T/L design were rated comparably and received the same net score. Because these two designs were comparable in nature and appeared to be meeting the selection criteria similarly, the research team decided to only continue with the T/L design because the controls were thought to be superior to the controls in the BMW design. In addition, the BMW FEDIC components were not selected for testing in the usability study due to the fact that similar components were already considered for usability testing; specifically the leftward pointing fuel economy meter and tank average miles per gallon were already selected from the T/L design.
7. Fiat eco:Drive. Although the eco:Drive was eliminated after the first iteration due to its low ranking in the hierarchical matrix, it was reprised because of the post-drive analysis component. The post-drive analysis component provides information about fuel economy through a computer program. This program can instruct drivers in ways to change their behavior in order to improve fuel economy. During the hierarchical matrix evaluation, the post-drive nature of this FEDIC was often seen as a disadvantage because the feedback was not instantaneous and could not be accessed while driving. However, this same factor was also seen as an advantage in that this display could not be distracting to drivers because it was not available while they were driving. When considered as a mechanism for training drivers, this FEDIC design provides detailed feedback on driving style such that a driver can learn fuel efficient driving practices at a time when the driver (sitting at a computer) can focus on these lessons. From this FEDIC design, the following components were selected for testing within the usability study:
    a. Post-drive analysis presents information on fuel economy and driving behavior to a user though a computer program. The user can receive detailed information on how to improve acceleration, shifting, and other behaviors and see instances when they may not have been driving as fuel efficiently as they could have. No information is displayed to the driver while in the vehicle (unless there is a separate FEDIC that accomplishes this).
8. Toyota Prius consumption display & energy monitor. The Toyota Prius display was eliminated after the first iteration of the hierarchical matrix due to its low ranking. This low ranking was most likely the result of its visually-demanding design with multiple components that were displayed in the central stack, away from the driver's forward view of the road. However, this display is one of the most prevalent designs that is currently available in vehicles and drivers may already be familiar with it. For this reason, the mpg bar graph was tested within the usability evaluation as a standard for comparing the other components:
    a. A vertical bar graph that displays fuel economy history of the previous 30 minutes, where each bar represents a five-minute period of time. This display also shows current instantaneous fuel economy on a vertical bar in comparison to the historical bar graph information. This component provides information about current and past fuel economy so that drivers can see how fuel efficiently they are (and have been) driving.

By separating these recommended components from the FEDIC designs that were evaluated within the hierarchical matrix, nine FEDIC component-sets (CS) were generated for further evaluation within the usability test (Table 6). Because it had yet to be determined what fuel economy information type was most useful to drivers (as concluded in Task 2, Jenness et al., 2009) these CS represent two types of fuel economy information simultaneously. The fuel economy information types featured by each CS are outlined in Table 6 as are the specific FEDIC design components that were taken from the recommendations of the hierarchical matrix exercise. Further illustrations of these CS displays can be found in Appendices E and F.

2.5 Key Concept Development Conclusions

- There were multiple methods by which FEDICs portray fuel economy information;
- FEDIC designs that presented multiple types of fuel economy information or behavioral information (e.g., acceleration that may be indicative of safety) within a *simple* display aligned best with user-needs;
- The more useful FEDIC designs displayed more than one component at a time (a component is an interface element of a FEDIC design that provides information to a driver).

Table 6. FEDIC Component-Sets tested during the usability evaluation

FEDIC Component-Sets	Display used in Usability Evaluation	Components	Fuel Economy Information Type[1]			FEDIC Design Components						
			I	TA	OA	Intensity-Changing Light	Representative Pictures	Graph	Single Dial	Single Bar	Text	Other Modality
CS01		Intensity-changing light + Text MPG		X	X	Around Speedometer (arc-light)	-	-	-	-	MPG underneath speed-ometer	-
CS02		Representative picture + Acceleration/ Deceleration Bar	X	X		-	Honda Eco Score Images	-	-	Honda MID Accel/Decel Bar	-	-
CS03		Representative picture + Horizontal MPG Bar		X	X	-	Honda Eco Score Images	-	-	Honda Eco Score Bar	-	-
CS04		Vertical Graph of Instantaneous + Trip MPG	X	X		-	-	Prius Histogram, 5 min epochs	-	Prius Histogram, Instantaneous	-	-
CS05		Horizontal Graph of Trip + Horizontal Graph of Average MPG		X	X	-	-	Honda 3 Previous Drive MPG Bars	-	Honda Trip Average MPG Bar	-	-
CS06		Horizontal Graph of Instantaneous + Trip	X	X		-	-	Kiwi Comparison Bars	-	-	-	-
CS07		Leftward Dial + Text MPG	X		X	-	-	-	Honda Leftward Instantaneous Dial with 0 at top, "high FE" at bottom	-	MPG underneath Dial	-
CS09t[2]		Acceleration & Smoothness training exercises	X	X		-	-	Kiwi "game" comparison	-	-	-	-
CS010t		Fiat post-drive training exercises	X	X	X	-	Tach. & Gearbox Diagrams	Fiat Post-Drive graphs	-	-	Descriptions of how to improve behavior	Post-Drive Data

1. For Fuel Economy Information Types, (I) = Instantaneous fuel economy; (TA) Trip Average fuel economy; (OA) = “Overall” or Tank Average fuel economy
2. CS08t was removed after the numbers had been established.

3. Usability Evaluation

The concept development task evaluated existing FEDICs to determine their potential to support user needs. Results of this task identified specific components within each FEDIC design that may best assist users to increase fuel economy while driving. These components were used to generate nine recommended prototype FEDIC component-sets (CS). Each CS included two components and two separate types of fuel economy information (e.g., instantaneous, trip average, and overall average). Two of the CS were *training interfaces*, which included an instructional component to help users better understand the system. The training interface evaluations are discussed in greater detail in Section 3.1.2.3.3.

While the FEDIC concept development task provided an initial indication of usability and comprehension (albeit from a user needs perspective), one of its central limitations was the lack of usability and comprehension data from drivers who would use this technology. In particular, drivers who are inexperienced with FEDIC designs may comprehend them differently than the research team. For this reason, it was necessary to gather this information from potential FEDIC users.

Each CS integrated at least two types of information into a design. In general, each of the CS focused on presenting fuel economy and related behavioral information to drivers. Users must perceive, comprehend, and interpret the fuel economy display content as a secondary task to driving. Exposing drivers to additional information may distract them from their main goal of driving safely (Rakauskas et al., 2008). Therefore, it is important to evaluate how users understand and comprehend FEDIC CS information and to improve these designs.

The research team conducted a usability evaluation that consisted of three separate subtasks. The first subtask was an initial comprehension task where users were asked to identify components that changed and to describe how the components changed. This task also served to provide users with an initial exposure and bring them to a standard level of understanding on all CS. Within the second subtask, fuel economy comprehension users were presented images of the CS in a series of fuel economy states to determine if the user could identify if the image depicted fuel efficient driving. The third subtask was a set of general usability questions that identified participants' opinions in terms of overall usability, safety, and effectiveness of each FEDIC.

The primary research questions for this evaluation included:

- Do users understand the FEDIC CS after a short exposure?
- Can users accurately comprehend changes in fuel economy state presented within the FEDIC CS?
- Do users find the FEDIC CS to be usable? Specifically: Do users find the information provided by the FEDICs valuable for improving fuel economy and safety?

The usability evaluation was intended to provide an indication of usability and users' comprehension. This evaluation provided an objective method to reduce the number of FEDIC CS to be evaluated further to a more reasonable number (two). These results allowed the project team to design *useable* CS to be evaluated during the subsequent simulation evaluation and possible field operational testing. In summary, those CS that performed well on the usability measures warrant further evaluation because they have a greater propensity to improve fuel economy. Conversely, those FEDICs that exhibit poor usability are not likely to improve driver behavior and were subsequently eliminated from further testing.

3.1 Methodology

3.1.1 Participants

The HumanFIRST Program recruited sixteen participants for the current study via an advertisement (see Appendix B). All respondents passed the minimum age and vision requirement to participate in this study and had better than 20/40 visual acuity. Pilot data was collected from two participants. Data from one participant was excluded because the participant did not complete the task. Data from the remaining thirteen participants are reported (7 females, 6 males) which exceeded the goal of ten participants. A usability study sample size of ten can identify on average 95% of problems with an interface (Faulkner, 2005). The participant mean age was 28.5 years (*SD* = 9.82) with an age range between 19 and 50 years.

3.1.2 Procedures

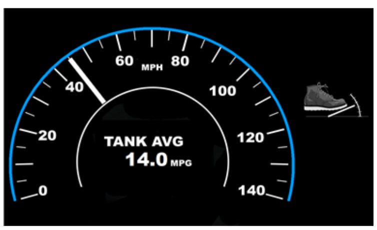
Participants read and signed the University of Minnesota Institutional Review Board-approved consent form prior to the start of the study (see Appendix C). Participants then completed a demographic questionnaire to collect information regarding number of years driving, type of car driven, history of traffic accidents, etc.

Participants completed three subtasks: Initial Comprehension, Fuel Economy Comprehension, and General Usability. A separate evaluation of two training CS was completed at the end of the General Usability Measures. These tasks are described in detail below and a script of the instructions presented to participants during each task can be found in Appendix D.

3.1.2.1 Initial Comprehension Task

The purpose of the Initial Comprehension task was to determine if users understood the CS after a short exposure. More specifically, this task evaluated how well participants identified state changes and understood information presented on each CS after receiving a short set of instructions about CS functioning. Good performance by users indicated that the CS could potentially be used in a FEDIC without having to include additional operational instructions.

For the Initial Comprehension task, participants were first introduced to each CS through a *vignette*. Each vignette presented six *driving events* and corresponding *CS states*. *Driving events* were written descriptions of typical driving situations/scenarios that could be encountered in the real-world and presented on a computer screen. Depending on the information types displayed on a particular CS (see Table 6), the text described an event that spanned the course of one trip or a set of consecutive trips. For example, CS02 featured instantaneous acceleration and trip average fuel economy information types which can both be represented over the course of a single drive. On the other hand, CS05 featured trip and overall average fuel economy information types which required that the participant be shown how the CS behaved over 3 separate trips in order to gain a full understanding of the components. After reading the text for each driving event, participants clicked a mouse button to continue with the vignette and were then presented with a corresponding *CS state* video (the complete list of CS states can be found in Appendix E). For those driving events that described a static vehicle state, such as arriving at one's destination or just after starting the car, an image of the CS was shown instead of a video (states that used an image instead of a video are noted in Appendix E). During the FEDIC state presentation, an image of a shoe pressing on an accelerator pedal was also presented (see Figure 1 for an example of CS state presentations) in which the shoe and pedal moved in relation to changes in the CS state. This information was intended to help the participant understand the relationship between pedal position changes and CS state changes. For all CS, the first state image shown was during vehicle start-up (i.e., a static vehicle state) where the pedal and foot were shown at the highest angle (see Figure 1c). This position indicated that the accelerator pedal was not being pressed during the depicted FEDIC state.

a. 

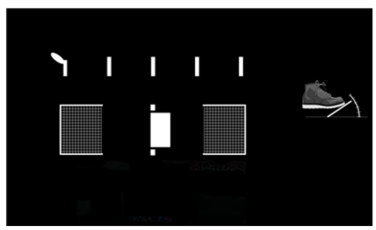
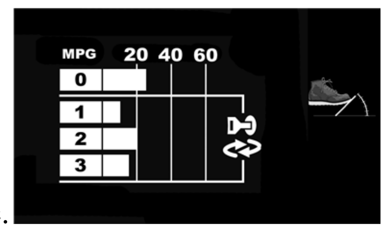
b. 
c. 

Figure 1. FEDIC CS state images featuring three accelerator pedal position activation levels: a) moderate, b) light, and c) none

The experimenter then further demonstrated the functions of the CS by manipulating (with a mouse) the foot on the accelerator pedal to indicate "how" the CS states would change dynamically while: cruising at a constant speed, when the pedal was accelerating excessively, and when the pedal was returned to a cruising speed. The purpose of this activity was to allow participants to experience (albeit limited) the relationship between pedal activity and CS state changes over a continuous series of states. Because many of the CS function on a timescale longer than permitted in the evaluation and the need to allow participants to view the full functionality of the CS, each of the CS displayed trip average and overall average fuel economy information at an expedited rate. For example, CS04 (see Table 6) presented a bar graph history of instantaneous fuel economy in five-second intervals instead of its typical rate of five-minute intervals.

After the demonstration, participants were presented with four images of the CS at different fuel economy levels for reference and instructed to provide open-ended responses to two questions to assess their comprehension of how the CS worked. The first question asked participants to "Please describe the components of the display that *changed*" while the second asked participants to "Please describe how this display *works*."

Participants completed the initial comprehension test for all seven CS. A diagram of the task flow for the initial comprehension task is located in Figure 2. The presentation order of component-sets CS01 through CS07 was randomized across participants to prevent confounds due to presentation order.

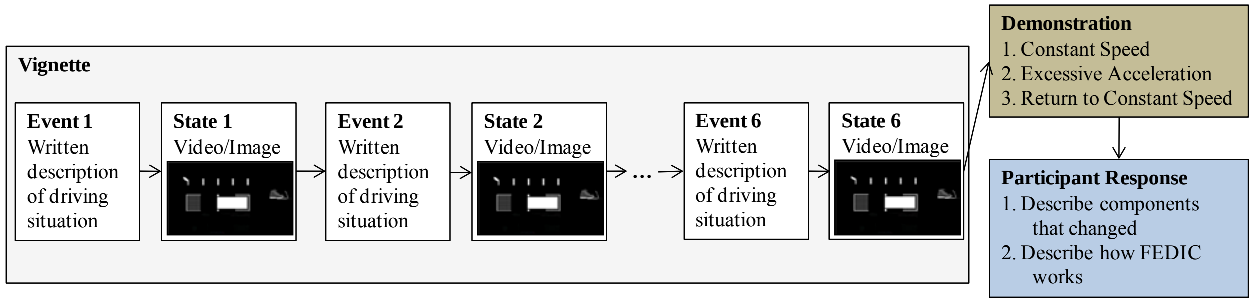


Figure 2. Diagram of the task flow for one FEDIC during the Initial Comprehension Task

Participant responses to the two questions were scored from 0 to 2 to indicate how well their understanding of the CS matched the actual functioning of the CS. The scoring process was completed separately by two raters who based their ratings on the descriptions provided to the participants after the completion of the initial comprehension task (Appendix F). A score of 0 represented a complete lack of understanding, a score of 1 represented minimal understanding, and a score of 2 represented complete understanding. The responses within each question were combined to create a mean score for each CS. A mean score closer to 2 for the “what changes” question would indicate that most participants were able to identify changes in FEDIC-CS state. A mean score closer to 2 for the “how it worked” question would indicate that most participants were able to describe how FEDIC-CS state changes related to fuel economy. Due to the subjective nature of these measures, no statistical analyses were run on these data; instead these results provided high-level insight into the degree to which participants understood, comprehended, and interpreted each FEDIC after a short exposure.

After completing the Initial Comprehension task procedure for all CS, participants were provided a description of each CS along with representative images of four FEDIC states (descriptions and images can be found in Appendix F) and then were provided with a summary of the functionality of each CS by the experimenter. Participants were also given an opportunity to ask questions about CS functioning. The purpose of this activity was to ensure that the capabilities and functionality of each CS was understood completely before proceeding to the subsequent fuel economy comprehension task.

3.1.2.2 Fuel Economy Comprehension Task

The purpose of the Fuel Economy Comprehension task was to determine if users could accurately comprehend how changes in CS state related to fuel economy. This task evaluated whether participants could discriminate fuel efficient driving from fuel inefficient driving based on the CS state that was displayed. These results identified which components provided users with comprehensible and (more importantly) “differentiable” CS states. Good performance on these measures indicated users found it easy to determine fuel efficiency based on the FEDIC-CS state.

Participants were instructed to envision themselves in the following situation: “You are driving a rental car that gets 30 miles per gallon on average. As you drive, your low fuel light has come on and you must monitor your fuel to make sure you know how much further you can go before running out of gas” (see Appendix D for the complete participant instructions). To prevent participants from relying on their own experience when making judgments of fuel economy, they were instructed to consider 30 miles per gallon as the average fuel efficiency for their vehicle within this situation.

Participants were then instructed that they would be presented with an image of a CS on a computer screen and that they were to answer the question “Are you driving fuel efficiently?” The participant’s task was to respond as quickly and accurately as possible by pressing a green button on a response box to answer “yes” or by pressing a red button to answer “no” (see Figure 3 for a depiction of the response box). The amount of time between image presentation and the participant’s response was recorded. The CS image disappeared after the participant pressed the button to prevent participants from continuing to view the FEDIC state and thus bias subsequent image presentations due to increased viewing time. The purpose of the timed binary (yes/no) response was to see how accurately and quickly participants could identify the CS state. After providing a response, participants were asked to provide a *scaled response* to report the degree to which they felt they were driving fuel efficiently based on the FEDIC state. The scaled responses ranged from -2 (not at all fuel efficient) to 2 (extremely fuel efficient), which were labeled on the response box (Figure 3). The purpose of the scaled response was to see how accurately participants could identify the fuel economy level of the CS state. This was important because, in practice, it would be necessary for drivers to first assess the degree of current fuel economy status (i.e., system state) before they could determine what actions would be necessary to improve their own fuel economy.

Figure 3. Response box used during the fuel economy comprehension test

In total, seventy-seven images were presented during this task, one at a time. Each image represented a unique FEDIC fuel economy state. These images presented each CS in one of five possible instantaneous fuel economy states (50% below average (15 mpg), 25% below average (22.5 mpg), average (30 mpg), 25% above average (37.5 mpg), and 50% above average (45 mpg)) for each of the seven CS. Each of these state images contained one of two overall/trip average fuel economy levels (low overall average fuel economy (15 mpg) and high average fuel economy (30 mpg)). Participants completed seven practice trials before beginning the experimental trials. Each image presented a combination of instantaneous and average fuel economy levels not presented in the remaining experimental trials. The remaining seventy images (7 CS x 5 fuel economy states x 2 levels overall/trip average) were randomly presented in a block of trials to prevent confounding due to order effects. The stated average (30 mpg) CS fuel economy state was excluded from the timed and response accuracy analyses because it was thought to be unclear whether this meant they were driving fuel efficiently or inefficiently.

3.1.2.2.1 **Binary (Yes/No) Response Analysis**

After the removal of the 30 mpg fuel economy state, four opportunities existed for participants to make a correct binary response for each CS presentation. For the CS states 25 and 50% higher than average fuel economy, participant responses were correct if they indicated "yes." For the CS states 25 and 50% below average fuel economy, participant responses were correct if the response was "no." Correct responses were coded as "1," incorrect responses were coded as "0."

The binary response data were analyzed by conducting a repeated measures Binary Logistic Regression (BLR). The BLR was employed to compare the probability of responding to one CS correctly to the probability of responding to another CS correctly. The BLR first required calculating the *odds ratio* of responding correctly (i.e., the percentage of correct responses) for CS i where p equals the probability of making a correct response. The following equation was used for these calculations; *Odds Ratio* $= p^i/1\text{-}p^i$.

To compare the odds of responding correctly to different CS, *accuracy ratios* were generated by placing the odds ratio for one CS in the denominator position of a ratio and another CS in the numerator position of the ratio. The accuracy ratio indicated the magnitude of the difference in correct responses between two CS. Seven BLRs were calculated to compare the accuracy ratios of all possible combinations of CS. Within each BLR the denominator was kept constant. For example, within one BLR, an analysis was run comparing six different ratios keeping the odds for correctly responding to CS01 in the denominator while the numerator corresponded to the odds of responding correctly to CS02, CS03, CS04, CS05, CS6 or CS07. A Wald statistic (reported as χ^2) was then employed to calculate the relationship between each ratio-pair. A significance level of $p \leq 0.05$ was used for these analyses. The accuracy ratios resulting from the BLR allowed a direct comparison of CS in terms of accuracy on the binary responses to the comprehension task.

3.1.2.2.2 **Analysis of Binary Response Timed Performance**

Only accurate responses were included in this analysis, as determined during the binary response evaluation. Longer response times were considered to have indicated greater confusion and low comprehension in deciding whether the FEDIC fuel economy state was the result of fuel efficient or fuel inefficient driving behavior. A CS that produced slow accurate responses indicated that it may be distracting or may cause drivers to make poor decisions relating to fuel economy. These data were compared across participants and across fuel economy states to evaluate the differences between CS.

Timed performance data were analyzed using a 7 x 4 x 2 (CS by fuel economy state by average fuel economy) fixed factor model ANOVA. FEDIC component-set (CS01 through CS07 as shown in Table 6), instantaneous fuel economy state (Average + 50%, + 25%, – 25%, or – 50%), and overall/trip average fuel economy state (high or low) were considered within subject factors. A significance level of $p \leq 0.05$ was considered significant.

3.1.2.2.3 Analyses of Scaled Responses

Scaled responses were converted into *absolute difference scores* to report the degree of accuracy in their response. Difference scores were calculated as the absolute number of states that separated a participant's response from the actual CS fuel economy state. For example, if the participant responded that a CS fuel economy state was "1" when the CS state was "1" then the difference score would be 0 because they are the same (i.e., 0 difference between them). If a participant had responded "-1" for the same CS state then the difference score would be 2 because the participant's response was two less than the correct score. A 'good' CS resulted in the lowest absolute difference scores (i.e., those closest to zero). A CS that resulted in a high absolute difference score suggests that it was not understood correctly.

Absolute difference scores were analyzed using a 7 x 2 (CS by overall/trip average fuel economy level) ANOVA with a fixed factor model. FEDIC component-set (CS01 through CS07 as shown in Table 6) and overall/trip average fuel economy (high or low) were within-subject variables. A significance level of $p \leq 0.05$ was used for this analysis. The main effect for CS fuel economy state was not examined because differences between fuel economy states are pre-existing due to the method in which the absolute difference scores were calculated. Specifically, fuel economy states -2 and 2 have the potential to range from 0 to 4; fuel economy states -1 and 1 have the potential to range from 0 to 3; and 0 can only range from 0 to 2.

3.1.2.3 General Usability Measures

The purpose of the General Usability measures were to determine whether users found the CS to be usable and whether users found the information presented on the CS valuable for improving fuel economy and safety. To accomplish this, participants completed two questionnaires. The first was a *usability scale* that assessed the extent of usefulness and satisfaction of the FEDICs. The second was a perceived safety and effectiveness inventory.

3.1.2.3.1 Usability Scale (Usefulness & Satisfying Scores)

Participants were given a usability scale developed to assess driver acceptance of new technology (van der Laan, Heino, & de Waard, 1997, see Appendix G). The scale consisted of nine questions that were on a five-point rating scale and presented one at a time on a computer. This scale quantified participants' opinions about the usefulness and satisfaction of using each CS. Data were aggregated across participants and resulted in usefulness and satisfying values for each CS. Results from the usability scale provided standardized ratings of usefulness and satisfaction that were compared between CS. High usefulness scores suggest that users thought the information presented on the CS would be useful. High satisfaction scores suggest that users thought the information presented on the CS would be enjoyable to use and suggests that they might use it more often.

3.1.2.3.2 **Perceived Safety and Effectiveness Inventory**

The perceived safety and effectiveness inventory (see Appendix H).was analyzed with one-way ANOVA that was run on each of the 12 measures to determine the main effect of CS. A significance level of $p \leq 0.05$ was considered significant. Bonferroni follow-up tests identified differences between main effects of CS type. Significant differences between CS indicated that users favor one CS over another for that measure.

3.1.2.3.3 **Training CS Evaluations**

Two of the nine CS tested in the usability evaluation were *training interfaces* as denoted by a "t" after their CS number in Table 6. These CS are described below:

- CS09t was a training exercise that contained two horizontal bars (similar in the layout to CS06) to display acceleration. Both bars featured vertical lines within the horizontal acceleration bars to indicate when acceleration was over a target level. The display provided a 3-minute training session on acceleration. Because this training CS was similar in appearance to CS06 it was evaluated separately to avoid confusing participants.
- CS10t was a training system that involved in-vehicle data collection and a computer interface. Using this CS, drivers would be able to download data about their driving performance from their car via a USB port and then upload these data to an online computer program. This program had training tips based on data collected from a drive, performance charts, and a social network by which users can compare their performance and share information. This training interface was evaluated separately because it was not an interface that the driver could access while driving and because it included a number of other features that were not available from the other CS,.

The training interfaces were evaluated only though the general usability measures; they were not evaluated in the initial comprehension or fuel economy comprehension tasks. Understanding how users comprehend and perceive these training components allowed the research team to evaluate the utility of training features within FEDIC designs. This set of evaluations was important because both of the training CS represent unique components that are currently available to drivers. However because these CS present fuel economy information in dramatically different ways and methods, it was important to test them separately so as not to affect participants' opinions of the other seven CS.

These two evaluations occurred after the General Usability Measures activity was conducted for the initial seven CS. The procedure for these evaluations began by viewing a vignette for the CS focusing on how each training CS instructed participants to improve their fuel economy (see Appendix E). Participants then completed the same General Usability Measures for the training CS as described above. Because CS10t was not intended to be displayed while driving and could not be assessed on questions 1 through 4 of the Perceived Safety and Effectiveness Inventory, three alternative scaled questions were presented using the same 5-point scale as before (Appendix H). These included their agreement with the following three statements:

- "This was useful for learning to conserve fuel in traffic."
- "I think this application is useful for highway driving."
- "This is useful for learning to conserve fuel on the highway."

3.2 Results

3.2.1 Initial Comprehension Task

For the question, “Please describe the components of the display that changed” participants’ responses were more accurate for CS02 when compared to all other displays. One participant responded that “The white bar would move right and then move back towards the center depending on how much the pedal was pressed down. Leaves would pop up on the trees depending on how much and where the white bar moved.” The average accuracy scores for the remaining CS were close to 1, indicating participants noticed changes within all of the displays. CS01 was associated with the lowest average accuracy, most likely due to the fact that many participants did not report noticing the change in state (brightness) of the colored arc-light source around the speedometer.

For the question “Please describe how this display works” four FEDICs (CS07, CS06, CS04, & CS02) had average accuracy scores at or above 1, suggesting participants understood these displays. In general, participants were more accurate when the CS displayed short-term information (instantaneous) when compared to CS that displayed more long-term information (overall average, e.g., CS03 and CS05). This finding was expected because this task was based on short, initial impressions that would naturally favor CS with short-term information presentations. Overall, results suggest that after a short exposure to these CS most users were able to describe some of the state-changes and possessed a modest understanding of functioning. Average accuracy scores for each of the initial comprehension task questions are presented in Figure 4.

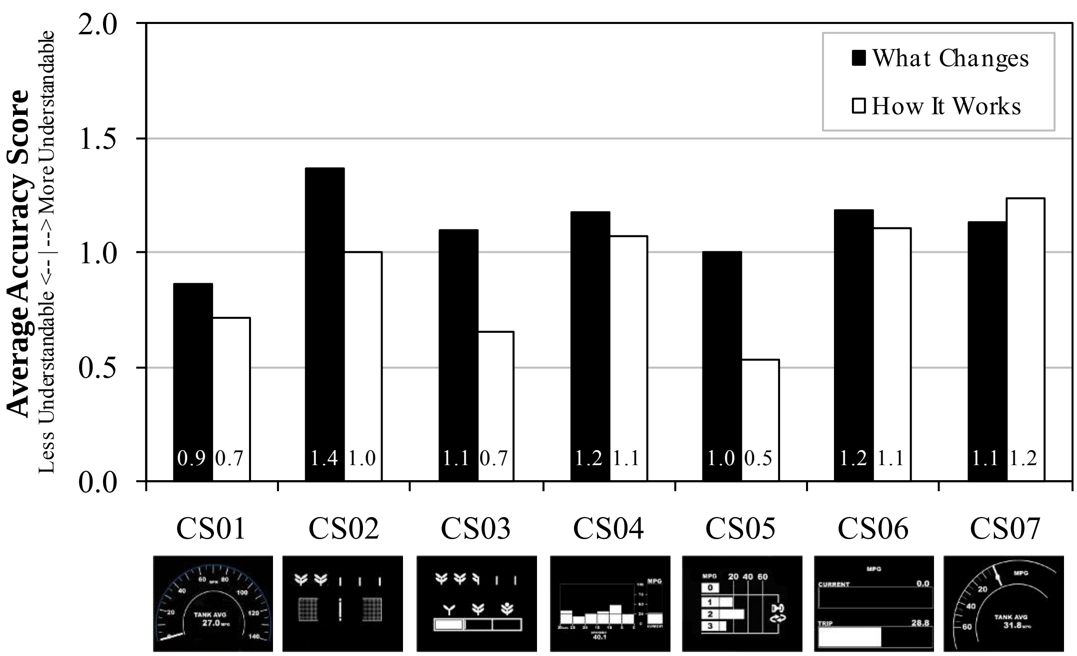


Figure 4. Average accuracy scores for initial comprehension questions by FEDIC

3.2.2 Fuel Economy Comprehension Task

3.2.2.1 Binary (Yes/No) Response Accuracy

There were few differences between high and low average fuel economy conditions (see Appendix I for all results and Figure 5 for the percentage of correct responses across trials for each CS). The accuracy ratios resulting from the BLR (reported in Table 7) indicate the percentage of how likely a participant was to identify the fuel economy on one CS compared to another CS. As an example, the comparison between CS02 and CS01 in Table 7 was 1.79, which indicates that CS02 was 1.79 times more likely to have a correct response than CS01. Results indicated participants were significantly less accurate responding to CS01 compared to all other CS (for all $p < 0.05$). Participants were significantly more accurate responding to CS02 compared to all other CS (all $p \leq 0.05$). Participants were significantly less accurate responding to CS04 compared to CS05 ($\chi^2(1, N = 104) = 4.52$, $p < 0.05$) and CS06 ($\chi^2(1, N = 104) = 4.05$, $p < 0.05$). It is interesting to note that correct responses to CS01 overall were slightly greater than chance at the 55th percentile accuracy suggesting that CS01 did not effectively facilitate an accurate determination of fuel economy.

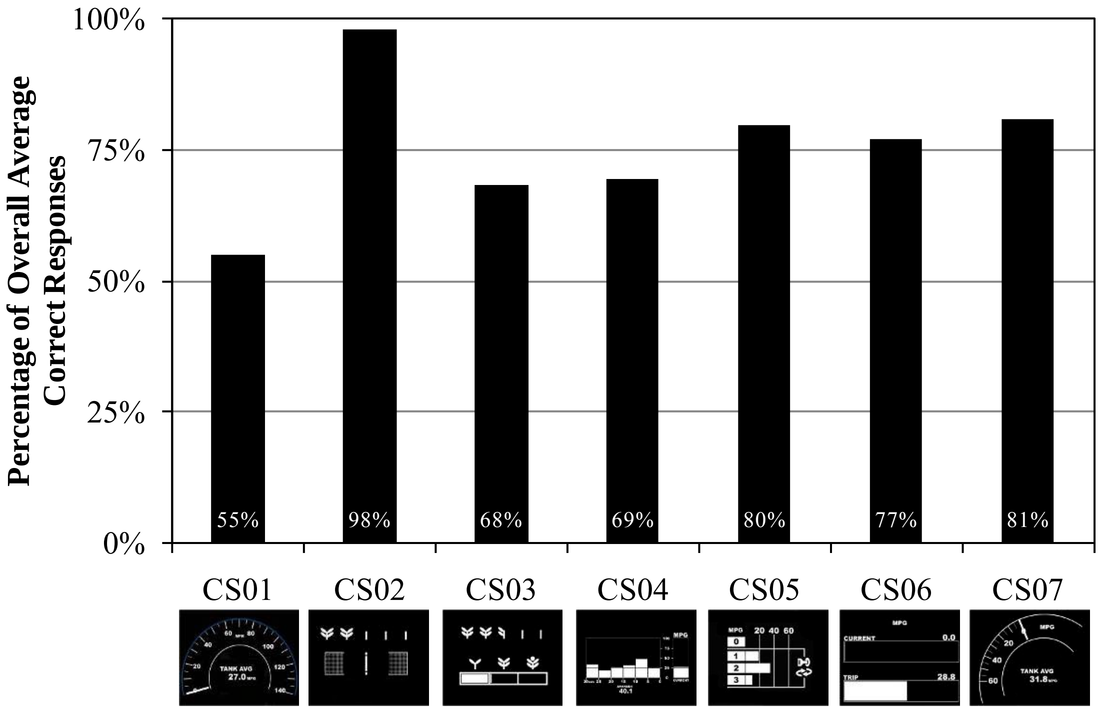
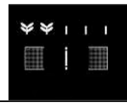
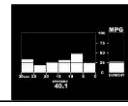
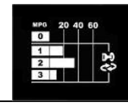
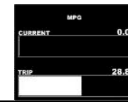
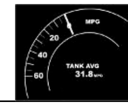


Figure 5. Percentage of overall average correct responses by FEDIC CS.

Table 7. Accuracy ratio (percentage) of the likelihood to make a correct response for each FEDIC based on the Binary Logistic Regression (BLR) odds ratios.

	Denominator FEDIC CS						
Numerator FEDIC CS	CS01 	CS02 	CS03 	CS04 	CS05 	CS06 	CS07 
CS01	-	-	-	-	-	-	-
CS02	1.79*	-	-	-	-	-	-
CS03	1.25*	0.70*	-	-	-	-	-
CS04	1.26*	0.71*	1.01	-	-	-	-
CS05	1.46*	0.81*	1.17	1.15*	-	-	-
CS06	1.40*	0.78*	1.13	1.11*	0.96	-	-
CS07	1.47*	0.82*	1.18	1.17	1.01	1.05	-

* $p < .05$.

3.2.2.2 Timed Performance of Binary Responses

Results indicated a main effect of CS for the correct timed responses, $F(6,511) = 2.86$, $p < 0.05$. Post hoc Bonferroni tests indicated participants were significantly slower when responding to CS07 than when responding to CS02 ($p = 0.007$) or CS06 ($p = 0.008$). As presented in Figure 6, these findings suggest that participant responses were significantly longer when they correctly ascertained their fuel economy using the dial (CS07) than while using any other CS. This suggests that CS07 may present a distraction to drivers because participants required a significantly longer time to process the information on the dial compared to the time taken for the other CS. Therefore it was concluded that viewing horizontal graphs representing their acceleration (CS02) or instantaneous and average fuel economy (CS06) required less processing time than viewing the dial (CS07).

There was also a main effect for overall/trip average fuel economy level, $F(1,511) = 4.53$, $p < 0.05$. Results indicated that participants' accurate responses were faster when the average fuel economy shown was high ($M = 4.16$ s) compared to when it was low ($M = 4.89$ s). This suggests that higher overall/trip fuel economy was easier for participants to recognize.

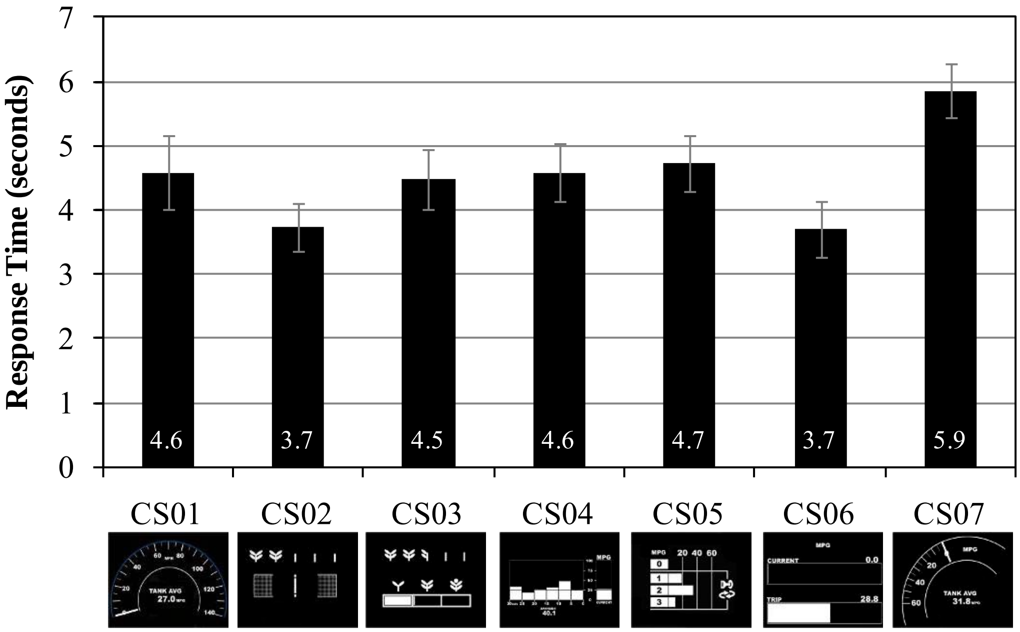


Figure 6. Response time for timed performance of yes/no responses by FEDIC CS (error bars represent ± 1 standard error from the mean)

3.2.2.3 Accuracy of Scaled Reponses

There was a significant main effect for CS, $F(6,894) = 8.51$, $p < 0.05$, for the difference scores that represent the accuracy of scaled responses. Post hoc Bonferroni tests indicated two significant differences between the CS. First, participants exhibited significantly larger absolute difference scores for CS01 than for all other CS (all $p \leq 0.05$) (see Figure 7). This result indicated that participants made the largest errors in identifying the fuel economy level of a CS state while using an intensity-changing light representing trip economy (CS01). Second, participants exhibited significantly smaller absolute difference scores for CS02 than for CS01, CS03, and CS04 (all $p \leq 0.05$). This result suggests that participants were also more accurate at identifying fuel economy states using a picture representing trip economy with instantaneous acceleration information (CS02) than other CS. Figure 7 indicates that CS05, CS06, and CS07 were associated with relatively small absolute difference scores (i.e., less than 1) for both high and low average fuel economy levels. This suggests participants can effectively use instantaneous, trip, or multiple-trip fuel economy information presented in horizontal bars.

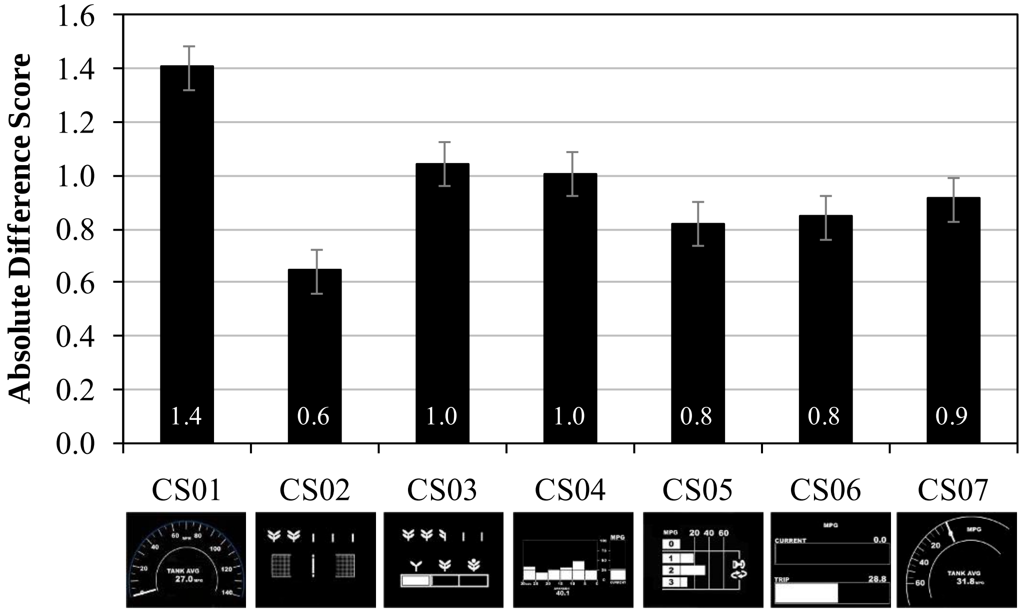


Figure 7. Absolute difference scores for all FEDICs by average fuel economy level (error bars represent ± 1 standard error from the mean)

3.2.3 General Usability Measures

3.2.3.1 Usability Scale (Usefulness & Satisfying Scores)

Participant responses on the nine usability scale questions were reduced into usefulness and satisfying scores ranging between -2 and 2 for each CS (see Figure 8). CS that populate the upper-right quadrant of this figure were perceived by participants as being both satisfying and useful; as a general reference these CS should be considered the most useful and satisfying. Three CS populated this quadrant, CS05, CS03, and CS02, which suggested they all were moderately satisfying and useful. Both CS05 and CS03 displayed long-term fuel economy in representational form (i.e., pictorial rather than textual) that may suggest that participants find this type of information more satisfying and useful than the other CS. Supporting this notion was the higher ranking of CS02 that presented trip average information (that was similar to CS03) but also provided instantaneous information. Collectively, these results suggest that participants placed the highest value in CS that featured non-text overall/trip average fuel economy information components as exemplified by CS05 and CS03. Participants also found satisfaction in seeing their fuel economy behavior and how they could improve their performance during the current trip, again in non-text form, as exemplified by CS02, CS03, and CS05.

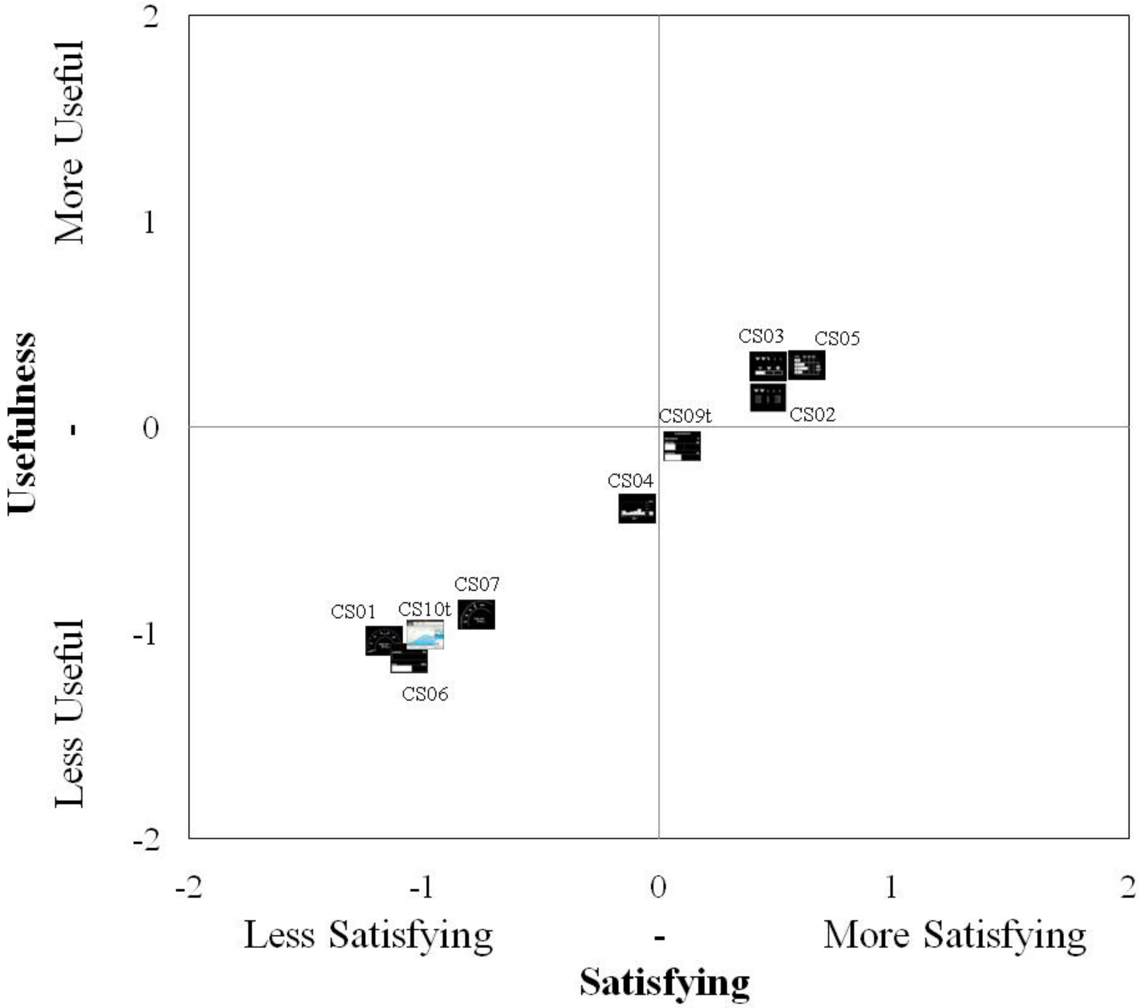


Figure 8. Usefulness and satisfying ratings from the usability scale for all FEDIC CS

3.2.3.2 Perceived Safety and Effectiveness Inventory

Mean responses for the entire inventory of questions (questions 1 – 12) for all CS are presented in Table 8. Inventory statements that yielded statistically significant differences between CS are reported below.

Statement 5 - "I think this component is difficult to figure out." There was a significant main effect for CS, $F(8, 108) = 7.94$, $p < 0.05$. Post hoc Bonferroni tests indicate that mean responses to CS02, CS03, and CS05 were significantly higher than means responses to CS01, CS06, CS07, and CS10t. This suggests that participants thought CS02, CS03 and CS05 were more difficult to "figure out" compared to CS01, CS06, CS07, and CS10t.

Statement 7 - "I would use this regularly." There was a significant main effect for CS, $F(8, 108) = 4.01$, $p < 0.05$. Post hoc Bonferroni tests indicated that mean responses to CS01 and CS07 were significantly higher than those to CS05. Participants also reported CS01 significantly higher than

CS03. This suggested that participants thought they would use CS01 or CS07 more regularly than they would use CS05 or CS03.

Statement 8 - "I would tell my friends about this." There was a significant main effect for CS, $F(8, 108) = 4.04$, $p < 0.05$. Post hoc Bonferroni tests indicated that mean responses to CS10t were significantly higher when compared to CS02, CS03, CS04, CS05, and CS09t. This suggested that participants thought they were more likely to tell friends about CS10t than CS02, CS03, CS04, CS05, or CS09t.

Statement 9 - "I trust the information is accurate." There was a significant main effect for FEDIC, $F(8, 108) = 2.47$, $p<0.05$. Post hoc Bonferroni tests indicated that mean response to CS10t was significantly higher than CS02 which suggested that participants exhibited more trust in the accuracy of information presented in CS10t than in CS02.

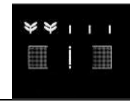
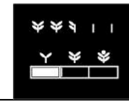
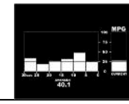
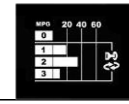
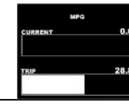
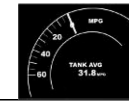
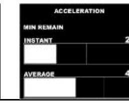
Statement 10 - "I think other drivers should use this." There was a significant main effect for CS, $F(8, 108) = 2.95$, $p<0.05$. Post hoc Bonferroni tests indicated that the mean response to CS10t was significantly higher when compared to CS05 which suggested that participants felt more strongly that other drivers should use CS10t than CS05.

Question 11 - "Describe your attitude towards using this." There was a significant main effect for CS, $F(8, 108) = 5.79$, $p<0.05$. Post hoc Bonferroni tests indicate that mean responses to CS01, CS06, CS07, and CS10t were significantly higher than CS03 and CS05. Participants also reported CS01 and CS06 significantly higher than CS02. This suggested participants had more positive attitudes towards CS01, CS06, CS07, and CS10t than they did about CS03, CS05, and CS02.

Question 12 - "What would you pay?" There was a significant main effect for CS, $F(8, 108) = 2.17$, $p<0.05$. Post hoc Bonferroni tests indicated that mean responses to CS10t were significantly higher than CS05 and Cs09t. This suggested that participants would be likely to pay more money to use a system such as CS10t than they would CS05 or CS09.

In summary, participants were positive most often in reference to the Fiat post-drive training exercise (CS10t), the leftward dial with text MPG (CS07), the color changing light with text MPG (CS01), and the horizontal graph of instantaneous and trip MPGs (CS06) CS.
The means and standard deviations of each measure of the perceived safety and effectiveness inventory are presented in Table 8.

Table 8. The mean (standard deviation) response to each of the questions in the Perceived Safety and Effectiveness Inventory by FEDIC CS

Measure	FEDIC CS								
	CS01	CS02	CS03	CS04	CS05	CS06	CS07	CS09t	CS10t
									
1. Useful in traffic	3.62(0.96)	-[a]	2.38(1.39)	3.00(1.29)	2.38(1.19)	3.77(1.01)	3.69(1.18)	3.00(1.22)	-[b]
2. Useful on highways	4.15(0.80)	3.47(1.13)	2.85(1.28)	3.38(1.12)	2.92(1.38)	4.15(0.90)	3.92(1.26)	3.15(1.28)	-[b]
3. Increases mental effort	2.69(1.11)	3.54(1.56)	3.54(1.56)	3.69(1.32)	3.08(1.26)	2.54(1.05)	3.00(1.15)	3.15(1.21)	-[b]
4. Distracts from driving	2.46(1.05)	3.69(1.18)	3.38(1.45)	3.85(1.14)	3.77(1.17)	2.46(1.13)	2.85(1.21)	3.23(1.24)	-[b]
5. Difficult to figure out	2.15(1.14)	3.92(1.44)	4.38(1.12)	3.08(1.12)	3.77(1.36)	2.08(1.12)	2.15(1.14)	3.15(1.07)	2.13(0.92)
6. Will help improve fuel economy	3.92(0.95)	3.38(1.12)	3.15(1.14)	3.85(0.99)	2.69(1.44)	3.92(1.04)	3.77(0.60)	.92(1.04)	4.13(1.19)
7. I would use this regularly	3.85(0.99)	2.38(1.39)	2.31(1.25)	3.08(1.32)	2.23(1.17)	3.62(1.12)	3.77(0.83)	2.62(1.04)	3.60(1.40)
8. I would tell my friends about this	3.23(1.24)	2.31(1.18)	2.31(1.44)	2.62(0.77)	2.15(0.90)	3.15(1.14)	2.85(1.14)	2.46(0.66)	4.13(1.13)
9. I trust the information is accurate	3.77(1.01)	2.31(0.95)	3.46(1.13)	3.54(1.13)	3.15(1.34)	3.54(1.33)	3.77(1.24)	3.38(1.04)	4.13(1.06)
10. I think other drivers should use this	3.85(0.80)	3.15(0.99)	2.77(1.24)	3.08(0.64)	2.54(0.97)	3.54(1.05)	3.23(0.93)	2.77(0.83)	3.93(1.22)
11. Describe your attitude towards using this	4.00(0.91)	2.38(1.33)	2.23(1.24)	3.15(1.07)	2.31(1.03)	3.85(1.07)	3.77(0.83)	2.69(1.11)	3.93(1.22)
12. What would you pay?	1.62(0.51)	1.85(0.69)	1.54(0.97)	1.69(0.63)	1.31(0.48)	1.69(0.63)	1.69(0.48)	1.31(0.48)	2.27(0.80)

Note: Responses to measures 1 - 10 were on a 5-point scale: 1= disagree strongly, 2= disagree somewhat, 3= neither agree nor disagree, 4= agree, 5= agree strongly;

Responses to measure 11 were on a 5-point scale: 1= very negative, 2= slightly negative, 3= neutral, 4= slightly positive, 5= very positive;

Responses to measure 12 were on a 7-point scale: 1= <$100, 2= $101 to $500, 3= $501 to $1000, 4= $1001 to $2000, 5= $2001 to $3000, 6= $3001 to $4000, 7= $4001 and up.

[a] Due to a data coding error, these data are unavailable

[b] These questions did not directly pertain to CS10t. Alternative questions are presented in the Training CS Evaluations section.

3.2.3.3 Training CS Evaluations

Results presented in section 3.2.3.2 for the Perceived Safety and Effectiveness Inventory section indicated that participants tended to favor CS10t against at least one other CS in terms of the following questions: being less difficult to understand; being something they would tell their friends about; trusting the information as accurate; something they think other drivers should use; having a more positive attitude toward the CS; and willing to pay to have it in their vehicle. Compared to the other training interface (CS09t) participants reported being more willing to pay to have CS10t in their vehicle and more likely to tell their friends about CS10t.

Three alternative questions were posed for CS10t using the same 5-point scale as questions 1 through 10 that was used in the Perceived Safety and Effectiveness Inventory (see Appendix H). Participants reported a mean agreement of 4.27(SD = 0.80) with the statement "This was useful for learning to conserve fuel in traffic." Participants also reported a mean agreement of 4.00 (SD = 1.20) with the statement "I think this application is useful for highway driving" and a mean agreement of 4.20 (SD = 1.21) with the statement "This is useful for learning to conserve fuel on the highway." Participants' positive responses to CS10t indicated that this type of training interface was thought to have great utility for providing fuel economy information to drivers. These findings also suggest that participants saw this post-drive reporting and training CS as a desirable method to obtain fuel economy information.

3.3 Usability Evaluation Summary

The usability evaluation aimed to answer three primary research questions relative to FEDIC CS design. The first research question determined if users could understand the CS after a short exposure. Results indicated that participants were moderately accurate at identifying when the fuel economy state changed for most CS. Participants were particularly good at noticing when the fuel economy state changed when they were shown a CS with an indicator of acceleration behavior (CS02). When asked to explain how the CS worked, participants were moderately accurate in identifying how most of them worked. Participants were more accurate when the information related to instantaneous fuel economy, as displayed by CS07, CS06, CS04 and CS02.

The second research question determined if users could accurately comprehend changes in CS fuel economy state. While viewing CS02 participants were more likely to be accurate compared to all other CS. Participants were faster to make this identification accurately (timed performance of binary response) and were most accurate when identifying the fuel economy state (scaled response) while using CS02. These results strongly suggest that behavioral information displayed in a horizontal bar and a representative picture depicting trip average fuel economy facilitated accurate comprehension of CS fuel economy state. This was likely facilitated by participants being able to compare the performance from the bar with references (e.g., grid regions on CS02 or lines on CS04) compared to when these references were not present (e.g., CS06).

There was additional evidence that representative horizontal bars were useful for portraying fuel economy information accurately. Participants were more likely to accurately match CS fuel economy state with behavior (binary response) while viewing horizontal bars depicting fuel economy information (CS06) compared to vertical bars (CS04). Furthermore, components featuring short-term information in horizontal bar form (CS02, CS05, and CS06) were associated with the highest accuracy when identifying CS fuel economy state (scaled response).

Conversely, participants were least likely to be accurate at matching FEDIC CS fuel economy state with behavior (binary response) and least likely to be accurate at identifying the CS fuel economy state (scaled response) while using CS01 compared to all other CS. This suggested that participants were not able to accurately comprehend changes in CS fuel economy state while using trip average fuel economy information presented via the changes of intensity of the colored arc-light source.

The third research question determined if users found the CS to be usable. In terms of participant's ratings of usefulness and satisfaction, CS02, CS03, and CS05 were the only CS to receive positive ratings on usefulness and satisfaction. Because all these CS featured information in horizontal bars, this again suggested that participants preferred fuel economy information in this form. In terms of the ratings of effectiveness and safety, horizontal bars were once again positively represented; CS06 featured horizontal bars to display instantaneous and trip average fuel economy information and participants reported that it was less difficult to figure out and they had positive attitudes toward it.

Responses for two FEDIC CS (CS01 and CS07) were significantly more positive than responses for the remaining FEDIC CS. It should be noted that CS01 was associated with the lowest accuracy in the fuel economy comprehension test. In contrast, participants reported that CS01 was easier to figure out, that they would use it more often, and had more positive attitudes towards it than other CS that performed better on the objective measures. Also, participants had the longest response times to make accurate responses during the objective measures while using CS07. Similar to CS01, participants reported that CS07 was easy to figure out and had more positive attitudes towards it than other CS. Perhaps participants' were more positive because these CS had a familiar appearance. Regardless, it was clear that participants' subjective preference during the General Usability evaluation was not consistent with their performance on the Initial Comprehension and Fuel Economy Comprehension tasks (see Table 9).

Overall, the usability evaluation examined whether potential users could understand the information presented on a CS after an initial exposure. Although this exposes ways in which FEDIC designs can facilitate fast and accurate comprehension of fuel economy information, it is not possible to conclude which CS will best promote fuel efficient and safe driving behavior from these findings alone. One reason for this is that drivers may use this information differently over time as they grow accustomed to having it present and better understand how it relates to their driving behavior. Drivers' experience with a FEDIC will likely affect how they understand and prioritize this information while driving. Furthermore, drivers may have different motivations for driving fuel efficiently which may affect how frequently they use a FEDIC. It is therefore necessary to investigate how drivers use FEDICs in the context of driving, starting with the examination of driver behavior in the subsequent driving simulation experiment. Following that, an examination of long-term usage trends using a field study will allow for the examination of usage trends over longer periods of time under naturalistic conditions.

3.3.1 FEDIC CS Discussion

The results of the usability tests are rank-ordered by CS in Table 9. This rank-order ranges from "strong recommendation for further testing" (Rank 1) to "weak recommendation for further testing" (Rank 7).

Results of the usability testing indicated participants comprehended CS02 better than the other FEDICs. This was likely due to the information available in the leaves and dynamic bar graph with gridded references to fuel efficiency. Although participants agreed that CS02 was more "difficult to figure out" than others, their performance suggests that this was overcome during repeated exposure to the CS. Therefore, for the simulator test CS02 was used as a reference design to develop a FEDIC to display instant fuel economy.

An important distinction that emerged during the usability evaluation was whether information relating to driver *behavior* might be more useful than information relating to *fuel economy*. Specifically, it was noted that CS02 displayed a measure of driver behavior (i.e., acceleration and deceleration) while the remaining CS displayed measures of fuel economy. For this reason, during the simulation testing, CS02 was referred to as "FEDIC-B" because it displayed behavioral information. To determine which type of CS (i.e., behavior versus fuel economy) may result in behavior changes that affect fuel economy, each of the two CS evaluated within the simulator study were similar in design style to reduce participant response bias due to design differences.

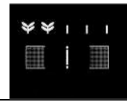
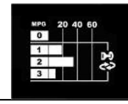
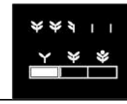
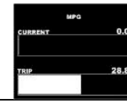
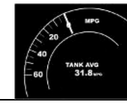
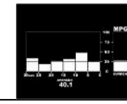
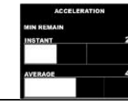
The design of the bottom portion of FEDIC-FE was inspired by the findings for CS03 and CS05; namely that participants favored the information presented on horizontal bars that had distinct end regions. CS06 also presented fuel economy information using horizontal bars and participants agreed it was easier to "figure out," although this CS received lower ratings overall for satisfaction and usefulness. It is likely these ratings indicate that participants understood the information on this CS but did not like that it lacked references for fuel economy information on the horizontal bar. Therefore, FEDIC-FE was designed to take these findings into account by presenting fuel economy information in a horizontal bar with references at each end to indicate high and low instantaneous mpg. FEDIC-FE was composed of a horizontal bar indicating instantaneous fuel economy, similar in function to the top bar in CS06, with marked mid-points and end-points (see Figure 11). To create design consistency between the FEDIC-B and FEDIC-FE designs, a hatched region was added to the left quarter of the horizontal bar to indicate fuel inefficiency (i.e., lower fuel economy), similar in design to the hatched regions in FEDIC-B (CS02). This created design consistency between the FEDIC-B and FEDIC-FE designs.

Table 6 highlights the timeframes of fuel economy information presented in each CS (i.e., instantaneous average, trip average, or overall fuel economy average). There was no single combination of timeframes that emerged as optimal during the usability results or that dominated the recommendations made in Table 9. However, the 30-minute time intervals presented in CS04 and cumulative averages shown in CS03 were related to a low percentage of binary response accuracy, suggesting that information presented in longer timeframes may require longer exposure for users to understand their meaning. It is likely that the combination of more than one timeframe (e.g., instantaneous fuel economy presented alongside trip fuel economy) helped participants make accurate responses to the measures during the usability evaluation. For this reason, drivers may be able to improve their fuel economy performance by viewing combinations of shorter (instantaneous) and longer-term (overall or trip average) CS fuel economy state information within a single FEDIC design.

3.4 Key Usability Evaluation Conclusions

- Horizontal bars and/or simple representations (i.e., pictures) of fuel economy information were the most usable.
- Participants preferred representative or symbolic forms of fuel economy information (e.g., bars or pictures) rather than text representation.
- Text representation can improve comprehension when presented along with representative component features.
- Presenting information relating directly to behavior may be as useful as presenting fuel economy information.
- The post-drive training CS was well received.

Table 9. Summary of the important findings from the usability test

Measure	FEDIC CS, Rank-Ordered by Performance							Training FEDIC CS	
	1. CS02	2. CS05	3. CS03	4. CS06	5. CS07	6. CS04	7. CS01	1t. CS10t	2t. CS09t
									
Initial Comprehension Task [a]	+	0	0	+	+	+	-	NA	NA
Fuel Economy Comprehension Task [b]									
Binary Response Accuracy	+	+	0	+	0	0	-	NA	NA
Timed Binary Performance	+	0	0	+	-	0	0	NA	NA
Accuracy of Scaled Responses	+	0	-	0	0	-	-	NA	NA
General Usability Measures									
Usability Scale [c]	+	+	+	-	-	-	-	-	0
Perceived Safety & Effectiveness [d]	-	-	-	+	+	-	+	+	-

Legend (by footnote):

[a] + indicates a mean score greater than 1 for both measures
- indicates a mean score less than 1 for both measures
0 indicates a mean greater than 1 for "what changes" and a mean less than 1 for "how it works".

[b] + indicates significant improvement compared to at least one other CS
- indicates significant decrement in performance compared to at least one CS
0 indicates mixed results.

[c] + indicates positive mean ratings for both "usefulness" and "satisfying" scales
- indicates negative mean ratings for both scales
0 indicates positive satisfying and negative usefulness ratings.

[d] + indicates significantly more favorable ratings for at least one question
- indicates significantly less favorable ratings for at least one question.

4. Driving Simulation Evaluation

The results of the focus groups conducted by Jenness et al. (2009), discussed earlier within this paper, suggested that drivers were aware of driving techniques (apart from, or during driving) that could reduce fuel consumption. It is not likely that the focus group participants had received any training on fuel efficient driving practices; they may have developed their techniques from experience. Interestingly, Voort et al. (2001) found a nearly 15% decrease in fuel consumption by asking drivers in a control group to drive fuel efficiently during their second drive through a 5 km urban scenario. In this case, it seems that the drivers carried-out latent driving strategies after they were asked to drive fuel efficiently. Although not reported, these driving strategies could have been similar to those reported by the Task 1 Focus Group.

Within the Voort et al. study, a group of drivers that used the fuel economy support tool exhibited a 23% reduction in fuel consumption while driving the same urban scenario. It is possible that this large reduction in fuel consumption was a result of a combination of the latent strategies and strategies conveyed via the fuel economy support tool. The fuel economy support tool encouraged fuel efficient driving practices, such as accelerating faster or slower depending on the driving context. For example, the support tool would suggest "smooth" use of the accelerator when cruising, during which a driver has fewer options for conserving fuel. The support tool also encouraged accelerating (i.e., changing gear) quicker to reach a cruising speed requiring the vehicle's drive gear. Driving in the highest gear is fuel efficient. In fact drivers can skip over lower gears in order to spend more time driving in the highest gear. Once drivers learn these types of strategies, long-term fuel savings can be achieved.

Johansson, Gustafsson, Henke and Rosengren (2003) found that drivers trained in EcoDriving decreased fuel consumption continuously over two weeks. EcoDriving training, which is now a requirement for obtaining a license in Sweden, teaches fuel efficient driving techniques (e.g., reaching the highest gear quickly, avoiding complete stops, using the engine for braking, coast to a stop, reversing with a warm engine, etc.). Johansson et al. found that EcoDriving helped drivers decrease fuel consumption by 8% over a two-week period. The drivers that exhibited greater decreases in fuel economy drove a Volvo S80 (large 5-cylinder engine). In comparison, there was no difference in fuel economy comparing a similar set of drivers that drove a less powerful Toyota Corolla (small 4-cylinder engine). Essentially, because of the fuel efficiency of the Toyota Corolla, there was little opportunity to improve fuel economy. Throughout the duration of the study, the fuel consumption of Toyota drivers, trained or not, was roughly 20% less than Volvo drivers. In light of these results, it may appear that drivers have two options to conserve fuel: they can modify their driving behavior or they can drive cars that are more fuel efficient. Despite these results, Johansson et al. argue that the combination of employing fuel efficient driver behavior while driving a fuel efficient car will result in the greatest fuel savings.

The fuel efficient driving behaviors trained through EcoDriving, intuitively, sound like safe driving behaviors. An exploration of the fuel efficiency of drivers that have had crashes could provide some perspective on the safety of driving fuel efficiently. Haworth and Symmons (2001) conducted an archival study and found that the fuel consumption of fleet vehicles involved in a crash was 11% to 13% greater than that of fleet vehicles not involved in a crash. Drivers that did not crash likely drove in a fuel efficient manner that decreased crash risk. Haworth and Symmons claim that these drivers maintained the speed limit and had greater smoothness of driving. Yet their conclusions are met with a high degree of speculation because the fleet vehicles in their sample were not often driven by the same person, rather there were several operators for each vehicle in the fleet. Although a true measure of crash risk is difficult to obtain, the safety of fuel efficient driving behavior could be inferentially measured.

Celeration, which is a measurement of absolute changes in speed, has been shown to be loosely related with crash likelihood. Wahlberg (2008) has reported correlations between celeration and crash frequency ranging from .38 to .51. In light of several fuel efficient driving behaviors that required drivers to reduce the variability in speed (e.g., smooth driving, maintaining an optimal cruising speed, slow acceleration, slow braking) celeration may be a useful measure for inferring the safety of fuel efficient driving such that if fuel efficiency is high, celeration is likely low.

Assuming that the fuel efficient driving behavior mentioned throughout this report is safe and that fuel efficient driving can be facilitated by in-vehicle driver assistive systems like a FEDIC, should there be a concern for driver distraction? As previously mentioned in this paper, in-vehicle information systems, particularly visual displays, have been shown to increase driver distraction such that vehicle control is compromised (Jamson & Marat, 2005). Mental workload has been shown to increase while drivers interact with in-vehicle information systems (Rakauskas et al., 2008). In-vehicle technologies that create high mental workload may not be well received by drivers and, as a result, may not be used or may be turned off. Within the Usability Evaluation described earlier in this report, the FEDIC CS that presented acceleration information relative to fuel economy was determined to be the easiest to comprehend. As a result, mental workload associated with this CS would be expected to be low. Because this CS does not provide a direct metric of fuel economy, the project team designed a novel FEDIC that was similar in appearance; this new FEDIC presented instantaneous fuel economy along with the trip fuel economy.

A driving simulator evaluation was conducted to investigate the effect that a FEDIC would have on fuel economy and behavior. The simulator evaluation employed three driving scenarios in which drivers had the opportunity to alter their driving behavior to affect their fuel economy. The first scenario was in an urban setting that contained multiple stops, to follow up on the results obtained by Voort et al. (2001) and Larson and Erickson (2009), which suggested that altering driving behavior to conserve fuel can have a larger impact in an urban setting. The second scenario consisted of several miles of highway without other vehicles. This permitted evaluation of driver behavior unbounded by traffic conditions. The third scenario consisted of a highway setting with a lead vehicle. This permitted evaluation of the extent to which driving fuel efficiently would couple with lead vehicle speed. Similar to Voort et al. (2001), this method required 3 conditions: baseline, driving fuel efficiently, and driving fuel efficiently with a FEDIC. All participants performed baseline driving within the three scenarios to provide measures of fuel economy and driving behavior. Following the baseline drive, all of the drivers were asked to drive fuel efficiently for a second set of drives. These drivers were split into three groups: one group drove with the acceleration FEDIC (B), the second group drove with the fuel economy FEDIC (FE) and the third group drove without a FEDIC.

Voort et al (2001) and Larsson and Ericsson (2009) found driving behavior changed as a result of fuel economy support tools being present within vehicles. Yet, the circumstances under which driver behavior changed, resulting in increased fuel economy, mainly occurred under conditions that required drivers to stop frequently. Alternatively, the benefit of training drivers on fuel efficient driving behavior translates fuel savings to broader driving situations (e.g., driving smoothly on the highway). Thus, the research questions remain:

1. Does the presence of a FEDIC in the vehicle improve fuel economy? In particular, which FEDIC (FEDIC-B or FEDIC-FE) may influence behavior to the greatest degree?
2. Can a driver be fuel efficient without the assistance of a FEDIC display?
3. Does a FEDIC improve fuel economy beyond what a driver can accomplish without a FEDIC?

Specifically, can the FEDICs tested help drivers change behavior to increase fuel economy within urban and highway settings? By asking drivers to drive fuel efficiently, a comparison between fuel efficient driving with and without the support of a FEDIC can be made to determine the extent to which a FEDIC facilitates fuel efficient driving and encourages behavioral adjustments. Another consideration is that the addition of a FEDIC to the vehicle is equivalent to adding another information source that may take a driver's attention away from the road and increase mental workload. Within the context of this evaluation, therefore, it would be prudent to answer the question of whether the use of a FEDIC influences driver workload or stress. Finally, should a FEDIC's information or design be confusing to drivers, they are likely not to use it. In this instance, the drivers will not benefit from having the FEDIC within the vehicle, so drivers must be asked whether they perceive these FEDICs as user-friendly devices. If these FEDICs are found to be usable, it may be assumed that drivers using them in actual driving environments will also use them and will benefit from the additional information.

The behavior observed during this study should be comparable to behavior of drivers during initial FEDIC use only. The long-term impact of FEDIC use on fuel economy and safety will be understood only through a longer-term examination, such as a field operational test. Findings from this experiment will be useful for understanding how drivers react to and use these systems, and will be used to recommend CS for field testing (as part of Task 4).

4.1 Methodology

4.1.1 Participants

Thirty participants (15 females and 15 males) between the ages of 18 and 50 (M = 32.2 years of age, *SD* = 10.8) were recruited for the current study (see Appendix J for recruitment ad content). This participant sample size was selected because previous experience with simulation evaluations of driving performance of this size typically exhibit sufficient power to find statistical differences if they exist, no driving simulation experiments relative to FEDICs could be found that provided sufficient information to conduct a power analysis to more accurately determine sample size, and recruiting additional participants was beyond the scope and budget of the project. Participants were screened using a simulator sickness questionnaire (see Appendix K) to avoid recruiting participants who were susceptible to simulator-induced sickness. All participants possessed a valid Minnesota or Wisconsin driver's license, had 20/40 or better vision (corrected or uncorrected that was confirmed using a visual acuity test (Optec Vision Tester, Model No. 2500 (Stereo Optical Co., Inc, Chicago, IL), as described in the procedures section), and possessed no known cognitive or physical limitation that would interfere with their performance in the study. The average estimated annual mileage per participant was 18,300 miles per year (*SD* = 10,600 miles per year).

In light of the notion that previous experience with a FEDIC may bias participant perceptions or driving behaviors in the current study, it was necessary to query participants about FEDIC use to verify homogeneity of this factor across groups. Using a scale from "Never" (1) to "Always" (5), participants were asked "how frequently" they thought about fuel economy while driving. The mean participant response was 3.7 (*SD* = 1.1) and a one-way between-subjects ANOVA showed no significant differences between the between-subjects FEDIC groups (Table 10), all $p > 0.05$. Also 23% of the total participant sample (7 participants across all three groups) reported that they had some display in their vehicle that depicted fuel economy information. Participants drove a similar amount of annual miles and were similarly concerned about fuel economy.

4.1.2 Apparatus

4.1.2.1 Driving Environment Simulator

The study was conducted using the HumanFIRST Program's driving environment simulator (manufactured by Oktal) within the ITS Institute at the University of Minnesota. The driving environment simulator consisted of a full-sized Saturn vehicle with realistic operational controls and instrumentation. The display consisted of a high-resolution visual scene (1.96 arc minutes per pixel) projected to a 5-channel 210-degree forward field-of-view screen. The rear visual scene was projected onto a screen behind the vehicle and was visible in the vehicle's rear-view mirror. LCD panels placed on the side mirrors provided rear-view mirror views. Auditory and haptic feedback were provided by a 3D surround audio system, subwoofer, car body vibration, and a three-axis electric motion system (roll, pitch, z-axis) system. See Figure 9 for a depiction of the driving environment simulator.

Figure 9. Depiction of the HumanFIRST program driving environment simulator

4.1.2.2 Fuel Economy Driver-Interface Concept (FEDIC) Conditions

Results of the usability testing identified two FEDIC CS to be evaluated within the driving environment simulator study. In the current study each of the FEDIC CS was 1) presented on a liquid crystal display (LCD) panel in the cockpit of the vehicle to mimic the type of display that would be employed in an actual vehicle, 2) was positioned over the center instrument cluster (by having all displays in one location so that any bias due to location was minimized), and 3) was designed so that participants could interact with the display only visually to reduce the potential for physical interaction and subsequent distraction. See Figure 10 for a depiction of the FEDIC-FE within the instrument cluster on the right side (FEDIC-B was placed in the same location). Note that the bright points of light near the bottom, center of Figure 10 are infrared LEDs that surround a camera and were used to illuminate the driver's face, but they were not visible to the driver.

Figure 10. Display location of FEDIC-FE within the driving simulator instrument cluster

4.1.2.2.1 Behavior Information FEDIC

In the usability evaluation task, CS02 (Figure 11), which depicted behavioral information (in the form of acceleration), was found to be highly usable and, due to its potential to influence driver performance, it was selected for testing in the current simulation evaluation study. This CS was termed here as “FEDIC-B” to denote its display of behavioral information. FEDIC-B displayed a horizontal bar that increased in size to either the left or right to provide instantaneous feedback regarding acceleration (increasing to the right) and deceleration behaviors (increasing to the left). The bar position depicted the moving average of acceleration (averaged over the previous one second), updated at a rate of 20 Hz. Hatched regions were depicted on each end of the display to indicate when a participant’s acceleration was excessive and would negatively affect fuel economy. The bottom of the deceleration scale was -2m/s^2, the top of the acceleration scale was +2m/s^2, and the hatched regions started at +/- 1.133 m/s^2. The interface functioned exactly as specified during the usability test (see CS02 in Appendix F). Note that the top portion of both FEDIC displays examined in this study contained a pictorial representation of fuel economy for the current trip, where leaves grew on stems as the driver’s fuel economy increased over the course of that drive (see the top portion of CS02 and CS03 as described in the usability description in Appendix F).

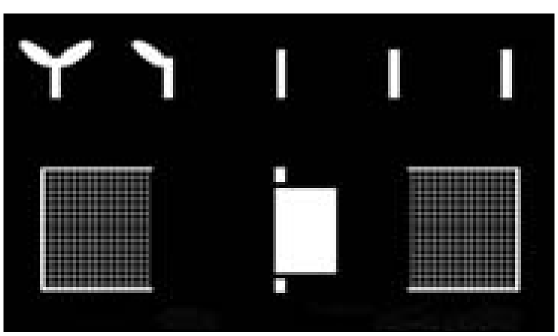
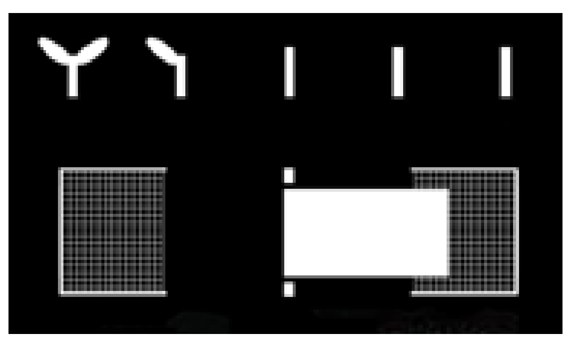
a.  b. 

Figure 11. The FEDIC-B display showing instantaneous behavioral (acceleration & deceleration) information during a) gentle acceleration, and b) heavy, fuel-inefficient acceleration

4.1.2.2.2 **Fuel Economy FEDIC**

As described in the usability evaluation results, a new FEDIC CS was developed that was similar in format and style to FEDIC-B (see Figure 12 for a depiction). This display was termed "FEDIC-FE" because it displayed fuel economy information. The FEDIC-FE displayed a horizontal bar that increased in size to the right to provide drivers instantaneous fuel economy feedback. The bar position depicted the moving average of fuel economy for the previous five seconds, updated at a rate of 20 Hz. This bar functioned similarly to the "instant" bar on CS06 as specified during the usability test (see Appendix F) and a vertical line was drawn in the middle of the bar-region to improve interpretation of fuel economy level, as recommended by the findings of the usability evaluation. In addition to this, a hatched region was provided at the end of the display to indicate to participants when their fuel economy was excessively low.

a. b.

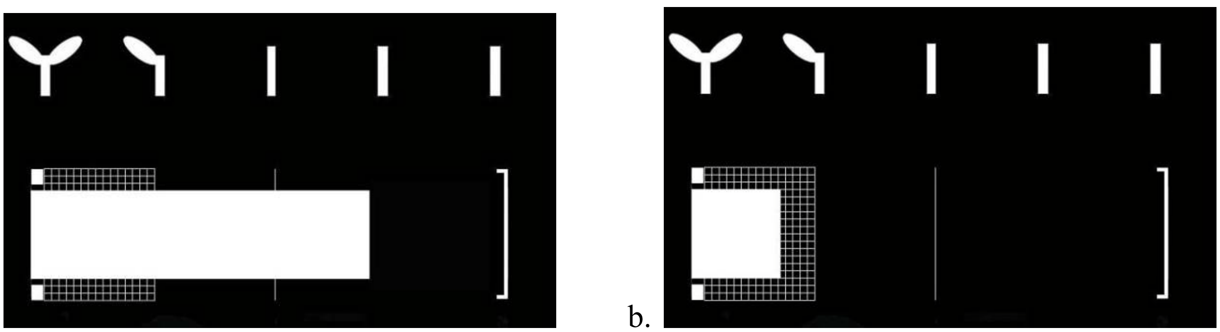


Figure 12. The FEDIC-FE display showing instantaneous fuel economy information during a) gentle acceleration, and b) heavy, fuel-inefficient acceleration

4.1.1 Driving World Landscape, Weather, and Traffic

The landscape for all driving worlds was generic for the Midwest and appeared believable for Minnesota. The sky within the driving world was partly cloudy and the road conditions were dry. Generic traffic existed on roadways to give the appearance of a naturally populated driving environment. The generic traffic included a mixture of cars, vans, and trucks and they did not interfere with the scripted behaviors of the target vehicles, scenarios, or events. The volume of the generic traffic was moderate (i.e., 1 to 2 vehicles per mile).

4.1.2 Driving Scenarios

Participants completed three separate driving scenarios that were repeated in each of two "drives." The driving scenarios were representative of those that are typically experienced in actual driving and represent scenarios where drivers could change fuel economy through driving behavior changes. The scenarios included "stop-and-go," free driving, and car following. Both the stop-and-go and the car following scenarios required participants to follow a lead vehicle. Research has shown that the introduction and continued use of an in-vehicle task typically results in decreased car following performance (Manser, Ward, Kuge, & Boer, 2004; Rakauskas et al., 2008). However, in the current study it was necessary for participants to feel as if their behaviors were not restricted to those exhibited by the lead vehicle so they could drive in a more fuel efficient manner when asked to do so or when they were provided with a FEDIC. Descriptions of the research scenarios, environments, vehicle dynamics, and dependent measures for each of the driving scenarios are presented below. The dependent variables for each driving scenario were grouped according to primary research constructs that provided insight into driving behavior, effort (comfort), and usability. The driving behavior dependent variables are described within the description of each scenario while the dependent variables for the effort and usability constructs are presented in the Effort and Usability Questionnaires section.

4.1.2.1 Stop-and-Go (SG)

The world for the SG driving scenario consisted of an approximately two-mile long, four-lane (non-divided) roadway with emergency lanes on both sides. The roadway traveled through both suburban and urban environments. The suburban environment depicted typical suburban buildings with storefronts, parking lots for the stores extending to the road, and parked cars. The urban environment consisted of tall buildings, sidewalks, pedestrians, parked cars, and emergency lanes (see Figure 13 for a depiction of this environment).

The SG scenario presented a lead vehicle traveling along the road at the posted speed limit (35 mph). Participants were presented with a narrative that indicated they were following a friend who was driving the lead vehicle and going to the airport. Participants were told it was important that they not lose their friend because only the friend knew the route. The participant was instructed to follow their friend at a close but safe distance so they would not become separated from their friend and to obey all traffic laws. These instructions ensured that participants would follow at a reasonably close but safe distance to the lead vehicle (this was needed to calculate several dependent variables). During its journey the lead vehicle encountered three intersections with stop signs as traffic control devices. As the lead vehicle approached an intersection it decelerated at a linear rate of 1.5 m/s^2 to a complete stop at the stop sign, remained at the stop sign for one second, and then accelerated at a linear rate of 1.5 m/s^2 to the posted speed limit. After the third intersection the lead vehicle pulled out of the participant's lane and the participant was instructed to continue driving. The participant then approached a fourth intersection with a stop sign (no lead vehicle). The entire scenario lasted approximately 10 minutes.

The SG scenario was chosen for inclusion in this study because it is experienced frequently in real-world driving and represents a scenario in which drivers could modify their behaviors to improve fuel economy. For example, drivers who desire to increase fuel economy could drive in a less assertive manner when approaching and departing from the stop sign. Less assertive driving may also result in improved safety. Participants were presented with a lead-vehicle following scenario to examine how fuel economy might be affected by the presence of a lead vehicle (Stops 1, 2, & 3) that may limit driver behaviors, at least longitudinally. In contrast, the final SG Stop (4) was intended to examine how drivers would modify fuel economy and safety without the limits imposed by a lead vehicle.

Performance was examined before and after each of the four stop sign events to identify any learning effects over the four stops. This examination included a subset of all dependent variables to better focus on the question of learning. The fuel economy dependent variables consisted of celeration and fuel economy (calculated from the vehicle). Minimum speed was also used as a dependent variable because drivers who attempt to drive fuel efficiently may not stop completely (rolling through a stop sign could be more fuel efficient than coming to a complete stop, which could negatively affect safety) . The results of these analyses suggested that there was not a significant learning effect (see results in Appendix R, section 6.1.1.3).

Dependent variables were categorized according to the primary research constructs of: 1) fuel economy, and 2) associated behaviors, which provided insight into behavior changes that may affect safety. Performance while following the lead vehicle (Stops 1, 2, & 3) was examined separately from the behavior while not following a lead vehicle (Stop 4) in a first set of analyses by averaging performance across the three lead vehicle Stops. The following dependent variables were collected across all SG scenarios:

<u>Fuel Economy</u>

- Fuel Economy (FE) – Fuel economy (miles per gallon) was derived by taking the distance traveled by the participant divided by the amount of fuel used based on the driving simulator's measure of fuel consumption (mL/s). This measure was representative of fuel consumption in an on-road Saturn vehicle with an average fuel economy of 30 mpg. The analysis of FE data focused on the 50 meters before and after each stop sign due to the notion that FE in this area would be most sensitive to changes in performance. Higher values of FE were taken as an indicator of increased fuel efficiency.
- Celeration – The average of the differences between successive speed data points over time with respect to a finite distance. Low celeration values indicated lower variability in speed control and, as a result, higher FE. This measure is also directly related to crash risk (af Wahlberg, 2008). Individual celeration values were calculated for the 250 meters before and after each stop sign (minus the time spent at 0 mph).
- Time to Stop (TTS) – Elapsed time from the release of the accelerator pedal to minimum speed. Longer TTS scores represented longer, more gradual decelerations and, as a result, higher FE.
- Time to Accelerate (TTAc) – Elapsed time from initial acceleration from a stop sign to the posted speed limit. Longer TTAc scores represented longer, more gradual accelerations and, as a result, higher FE.
- 85^{th} Percentile Deceleration Rate (85% Dec) – 85^{th} percentile deceleration rate between the start of lead vehicle deceleration to minimum speed. A lower 85% Dec indicated more gradual braking and, as a result, higher FE.
- 85^{th} Percentile Acceleration (85% Acc) – 85^{th} percentile acceleration rate between minimum speed at the stop sign and reaching the posted speed limit. A lower 85% Acc indicated more gradual accelerating and, as a result, higher FE.

<u>Associated Behaviors</u>

- Minimum Speed (Speed Min) – The minimum speed observed during the approach to and arrival at each stop sign. A lower speed (ideally, 0 mph) indicated higher compliance with the stop sign.
- Maximum Brake Pedal Position (Max BP) – Maximum brake pedal position (0 = no pedal depression, 1 = full pedal depression) between lead vehicle brake initiation and minimum speed achieve by participants. Higher Max BP indicated a participant was

reacting to the lead vehicle brake event instead of anticipating the lead vehicle brake event and, therefore, this behavior was associated with reduced attentiveness.

- Time-to-Contact at Lead Vehicle Braking (TTC Brake) – Time-to-contact was calculated by taking the distance from the participant's vehicle to the lead vehicle and dividing that by the difference in speed between the two vehicles. TTC Brake was measured at the first onset of lead vehicle braking. Low TTC Brake scores were indicative of close following, which could increase the likelihood of a crash.
- Minimum Time-to-Contact (TTC Min) – Time-to-contact was calculated by taking the distance from the participant's vehicle to the lead vehicle and dividing that by the difference in speed between the two vehicles. The minimum TTC value observed between the lead vehicle and participant vehicle during the approach to each stop sign. Low TTC scores were indicative of close following and/or delayed response to the lead vehicle braking, which could increase the likelihood of a crash.
- Eye Glance Frequency (EGF) – Frequency of eye glances to the FEDIC and/or speedometer from 250 meters before to 250 meters after each stop sign. A high frequency of glances to a FEDIC is indicative of distraction. The protocol that was employed for coding eye glances can be found in Appendix N.

Figure 13. Depiction of the Stop-and-Go (SG) scenario environment

4.1.2.2 Free Driving Scenario (FD)

The FD scenario consisted of a 10-mile long, four-lane divided highway through a suburban environment. The roadway contained both straight and curved sections and was modeled after a local highway, Minnesota Highway 169, to increase the realism of the simulation and ecological validity of the results. The sides of the roadway contained tall buildings with photo-realistic texture patterns. Off-ramps, highway road signs, and ambient traffic also populated the scenario to increase realism. See Figure 14 for a depiction of a typical section of the FD scenario. Drivers were asked to maintain a speed at or near as possible to the posted speed limit. This scenario lasted approximately 10 minutes. In light of the notion that drivers often "settle into" a drive after a few minutes and potentially become impatient near the end of a drive, only data between the second and sixth minutes (4 minutes of data in total) of the 10-minute drive were analyzed to remove potentially biased results. The FEDIC conditions for this scenario were compared on the following dependent variables:

<u>Fuel Economy</u>

- Fuel Economy (see description in methods for SG scenario)
- Celeration (see description in methods for SG scenario)

<u>Associated Behaviors</u>

- Steering Entropy (SEnt) – SEnt is analogous to the standard deviation of steering wheel position over time (Nakayama, Futami, Nakamura, & Boer, 1999). Increased variability in steering position was indicative of decreased lane keeping ability. When a driver was focused on vehicle steering control, the variability in steering wheel position was expected to decrease due to making frequent, small corrections in steering behavior. This would be identified by low SEnt. Therefore higher SEnt indicated decreased attention to lateral control.
- Pedal Entropy (PEnt) – PEnt is analogous to the standard deviation of pedal position over time (Nakayama et al., 1999). Pedal entropy was calculated using pedal position as the input variable with the SEnt formula. When a driver was focused on controlling vehicle acceleration, the variability in accelerator pedal position was expected to decrease due to making frequent, small corrections in pedal behavior. This would be identified by low PEnt. Therefore higher PEnt indicated decreased attention towards longitudinal control.
- Eye Glance Frequency (EGF) – (see description in methods for SG scenario).

Figure 14. Depiction of the free driving and car following scenario environment

4.1.2.3 Car Following Scenario (CF)

The roadway and environment employed for the CF scenario was identical to the FD scenario. Within the car following scenario a lead vehicle was scripted to follow a specified speed profile in which the speed pattern of the lead vehicle varied in a sinusoidal wave-form pattern with an amplitude between 45 to 60 mph and at a randomly shifting frequency between .02 to .04 Hz. This random speed profile was chosen so that drivers could not anticipate lead vehicle speed changes and because they were similar to real-world driving situations.

Traditionally, participants in CF scenarios are instructed to follow the lead vehicle at a constant, close, but safe distance at all times. Participants' driving behaviors are expected to be restricted because they are attempting to conform their behaviors to those of a lead vehicle. To reduce the emphasis on conformity, participants were presented with a narrative that indicated they were following a friend who was driving the lead vehicle and was going to the airport. Participants were told that it was important that they not lose their friend because only the friend knew the route. With these instructions, participants were able to car follow at a distance where they did not become separated from their friend while also employing behaviors that they felt were fuel efficient. The FEDIC conditions within the CF scenario were compared on the following dependent variables:

Fuel Economy

- Fuel Economy – (see description in methods for SG scenario)
- Celeration – (see description in methods for SG scenario)
- Coherence (Coh)[2] – Coherence was defined as "a measure of squared correlation that provided an indication of the accuracy of drivers' speed adaptations" (see Brookhuis, DeWaard, & Mulder, 1994). This was a measure of how well a driver was able to maintain a safe, constant distance between their vehicle and the lead vehicle. It is similar to R^2 with a range between 0 and 1. A perfect match in speed signals has a value of 1. Typically, a value < 0.3 suggests that car following was not achieved which suggest that this measure and other measures of CF should not be evaluated. This measure (as well as MinTH, Mod, and Delay) has been employed to examine the effects of distraction due to the inclusion of in-vehicle devices because of its sensitivity to driving behavior changes. Poor car following performance results in a low Coh score. However, when participants were asked to drive fuel efficiently in this study, Coh was expected to be low because participants would adopt a CF pattern that would be different from the lead vehicle to improve fuel economy. For example, instead of a marked change in speed (as exhibited by the lead vehicle) the participant may have opted to gradually change speed. Therefore lower coherence was indicative of an increased attempt to improve fuel economy.
- Amplification/Modulus (Mod) – A measure representing the amplification of the participant speed signal with respect to the lead vehicle. It can be interpreted as the magnitude of overshoot (Mod > 1) or undershoot (Mod < 1) in the participant speed signal. Overshooting was indicative of distraction (i.e., the participant was not attending to the lead vehicle speed change and overshot the peak speed) while undershooting was indicative of an attempt to improve fuel economy by maintaining a smooth speed profile that sacrificed good car following performance.
- Phase Shift (Delay) – Delay represents the lag between the two speed signals. It represented the time delay of the participant response to the speed increase or decrease initiated by the lead vehicle. Larger delays were indicative of an attempt to improve fuel economy by maintaining a smooth speed profile while sacrificing good car following performance.

An example of Coh, Mod, and Delay is presented in Figure 15. This example indicates high correspondence between the lead and following vehicles (i.e., Coh = 0.97, Mod = 0.96, Delay = 1.1 sec). In contrast, the example in Figure 16 indicates low correspondence between the lead and following vehicles (Mod = 1.14, Delay = 5.77 sec). This example demonstrates that changes in car following performance can be evident from these different performance measures. The metrics of mean time headway, coherence, amplification, and delay were included in the current

[2] Coherence was only computed when the average time headway for the scenario was less than 6 seconds. Modulus and delay were computed with an associated valid coherence value greater than 0.30. Participants who did not meet both of these criteria were excluded from all three coherence measures.

study due to their sensitivity in detecting changes in CF performance as a result of the inclusion of an in-vehicle device.

Associated Behaviors

- Minimum Time Headway (MinTH) – Time headway was calculated by taking the distance from the participant's vehicle to the lead vehicle and dividing that by the speed of the participant's vehicle. MinTH was the minimum time headway value observed between the lead and participant vehicles throughout the scenario. Lower MinTH indicated that the driver would have less time to react if the lead vehicle were to brake.
- Minimum Time-to-Contact (TTC Min) - Time-to-contact was calculated by taking the distance from the participant's vehicle to the lead vehicle and dividing that by the difference in speed between the two vehicles. The TTC Min value was observed between the lead and participant vehicles throughout the scenario. Lower TTC Min scores were indicative of close following and/or delayed response to the lead vehicle braking, which could increase the likelihood of a crash.
- Eye Glance Frequency (EGF) – (see description in methods for SG scenario)

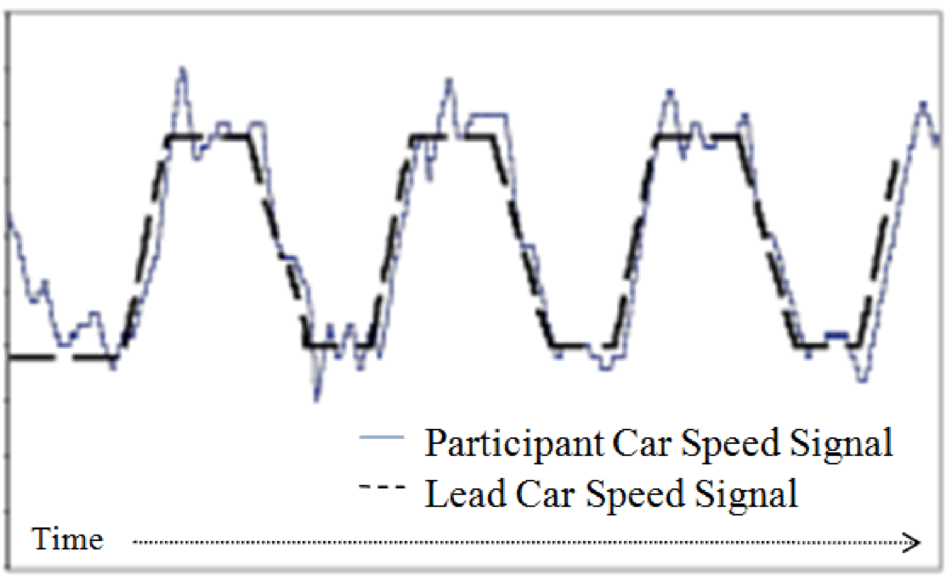


Figure 15. High correspondence between lead and following vehicle speed profiles during sustained car following

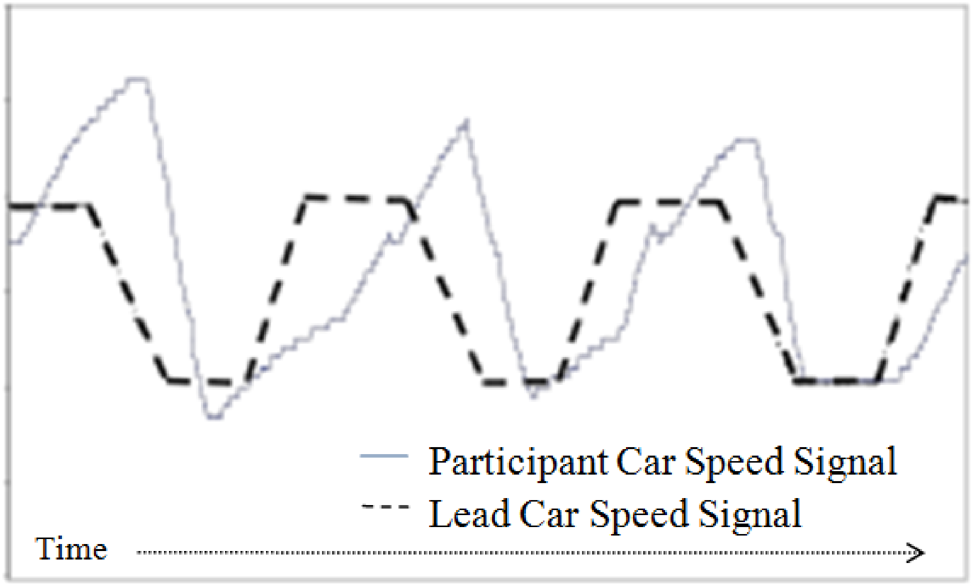


Figure 16. Low correspondence between lead and following vehicle speed profiles during sustained car following

4.1.3 Effort and Usability Questionnaires

4.1.3.1 Measure of Effort

Driver effort relative to FEDIC use was examined through the use of the Rating Scale Mental Effort questionnaire (Zijlstra, 1993) (see Appendix O). The Rating Scale of Mental Effort (RSME) quickly assesses levels of effort while driving with and without in-vehicle devices. High ratings are indicative of high mental workload. It is important to examine mental effort because a device (e.g., one of the two FEDICs being evaluated) that promotes high mental effort may not be well-received by drivers and, as a result, may not be used by drivers.

4.1.3.2 Measures of Usability

Usability assessment tools provided qualitative data regarding perceived use, benefit, value, usefulness, satisfaction, and trust relative to each FEDIC. FEDIC-B and FEDIC-FE were compared using the following usability assessment tools:

- The Usability Scale (van der Laan, Heino, & DeWaard, 1997) (see Appendix G) employed during the usability evaluation was again used to assess participants' opinions about the usefulness and satisfaction of the FEDIC they experienced. The survey consisted of 9 questions with each question having a five-point Likert rating scale. Data were aggregated across participants for each FEDIC. FEDIC designs that received high usefulness (scores close to 2) and satisfying scores (scores close to 2) were considered to be indicators of high usability. To verify correspondence of scores between the usability and driving simulation evaluations, Usability Scale results for the FEDIC-B and FEDIC-FE have been graphed alongside Usability Scale results from the top four recommended FEDIC-FE from the Usability Evaluation (Task 3, subtask B, phase I).

- Trust Questionnaire - Developed by Lee & Moray (1992), the Trust Questionnaire contains an array of questions that, when aggregated according to topic, evaluated four basic constructs consisting of performance, process, foundation, and purpose (see Appendix P). The performance construct provides insight into participants' feelings of how consistent, stable, and how desirably the system performed (questions 1 and 4). Process takes into consideration a fundamental comprehension of the rules that govern behavior (questions 2 and 5). Foundation is the most basic construct and it assesses the degree to which a participant feels the system is consistent with natural laws of behavior (questions 3 and 8). The purpose construct assesses the degree to which participants trust the underlying motives or intentions of the system (questions 6 and 7). A FEDIC that is trusted, as compared to one that is not, is more likely to be used by drivers.
- The Post Experiment Usability Survey asked drivers whether they would purchase a FEDIC if buying a car and the reason for their choice (see Appendix Q). It was important to examine this issue because driver perception regarding a FEDIC purchase can provide an indication of potential market penetration along with an indication of how a primary factor (cost) may influence market penetration.

4.1.4 Procedures

Participants first read and signed an approved human subject consent form (Appendix L)[3]. Participants then completed acuity (stereo, for far distances) and lateral visual field peripheral vision detection (35^o nasal and 55^o, 70^o, & 85^o temporal) tests using an Optec Vision Tester, Model No. 2500 (Stereo Optical Co., Inc, Chicago, IL) to verify nominal visual performance needed to use the driving simulation environment. Demographic and driving history questionnaires (e.g., number of years driving, type of car driven, history of traffic accidents) were then completed. This information was then used to verify homogeneity of participants across experimental conditions. In addition, if a participant's performance was dissimilar to other participants, the questionnaire data could have been used to identify the reason and support a rationale for exclusion from the study.

In light of the notion that previous experience with a FEDIC may bias participant perceptions or driving behaviors in the current study, it was necessary to query participants about FEDIC use to verify homogeneity of this factor across groups. Using a scale from "Never" (1) to "Always" (5), participants were asked "how frequently" they thought about fuel economy while driving. The mean participant response was 3.7 (SD = 1.1) and a one-way between-subjects ANOVA showed no significant differences between the between-subjects FEDIC groups (Table 10), all $p > 0.05$. Also, 23% of the total participant sample (7 participants across all three groups) reported that they had some display in their vehicle that depicted fuel economy information. This suggests that the three randomly assigned groups of participants were homogeneous in that the they drove a

[3] All experimental materials (e.g., consent forms, questionnaires) and procedures were reviewed and approved by the University of Minnesota Institutional Review Board before beginning the driving simulator study.

similar amount of annual miles, were similarly concerned about fuel economy, and a relatively equal number had fuel economy information available in their own vehicles.

Participants then performed a seven-minute practice drive along a two-lane, rural highway at moderate speeds to become familiar with the simulator and associated equipment thus reducing possible learning effects during the experimental drives.

Each participant was then randomly assigned to one of three experimental groups (see Table 10). Within each group, participants first completed a no-FEDIC baseline drive (Drive 1) in which participants were instructed to drive as they normally would in the real world. Participants then completed an experimental drive (Drive 2) in which they were instructed to drive as fuel efficiently as they could. Ten participants were provided with the FEDIC-B (Group 1), ten were provided with FEDIC-FE (Group 2), and ten were not provided with any FEDIC (Group 3). See Table 10 for grouping information, drive order, and participant instructions. A five-minute "break" was provided to participants between drives to reduce potential bias due to visual or physical fatigue associated with driving environment simulator use. Within each drive participants completed three driving scenarios (SG, FD, and CF) that were counterbalanced across participants and drive to reduce potential bias due to presentation order.

Participants completed the RSME after each scenario. At the conclusion of Drive 2, Groups 1 and 2 (i.e., groups using a FEDIC) completed the Usability Scale, Trust Questionnaire, and Usability Survey. All participants then read the debriefing protocol (Appendix M) and were compensated with $75.

Table 10. Participant grouping, drive order, and drive instructions

Group	N	Drive 1: "Drive as you would normally."	Drive 2: "Drive as fuel efficiently as you can."
1	10	Baseline	FEDIC-B
2	10	Baseline	FEDIC-FE
3	10	Baseline	No FEDIC

The experimental procedures summarized above were designed to allow for comparisons that provided insight into the utility of FEDICs when compared to normal "baseline" driving, into the utility of FEDIC-B versus FEDIC-FE, and whether drivers could be fuel efficient without the aid of a FEDIC. All participants experienced the same set of conditions during Drive 1 so that differences between groups during this drive could be identified and controlled for during the between-subjects comparison of FEDIC conditions of Drive 2. In cases when differences existed between groups during Drive 1, the baseline performance was used to standardize performance from the FEDIC condition drives during Drive 2. Comparisons within each Group between Drive 1 and Drive 2 show the within-subject effect of placing a FEDIC within a vehicle on driving performance and fuel economy. Comparisons of the three Drive 2 conditions show the between-subject difference between FEDIC conditions. Figure 17 presents a conceptual representation of the primary comparisons that relate to the three main research questions.

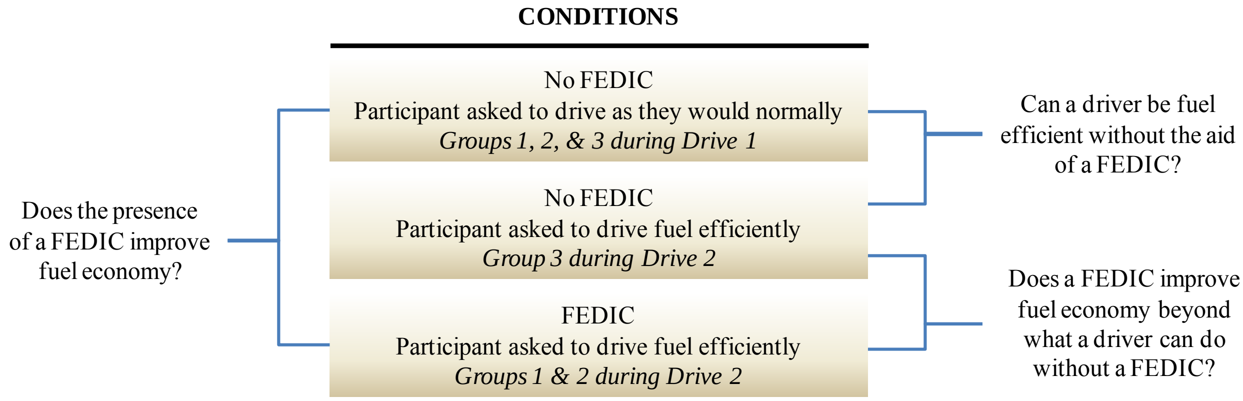


Figure 17. A conceptual representation of three group comparisons that will address each of the primary research questions

4.1.5 Statistical Methods

4.1.5.1 Independent Variables

The independent variables included Drive (Drive 1, Drive 2), FEDIC (FEDIC-B, FEDIC-FE, No FEDIC), and Stop, (Stop 1, Stop 2, Stop 3, Stop 4).

4.1.5.2 Statistics

First, regression analyses were conducted to determine the strength of the relationship between fuel economy and celeration within each scenario. Wahlberg (2002) reported a significant relationship between deceleration and fuel economy for bus drivers within an urban setting. However, the relationship between fuel economy and celeration has not been reported for urban, rural and highway settings, per se.

Before conducting any between-groups statistical comparisons it was necessary to verify that the three groups of participants were similar to each other in their baseline driving behavior. To determine this, t-tests were conducted between each of the Baseline driving scores (i.e., Group 1 Baseline versus Group 2 Baseline, Group 2 Baseline versus Group 3 Baseline, Group 1 Baseline versus Group 3 Baseline) for each dependent variable. Differences between means were considered significant at the $\alpha = .05$ level. A lack of significant differences between groups would support the contention that all groups were similar and that any differences between the groups were due solely to the FEDIC conditions. In cases where differences existed between groups for baseline data, then all individual participants' raw data were transformed by subtracting the group mean value of the baseline condition from each participants mean value before proceeding with subsequent between group comparisons. In other words, the mean baseline value for Group 1 was subtracted from the raw measures for individuals in Group 1.

Fuel economy and associated behavior variables for the CF scenario were examined by three within-subject paired comparison t-tests comparing Drive 1 against Drive 2 for each of the three groups (i.e., Group 1: Baseline versus FEDIC-B, Group 2: Baseline versus FEDIC-FE, and

Group 3: Baseline versus No FEDIC). A one-way between-subjects ANOVA was then performed on FEDIC-B, FEDIC-FE, and No-FEDIC dependent variable scores for fuel economy, behaviors, and mental workload to determine which treatment was the most influential.

Eye glance frequencies for each of the FEDIC conditions were compared through the use of a between-subject one-way ANOVA. For all analyses, differences between means were considered significant at the .05 level and were evaluated using a Tukey's HSD post hoc procedure.

To investigate if there were any learning effects over the four Stops during the SG scenario, a 2 x 3 x 4 (Drive x Group x Stop) mixed model ANOVA was performed. Drive (Drive 1 and Drive 2) and Stop (Stop 1, Stop 2, Stop 3, & Stop 4) were repeated within-subjects variables while Group (Group 1, Group 2, Group 3) was a between-subjects variable. These analyses were followed up with an examination of the fuel economy and behavior dependent variables for the first three stops to determine the extent to which behavior within these two constructs may have been influenced by the use of either FEDIC. This examination consisted of a 3 x 3 (Stop x Group) mixed model repeated measures ANOVA with Stop (Stop 1, Stop 2, & Stop 3) as a within-subject variable and Group as a between-subjects variable.

Ratings of mental effort (RSME) across FEDIC (FEDIC-FE and FEDIC-B) were analyzed with a one-way ANOVA with FEDIC as a between-subjects variable. Usability and trust scores for FEDIC (FEDIC-B, FEDIC-FE) were analyzed using one way ANOVAs to determine which FEDIC was perceived as being more usable and which was perceived as being more trustworthy. Responses from the Post Experiment Usability Survey question are presented as descriptive statistics.

4.2 Results

The results for all measures of the driving simulation evaluation are presented in Appendix R. However, a subset of results is presented in the following section that represents primary findings within each scenario. In both the results presented here and in Appendix R, only significant results are presented (non-significant results are not presented). An exception to this is when results were not significant but have strong trends that may be important to future research and FEDI design. Then results are organized according to the dependent variable analyses within each of the three driving scenarios. Note that in all figures, error bars represent ± one standard error from the mean.

4.2.1 Fuel Economy as a Function of Celeration

The relationship between fuel economy and celeration was significant within the Stop-and-Go scenario ($F(1, 57) = 322.5$, $p < .001$), the Free Drive scenario ($F(1, 59) = 13.7$, $p < .001$), and the Car Following scenario ($F(1, 59) = 25.3$, $p < .001$). As shown in Figure 18 the correlation between fuel economy and celeration was large within the Stop-and-Go scenario ($r^2 = .85$) but was small within the Free Drive ($r^2 = .19$) and the Car Following ($r^2 = .30$) scenarios.

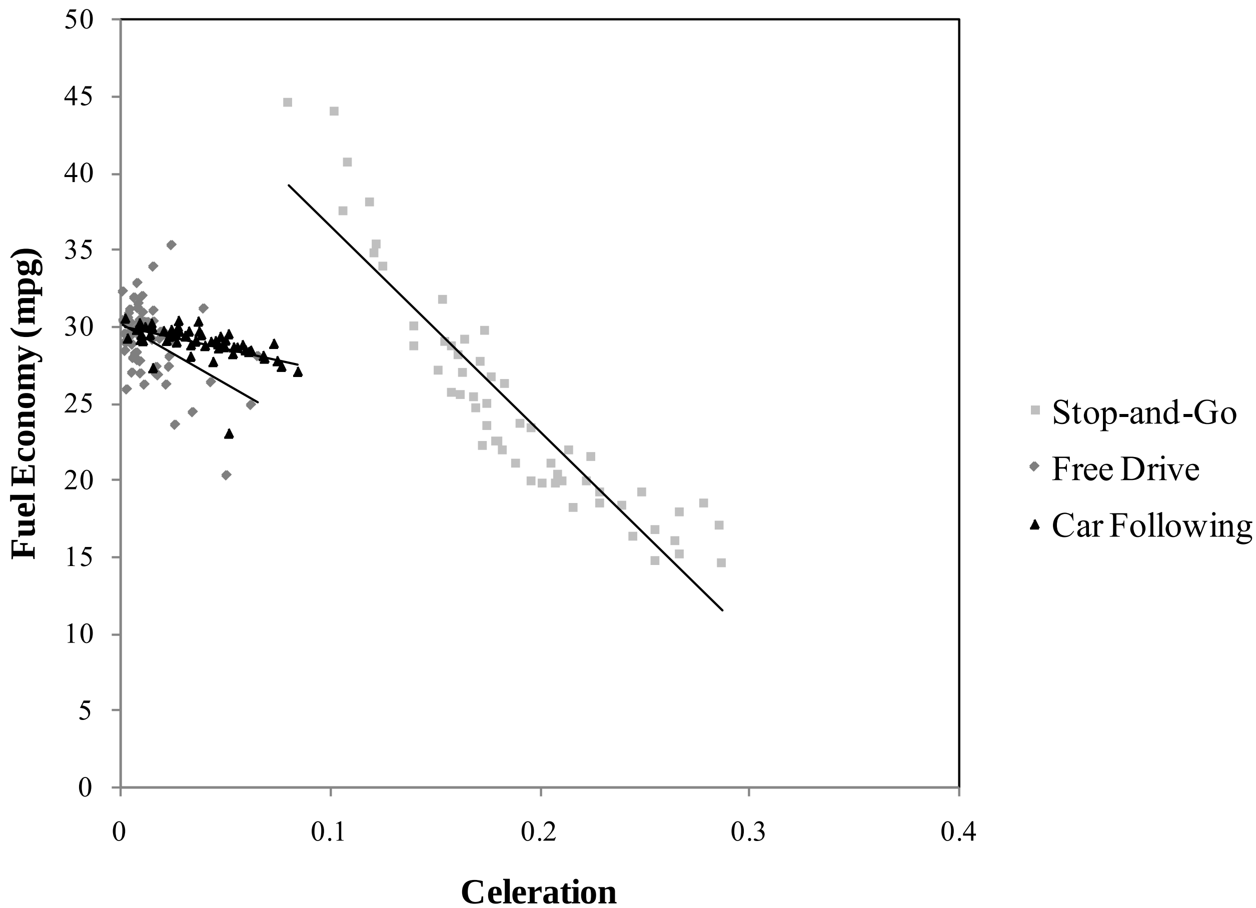


Figure 18. Fuel economy as a function of Celeration, where each data point represents a participant within the SG, FD, or CF scenario

4.2.2 Stop-and-Go (SG) Scenario

4.2.2.1 Fuel Economy

The results of the within-subject tests indicated significant differences for average fuel economy between Drives 1 and 2 for Groups 1, 2, and 3. Figure 19 shows that the significant difference within Group 1 ($t(29) = 6.61$, $p < .001$, $d = 1.27$) was due to the greater fuel economy exhibited by participants during Drive 2 ($M = 28.5$ mpg, $SD = 8.04$ mpg) as compared to Drive 1 ($M = 20.2$ mpg, $SD = 4.61$ mpg). The significant difference within Group 2 ($t(29) = 6.94$, $p < .001$, $d = 1.27$) was due to the greater fuel economy exhibited by participants during Drive 2 ($M = 32.1$ mpg, $SD = 8.95$ mpg) as compared to Drive 1 ($M = 21.0$ mpg, $SD = 4.91$ mpg). The significant difference within Group 3 ($t(26) = 6.35$, $p < .001$, $d = 1.54$) was due to the greater fuel economy exhibited by participants during Drive 2 ($M = 26.6$ mpg, $SD = 6.4$ mpg) as compared to Drive 1 ($M = 20.3$ mpg, $SD = 5.73$ mpg).

The one-way ANOVA indicated that fuel economy differed significantly as a function of Group ($F(2, 86) = 3.56$, $p <.05$). Follow-up Tukey paired comparisons indicated that the average fuel economy exhibited by Group 2 (M = 32.1 mpg, SD = 8.95 mpg) was significantly greater as compared to Group 3 (M = 26.6 mpg, SD = 6.4 mpg).

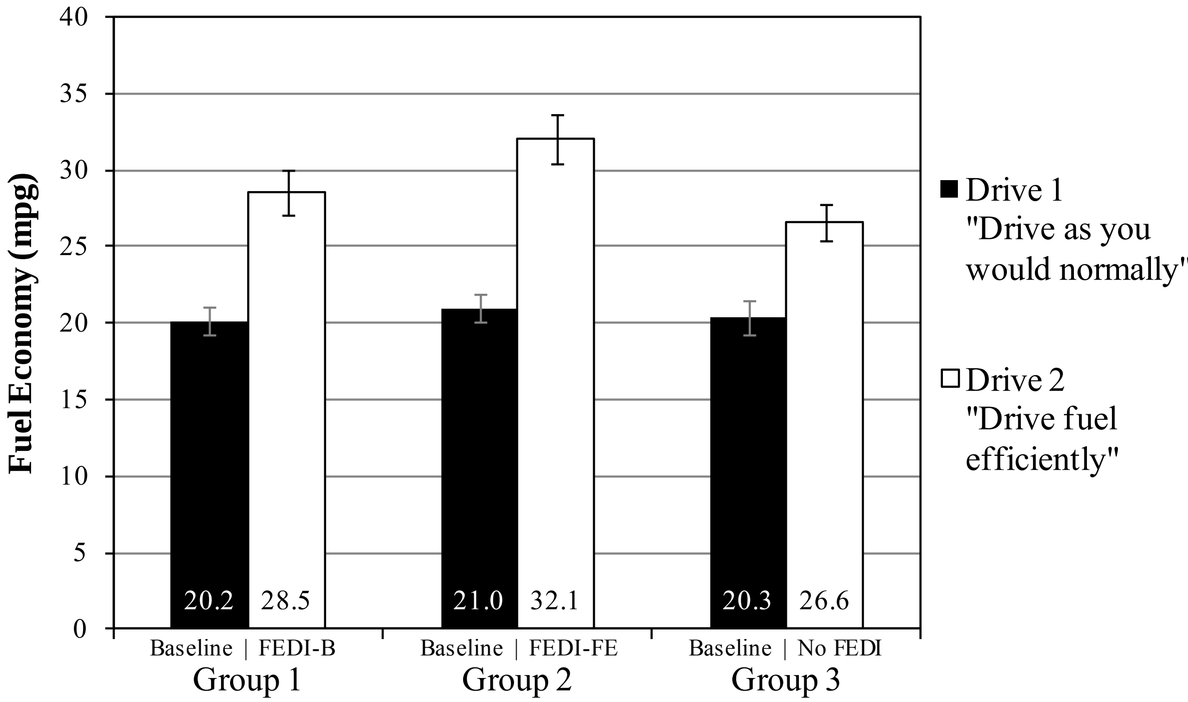


Figure 19. Average Fuel Economy (mpg) during the first three stops in the SG scenario

4.2.2.2 Celeration

The results of the within-subjects tests indicated significant differences for average celeration between Drives 1 and 2 for Groups 1, 2, and 3. Figure 20 shows that the significant difference within Group 1 ($t(29) = 8.67$, $p < .001$, $d = 1.53$) was due to the greater celeration exhibited by participants during Drive 1 (M = 0.23, SD = .051) as compared to Drive 2 (M = 0.16, SD = .036). The significant difference within Group 2 ($t(29) = 7.72$, $p < .001$, $d = 1.63$) was due to the greater celeration exhibited by participants during Drive 1 (M = 0.21, SD = .05) as compared to Drive 2 (M = 0.14, SD = .04). The significant difference within group 3 ($t(26) = 5.18$, $p < .001$, d =.98) was due to the greater celeration exhibited by participants during Drive 1 (M = 0.21, SD = .046) as compared to Drive 2 (M = 0.17, SD = .04).

The one-way ANOVA indicated that Drive 2 celeration differed significantly as a function of Group ($F(2, 86) = 5.14$, p <.01). The follow-up Tukey paired comparisons indicated that average celeration for participants in Group 3 (M = 0.17, SD = .04) was significantly greater compared to Group 2 (M = 0.14, SD = .05).

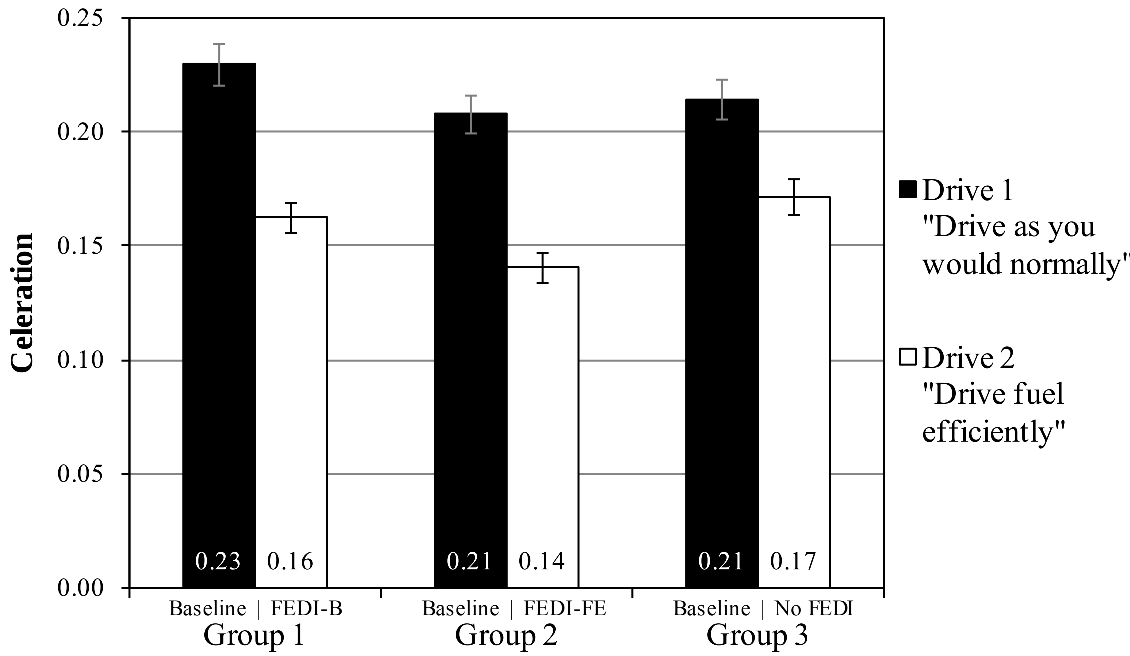


Figure 20. Average Celeration during the first three stops in the SG scenario.

4.2.2.3 Minimum Time-to-Contact (TTC Min)

The results of the within-subjects tests indicated a significant difference for TTC Min between Drives 1 and 2 for Group 1. Figure 21 shows that the significant difference within Group 1 ($t(29) = 4.36$, $p < .001$, $d = .96$) was due to the greater TTC Min exhibited by participants during Drive 1 ($M = 4.58$ s, $SD = 2.46$ s) as compared to Drive 2 ($M = 2.59$ s, $SD = 1.59$ s).

The one-way ANOVA indicated that Drive 2 TTC Min differed significantly as a function of Group ($F(2, 86) = 9.01$, $p <.001$). Follow-up Tukey paired comparisons indicated that Group 3 had significantly greater TTC Min ($M = 5.09$ s, $SD = 2.6$ s) compared to Group 1 ($M = 2.59$ s, $SD = 1.59$ s) and Group 2 ($M = 4.22$ s, $SD = 2.51$ s).

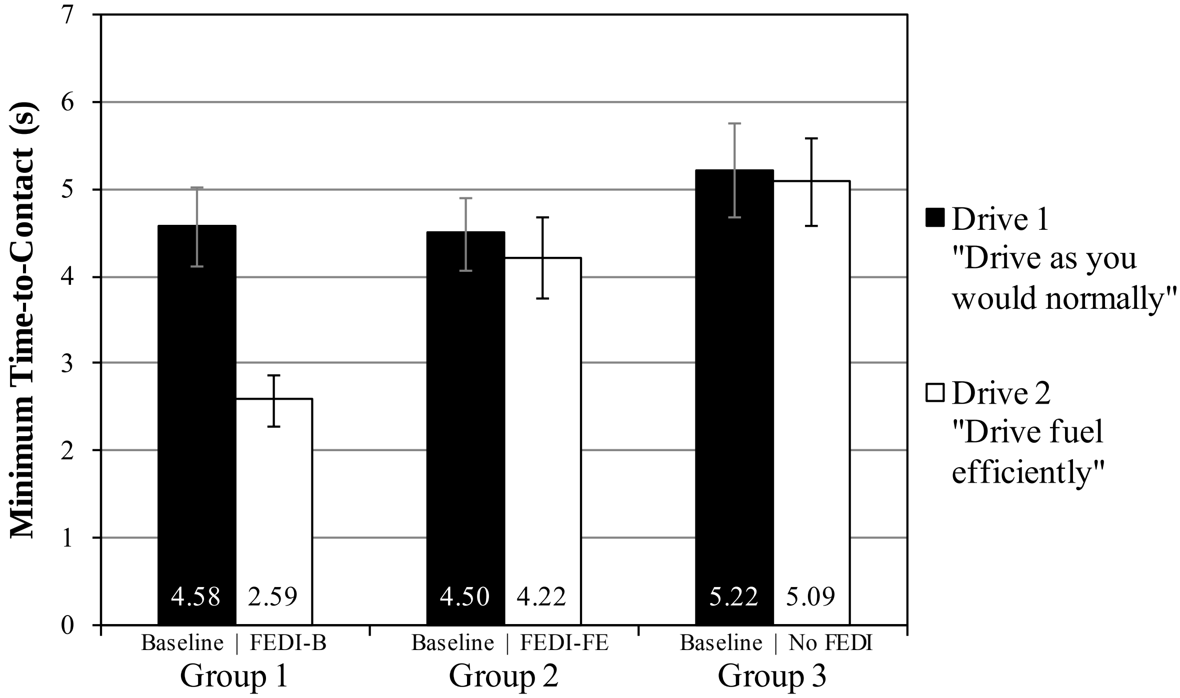


Figure 21. Minimum Time-to-Contact during the first three stops in the SG scenario

4.2.2.4 Eye Glance Frequency (EGF)

The within-subjects tests indicated significant differences in EGF between Drives 1 and 2 for Groups 1 and 2. Figure 22 shows that the significant difference within Group 1 ($t(8) = 3.70$, $p < .01$) was due to the greater EGF exhibited by participants during Drive 2 ($M = 30$, $SD = 12.6$) as compared to Drive 1 ($M = 11$, $SD = 5.9$). The significant difference within Group 2 ($t(9) = 3.79$, $p < .01$) was due to the greater EGF exhibited by participants during Drive 2 ($M = 25$, $SD = 9.2$) compared to Drive 1 ($M = 12$, $SD = 4.6$).

The one-way ANOVA indicated that Drive 2 EGF differed significantly as a function of group ($F(2, 24) = 4.10$, $p <.05$). Follow-up Tukey paired comparisons indicated that Group 3 had significantly lower EGF ($M = 16$, $SD = 5.6$) compared to Group 1 ($M = 30$, $SD = 4.2$).

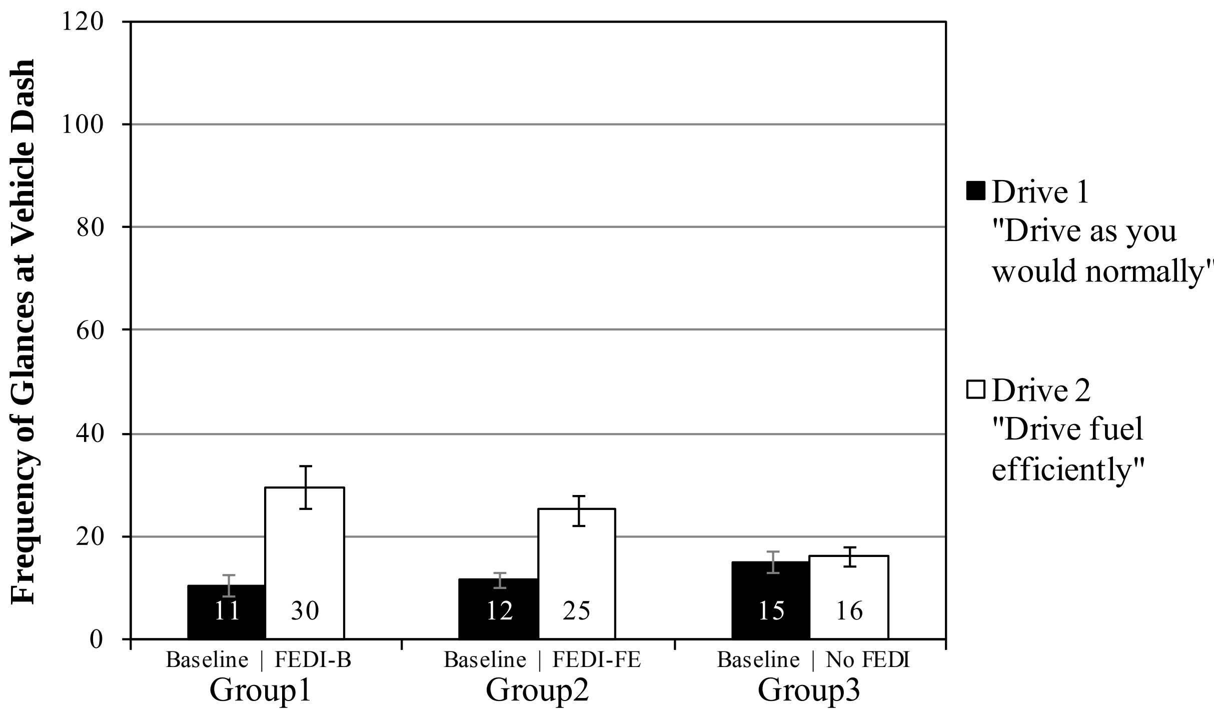


Figure 22. Eye glance frequency during all four Stops of the SG scenario

4.2.3 Free Drive (FD) Scenario

4.2.3.1 Fuel Economy

The within-subjects tests indicated significant differences in average fuel economy between Drives 1 and 2 for Groups 2 and 3. Figure 23 shows that the significant difference within Group 2 ($t(9) = 3.79$, $p < .01$, $d = 1.31$) was due to the greater average fuel economy exhibited by participants during Drive 2 ($M = 31.24$ mpg, $SD = 2.97$ mpg) as compared to Drive 1 ($M = 27.96$ mpg, $SD = 2.33$ mpg). The significant difference within Group 3 ($t(9) = 2.97$, $p < .05$, $d = .97$) was due to the greater fuel economy exhibited by participants during Drive 2 ($M = 30.16$ mpg, $SD = .986$ mpg) as compared to Drive 1 ($M = 28.97$ mpg, $SD = 1.42$ mpg).

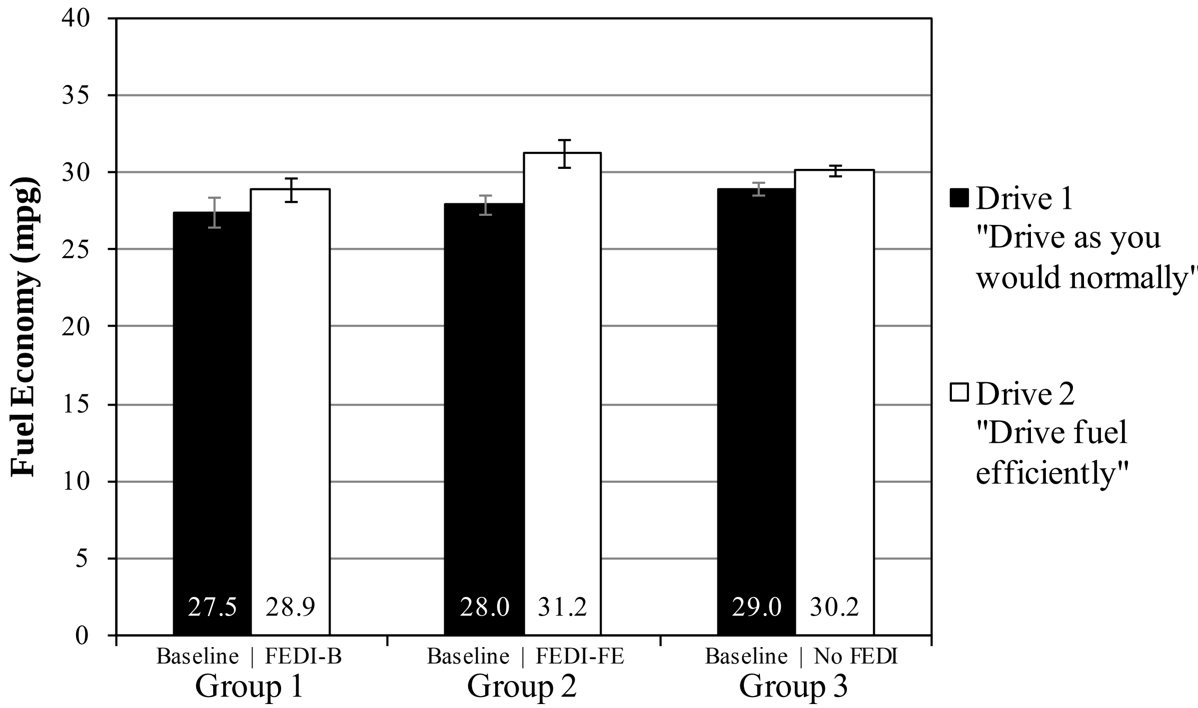


Figure 23. Average Fuel Economy (mpg) during the FD scenario

4.2.3.2 Celeration

The within-subjects tests indicated significant differences in average celeration between Drives 1 and 2 for Groups 1 and 3. Figure 24 shows that the significant difference within Group 1 ($t(9) = 2.76$, $p < .05$, $d = .75$) was due to the greater celeration exhibited by participants during Drive 1 ($M = .02$, $SD = .02$) as compared to Drive 2 ($M = .01$, $SD = .01$). The significant difference within Group 3 ($t(9) = 2.72$, $p < .05$, $d = .46$) was due to the greater celeration exhibited by participants during Drive 1 ($M = .013$, $SD = .008$) as compared to Drive 2 ($M = .009$, $SD = .006$).

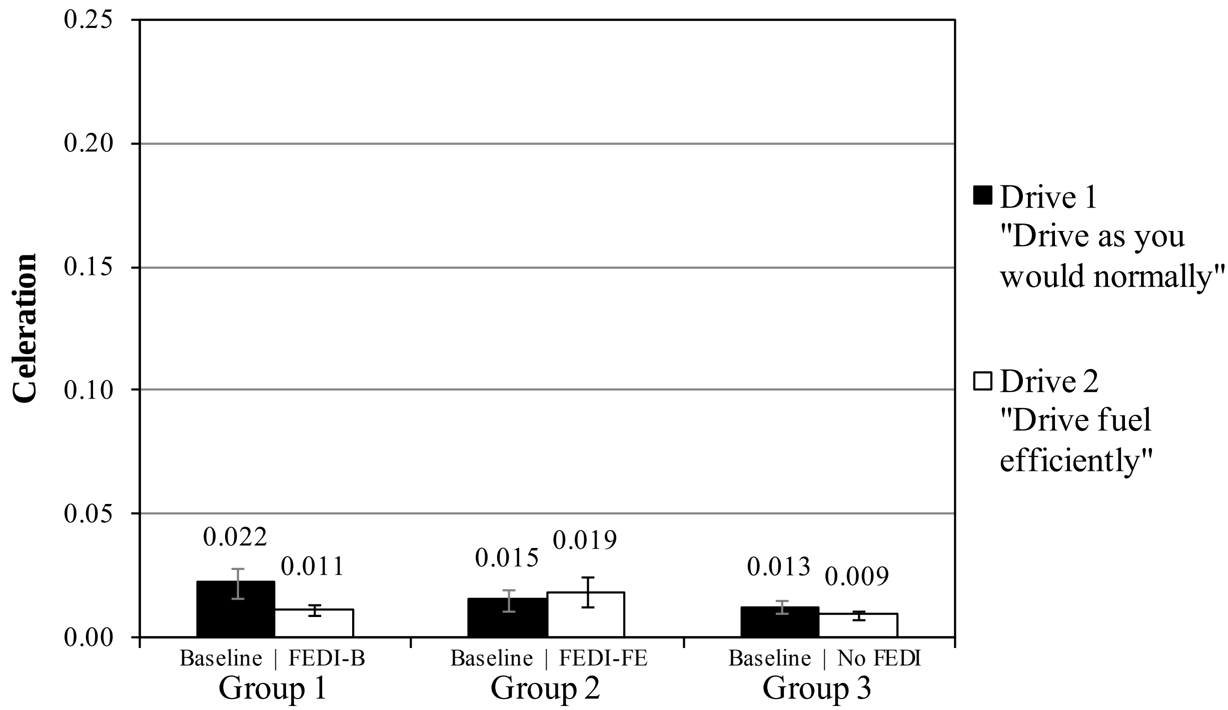


Figure 24. Celeration during the FD scenario

4.2.3.3 Pedal Entropy (PEnt)

The within-subjects tests indicated significant differences in average PEnt between Drives 1 and 2 for Groups 2 and 3. Figure 25 shows that the significant difference within Group 2 ($t(9) = 2.96$, $p < .05$, $d = .33$) was due to the greater PEnt exhibited by participants during Drive 1 ($M = .50$, $SD = .04$) as compared to Drive 2 ($M = .48$, $SD = .07$). The significant difference within Group 3 ($t(9) = 2.39$, $p < .05$, $d = .51$) was due to the greater PEnt exhibited by participants during Drive 2 ($M = .52$, $SD = .03$) as compared to Drive 1 ($M = .49$, $SD = .06$).

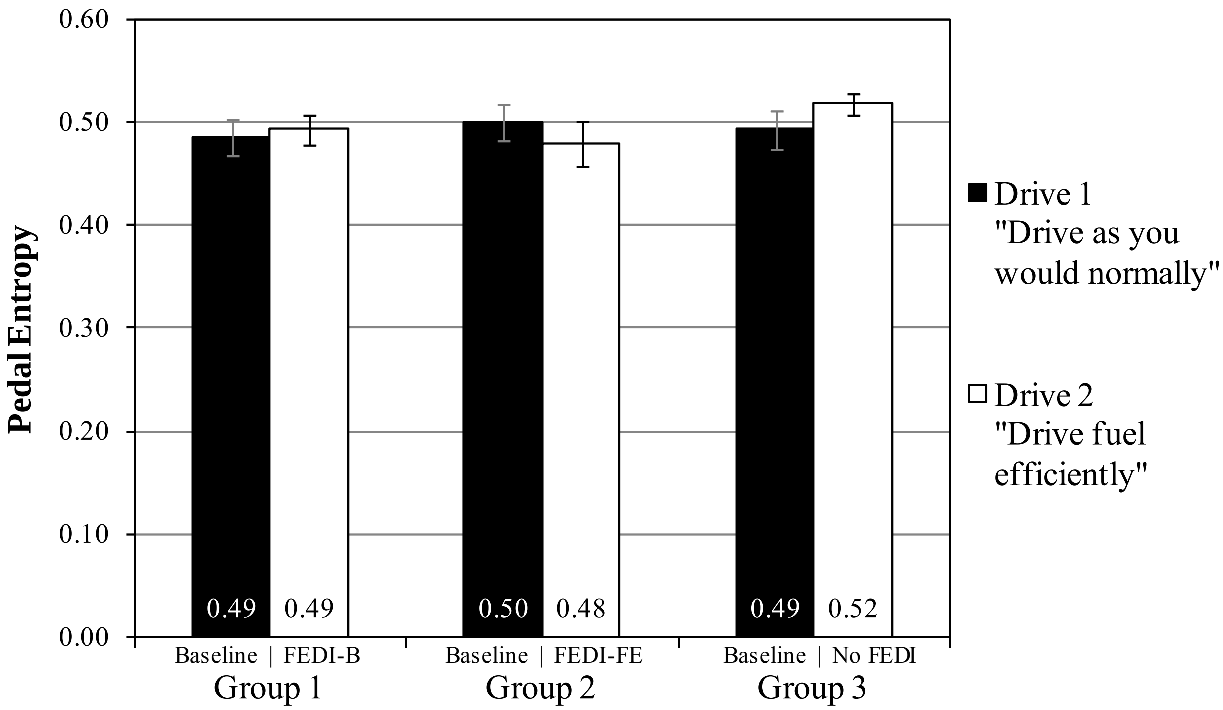


Figure 25. Average Pedal Entropy during the FD scenario

4.2.3.4 Eye Glance Frequency (EGF)

The results of the within-subjects tests indicated a significant difference for average EGF between Drives 1 and 2 for Group 2. Figure 26 shows that the significant difference within Group 2 ($t(9) = 4.80$, $p \leq .001$) was due to the greater EGF exhibited by participants during Drive 2 ($M = 83$, $SD = 38.6$) as compared to drive 1($M = 40$, $SD = 23.9$).

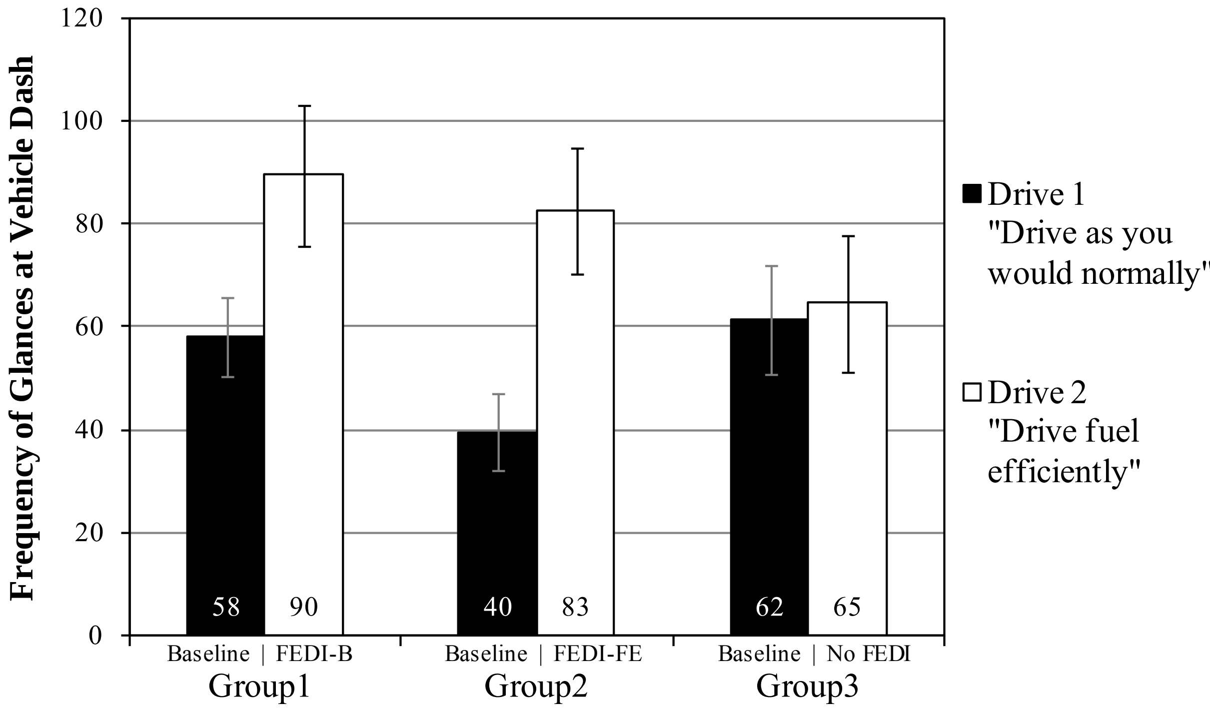


Figure 26. Average eye glance frequency for all three groups during the FD scenario

4.2.4 Car Following (CF) Scenario

4.2.4.1 Celeration

The within-subjects tests indicated significant differences in average celeration between Drives 1 and 2 for Groups 1 and 3. Figure 27 shows that the significant difference within Group 1 ($t(9) = 4.16$, $p < .01$, $d = 1.07$) was due to the greater celeration exhibited by participants during Drive 1 ($M = .05$, $SD = .02$) as compared to Drive 2 ($M = .03$, $SD = .02$). The significant difference within Group 3 ($t(9) = 3.32$, $p < .01$, $d = 1.11$) was due to the greater celeration exhibited by participants during Drive 1 ($M = .04$, $SD = .02$) as compared to Drive 2 ($M = .02$, $SD = .01$).

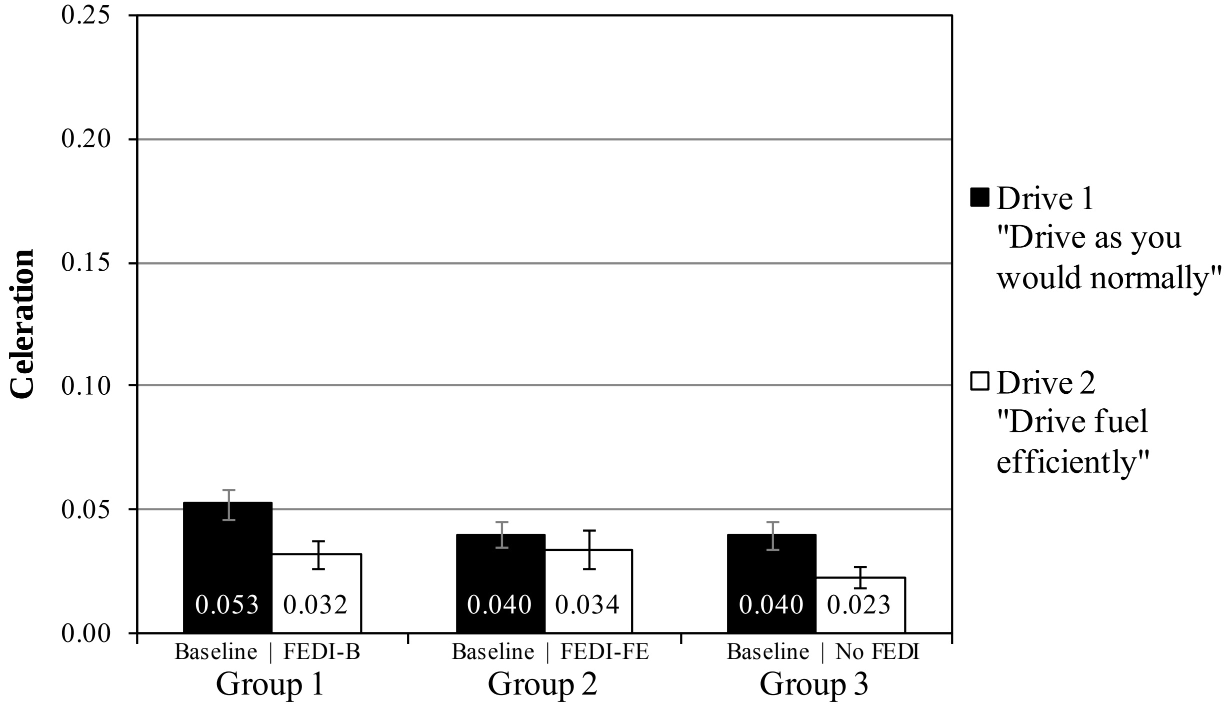


Figure 27. Average Celeration during the CF scenario

4.2.4.2 Coherence

Data from seven participants were excluded from the coherence analysis (and from amplification and delay) because of low sample rates during their drives (i.e., following distance was too great to calculate coherence). The within-subjects tests indicated significant differences in average coherence between Drive 1 and 2 for Groups 1, 2, and 3. Figure 28 shows that the significant difference within Group 1 ($t(7) = 2.79$, $p < .05$, $d = 1.20$) was due to the greater average coherence exhibited by participants during Drive 1 ($M = .74$, $SD = .16$) as compared to Drive 2 ($M = .56$, $SD = .14$). The significant difference within Group 2 ($t(5) = 3.85$, $p < .05$, $d = 1.87$) was due to the greater coherence exhibited by participants during Drive 1 ($M = .75$, $SD = .13$) as compared to Drive 2 ($M = .46$, $SD = .18$). The significant difference within Group 3 ($t(8) = 3.4$, $p < .01$, $d = 1.29$) was due to the greater coherence exhibited by participants during Drive 1 ($M = .65$, $SD = .19$) as compared to Drive 2 ($M = .41$, $SD = .19$).

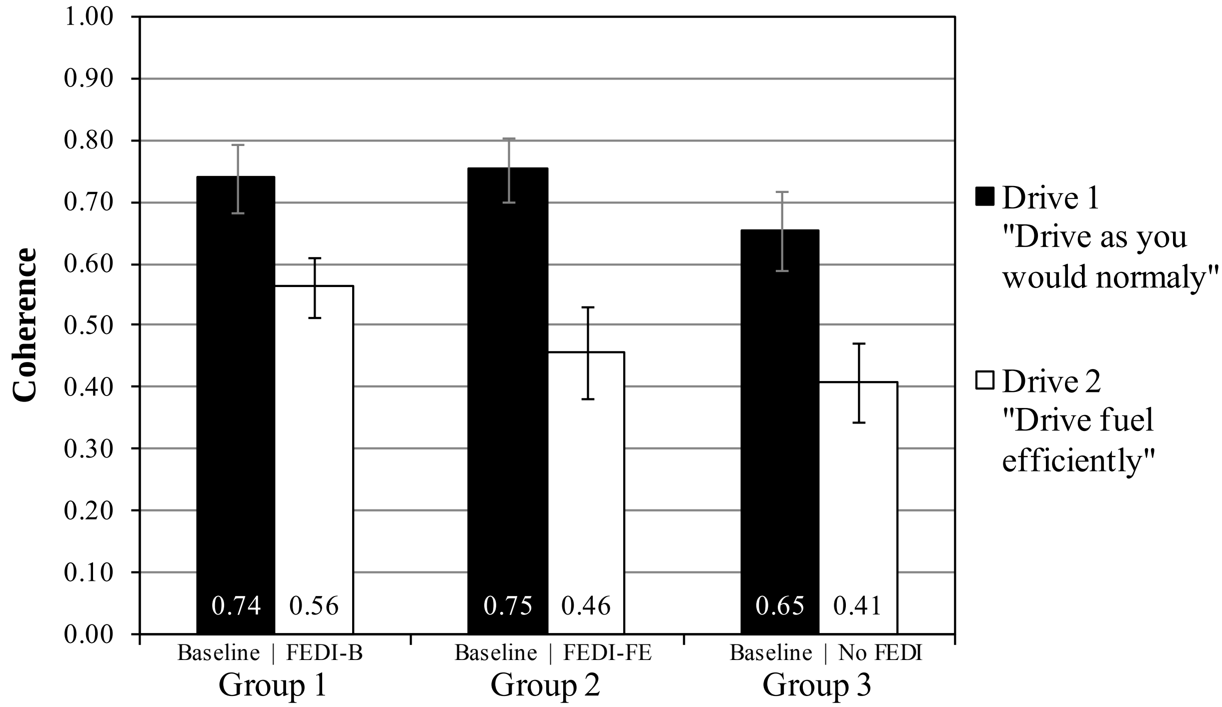


Figure 28. Coherence scores for Groups 1 through 3 for the CF scenario

4.2.4.3 Minimum Time-to-Contact (TTC Min)

The within-subjects tests indicated significant differences in average TTC Min between Drive 1 and 2 for Groups 1 and 2. Figure 29 shows that the significant difference within Group 1 ($t(9) = 4.23$, $p < .01$, $d = 1.47$) was due to the greater TTC min exhibited by participants during Drive 1 ($M = 4.99$ s, $SD = 3.52$ s) as compared to Drive 2 ($M = 1.18$ s, $SD = 1.04$ s).The significant difference within Group 2 ($t(9) = 3.78$, $p < .01$, $d = 1.36$) was due to the greater TTC Min exhibited by participants during Drive 1 ($M = 6.51$ s, $SD = 4.47$ s) as compared to Drive 2 ($M = 1.83$ s, $SD = 1.90$ s).

The one-way ANOVA indicated that Drive 2 TTC Min differed significantly as a function of Group ($F(2,19) = 15.00$, $p <.001$). Follow-up Tukey paired comparisons indicated that Group 3 had significantly greater mean TTC Min ($M = 7.8$ s, $SD = 4.69$ s) compared to Group 1 ($M = 1.18$ s, $SD = 1.04$ s) and Group 2 ($M = 1.83$ s, $SD = 1.9$ s).

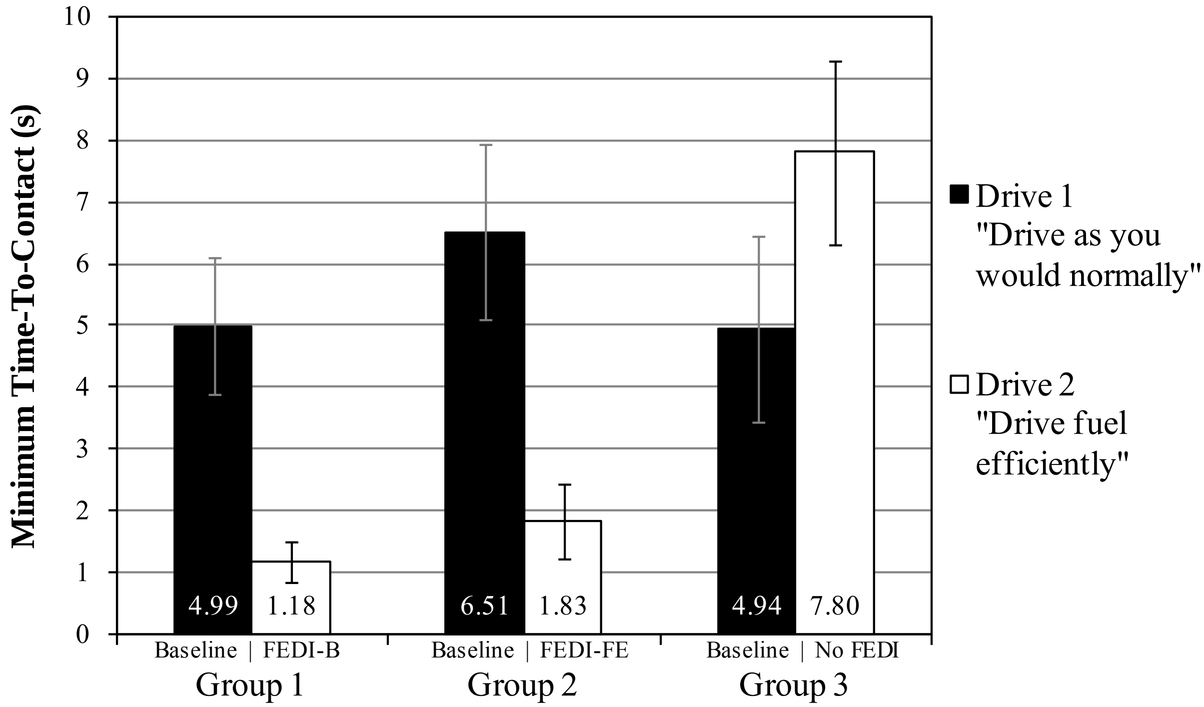


Figure 29. Average Minimum Time-to-Contact (s) during the CF scenario

4.2.4.4 Eye Glance Frequency

The within-subjects tests indicated significant differences in EGF between Drive 1 and 2 for Groups 1 and 2. Figure 30 shows that the significant difference within Group 1 ($t(8) = 4.61$, $p < .01$) was due to the greater EGF exhibited by participants during Drive 2 ($M = 60$, $SD = 25.5$) as compared to Drive 1 ($M = 17$, $SD = 12.4$). The significant difference within Group 2 (9) = 3.03, $p < .05$) was due to the greater EGF exhibited by participants during drive 2 ($M = 49$, $SD = 28.5$) compared to Drive 1 ($M = 26$, $SD = 20.7$).

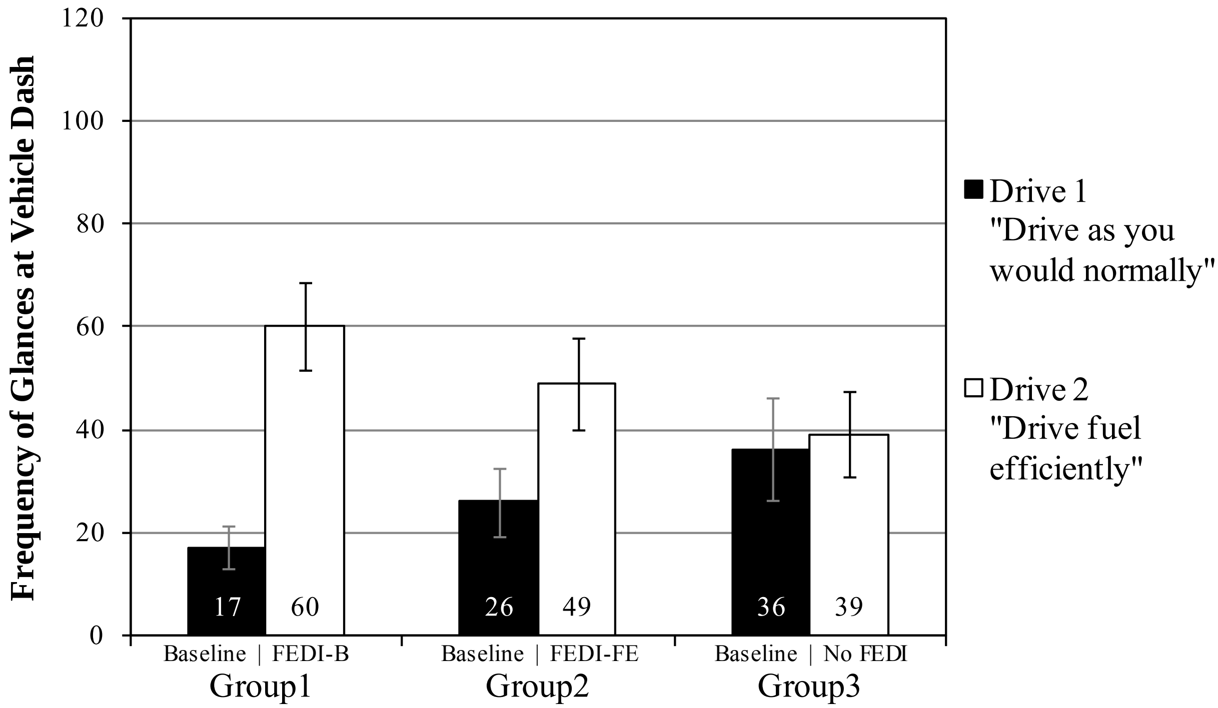


Figure 30. Average Frequency of Glances at Vehicle Dash during the CF scenario

4.2.5 Usability Comparisons

4.2.5.1 Usability Scale (Usefulness & Satisfying Scores)

As shown in Figure 31, participants from the simulator study tended to provide higher usefulness ratings for FEDIC-B and FEDIC-FE compared to the usefulness ratings provided by the participants from the usability study for the top four recommended CS: CS02, SC03, CS05 and SC06. However, a limitation of these comparisons is that the usability participants interacted with these interfaces in a different way than did participants in the driving simulation study.

Focusing only on the responses during the simulation evaluation (FEDIC-B and FEDIC-FE), average usefulness and satisfaction ratings between the FEDIC-B and FEDIC-FE were not significantly different, both $p > .05$. However, Figure 31 suggests that FEDIC-B may have received higher mean ratings for satisfaction compared to all other FEDICs. As also indicated by the higher mean usefulness of FEDIC-FE, these results may suggest that employing a FEDIC within a driving context may have led to a greater understanding of the FEDIC by allowing participants the opportunity to match FEDIC information to their own driving performance.

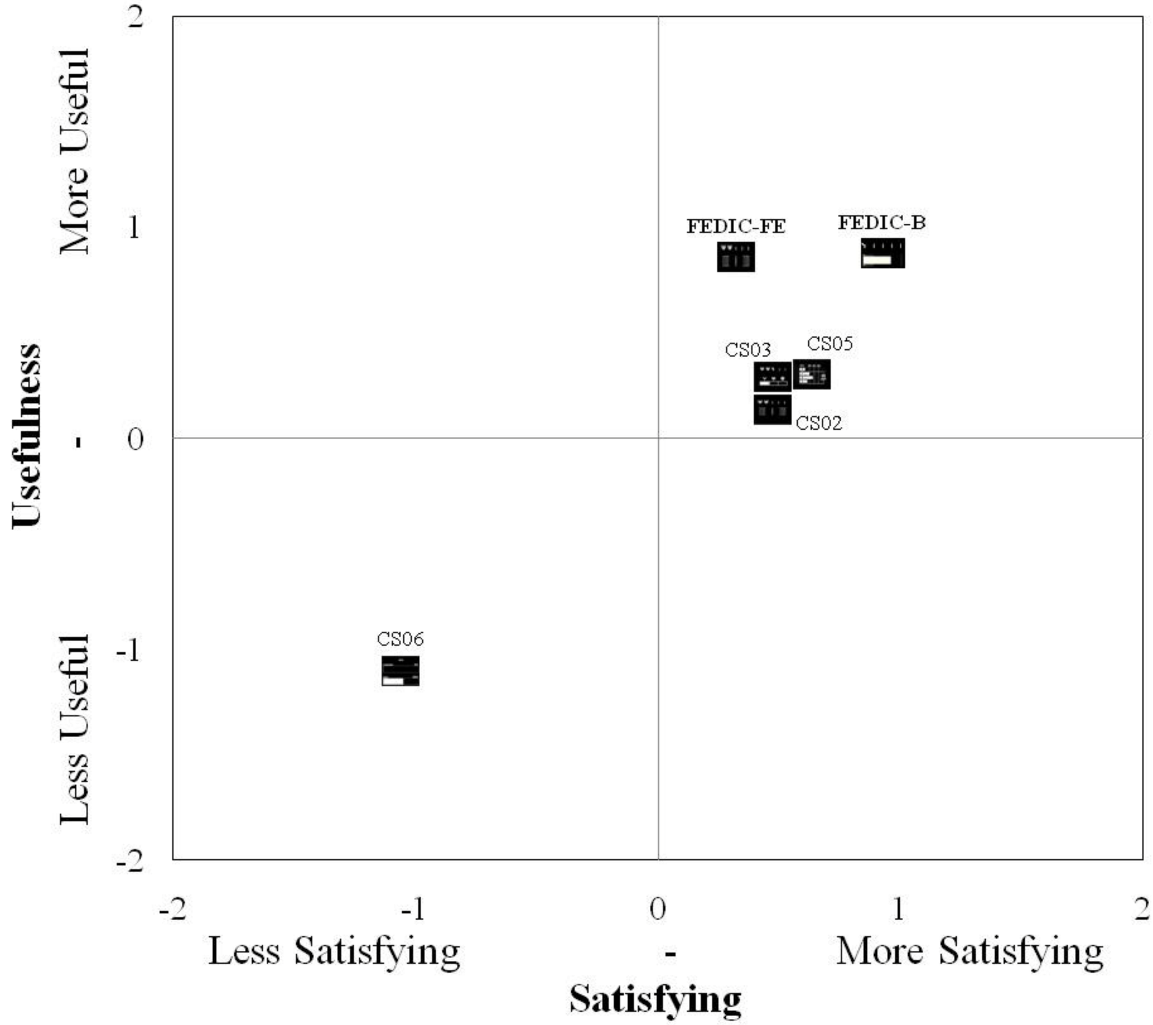


Figure 31. Usability scale usefulness and satisfying ratings for FEDIC-B and FEDIC-FE during the simulation study and the top 4 recommended FEDIC CS from the usability study

4.2.5.2 The Post Experiment Usability Survey

There was a significant difference in responses between FEDIC-B and FEDIC-FE when asked, "Having tried it, do you think this FEDIC had any benefits for you as a driver?" $\chi^2(2) = 6.52$, $p < 0.05$. Participants who drove with FEDIC-FE reported a higher rating for major benefits while participants who drove with FEDIC-B reported more minor benefits (see Table 11).

74% (14 of 19) of the respondents reported having minor or major problems with both FEDICs, although only one participant reported having a major problem with FEDIC-B. Participants' follow-up responses indicated their issues were related to the potential distraction that a new interface might cause while driving and not any particular element of the FEDIC designs. Seventy-four percent (14 of 19) of the respondents reported that "yes" they would choose to own their FEDIC if it were offered for free in their vehicle while only one person (FEDIC-B group) reported that “no” they would not have it included if offered for free. Seventy-nine percent (15 of 19) of the respondents reported that “yes,” having a FEDIC like the one they used would motivate them to drive more fuel efficiently. Only one person (FEDIC-B group) reported that “no” it would not. Eighty-nine percent (17 of 19) of the respondents reported that if added to the cost of the vehicle, they would be willing to pay for a FEDIC. Of these respondents, 82% (14 of 17) would only be willing to pay less than $100 for the FEDIC system, while the other 18% (3 of 17) would be willing to pay between $100 and $500.

Table 11. Frequency of responses when asked whether the FEDIC had a benefit for participants

Any benefit for you?	FEDIC-B	FEDIC-FE
No benefits	0	1
Minor benefits	7	2
Major benefits	2	7

4.3 Driving Simulator Results Summary

Previous research has indicated that drivers can significantly reduce fuel consumption using devices similar to the FEDIC displays used in this experiment (Voort et al., 2001; Larsson & Ericsson, 2009). In these cases, and as observed during this simulator experiment, participants significantly increased fuel economy during the stop-and-go scenario. The lowest fuel economy during the current simulator evaluation was exhibited by participants during Drive 1 of the Stop-and-Go scenario (20.5 mpg). There was a 41% increase in average fuel economy during Drive 2 as compared to Drive 1; this indicated the potential to increase fuel economy was much greater compared to other scenarios. Within the Free Drive scenario there was a 5.6% increase in fuel economy during Drive 2 as compared to Drive 1. However, there was not a similar increase in fuel economy within the Car Following scenario. The driving behavior exhibited within Drive 2 of the Stop-and-Go scenario and the Free Drive scenario increased fuel economy, yet within the Car Following scenario driver behavior changed without showing an increase in fuel economy.

The large decrease in celeration from Drive 1 to Drive 2 within the Stop-and-Go scenario contributed to the large increase in fuel economy. The large drop in celeration indicates that the participants drove “smoother,” which has been linked to a reduction in crash likelihood (Wahlberg, 2008). As shown in Figure 18, celeration was strongly related to fuel economy within the slower-speed urban setting that had frequent stops. Accordingly, participants increased their fuel economy while driving through the Stop-and-Go scenario by driving smoother. The average celeration within Drive 1 of the Stop-and-Go scenario was much greater compared to the Free Drive and Car Following scenarios. Thus, the Stop-and-Go scenario provided a greater opportunity for participants to smooth-out their natural acceleration and deceleration behavior. There were fewer opportunities to smoothly apply the gas or brake within the Free Drive and Car Following scenarios such that celeration was close to zero during Drive 1 and Drive 2. Therefore, the capacity to increase fuel economy was greatest during the Stop-and-Go scenario.

Fuel efficient driving behaviors are for the most part assumed to be safe, as discussed by Johansson et al. (2003). Most FEDIC designs are visual displays, which have been associated with distraction while driving. Fuel efficient driving has been tenuously linked with low involvement in crashes (Haworth & Symmons, 2001). Accordingly, a display that facilitates safe and fuel efficient driving may help overcome driver distraction that may be associated with crash risk. Although the current study did not directly evaluate safety, the behavioral measures that were evaluated may provide an initial indication of potential safety effects. Further research into the potential safety effects is strongly recommended.

Drivers were more likely to direct their gaze away from the road while driving with a FEDIC which indicates a potential for these devices to cause distraction. FEDICs should be designed to have a noticeable presence within the vehicle that requires a short amount of time to view and understand the information presented. Furthermore, designers should refer to available standards and guidelines (e.g., FMVSS 101) to reduce distraction. The results of the study are summarized in Table 12 and discussed in greater detail below.

4.3.1 Does the presence of a FEDIC in the vehicle improve fuel economy?

There was an 11% increase in fuel economy from Drive 1 to Drive 2 for participants who drove with FEDIC-FE within the Free Drive scenario. This translated into an approximate improvement of 3 miles per gallon. This was roughly double the increase in fuel economy compared to the other two Groups (FEDIC-B and no FEDIC). Celeration, which had a strong relationship with fuel economy during the Stop-and-Go scenario, was less influential within the Free Drive scenario because changes in vehicle speed were infrequent and small; thus changes in fuel economy resulted from *other* changes in driver behavior. The 4% decrease in pedal entropy exhibited by participants who drove with FEDIC-FE suggests that participants made more corrections to the pedal position in an effort to maintain a stable speed. This suggests that participants thought that greater pedal control (lower pedal entropy) was related to increased fuel economy. Participants who drove with FEDIC-FE were probably better able to determine how their pedal control behavior affected fuel economy compared to the other Groups because of the instantaneous fuel economy feedback provided by FEDIC-FE. Similarly, during the Stop-and-Go scenario, the (non-significant) decreasing trend in celeration for participants that drove with FEDIC-FE through Stops 1, 2 and 3 suggests they may have been learning how to control acceleration (and deceleration) to achieve greater fuel economy. FEDIC-FE may have assisted with learning how to control acceleration during the Free Drive and the Stop-and-Go scenario, which may explain the significant improvements in fuel economy.

Participants using FEDIC-B reduced celeration in all three scenarios, but this behavior only produced practical benefits in fuel economy during the Stop-and-Go scenario. Participants using FEDIC-B did not make many small corrections to pedal position (lower pedal entropy) as participants using FEDIC-FE. Because these participants did not show the same improvements in fuel economy as those using FEDIC-FE, this suggests that accelerator pedal corrections were related to improved fuel economy.

Table 12. Summary of significant within and between group (drive 2) findings by scenario

Scenario	Measure	Predicted Improvement	Performance by FEDIC Group		
			Group 1 FEDIC-B	Group 2 FEDIC-FE	Group 3 No FEDIC
Stop & Go – Fuel Economy					
	Fuel Economy	+	+	+, FE>No	+
	Celeration	-	-	-, FE<B, FE<No	-
	Time to Accelerate	+	+		
	85th % Deceleration	-	-	-	-
	85th % Acceleration	-	-, B<No	-	-
Stop & Go – Associated Behaviors					
	Minimum Speed	-			
	Maximum Brake	-	-		-
	Minimum TTC	+	-	FE>B	No>B
	Eye Glance Frequency	-	+	+	No<B
	Mental Effort	-	+		
Free Drive – Fuel Economy					
	Fuel Economy	+		+	+
	Celeration	-	-		-
	Steering Entropy	-	-	-	
Free Drive – Associated Behaviors					
	Pedal Entropy	-		-	+
	Eye Glance Frequency	-	+	+	
	Mental Effort	-		+	
Car Following – Fuel Economy					
	Fuel Economy	+			
	Celeration	-	-		-
	Coherence	-	-	-	-
	Amplification (Mod)	-	-		-
Car Following – Associated Behaviors					
	Phase Shift (Delay)	+			
	Minimum TTC	+	-	-	No>B, No>FE
	Eye Glance Frequency	-	+	+	
	Mental Effort	-			

Legend for predicted direction:
+ indicates increase in value,
- indicates decrease in value,
> or < indicate significant between-group difference during drive 2, e.g., “B>No” denotes higher performance on FEDIC-B compared to No FEDIC.
Note: Highlighted cells indicate an improvement in the predicted direction.

Therefore, the results suggest that having a FEDIC in the vehicle did improve fuel economy. FEDIC-FE assisted with fuel efficient driving behavior that increased fuel economy to a greater extent than FEDIC-B. It still remains to be seen whether using these FEDICs over longer periods of time would contribute to maintaining fuel efficient driving.

4.3.2 Can a driver be fuel efficient without the assistance of a FEDIC display?

Participants driving without a FEDIC significantly increased their pedal entropy by 5% during the Free Drive scenario. These participants attempted to reduce the variability in their acceleration behavior (celeration) by making larger corrections in their pedal behavior (pedal entropy). The results indicated that this behavior allowed participants to improve their fuel efficiency without the assistance of a FEDIC. Participants who did not use a FEDIC were found to have lower celeration during all three scenarios, which suggests that telling a driver to drive fuel efficiently may influence them to maintain consistent speed behavior which has been shown to be related to a reduced likelihood of being involved in a crash (Wahlberg, 2008). Therefore, drivers can be fuel efficient without the assistance of a FEDIC display.

4.3.3 Does a FEDIC improve fuel economy beyond what a driver can accomplish without a FEDIC

The significant increase in fuel economy from Drive 1 to Drive 2 within the Stop-and-Go scenario was not equivalent across all three Groups. Participants who drove with FEDIC-FE had a 52% increase in fuel economy, participants who drove with FEDIC-B had a 41% increase in fuel economy, and participants who drove without a FEDIC had a 31% increase in fuel economy. Coincidently, the participants who drove with FEDIC-FE had the largest decrease in celeration indicating that their increased fuel economy resulted from smoother acceleration as compared to participants who drove with FEDIC-B and without a FEDIC.

During the Stop-and-Go scenario, the fuel economy for participants who drove with FEDIC-B was roughly equivalent to those who drove without a FEDIC. Likewise, celeration and 85th percentile deceleration during Drive 2 were also equivalent for those two Groups. Within the Free Drive scenario, participants were not able to achieve a significant increase in fuel economy from Drive 1 to Drive 2 while using FEDIC-B, but participants driving with FEDIC-FE and driving without a FEDIC achieved significant increases in fuel economy. Participants who did not use a FEDIC during the Free Drive scenario also reduced their celeration and increased their pedal entropy, suggesting that they employed a strategy of frequent corrections to their pedal behavior resulting in less variable acceleration. This suggests that participants knew how to change their behavior to be fuel efficient to a degree that was equally effective as the behavior influenced by FEDIC-B (e.g., Stop-and-Go scenario) or by FEDIC-FE (e.g., Free Drive scenario).

Using either FEDIC also had some additional behavior implications. Driving without the assistance of a FEDIC was associated with longer minimum time-to-contact (i.e., greater following distance) compared to participants using FEDIC-B during the Stop-and-Go scenario and compared to participants using either FEDIC display during the Car Following scenario. In other words, participants using FEDIC-B or FEDIC-FE may have driven similarly to participants not using a FEDIC except there was at least one moment within the drive that time-to-contact was less than 2 seconds. There were also more glances towards the dashboard when a FEDIC was present in the vehicle during the Stop-and-Go and Free Drive scenarios. Therefore, the short minimum time-to-contact was likely a result of attending to either FEDIC.

In summary, having FEDIC-FE in the vehicle improved fuel economy to a greater extent than not having a FEDIC in the vehicle during the Stop-and-Go situations. Having the FEDIC-B in the vehicle was not shown to improve fuel economy past what participants could accomplish without having a FEDIC. In general, drivers who were asked to be more fuel efficient may employ behavioral strategies in addition to improving fuel economy (e.g., minimum time-to-contact, glance frequency). Although participants in all Groups employed driving behavior that produced a net increase in fuel economy, the data described herein is inappropriate for determining the extent to which a FEDIC assists with long-term fuel efficient driving behavior. The changes in driver behavior within this study may have been a result of learning how the FEDICs functioned, and not the result of fully utilizing the information presented on these FEDIC displays. The extent to which drivers maintain fuel efficient driver behavior after an initial learning phase can be revealed by conducting a field study. This may be accomplished by reviewing and following lessons learned from the current literature and practice regarding the effects of small, in-vehicle displays on driver distraction. Furthermore, implementation standards such as the Federal Motor Vehicle Safety Standards (FMVSS, e.g., Standard 101) should be consulted and adhered to before implementing FEDICs within vehicles for research or when designing production systems.

4.4 Key Driving Simulator Evaluation Conclusions

- Although the information on the fuel economy FEDIC (FEDIC- FE) did not instruct participants how to modify their driving, participants using this display made changes to their driving behavior that improved their fuel economy within the Stop-and-Go and Free Drive scenarios.
- The behavioral FEDIC was associated with significantly greater fuel economy compared to baseline driving within the Stop-and-Go scenario. Although this FEDIC helped drivers to significantly smooth their speed profile compared to their baseline driving within the Stop-and-Go scenario, participants who drove with FEDIC-FE had the lowest celeration overall.
- Participants made significant improvements in fuel economy just by being asked to drive fuel efficiently, even without the presence of a FEDIC.
- As would be expected by introducing a novel visual display in a vehicle, drivers made more glances away from the road while the FEDIC displays were present. This indicates potential safety implications due to FEDIC use.

5. Overall Conclusions

The overall goal of Task 3 within the current project was to identify two FEDICs from existing and prototype FEDIC designs that would be associated to the greatest extent with behavior changes that result in both fuel economy and behavioral improvements. To accomplish this goal it was necessary to conduct three tasks, the first of which was a concept development task. The purpose of the concept development task was to identify several FEDIC designs that currently exist within the vehicle fleet that met user-needs and as a result may facilitate safe, fuel efficient driving. The concept development evaluation concluded:

- There were multiple methods by which FEDICs portray fuel economy information;
- FEDIC designs that presented multiple types of fuel economy information or behavioral information (e.g., acceleration) within a *simple* display aligned best with user-needs;
- The more useful FEDIC designs displayed more than one component at a single time (a component is an interface element of a FEDIC design that provides information).

The result of the concept development task was the identification of nine FEDIC component-sets (CS) that aligned with user-needs. A usability evaluation determined if users could accurately comprehend how changes in FEDIC CS state related to fuel economy. The usability evaluation also examined whether users would find the CS to be usable and valuable for improving fuel economy and safety. If users rated a CS highly on these “usability” characteristics it suggested the component may be well-received by users in driving situations. The usability evaluation concluded:

- Horizontal bars and/or simple representations (i.e., pictures) of fuel economy information were the most usable.
- Participants had a preference for more representative or symbolic forms of fuel economy information (e.g., bars or pictures) compared to text representation.
- Text representation can improve comprehension when presented along with representative component features.
- Presenting information relating directly to behavior may be as useful as presenting fuel economy information.
- The post-drive training CS was well received.

The third task consisted of a driving simulator evaluation to examine the utility of FEDIC use under conditions that were similar to those experienced in real-world situations. Participants drove through a series of typical driving scenarios that allowed them to modify their behaviors to improve fuel economy. Participants either did not use a FEDIC, used a FEDIC that displayed fuel economy information, or used a FEDIC that displayed acceleration (behavioral) information. This experimental configuration was employed to determine if either FEDIC would be associated with positive changes in fuel economy and to determine how well drivers would be able to improve fuel economy without the use of a FEDIC. Conclusions from the driving simulator evaluation were:

- Although the information on the fuel economy FEDIC (FEDIC- FE) did not instruct participants how to modify their driving, participants using this display made changes to their driving behavior that improved their fuel economy within the Stop-and-Go and Free Drive scenarios.

- The behavioral FEDIC that did not inform participants about *how* fuel efficiently they were driving was associated with less-consistent improvements in fuel economy. However, this FEDIC did lead drivers to significantly smooth their speed profile within the Stop-and-Go scenario compared to their baseline.
- Participants made significant improvements in fuel economy just by being asked to drive fuel efficiently, even without the presence of a FEDIC.
- As would be expected by introducing a visual display in a vehicle, drivers made more glances away from the road while the FEDIC displays were present. This indicates there are potential safety implications due to FEDIC use.

Results of this study showed that drivers could use a FEDI to increase their fuel economy during an initial exposure. To assess whether drivers would maintain behaviors over time that produce improved fuel economy, a longer-term evaluation in a real-world setting would be needed. Such an evaluation could explore the effects of behavioral adaptation to information type (behavioral versus fuel economy), information type (instantaneous, trip, overall timeframes), and driver interest in FEDIC information. FEDIC deigns could be improved by determining how useful FEDICs are for drivers who want to improve fuel economy, and how they affect safety over longer exposures in real-world driving situations. Such an evaluation would benefit from following these FEDIC design findings from this evaluation:

- Presenting more than one fuel economy information type may allow users to understand how their immediate behavior (instantaneous information) relates to their overall fuel efficiency (trip or average information).
- Horizontal bar and representative/symbolic depictions of fuel economy may be superior to text representations because they allow users to more quickly and accurately view fuel economy information.
- Bars or symbolic representations should have meaningful labels or reference points that indicate "good" versus "poor" performance.
- Presenting fuel economy information allows drivers to improve their fuel efficiency, perhaps better than directly presenting information on their behavior (e.g., acceleration). Examination of this relationship in longer-term and real-world settings is necessary to make more definitive distinctions between these information types.
- FEDIC designs could be optimized to display information during slower-speed or most stop-and-go scenarios, because drivers' capacity to improve fuel economy was shown to be the greatest in these types of situations.
- Because the act of asking drivers to drive fuel efficiently was shown to improve fuel efficiency, the presence of a FEDIC alone may be sufficient if it motivates drivers to drive fuel efficiently.
- However, viewing the displays was also shown to draw attention away from the road. Therefore, FEDIC designs should have a noticeable presence within the vehicle while striking a careful balance to limit the amount of attention required to view and understand the information presented. FEDIC displays should be available on an on-demand basis (as opposed to available at all times), so drivers can decide when it is safe to access fuel economy information. Furthermore, production FEDIC systems should adhere to standards and guidelines (e.g., FMVSS 101) to reduce the effect of distraction and inattention.

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Appendix A: Needs-Statement Development Notes

Cat.	Need; "the FEDIC…"	Statements & observations from Tasks 1 & 2	Findings from background literature & product research
Goal of Display	is **effective…**		• FEDIs should accurately and clearly deliver fuel economy information.
	promotes **safe driving behavior**		• FEDIC designs should also consider their effect on a driver's attention, cognitive limits, ability to maintain Situation Awareness for unexpected events, as well as their overall effect on driving behavior as it relates to safety.
	is perceived as affordable	• Low cost to manufacture; pass on low cost to driver • Must be affordable	• Reasonably priced (affordable when users consider cost-benefit relationship)
	keeps the drivers interest over time	• Some systems were found to be too boring; not interesting • Entertainment valued, although most may not make a game out of instantaneous display, or compete with other drivers in car	• Supports social community (drivers can share their fuel economy information)
Function	provides instantaneous info in a metric that the user understands	• Basic text and gauge displays were generally received favorably, though some participants recommended changing the appearance of the displays or questioned the importance of information	• Fuel consumption display is simple (drivers can understand by the icons in the display how the energy source is being consumed)
		• Current FEDIC users knew MPG; non-current users thought in terms of range per tank or miles to empty.	• Displays fuel economy in a way that impacts the driver (i.e., in dollars saved, cost per mile)
		• Minimal amount of FEDIC data preferable	• Alerts driver of low fuel economy
		• Meaning behind "symbology" lost if metaphor is too involved (e.g., leaves, growing trees)	• Fuel scale is clear/understandable (its likely the user will understand the fuel economy metric)
		• Color as indicator was generally well received but may not tell exact performance, some drivers wanted but may not be necessary (for instantaneous display)	• Has advanced user options (access to more information that novice users may not need)
		• Current FEDIC users knew MPG; normal population thought in terms of range per tank or miles to empty.	• Displays optimal and actual fuel economy
		• Range indication (in miles) was useful but they were less positive about fuel economy	• Accounts for vehicle context (vehicle state)
		• Not everyone cares about analyzing driving habits- they don't see benefit in doing so	• Shows components that consume power (e.g., power steering)
		• Cost in potential fuel savings, potential payoff	• Provides information about gradient
		• See benefit in saved cost to fuel car, then will be more likely to use	• Information has clarity (re: "you don't even have to think")
		• Current FEDIC drivers were more interested in environmental impact & fuel efficiency	• Display characteristics: text, pictorial, auditory
		• All drivers rated reducing fuel costs as, at least, "important"	

Table is continued on next page

Cat.	Need; "the FEDIC…"	Statements & observations from Tasks 1 & 2	Findings from our background literature & product research
Function	provides long-term or post-drive (higher-level) info in a metric that the user understands	• Complex graphical information such as energy flow diagrams, fuel economy history bar charts, & game-like displays were generally seen as excessive and distracting by drivers who did not have FEDIs; drivers who had FEDIs had mixed opinions	• Advice continuum: van der Voort et al 2001's concept of "advice" versus "extended advice"- any advice assisted users, suggests giving performance tips may assist driver better than just MPG
		• Many were interested in post-drive reporting technology as way to evaluate performance and track improvement over time.	• Information from multiple sources is not contradictory (van der Voort, 1997)
		• Some need for configurability of displays, to choose to view/hide displays users find useful	• Information takes into account environmental context (van der Voort, 1997)
		• Some might use on-line community for limited amount of time	• Post-drive reporting of complex fuel economy data
		• Many do not see need for in-depth data. (do they need to see benefit of changing behavior has on fuel economy?)	• Fuel economy information type/ level of information fidelity: instantaneous, miles to empty, average (overall, per trip, per tank), binary (good versus bad, e.g., "ECO" light), time idling
		• Some liked to see trends and the ability to offload data and be able to put in spreadsheet	
		• Some skeptical of how cost savings calculated- either make transparent or be general	• Provides miles per tank (e.g., "reset trip odometer")
		• Give more thought to planning trips, including reducing unnecessary trips, and combining trips to do errands	• Assists with budget setting/planning
		• All interested in avoiding congestion	
		• Liked having both instantaneous mpg and adjustable display showing range by speedometer	
		• Vertical design of instantaneous display - light indicates overall mpg over instantaneous mpg	
	information is easily visible / able to be perceived	• Visibility of display needs to be big enough to accommodate all driver ages/types	• Display compensates for changes in illumination (changes at night to facilitate visibility)
		• Location by speedometer was preferred	• Text is easy to read (readable display)
		• Display needs to be big enough to see displays	
		• Close to drivers line of sight	

Table is continued on next page

Cat.	Need; "the FEDIC…"	Statements & observations from Tasks 1 & 2	Findings from our background literature & product research
Function	vehicle adaptation technology gives appropriate level of control to user	• Vehicle adaptation technology was received unfavorably by most participants although some though it would be a useful tool to learn how to drive efficiently if the feature could be turned off • Drivers scared of losing control if system potentially modifies behavior (eco pedal) • Drivers scared of adaptation due to using technology and then not having it (in another car)	• improves fuel economy automatically (example: BlueEFFICIENCY cuts off power steering servo pump when the c-class is driven straight) • driver has full control during emergency situations (does not interfere with necessary driving behaviors or emergency maneuvers) • Has a safety check (occurring prior to interventions) • Restricted manual control from driver while driving (driver only has access to high level information if car is in drive)
	provides clear feedback from user input or behavior		• Provides clear/understandable feedback (Re: any feedback from the system - for behavior & system controls)
Behaviors Promoted	provides info on ways/behaviors to make driver more fuel efficient	• Desire to "drive gently" - avoiding extra maneuvers, coasting, and planning to avoid left turns/lights. • Speed had relationship to fuel consumption (but did not speak about optimal gears/speed) • Not using a/c and reducing power consumption • Look far down road ahead to maintain momentum (e.g., look at other vehicle brake lights, signals) • Safety still a concern- drafting seemed risky to most drivers • Did not like one interface where information on graph is not related to performance • Information can be more useful when driving same route daily and can make difference in fuel economy - watch and learn	• Driving advice is automatically cancelled under dangerous driving conditions (environmental context) • It trains drivers to drive more economically (gives advice on how to get better gas mileage- more the advice is related to behavior, the better) • Provides maintenance guidelines that enhance fuel economy • Assists with setting fuel economy goals (what fuel economy means, practically) • Reinforces safe driving & discourages risky driving • Motivates drivers to change driving behavior (including holding the users interest over time) • Provides driving behavior suggestions for all drivers (not just overly aggressive drivers) • Signals when to coast • Facilitates teaching younger drivers safe fuel efficiency techniques • Provides clear advice (types of advice do not conflict)

Table is continued on next page

Cat.	Need; "the FEDIC…"	Statements & observations from Tasks 1 & 2	Findings from our background literature & product research
Behaviors Promoted	keeps drivers attention on the road at most times	• Instantaneous speed may be distracting • Dash is too busy, cleaner layout is preferable • Complex energy monitoring and consumption bar graph screens may be distracting/useless • Need to be visible in a place where it won't be distracting to access/view display • Some resistant to adding more information displays to vehicle • Concerns negative safety impact of distraction	• Short (< 5 seconds?) driver attention/focus time away from the roadway • Low/limited driver manual control (driver rarely needs to reach for controls) • Facilitates forward looking (for traffic signals, other cars, turns, etc)
	is intuitive to set up and use	• Interface needs to be (and needs to seem to be) simple to pick-up-and-use • Want simple and did not have to figure things out • Aftermarket systems were stereotyped- seen as a toy, or masculine, or distracting • Cute displays demean some drivers - think too complex, stereotype for younger drivers… stigma • Unobtrusive system was desired • Easy to install or wouldn't buy	• Is salient/conspicuous (after a learning period information is instantly recognizable (i.e., minimal visual sampling)) • Low (to none) driver maintenance required through the lifecycle of the display (i.e., replace battery, setup…) • Easy to set up (calibrate to car)
	functionality is easily accessible	• Issues with crossing through multiple screens or setting defaults to display fuel economy as desired • Audio of MPG and miles to empty, by pressing button on steering wheel • Annoying to have to flip between FEDIC functioning and another source of info use often (i.e., temperature) • Want controls on steering wheel to flip through displays (if multiple screens necessary) • Having control of information important - too many info pieces overwhelming	• Economy information type is easy to select (e.g., the driver can easily select current fuel economy, average fuel economy, or fuel range) • Controls are easy to access (i.e., control switches on the turn signal arms)

Appendix B: Usability Recruitment Ad Content

PARTICIPANTS NEEDED FOR A DRIVING-RELATED STUDY

The University of Minnesota's HumanFIRST Program (www.humanfirst.umn.edu) is recruiting subjects to participate in a driving-related study on campus. This study is evaluating new displays for use in automobiles. In this study, you will be asked to view several new fuel economy displays and answer questions about them. We will require approximately 2 hours of your time and will pay you $75 to participate.

To participate, you must:

- Be 18 years of age or older
- Possess a valid driver's license
- Have 20/40 vision or better (corrected with glasses, contacts or surgery is fine)

If you are interested in participating, please contact <name of researcher> by email at <name@umn.edu> or by phone at 612-624-6524. Please provide your name and a phone number where you can be reached during the day. If you are eligible to participate, a time can be scheduled to participate.

Appendix C: Usability Consent Form Content

Consent Form

Fuel Economy Usability Study

You are invited to be in a research study designed to evaluate various automobile fuel displays. You were selected as a possible participant because you responded to a request for participation in this study and were found to be a suitable participant. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by: Michael Manser, Janet Creaser, Justin Graving and Mick Rakauskas from the HumanFIRST program at the University of Minnesota for the National Highway Traffic Safety Administration, an operating administration of the U.S. Department of Transportation and the study sponsor.

Background Information:

The purpose of this study is to find out what automobile fuel economy displays may lead users to change their driving behavior to impact their fuel economy.

Procedures:

If you agree to be in this study, we would ask you to do the following things: (1) provide us with some basic information about yourself and your driving history (e.g., age, number of years you have had your license); (2) view several fuel economy displays and answer some questions regarding the information presented on the display; and (3) we will have you look at each display and answer questions about display functionality. The total time to complete this study today is approximately 2 hours.

Risks and Benefits of being in the Study:

There are no direct benefits to you for participating in this study. There are no risks associated with participating in this study.

Compensation:

You will receive payment $75 for participation. If you decide to stop participating at any time during the study you will still receive full payment.

Confidentiality:

The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify you as a participant. Research records will be stored securely and only researchers and the study sponsor will have access to the records.

Voluntary Nature of the Study:

Participation in this study is voluntary and you may withdraw your participation in the study at any time. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions:

The researchers conducting this study are: Michael Manser, Janet Creaser, Justin Graving and Michael Rakauskas. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact them at HumanFIRST Program, 1100 Mechanical Engineering, 111 Church St. SE, Minneapolis, MN, 55455, 612-625-0447, mikem@me.umn.edu.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), **you are encouraged** to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455, (612) 625-1650.

You will be given a copy of this information to keep for your records.

Video, Audio, Data Release:

The usability room contains cameras that will record video of you and microphones that will record your voice. By agreeing to participate in this study you will allow the University of Minnesota study staff and the study sponsor to collect data, record video and record audio of you during your participation. The University of Minnesota study staff and study sponsor will have access to this data.

By agreeing to participate in this study you are also agreeing to allow the video, audio, and data to be used by the University of Minnesota study staff and study sponsor for research purposes (e.g., analysis, educational and professional presentations) and for non-research purposes. Examples of non-research purposes include the following:

1) Public release for regulatory purposes (e.g., to assist in regulating devices);
2) Public release for educational purposes (e.g., to assist with educational campaigns for members of the general public);
3) Public release for outreach purposes (e.g., to nationally-televised programs highlighting traffic safety issues);
4) Public release for legislative purposes (e.g., to assist the U.S. Congress with law-making/rule-making activities).

The University of Minnesota and the study sponsor will edit/alter any data collected so that your image and/or voice are not identifiable and will use only edited/altered data for non-research purposes. The University of Minnesota and the study sponsor also will not release any personal information that would allow you to be identified as a study participant.

By agreeing to participate in the study you are permanently releasing the University of Minnesota and the study sponsor, and any of their employees, agents, or assigns, from any and all claims that pertain to the video, audio, and simulator data collected during the study and the edited/altered versions of each, including, but not limited to, any claims based on the right of privacy, libel, or defamation.

Statement of Consent:

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature:____ Date: _________

Signature of Investigator:______________________________ Date: _________

Appendix D: Usability Participant Instructions

Initial Comprehension Task

- Thank you for participating in our study. This study will involve completing a demographic questionnaire and a series of tasks on the computer. You will start by filling out a demographic survey that asks about driving history on computer. Please answer these questions as truthfully as possible and to the best of your ability.

    <continue> brings up survey

- You will now complete 3 sets of tasks on this computer and will be explained in detail before you begin each task. The purpose of the first task is to evaluate some common types of interfaces that display fuel economy. Your task will be to view each display and identify what information is being provided to you.

    <continue> brings up next instruction

- For this task you will be ask you to imagine you are taking a drive. We will guide you through this drive by having you read a series of driving events. Each driving event is a short sentence describing a typical driving situation. After reading a sentence you will click on the *continue* button (bottom right of the screen) and a Fuel Economy Display will be presented. You are allowed to click on the *back* button (bottom left of the screen) to look at a display again or read the driving event again.

    <continue> to next instruction

- We want you to pay close attention to these displays. We want you to observe changes in the Fuel Economy Display that may result from the driving situation. Some of the displays may provide suggestions on how to drive your car over multiple drives. If this is the case, we will have you view a series of pictures of the display and ask you what you think afterwards.

    a. Also show image of CS00

    <continue> to next instruction

- You will notice that there is a foot and pedal located to the right of the display. This pedal is intended to mimic how you might use the accelerator in reality. You should pay attention to the pedal as well as the display because the changes in how the pedal is pressed relate to the changes in the display. To the immediate right of the foot pedal there is a set of hatch marks:

    a. The hatch mark at the top signifies that the pedal is not depressed

    b. The hatch mark at the bottom signifies that the pedal is completely depressed (to the floor)

    c. Press continue to see the pedal in action.

    <continue> to show video of CS00

- Once video is finished, <continue> to next instruction

- After you have viewed all of the driving events for one display, you will be allowed to interact with the display by moving the foot on the pedal up and down to see how these actions affect the display. After that, we will ask you to describe the changes that you saw in the display, and what you think the changes meant. After you have seen all of the displays we will provide you with a full explanation of each display.

<continue> to next instruction

- If you have any questions about what you are expected to do during this task, please ask the experimenter now. If you are ready to proceed, please press *continue* and remember that we would like you to pay attention to changes in each display.

  <continue> to initial comprehension protocol

Fuel Comprehension Task

- The purpose of this task is to see how easy it is to determine fuel efficient driving using the displays you learned about in the previous task. For this task you will view each display several times as you imagine yourself driving a rental car that gets 30 miles per gallon on average. As you drive, your low fuel light has come on and you must monitor your fuel to make sure you know how much further you can go before running out of gas.

  <continue> to next instruction

- The displays will appear at several different stages of fuel efficiency. While the display is present on the screen, you should respond as quickly and accurately as possible:

  a. You should respond "yes" (the green button on the response box) when the display indicates that you are driving fuel efficiently

  b. You should respond "no" (the red button on the response box) when the display indicates that you are not driving fuel efficiently

  <continue> to next instruction

- The display will disappear after you respond. At that time, we want you to rate how fuel efficient the display indicated you were driving using the scale below:

  a. -1 indicates you are driving the least fuel efficient;

  b. -2 indicates you are driving less fuel efficient;

  c. 0 indicates that you are driving at average fuel efficiency;

  d. 1 indicates you are driving at above average fuel efficiency;

  e. 2 indicates you are driving extremely fuel efficiently.

  <continue> to next instruction

- After providing your scale response another display will appear and you'll complete the same set of questions. After completing this task you will complete a series of questions assessing various aspects of the fuel economy displays that you used.

  <continue> to next instruction

- If you have any questions about what you are expected to do during this task, please ask the experimenter now. If you are ready to proceed, please press *continue*.

  <continue> to fuel economy comprehension protocol

Usability Survey

- A series of questions will appear on the computer screen about the fuel economy display you have been using. We want to know what you think about these displays so please response honestly. There is a separate set of usability questions for each display. If you have any questions about what you are expected to do during this task, please ask the experimenter now. If you are ready to proceed, please press *continue*.

<continue> to usability survey protocol

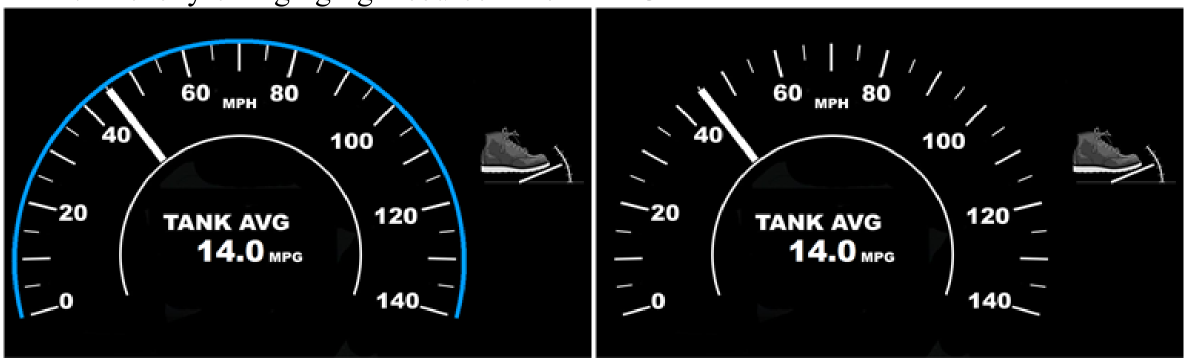
Post-Study Debrief

- Thank you for participating in our usability study on fuel economy displays. By doing so you have helped us understand how drivers use fuel economy displays while driving. The purpose of this study was to gain insight into how drivers think about fuel economy and to evaluate some prospective fuel economy displays. Fuel economy displays inform drivers about their fuel consumption while educating drivers on techniques that they can use to decrease the amount of fuel they use every time they drive. Aside from helping to reduce fuel costs these displays may also assist with safe driving behaviors. The findings from this study will be used to help design fuel economy displays that will appear in a variety of vehicles.
- If you feel you need to express concerns about the study or if you are interested in learning about the outcome of the study you can contact Mike Manser at 612-625-0447 or mikem@me.umn.edu

Appendix E: Usability Event Narratives

Listed are a set of narratives for each FEDIC CS along with example images. Images/videos of CS movement for each narrative will be produced once the narratives are agreed upon.

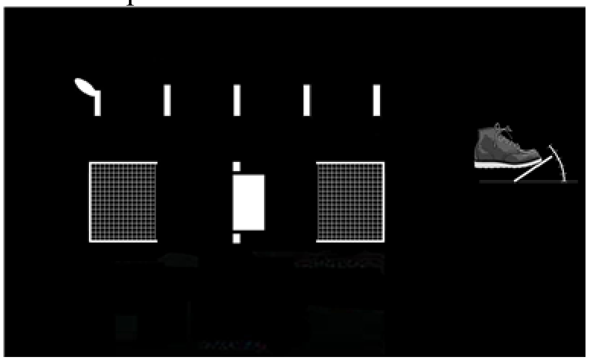
CS01: Intensity-changing light source + Text MPG

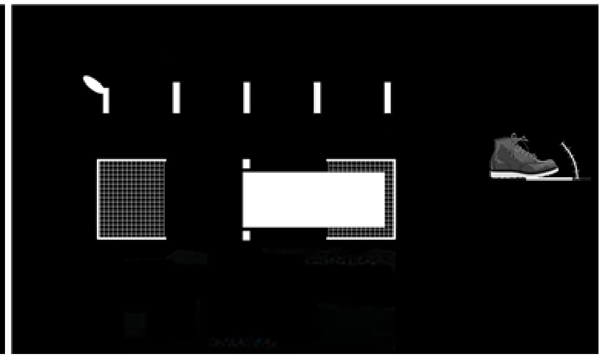


- You get in your car and begin driving.
- You drive at a consistent highway speed as you have been doing for the last few minutes.
- You have been driving in slow stop-and-go traffic for the last few minutes.
- You drive on neighborhood roads for a few minutes.
- You have arrived at your destination[4].
- Next time you start your car[4].

[4] Because this event involves the vehicle being stopped, no video will be played for this event only the image of the concept-set's state

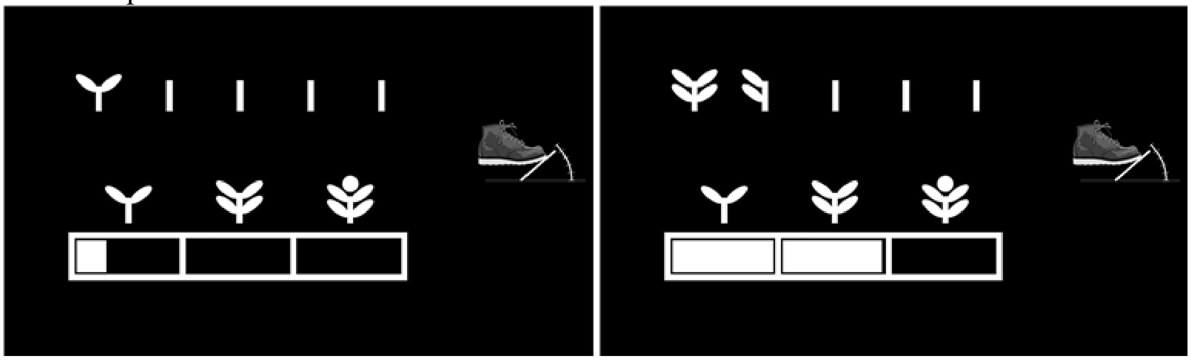
CS02: Representative Picture + Acceleration/Deceleration Bar





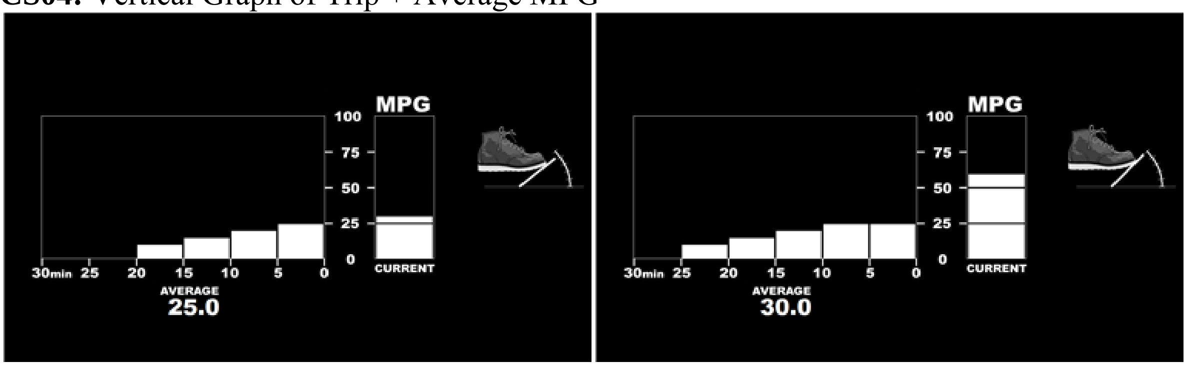
- You get in your car and begin driving.
- You enter the highway and merge with traffic.
- You drive at a consistent highway speed as you have been doing for the last few minutes.
- You exit the highway.
- You drive on neighborhood roads for a few minutes.
- You have arrived at your destination[4].

CS03: Representative Picture + Horizontal MPG Bar



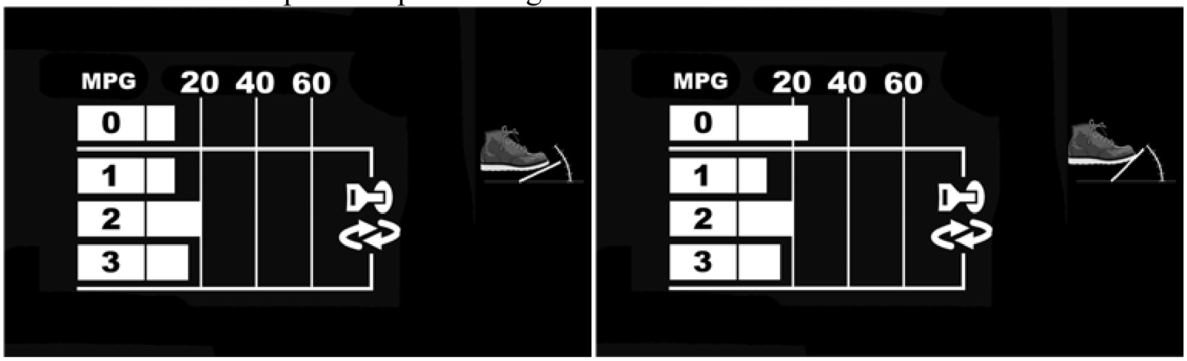
- You get in your can and begin driving.
- You drive at a consistent highway speed as you have been doing for the last half hour.
- You arrive at your destination[4].
- You get back in your car and begin driving again.
- You drive at a consistent highway speed as you have been doing for the last half hour.
- You arrive at your destination[4].

CS04: Vertical Graph of Trip + Average MPG



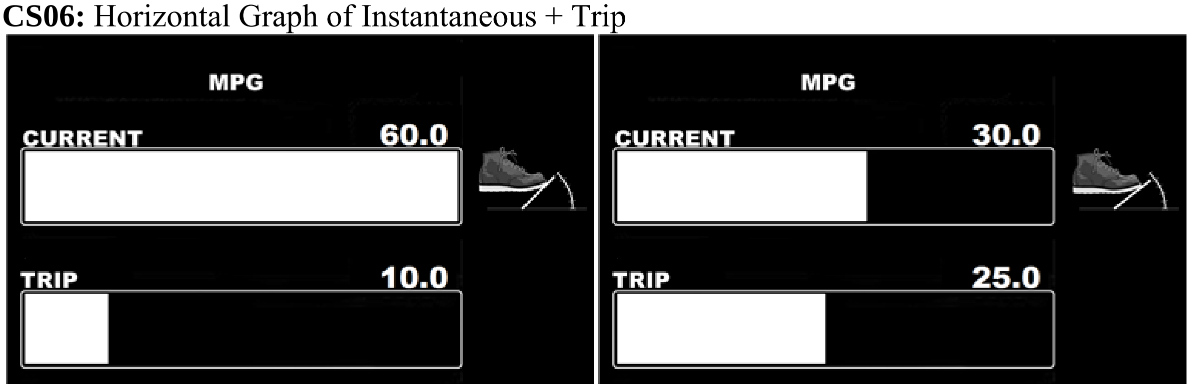
- You get in your car and begin driving.
- You enter the highway and merge with traffic.
- You drive at a consistent highway speed as you have been doing for the last few minutes.
- You exit the highway.
- You drive on neighborhood roads for a few minutes.
- You have arrived at your destination[4].

CS05: Horizontal Graph of Trip + Average MPGs



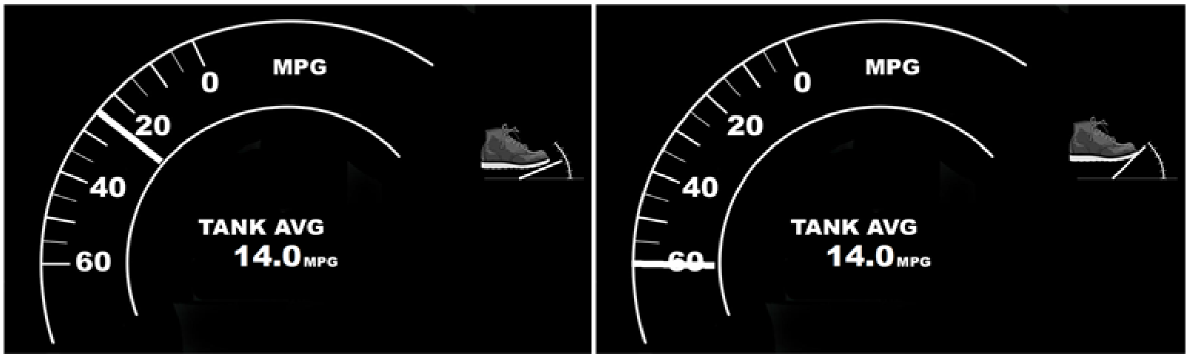
- You get in your car and begin driving.
- You drive at a consistent highway speed as you have been doing for the last half hour.
- You have arrived at your destination[4].
- You get back in your car before driving again[4].
- You have arrived at your second destination[4].
- You get back in your car before driving once again[4].

CS06: Horizontal Graph of Instantaneous + Trip



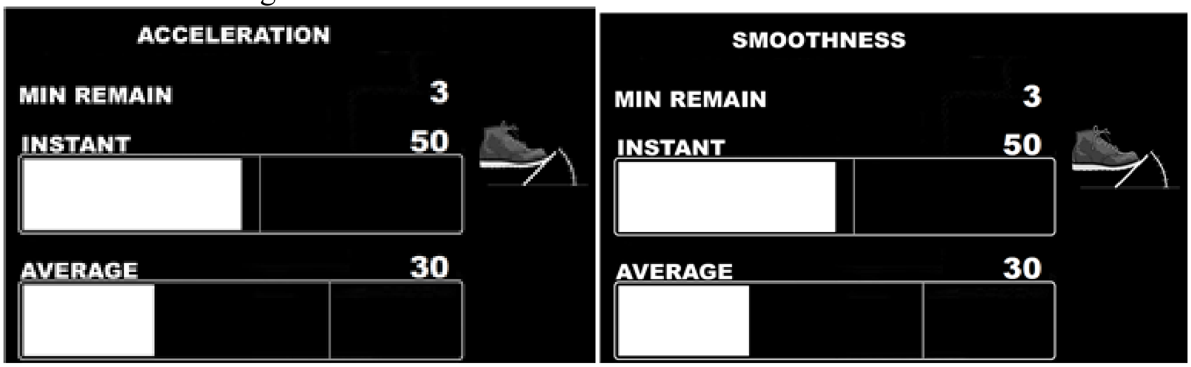
- You get in your car and begin driving.
- You merge with highway traffic.
- You drive at a consistent highway speed as you have been doing for the last few minutes.
- You exit the highway.
- You drive on neighborhood roads for a few minutes.
- You have arrived at your destination[4].

CS07: Leftward Dial + Text MPG



- You get in your car and begin driving.
- You enter the highway and merge with traffic.
- You drive at a consistent highway speed as you have been doing for the last few minutes.
- You exit the highway.
- You drive on neighborhood roads for a few minutes.
- You have arrived at your destination[4].

CS09t: Kiwi Training Exercises



- We want to show you a fuel economy driver interface that has a set of training features. These are short sessions where the interface monitors a specific driving behavior, such as acceleration or speed, and gives you an indication of what is optimal for fuel efficient driving.
- For example, when you "Acceleration" training display while driving at a consistent highway speed for a few minutes.
- This interface provides a score. In the next example you'll see the score get to a certain point before the display tells you if you've successfully completed the driving task. This score must be above 80 to pass.
- Similarly, this same interface provides training for "Smoothness". This next example will show you how the smoothness display looks.
- During a drive, if Traffic became slow, stop-and-go while using the "Smoothness" training display the score would be quite low as you'll see.
- If the score is below 80 the driver does not pass.

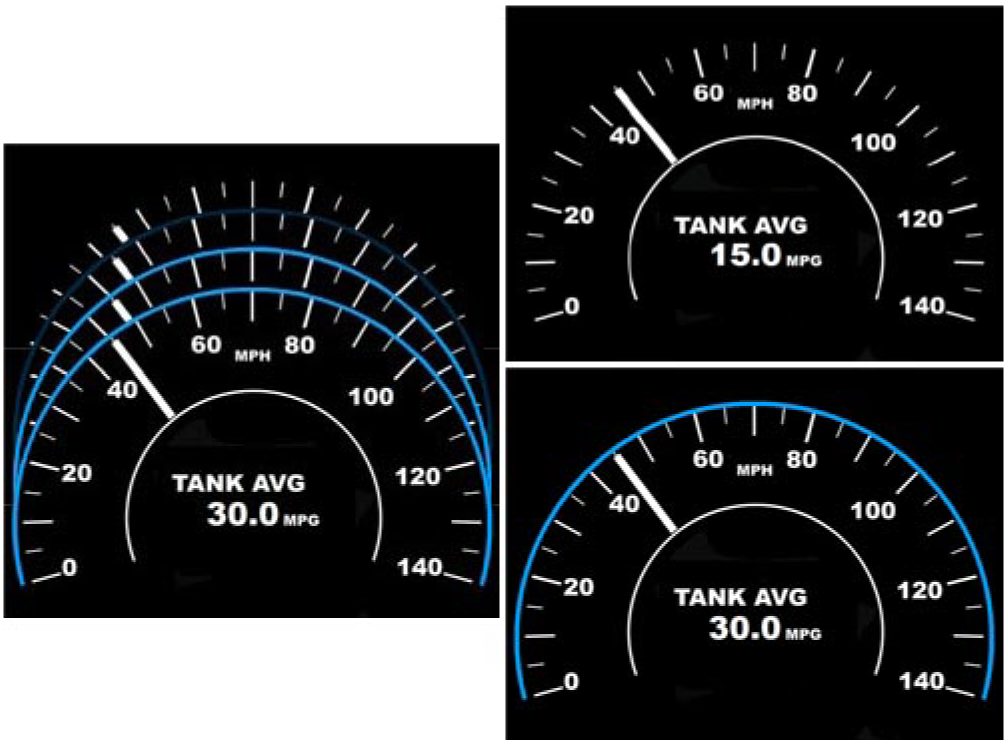
CS10t: Fiat Post-Drive training Exercises

- Your vehicle allows you to access information on your driving behaviors and resulting fuel economy using a program on your computer. Here is an overview of how this system works and what information is provided when you access it.
- Before this interface can be used, you must transfer your driving data from the car to the system. To do this you insert a USB stick into your vehicle, which automatically uploads the information to the USB stick. You then plug the USB stick into your computer and it takes care of the data automatically. Here is an example of what you might see after moving your data to this program.
- You turn some other features on and see the following page. This shows your progress over time by analyzing your driving technique and giving you a score out of 100, called your “eco-Index”. It then shows you how efficiently you've driven, based on your acceleration, deceleration, gear changes and speed.
- You select some other options and see the following page. This shows the history of your individual journeys, displaying information on their time, distance and cost. The eco-Calculator merges data from multiple journeys: the average eco:Index, average miles per gallon, total distance, fuel used, cost and CO_2 emissions.
- You navigate to the “eco:Driving” section of the program and see the following page. This offers hints on driving as efficiently as possible: from using your car's electric devices sparingly to making sure your tires are at the correct pressure.
- After using the program for a few weeks, you explore see the following page of tutorials. This one shows a gear change tutorial, which shows you how to change gear more efficiently so you can reduce both your fuel consumption and CO_2 emissions. It explains where you may be going wrong by playing back your worst journey and pointing out when you should be changing gear.

Appendix F: Usability FEDIC Component-Set Descriptions

CS01 – Intensity-Changing Light Source + Text MPG

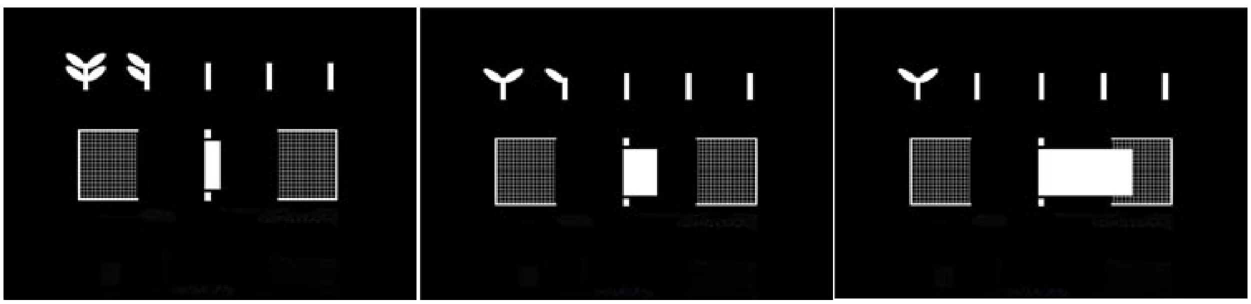
- In this display, the blue arc above the speedometer becomes more blue when the vehicle is burning smaller amounts of fuel. Such fuel efficient situations occur when a vehicle is at cruising speed, accelerating slowly, breaking gently, coasting, or exhibiting a combination of these behaviors.
- When the vehicle is driving in such a way that it is burning more fuel, the blue arc becomes less blue and will eventually disappear when fuel consumption is high. Examples of when this might happen are during quick acceleration, quick breaking and stop/go traffic.
- The tank average is reported as a number at the center of the speedometer, which does not change as quickly as the blue arc.



<continue> brings up next component-set

CS02 – Representative Picture + Accel/Decel Bar

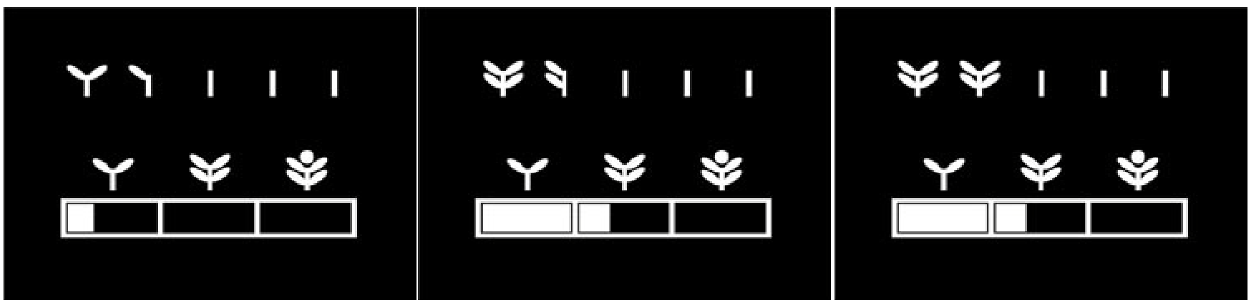
- This display provides information on braking and accelerating as well as showing overall trip mpg using leaf symbols. First, the bar moves to the right when the vehicle is accelerating. If the bar enters the grid it means that the drivers acceleration is not fuel efficient. The bar moves to the left when the driver decelerates or brakes. If the driver brakes to hard the bar may extend into the grid, again suggesting that hard braking leads to greater fuel consumption.
- The pictures show the display when a vehicle is: cruising (right), accelerating at a fuel efficient pace (middle) and accelerating at a pace that consumes a lot of gas (left).
- MPG for each trip and overall MPG are represented by the leaf symbols above the braking/acceleration bar. Driving fuel efficiently during a trip will populate more branches (vertical lines) with leaves, notice a leaf has been removed from the image on the right. Driving fuel efficiently during many trips will populate each branch with multiple leaves, as shown in the image on the left. This is similar to a trip fuel economy because over the course of a drive these leaves can increase in number or decrease in number.



<continue> brings up next component-set

CS03 – Representative Picture + Horizontal MPG Bar

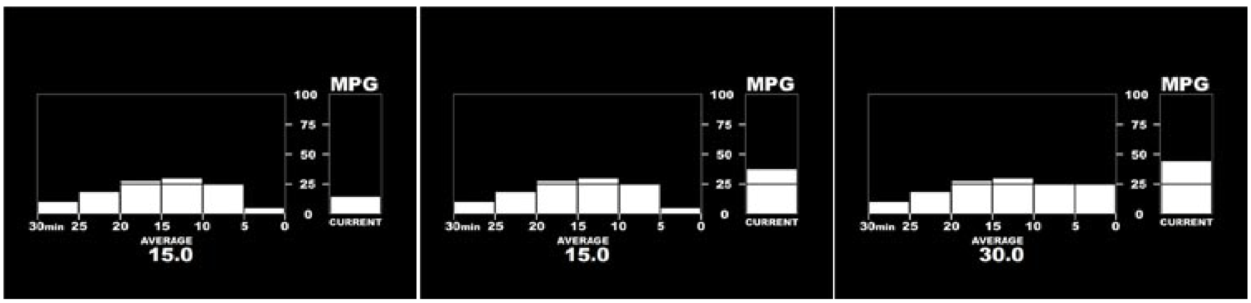
- MPG for each trip and overall MPG are represented by the leaf symbols above the braking/acceleration bar. Driving fuel efficiently during a trip will populate more branches (vertical lines) with leaves, notice a set of leaves has been added to the image on the right. Driving fuel efficiently during many trips will populate each branch with multiple leaves, as shown in the difference between the first and second images on the left. This is similar to a trip fuel economy because over the course of a drive these leaves can increase in number or decrease in number.
- The bottom portion of the display shows how well the driver has been driving over many trips in that vehicle. This bar moves slowly as driving data is collected over time. If a driver continually drives in a way that conserves fuel then the rectangle will grow towards the right. Eventually, the rectangle will pass over into the second (of three) bins and the leaf icon will change from having single leaves (image on left) into a double leaves (right two images). When the driver enters this new area, the leaves in the top portion fluctuate separately every time the vehicle is driven.



<continue> brings up next component-set

CS04 – Vertical Graph of Instantaneous + Trip MPG

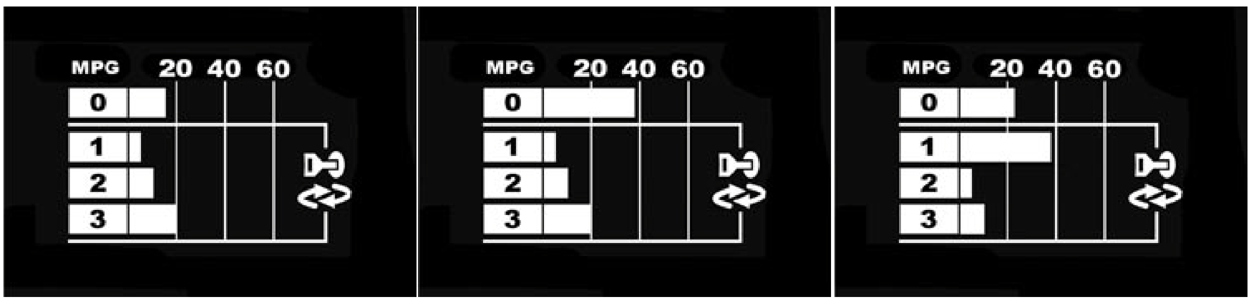
- This display Provides instantaneous mpg information as well as a history of mpg information during the drive. The instantaneous information is shown on the far right of the display, labeled, “Current MPG”. The current MPG bin moves quickly down (toward zero) when a driver depresses the accelerator, and moves quickly upwards (toward 100) when the drivers foot is off the accelerator.
- Every 5 minutes the vehicle samples the average mpg over that period of time. This average appears in the area to the left of the current mpg. Using this part of the display a driver is shown how much fuel is being consumed incrementally during a drive. The average fuel economy from when the vehicle is started is displayed in text at the bottom where it says “average”.



<continue> brings up next component-set

CS05 – Horizontal Graph of Trip + Average MPG

- This display provides a trip average MPG for driving sessions. The trip average MPG is the vehicle’s average MPG from the start of your drive (when you start the vehicle) to the end (when you stop the vehicle). It’s basically a rolling average that keeps being recalculated over time. The trip average slowly grows or increases as you drive, if your mpg is high. Trip mpg is not impacted by sudden breaking or accelerating to the same extent as instantaneous mpg.
- The other three bars in this display show mpg from previous drives allowing drivers make comparisons to previous drives. The current drive is marked with a zero and the three previous drivers are shown next to the 1, 2, and 3. Notice that the bar from drive 0 in the middle image becomes the bar for drive 1 in the left image.



<continue> brings up next component-set

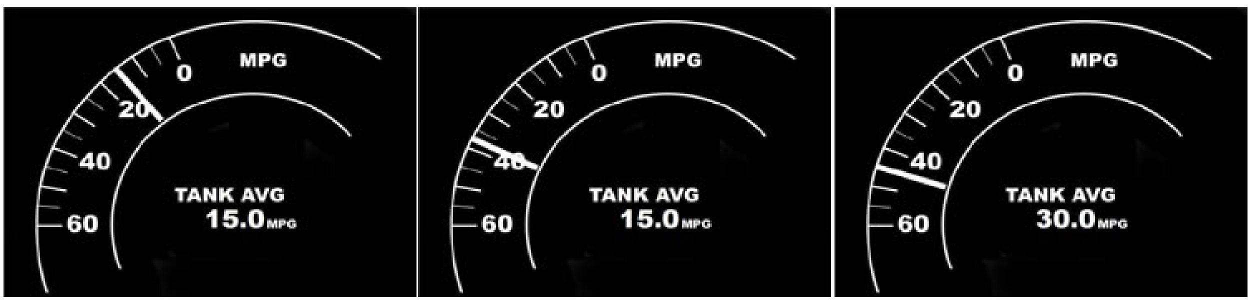
CS06 – Horizontal Graph of Trip + Instantaneous MPG

- Instantaneous MPG is shown in the top region. This bar fluctuates a lot during a drive, starting at zero when the vehicle is started and as the vehicle moves the bar grows to the right. For example, during a drive, the instantaneous bar will grow larger if the driver takes his foot off of the gas. When the driver depresses the gas again the instantaneous bar will shrink back to a central spot because the vehicle is consuming more fuel. This gauge is not affected by breaking.
- The bar in the lower region is the average fuel consumption (miles per gallon) between when the vehicle is started and the vehicle is stopped. When the vehicle starts this trip, average fuel economy is zero. As the vehicle is driven trip average fuel economy increases and will eventually stabilize at the vehicles fuel efficient zone.

<continue> brings up next component-set

CS07 – Leftward Dial + Text MPG

- This display provides feedback on instantaneous fuel economy (how much fuel a vehicle is burning at that very moment). The more fuel a vehicle is burning the closer the needle will be to zero. For example, the dial quickly moves toward Zero when a driver presses on the accelerator. This is because the vehicle is burning more gas as it accelerates. The less fuel a vehicle burns the farther the dial will move from zero as it gets closer to 60mpg. As one example, the needle quickly moves towards 60 when the driver takes his or her foot off the gas pedal. This is because the vehicle would not be consuming nearly as much fuel.
- Tank average mpg does not change as quickly as instantaneous mpg and is not as sensitive to breaking and accelerating as instant mpg. It changes so slowly (infrequently) that a driver may not notice.



<continue> ends set

Appendix G: Usefulness and Satisfying Scale

Please rate your opinion of the Fuel Economy Device shown using all the items listed below.

Example: If you thought the Fuel Economy Device was very easy to use but was somewhat confusing you might respond as follows:

Easy	☒	☐	☐	☐	☐	Difficult
Simple	☐	☐	☐	☒	☐	Confusing

Useful	☐	☐	☐	☐	☐	Useless
Pleasant	☐	☐	☐	☐	☐	Unpleasant
Bad	☐	☐	☐	☐	☐	Good
Nice	☐	☐	☐	☐	☐	Annoying
Effective	☐	☐	☐	☐	☐	Superfluous
Irritating	☐	☐	☐	☐	☐	Likeable
Assisting	☐	☐	☐	☐	☐	Worthless
Undesirable	☐	☐	☐	☐	☐	Desirable
Raising Alertness	☐	☐	☐	☐	☐	Sleep-inducing

Appendix H: Perceived Safety and Effectiveness Inventory

Perceived Safety and Effectiveness Inventory

You have just used a Fuel Economy Driver Interface Component (FEDIC) that provides information about how much fuel is used while driving. Answer the following questions while imagining that you just drove using this component. In comparison to driving without the component, please indicate how much you agree with the following statements:

"I think this component…"	(please circle your response)				
	Disagree completely				Agree completely
Is useful in traffic	1	2	3	4	5
Is useful on highways	1	2	3	4	5
Increases mental effort	1	2	3	4	5
Increases driver comfort	1	2	3	4	5
Distracts from driving	1	2	3	4	5
Is difficult to figure out	1	2	3	4	5
Will help improve fuel economy	1	2	3	4	5
I would regularly use this component	1	2	3	4	5
I would tell my friends about this component	1	2	3	4	5
I trust that this information is accurate	1	2	3	4	5
I think other drivers should use this component	1	2	3	4	5

For the remaining questions, place an 'X' in the box for the response that best you feel best represents your opinion of the device you just used. When completing these questions, try to compare your experience using the FEDIC

How would you describe your attitude towards driving with this FEDIC?

Very Negative	Slightly Negative	Neutral	Slightly Positive	Very Positive

Please explain the reason(s) for your answer.
....
....
....

If added to the cost of a vehicle, how much would you consider paying for the FEDIC system? Please circle your answer.
< $100
$101 to $500
$501 to $1000
$1001 to $2000
$2001 to $3000
$3001 to $4000
$4001 and up

Appendix I: Percentage of Correct Responses for Binary Logistic Regression Analysis

Table 13. Percentage of correct responses as a function of FEDIC CS and FEDIC CS state.

FEDIC CS State		FEDIC CS						
Average	Instantaneous	CS01	CS02	CS03	CS04	CS05	CS06	CS07
High	Avg + 50%	100	100	100	92	92	92	92
	Avg + 25%	92	100	85	85	92	92	92
	Avg - 25%	8	100	31	46	54	46	69
	Avg - 50%	8	100	54	62	92	85	85
	All High Avg	52	100	67	71	83	79	85
Low	Avg + 50%	62	85	69	85	92	85	69
	Avg + 25%	54	100	54	46	92	85	54
	Avg - 25%	54	100	69	54	54	62	92
	Avg - 50%	62	100	85	85	69	69	92
	All Low Avg	58	96	69	67	77	75	77
Overall (High & Low)	Avg + 50%	81	92	85	88	92	88	81
	Avg + 25%	73	100	69	65	92	88	73
	Avg - 25%	31	100	50	50	54	54	81
	Avg - 50%	35	100	69	73	81	77	88
	Overall Avg	55	98	68	69	80	77	81

Appendix J: Driving Simulation Recruitment Ad Content

PARTICIPANTS NEEDED FOR A DRIVING-RELATED STUDY

The University of Minnesota's HumanFIRST Program (www.humanfirst.umn.edu) is recruiting subjects to participate in a driving-related study on campus. This study is evaluating new gauge designs for vehicles. In this study, you will be asked to drive in a driving simulator and interact with the new gauges while driving. We will require approximately 2 hours of your time and will pay you $75 to participate.

To participate, you must:

- Be 18 – 50 years of age or older
- Possess a valid driver's license for at least one year
- Have 20/40 vision or better (corrected with glasses, contacts or surgery is fine)
- Have no physical limitations that prevent you from driving

If you fit these criteria, you may be eligible to participate in the study.

If you are interested in participating, please contact <name of researcher> by email at <name@umn.edu> or by phone at XXX-XXX-XXXX. Please provide your name and a phone number where you can be reached during the day. If you are eligible to participate, a time can be scheduled to participate.

Appendix K: Driving Simulation Study Screener

FEDIC Driving Simulator Study: Screener
v.MR2009-03-17

Yes or No, have you ever experienced the following conditions?

(exclude if any = YES)

- Claustrophobia
- Epileptic seizures
- Health problems that affect your ability to drive

How frequently have you experienced the following?
Never/Infrequently Sometimes or Often/Always?

(exclude if they respond "Often/Always" to ANY a. – h.)

a) Inner-ear problems
b) Dizziness
c) Vertigo
d) Balance problems
e) Migraines

(also exclude if they respond "Sometimes" to 2 or 3 f., g., or h.)

f) Motion sickness in the back seat of a car/vehicle
g) Motion sickness on a boat
h) Motion sickness on an amusement park ride

In what YEAR did you obtain your full drivers license (e.g., 2004)?

(exclude if 2008)

Appendix L: Driving Simulation Consent Form Content

Consent Form
Fuel Economy Display Simulator study

You are invited to be in a research study designed to evaluate various automobile fuel displays. You were selected as a possible participant because you responded to a request for participation in this study and were found to be a suitable participant. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by: Michael Manser, Janet Creaser, Justin Graving and Mick Rakauskas from the HumanFIRST program at the University of Minnesota for the National Highway Traffic Safety Administration, an operating administration of the U.S. Department of Transportation and the study sponsor.

Background Information

The purpose of this study is to evaluate automobile fuel economy displays for user comprehension and performance while used during simulated driving.

Procedures:

If you agree to be in this study, we would ask you to do the following things: (1) provide us with some basic information about yourself and your driving history (e.g., age, number of years you have had your license); (2) complete a series of drives using a simulated vehicle while using different fuel economy displays; (3) complete a set of questionnaires that asks you about your experiences interacting with the gauges and driving environment. The total time to complete this study today is approximately 2 hours.

Risks and Benefits of being in the Study

There are no direct benefits to you for participating in this study. There is a chance that you may experience motion sickness while driving in the simulator. If you believe that you are susceptible to carsickness, motion sickness, or anxiety we recommend that you not participate in this research. If you choose to participate and at anytime feel discomfort, nausea, or anxiety, you should immediately notify the experimenter and we will stop the study. Note: you are free to withdraw from the study for any reason at any time if you do not wish to continue.

Compensation:

You will receive payment $75 for participation. If you decide to stop participating at any time during the study you will still receive full payment.

Confidentiality:

The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a participant. Research records will be stored securely and only researchers and the study sponsor will have access to the records.

Voluntary Nature of the Study:

Participation in this study is voluntary and you may withdraw your participation in the study at any time. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions:

The researchers conducting this study are: Michael Manser, Janet Creaser, Justin Graving and Michael Rakauskas. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact them at HumanFIRST Program, 1100 Mechanical Engineering, 111 Church St. SE, Minneapolis, MN, 55455, 612-625-0447, mikem@me.umn.edu.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), **you are encouraged** to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455, (612) 625-1650.

You will be given a copy of this information to keep for your records.

Video, Audio, Data Release

The driving simulator contains cameras that record video of you while you are driving. The video cameras are located in such a manner that they will not affect you or obstruct your view while driving. The simulator contains microphones that will be recording your voice. By agreeing to participate in this study you will allow the University of Minnesota study staff and the study sponsor to collect data, record video and record audio of you during your participation. The University of Minnesota study staff and study sponsor will have access to this data.

By agreeing to participate in this study you are also agreeing to allow the video, audio, and data to be used by the University of Minnesota study staff and study sponsor for research purposes (e.g., analysis, educational and professional presentations) and for non-research purposes. Examples of non-research purposes include the following:

1) Public release for regulatory purposes (e.g., to assist in regulating devices);
2) Public release for educational purposes (e.g., to assist with educational campaigns for members of the general public);

3) Public release for outreach purposes (e.g., to nationally-televised programs highlighting traffic safety issues);
4) Public release for legislative purposes (e.g., to assist the U.S. Congress with law-making/rule-making activities).

The University of Minnesota and the study sponsor will edit/alter any data collected so that your image and/or voice are not identifiable and use only edited/altered data for non-research purposes. The University of Minnesota and the study sponsor also will not release any personal information that would allow you to be identified as a study participant.

By agreeing to participate in the study you are permanently releasing the University of Minnesota and the study sponsor, and any of their employees, agents, or assigns, from any and all claims that pertain to the video, audio, and simulator data collected during the study and the edited/altered versions of each, including, but not limited to, any claims based on the right of privacy, libel, or defamation.

Statement of Consent:

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature:____ Date: _________

Signature of Investigator:_____________________________ Date: _________

Appendix M: Driving Simulation Verbal Debriefing Protocol Content

Simulation Study to Evaluate Fuel Economy Displays Influence on Driving

Verbal Debriefing Protocol

Experimenters will read the following script upon completion of the study:
"Thank you for participating in this usability study. By doing so you have helped us understand how drivers use fuel economy displays while driving. The purpose of this study was to gain insight into how drivers think about fuel economy and to evaluate some prospective fuel economy displays. Fuel economy displays inform drivers about their fuel consumption while educating drivers on techniques that they can use to decrease the amount of fuel they use every time they drive. Aside from helping to reduce fuel costs these displays may also assist with safe driving behaviors. The findings from this study will be used to help design fuel economy displays that will appear in a variety of vehicles.

If you feel you need to express concerns about the study or if you are interested in learning about the outcome of the study you can contact Mike Manser at 612-625-0447 or mikem@me.umn.edu

Participants will also be given a copy of the consent form to take with them.

Appendix N: Protocol for Coding Eye Glance Behavior

Each participant is on a separate DVD, labeled by participant number, e.g., "99-1", where
99 = participant number
1 = experimental group (1, 2, or 3)

Each experimental session consisted of 7 separate scenarios:

- Practice drive
- Drive 1 with scenarios 1, 2, & 3 (counterbalanced)
- Drive 2 with scenarios 1, 2, & 3 (counterbalanced)

Participants will drive the following the three scenarios twice, once during Drive 1 and a second time during Drive 2: CF = Car Following; FD = Free Drive; SG = Stop & Go

I am continually updating a notes page that will tell you the order of the scenarios for each participant and any notes relevant to your tally; this spreadsheet is on the shared drive: "M:\m-hfirst\Projects\Fuel Economy Displays\Task 3 Materials\3 Refinement_Testing - Simulator Study\Data\EyeGlance\FEDIC Condition Notes.xls"

In the notes, I may reference a particular scenario. I will identify each scenario as follows, e.g.,:
FD_1 = Free Drive during Drive 1
CF_2 = Car following during Drive 2
SG_1 = Stop-and-Go during Drive 1

Scoring

Tally the number of times that the participant glances down from the driving scene to the fedic, speedometer, or just down (if hard to determine). See the table on the next page for examples.

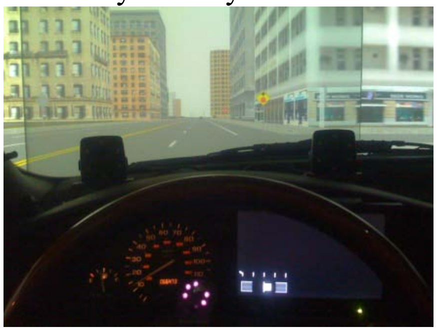
Duration of each scenario we are concerned with:

Car Following
Start: participant's vehicle starts moving
End: participant's vehicle comes to a stop

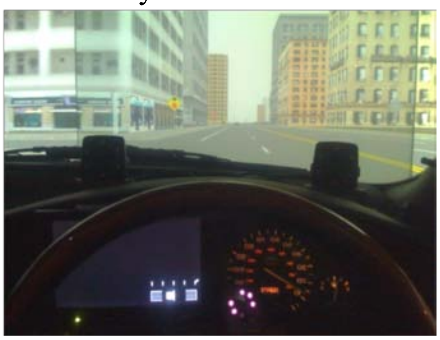
Free Drive
Start: participant's vehicle starts moving
End: participant's vehicle comes to a stop

Stop-and-Go
Start: yellow-diamond "stop ahead" sign in driving scene touches right side of frame
End: yellow-diamond "pedestrian" sign in driving scene touches right side of frame
NOTE: there are 4 stops during this drive. Combine the tally for the first 3 stops into a single tally (SG- 1, 2, & 3) and keep the tally of the fourth stop separate (SG-4).

What they actually see:



Horizontally-mirrored view:



This view was intended to be used by the scoring judge so that the direction of the eye gaze would match the location of the targets within this view. E.g., when the participant video shows a gaze down and toward the left, this conceptually matches with the FEDIC in the mirrored view. Table 14 shows the relationship between the scoring codes, horizontally-mirrored view examples, and participant video.

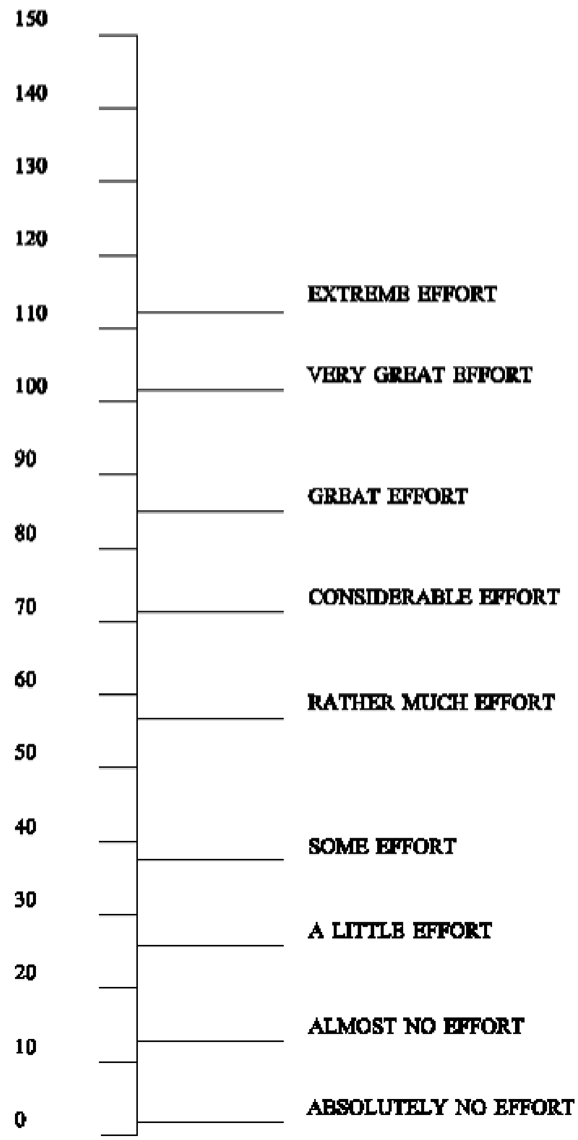
Table 14. Eye glance scoring codes.

Code	Direction	Horizontally-Mirrored View	Participant Video
0	Up and at road		
1	Down at FEDIC		
2	Down at Speedo-meter		
3	Down, but unclear whether at FEDIC or Speedo-meter		

Appendix O: Driving Simulation Measure of Mental Effort- RSME

DRIVING EFFORT SCALE

Below is the Rating Scale of Mental Effort. It shows you a single line with a range from 0 to 150. On this line you are to make a small horizontal line to show how much effort it took for you to complete the task you've just finished. You may use the labels on this scale to help locate your own rating.



Appendix P: Driving Simulation Measures of Usability – Trust Questionnaire

Trust Questionnaire

The performance of the system enhanced my driving safety.

0 Strongly Disagree	50	100 Strongly Agree

I am familiar with the operation of the system.

0 Strongly Disagree	50	100 Strongly Agree

I trust the system.

0 Strongly Disagree	50	100 Strongly Agree

The system is reliable.

0 Strongly Disagree	50	100 Strongly Agree

The system is dependable.

0 Strongly Disagree	50	100 Strongly Agree

The system has integrity.

0 Strongly Disagree	50	100 Strongly Agree

I am comfortable with the intent of the system.

0 Strongly Disagree	50	100 Strongly Agree

I am confident in my ability to drive the truck safely without the system.

0 Strongly Disagree	50	100 Strongly Agree

Appendix Q: Driving Simulation Measures of Usability – Usability Survey

USABILITY SURVEY

You have driven a vehicle that is fitted with a Fuel Economy Driver Interface Concept (FEDIC) that provides feedback to assist your driving. Based on your driving experience with this FEDIC in comparison to unassisted driving, please indicate how much you agree with the following statements:

“I view this system that supports my driving as…” (please circle your response)

	Disagree Completely				Agree Completely
A system to improve safety	1	2	3	4	5
A system to enhance performance	1	2	3	4	5
A source of confusion or distraction	1	2	3	4	5
Useful in urban areas	1	2	3	4	5
Useful in rural areas	1	2	3	4	5
Useful on highways	1	2	3	4	5
Useful in stop and go traffic	1	2	3	4	5
Increasing mental (and visual) effort	1	2	3	4	5
Increasing driver comfort	1	2	3	4	5
Creating difficulties on curves	1	2	3	4	5
Encouraging faster than normal speeds	1	2	3	4	5
Making the driver less vigilant	1	2	3	4	5
Making the driver less stressed	1	2	3	4	5
Making the passengers less stressed	1	2	3	4	5
Encouraging over-confidence in drivers.	1	2	3	4	5
Unreliable in its operations	1	2	3	4	5
Requires specialized training and practice	1	2	3	4	5

For the remaining questions, place an 'X' in the box for the response that best you feel best represents your opinion of the Active Cruise Control. When completing these questions, try to compare your experience using the FEDIC to how you felt while driving with the system:

Do you think that FEDIC made your driving more or less safe for you as a driver, in comparison to how you felt when driving without the system?

Much less safe	A little less safe	No change	A little more safe	Much More safe

Please explain the reason(s) for your answer.
....
....
....

Do you think that FEDIC made you feel more or less stressful as a driver, in comparison to how you felt when driving without the system?

Much less stressful	A little less stressful	No change	A little more stressful	Much more stressful

Please explain the reason(s) for your answer.
....
....
....

How would you describe your attitude towards driving with FEDIC?

Very Negative	Slightly Negative	Neutral	Slightly Positive	Very Positive

How would you describe your attitude towards driving without FEDIC?

Very Negative	Slightly Negative	Neutral	Slightly Positive	Very Positive

Did using FEDIC make driving more or less confident for you as a driver, in comparison to how you felt when driving without the system?

Much less confident	A little less confident	No change	A little more confident	Much more confident

Please explain the reason(s) for your answer.
....
....
....

Do you think that you paid more or less attention to the driving task while using the FEDIC, in comparison to how you felt when driving without the system?

Much less attention	A little less attention	No change	A little more attention	Much more attention

Please explain the reason(s) for your answer.
....
....
....

List the things you paid most attention to when driving with and without the FEDIC:

FEDIC	No assistance
1st	1st
2nd	2nd
3rd	3rd
4th	4th
5th	5th

Having tried it, do you think that FEDIC had any benefits for you as a driver?

No benefits	Minor benefits	Major benefits

Please explain the reason(s) for your answer.
....
....
....

Having tried it, are there any problems with FEDIC (e.g., that may reduce safety)?

No problems	Minor problems	Major problems

Please explain the reason(s) for your answer.
....
....
....

Please briefly describe the most difficult aspects of driving when using FEDIC:

....
....
....

Please briefly describe the problems (if any) when using FEDIC:

....
....
....

If the FEDIC were offered as a free option with a new vehicle would you include it with your vehicle? Please circle your answer.

Yes	No	Maybe

Would having a FEDIC like this in your vehicle motivate you to drive more fuel efficiently? Please circle your answer.

Yes	No	Maybe

If added to the cost of a vehicle, how much would you consider paying for the FEDIC system? Please circle your answer.

< $100	$2001 to $3000
$101 to $500	$3001 to $4000
$501 to $1000	$4001 and up
$1001 to $2000	

Appendix R: All Results from Driving Simulation Experiment

6.1.1 Stop-and-Go (SG) Scenario

6.1.1.1 Fuel Economy

6.1.1.1.1 **Fuel Economy**

The results of the within-subject tests indicated significant differences for average fuel economy between Drives 1 and 2 for Groups 1, 2, and 3. Figure 32 shows that the significant difference within Group 1 ($t(29) = 6.61$, $p < .001$, $d = 1.27$) was due to the greater fuel economy exhibited by participants during Drive 2 ($M = 28.5$ mpg, $SD = 8.04$ mpg) as compared to Drive 1 ($M = 20.2$ mpg, $SD = 4.61$ mpg). The significant difference within Group 2 ($t(29) = 6.94$, $p < .001$, $d = 1.27$) was due to the greater fuel economy exhibited by participants during Drive 2 ($M = 32.1$ mpg, $SD = 8.95$ mpg) as compared Drive 1 ($M = 21.0$ mpg, $SD = 4.91$ mpg). The significant difference within Group 3 ($t(26) = 6.35$, $p < .001$, $d = 1.54$) was due to the greater fuel economy exhibited by participants during Drive 2 ($M = 26.6$ mpg, $SD = 6.4$ mpg) as compared to Drive 1 ($M = 20.3$ mpg, $SD = 5.73$ mpg).

The One-way ANOVA indicated that fuel economy differed significantly as a function of Group ($F(2, 86) = 3.56$, $p <.05$). Follow-up Tukey paired comparisons indicated that the average fuel economy exhibited by Group 2 ($M = 32.1$ mpg, $SD = 8.95$ mpg) was significantly greater as compared to Group 3 ($M = 26.6$ mpg, $SD = 6.4$ mpg).

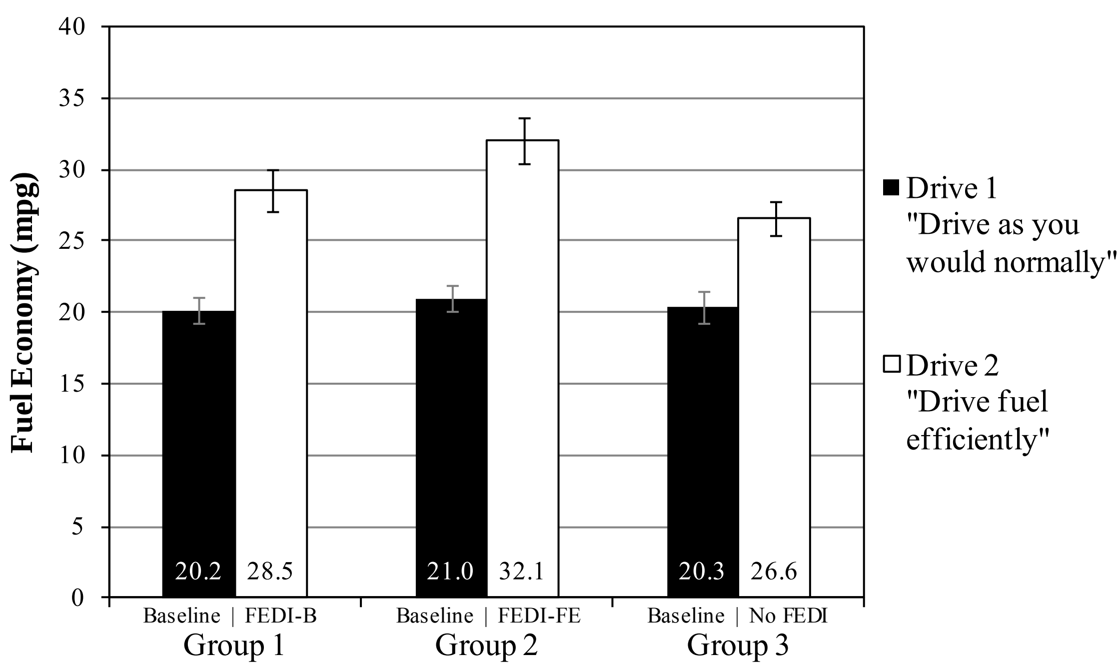


Figure 32. Average Fuel Economy (mpg) during the first three stops in the SG scenario.

6.1.1.1.2 **Celeration**

The results of the within-subjects tests indicated significant differences for average celeration between Drives 1 and 2 for Groups 1, 2, and 3. Figure 33 shows that the significant difference within Group 1 ($t(29) = 8.67$, $p < .001$, $d = 1.53$) was due to the greater celeration exhibited by participants during Drive 1 ($M = 0.23$, $SD = .051$) as compared to Drive 2 ($M = 0.16$, $SD = .036$). The significant difference within Group 2 ($t(29) = 7.72$, $p < .001$, $d = 1.63$) was due to the greater celeration exhibited by participants during Drive 1 ($M = 0.21$, $SD = .05$) as compared to Drive 2 ($M = 0.14$, $SD = .04$). The significant difference within group 3 ($t(26) = 5.18$, $p < .001$, d =.98) was due to the greater celeration exhibited by participants during Drive 1 ($M = 0.21$, $SD = .046$) as compared to Drive 2 ($M = 0.17$, $SD = .04$).

The One-way ANOVA indicated that Drive 2 celeration differed significantly as a function of Group ($F(2, 86) = 5.14$, $p <.01$). The follow-up Tukey paired comparisons indicated that average celeration for participants in Group 3 ($M = 0.17$, $SD = .04$) was significantly greater compared to Group 2 ($M = 0.14$, $SD = .05$).

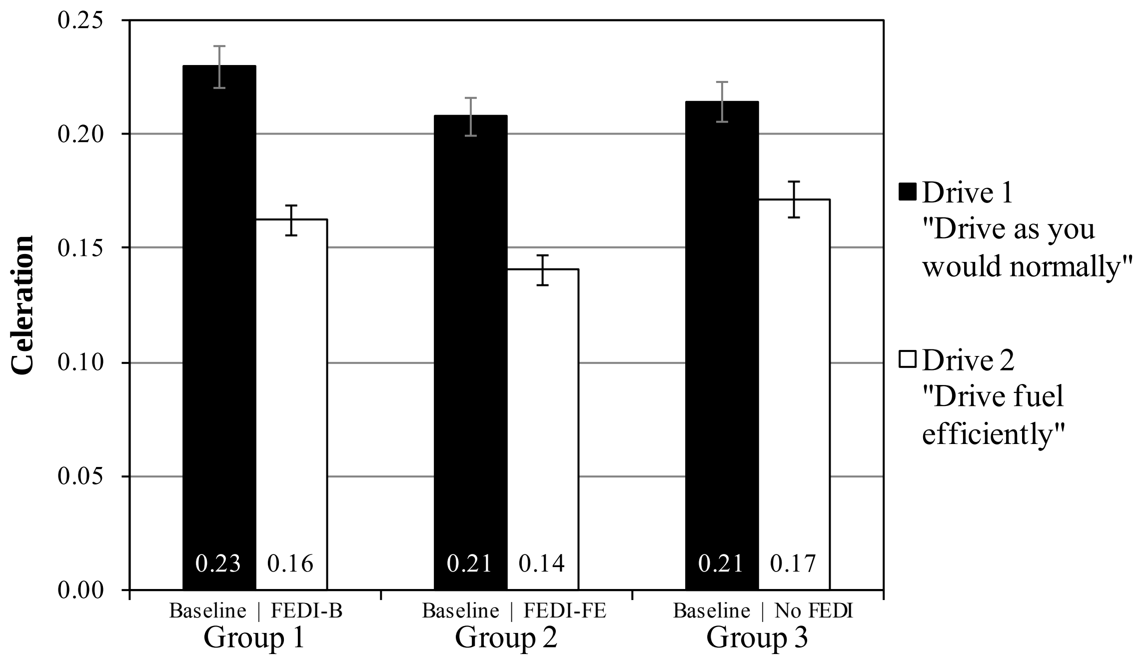


Figure 33. Average Celeration during the first three stops in the SG scenario.

6.1.1.1.3 **Time to Stop (TTS)**

A large number of participants drove through the stop sign at a slow speed. We were not able to calculate the time to stop for these participants. Because there were too few valid data for this metric we were unable to perform the originally planned calculations.

6.1.1.1.4 **Time to Accelerate (TTAc)**

The results of the within-subjects tests indicated a significant difference in average TTAc between Drives 1 and 2 for Group 1. Figure 34 shows that the significant difference within Group 1 ($t(21) = 2.11$, $p < .05$, $d = .63$) was due to the greater TTAc exhibited by participants during Drive 2 ($M = 46.99$ s, $SD = 87.9$ s) as compared to Drive 1 ($M = 7.58$ s, $SD = 1.41$ s).

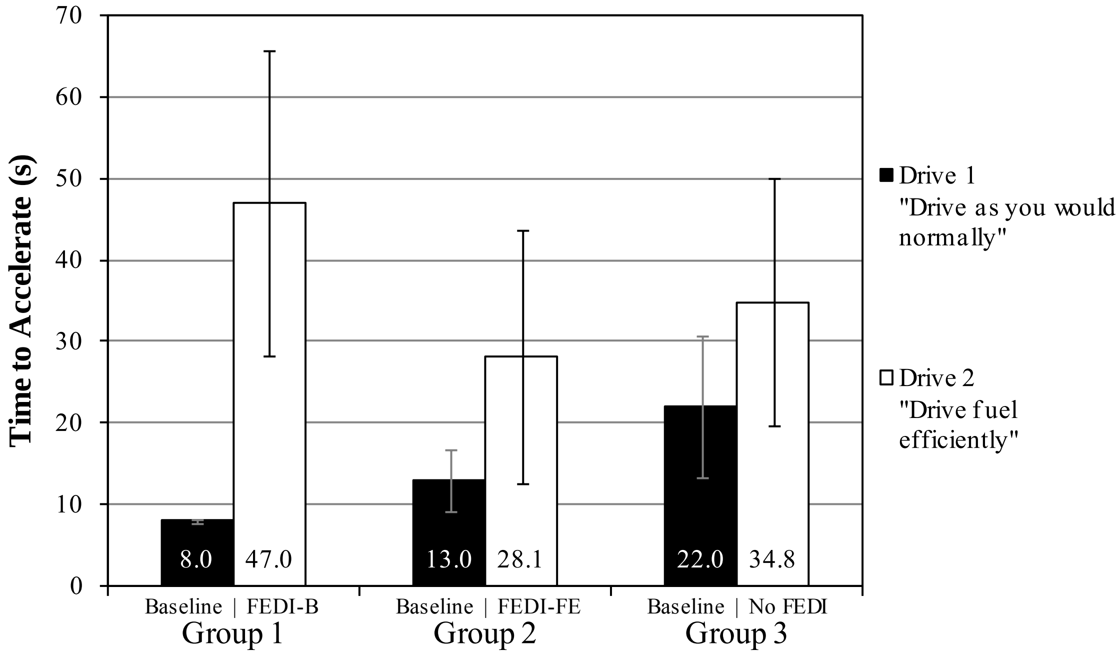


Figure 34. Average Time to Accelerate (s) during the first three stops in the SG scenario.

6.1.1.1.5 **85th Percentile Deceleration (85% Dec)**

The results of the within-subjects tests indicated significant differences in average 85% Dec between Drives 1 and 2 for Groups 1, 2, and 3. Figure 35 shows that the significant difference within Group 1 ($t(29) = 3.28$, $p < .01$, $d = .56$) was due to the slower 85% Dec exhibited by participants during Drive 2($M = -7.01$ m/s^2, $SD = 3.15$ m/s^2) as compared to Drive 1 ($M = -8.79$ m/s^2, $SD = 3.22$ m/s^2). The significant difference within Group 2 ($t(29) = 5.25$, $p < .001$, $d = 1.39$) was due to the slower average 85% Dec exhibited by participants during Drive 2 ($M = -5.41$ m/s^2, $SD = 2.68$ m/s^2) as compared to Drive 1 ($M = -9.36$ m/s^2, $SD = 3.01$ m/s^2). The significant difference within Group 3 ($t(22) = 2.41$, $p < .05$, $d = .59$) was due to the slower 85% Dec exhibited by participants during Drive 2 ($M = -6.94$ m/s^2, $SD = 3.22$ m/s^2) as compared to Drive 1 ($M = -9.84$ m/s^2, $SD = 6.18$ m/s^2).

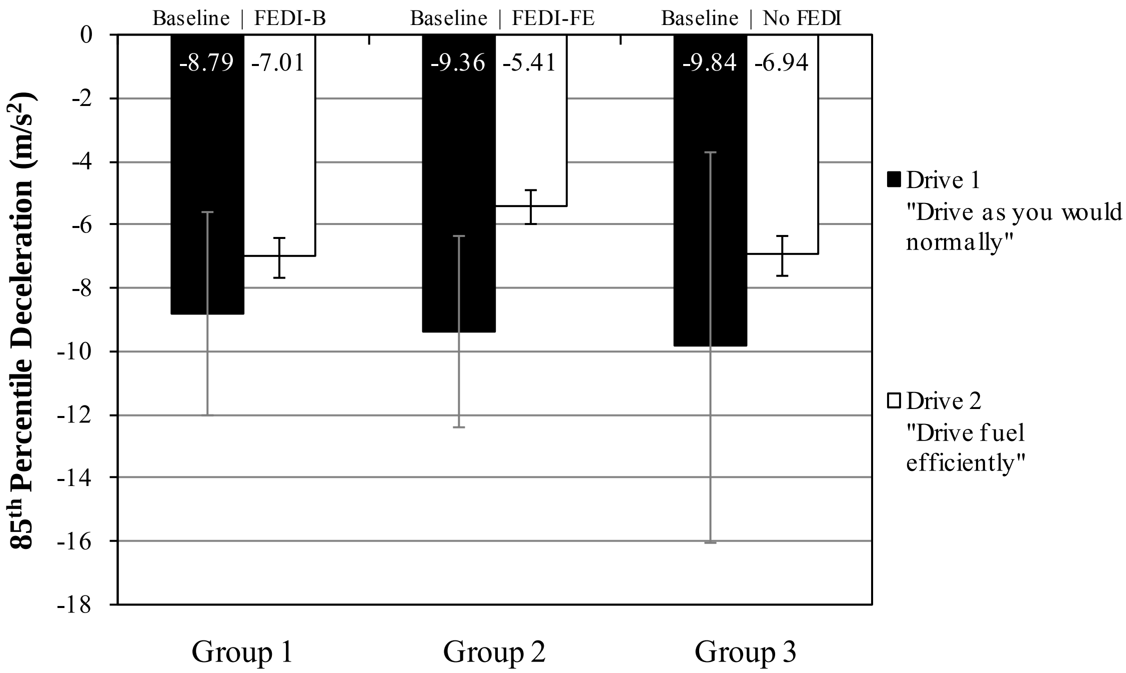


Figure 35. Average 85th Percentile Deceleration during the first three stops in the SG scenario.

6.1.1.1.6 85th Percentile Acceleration (85% Acc)

The within-subjects tests indicated significant differences in average 85% Acc between Drives 1 and 2 for Groups 1, 2, and 3. Figure 36 shows that the significant difference within Group 1 ($t(29) = 9.84$, $p < .001$, $d = 1.8$) was due to the greater average 85% Acc exhibited by participants during Drive 1 ($M = 8.53$ m/s^2, $SD = 1.15$ m/s^2) as compared to Drive 2 ($M = 5.66$ m/s^2, $SD = 1.94$ m/s^2). The significant difference within Group 2 ($t(29) = 5.25$, $p < .001$, $d = 1.19$) was due to the greater average 85% Acc exhibited by participants during Drive 1 ($M = 7.71$ m/s^2, $SD = 1.45$ m/s^2) as compared to Drive 2 ($M = 5.79$ m/s^2, $SD = 1.77$ m/s^2). The significant difference within Group 3 ($t(26) = 4.10$, $p < .001$, $d = .96$) was due to the greater average 85% Acc exhibited by participants during Drive 1 ($M = 7.55$ m/s^2, $SD = 1.20$ m/s^2) as compared to Drive 2 ($M = 6.18$ m/s^2, $SD = 1.61$ m/s^2).

The result of the between-subjects tests on participants' 85% Acc for Drive 1 (baseline drive) indicated significant differences between Groups 1 and 2 ($t(58) = 2.43$, $p < .05$), and between Groups 1 and 3 ($t(55) = 3.167$, $p < .01$). There was not a significant difference in 85% Acc between Group 2 and 3 during Drive 1. Due to these significant differences, the Drive 2 85% Acc data were normalized within Groups 1, 2, and 3. To accomplish this, each Group's mean for Drive 1 was subtracted from each participant's average 85% Acc. For example, the Drive 2 data for Group 1 were normalized by taking the Drive 1 85% Acc averaged across all of the Group 1 participants and subtracting it from each participant's 85% Acc obtained from Drive 2. The same normalization process was completed for Groups 2 and 3 and these normalized results were analyzed to examine the between subjects effects during Drive 2.

The One-way ANOVA indicated that the normalized average 85% Acc from Drive 2 differed significantly as a function of Group ($F(2, 86) = 5.21$, $p < .01$). Follow-up Tukey paired comparisons indicated that the normalized average 85% Acc from participants in Group 1 ($M = -2.87$ m/s^2, $SD = 1.60$ m/s^2) was significantly different compared to Group 3 ($M = -1.36$ m/s^2, $SD = 1.73$ m/s^2).

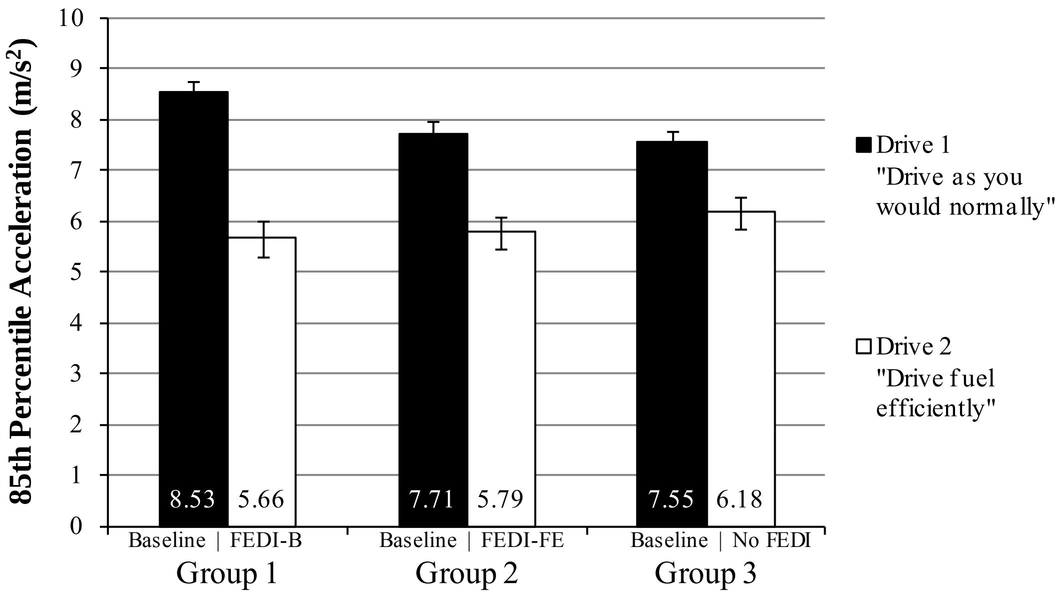


Figure 36. Average 85th Percentile Acceleration during the first three stops in the SG scenario.

6.1.1.2 Safety

6.1.1.2.1 **Max Brake Pedal Position (Max BP)**

The within-subjects tests indicated significant differences in average Max BP between Drives 1 and 2 within Groups 1 and 2. Figure 37 shows that the significant difference within Group 1 ($t(29) = 3.27$, $p < .01$, $d = .77$) was due to the greater Max BP exhibited by participants during Drive 1 ($M = .69$, $SD = .17$) as compared to Drive 2 ($M = .56$, $SD = .17$). The significant difference within Group 3 ($t(26) = 2.65$, $p < .05$, $d = .62$) was due to the greater Max BP exhibited by participants during Drive 1 ($M = .65$, $SD = .18$) as compared to Drive 2 ($M = .53$, $SD = .2$).

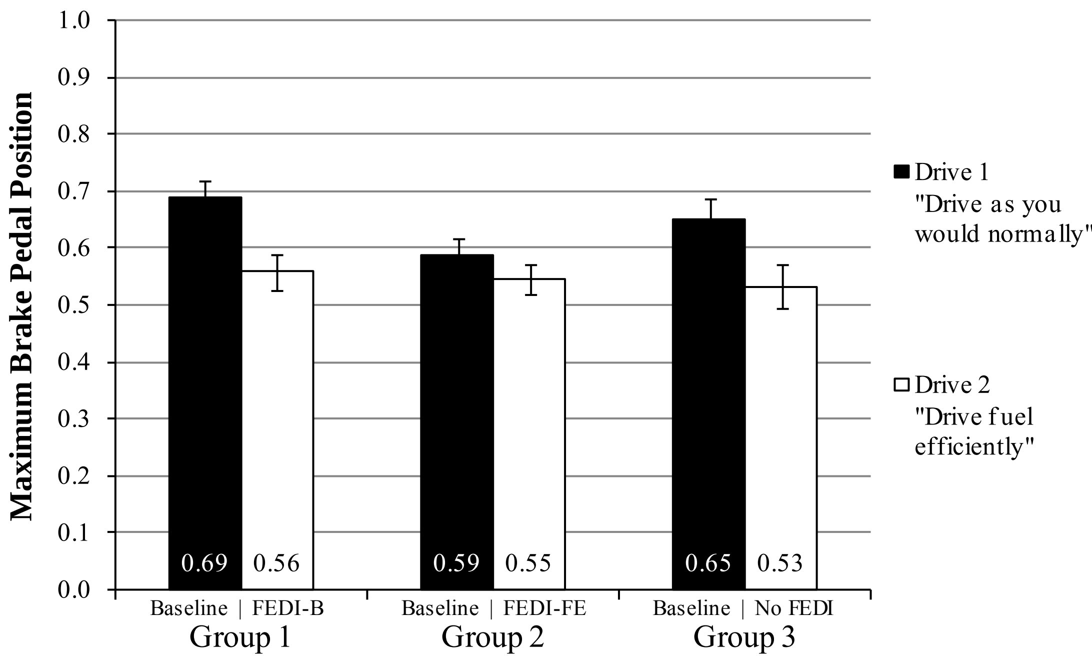


Figure 37. Average Maximum Brake Pedal Position during the first three stops in the SG scenario.

6.1.1.2.2 Time-to-Contact at Lead Vehicle braking (TTC Brake)

During most participants' drives, the distance between the lead-car and the participant's car during the breaking events increased. The increase in distance during the brake event lead to a calculated time-to-contact that was not meaningful and that approached infinity. Because there were too few valid data for this metric we were unable to calculate inferential statistics.

6.1.1.2.3 Minimum Time-to-Contact (TTC Min)

The results of the within-subjects tests indicated a significant difference for TTC Min between Drives 1 and 2 for Group 1. Figure 38 shows that the significant difference within Group 1 ($t(29) = 4.36$, $p < .001$, $d = .96$) was due to the greater TTC Min exhibited by participants during Drive 1 ($M = 4.58$ s, $SD = 2.46$ s) as compared to Drive 2 ($M = 2.59$ s, $SD = 1.59$ s).

The One-way ANOVA indicated that Drive 2 TTC Min differed significantly as a function of Group ($F(2, 86) = 9.01$, $p < .001$). Follow-up Tukey paired comparisons indicated that Group 3 had significantly greater TTC Min ($M = 5.09$ s, SD 2.6 s) compared to Group 2 ($M = 2.59$ s, $SD = 1.59$ s) and Group 3 ($M = 4.22$ s, $SD = 2.51$ s).

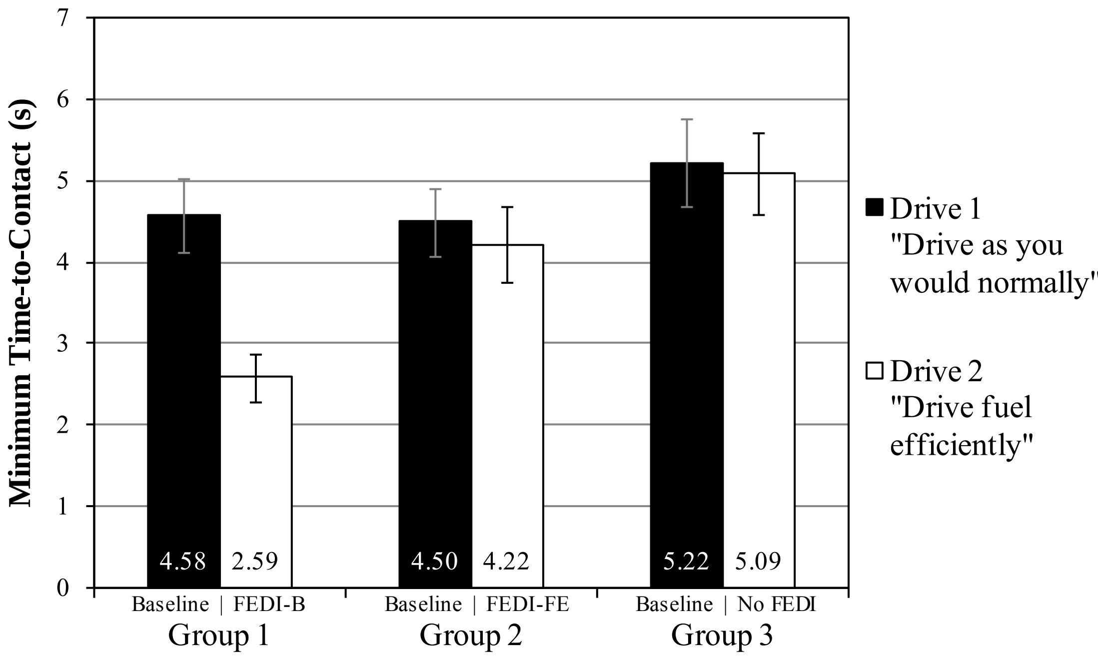


Figure 38. Minimum Time-to-Contact during the first three stops in the SG scenario.

6.1.1.2.4 Eye Glance Frequency (EGF)

The within-subjects tests indicated significant differences in EGF between Drives 1 and 2 for Groups 1 and 2. Figure 39 shows that the significant difference within Group 1 ($t(8) = 3.70$, $p < .01$) was due to the greater EGF exhibited by participants during Drive 2 ($M = 30$, $SD = 12.6$) as compared to Drive 1 ($M = 11$, $SD = 5.9$). The significant difference within Group 2 ($t(9) = 3.79$, $p < .01$) was due to the greater EGF exhibited by participants during Drive 2 ($M = 25$, $SD = 9.2$) compared to Drive 1 ($M = 12$, $SD = 4.6$).

The One-way ANOVA indicated that Drive 2 EGF differed significantly as a function of group ($F(2, 24) = 4.10$, $p <.05$). Follow-up Tukey paired comparisons indicated that Group 3 had significantly lower EGF ($M = 16$, $SD = 5.6$) compared to Group 1 ($M = 30$, $SD = 4.2$).

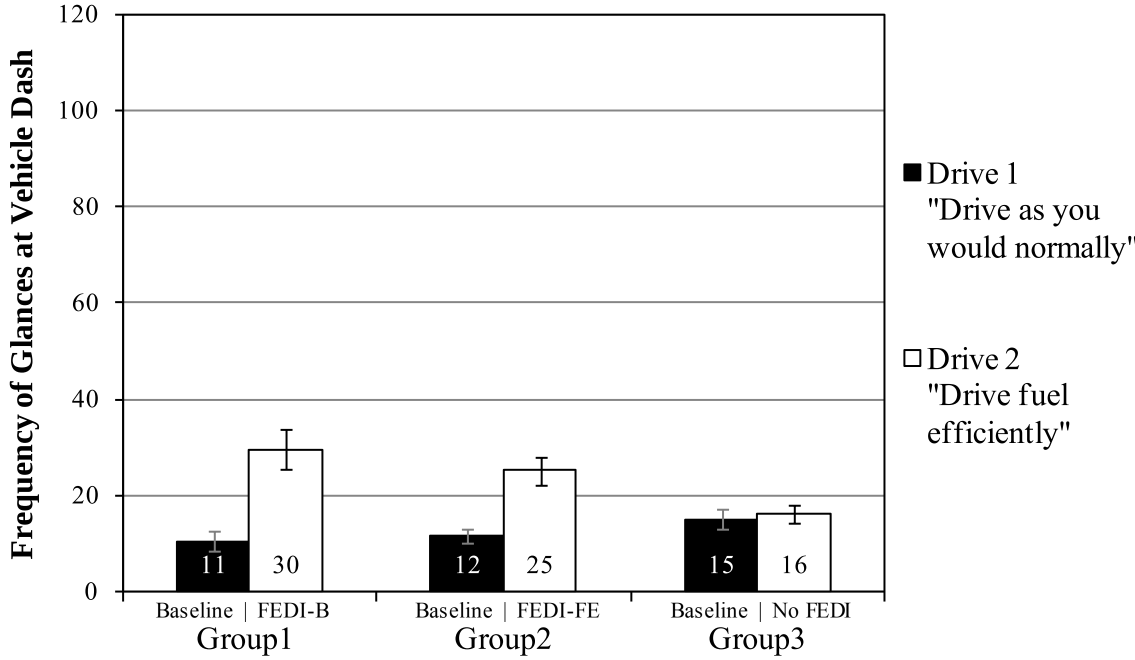


Figure 39. Eye glance frequency during all four Stops of the SG scenario.

6.1.1.3 Effect of Stop Order

6.1.1.3.1 **Fuel Economy x Stop**

There was a main effect of Drive ($F(1, 26) = 53.13$, $p <.001$). Fuel economy was significantly greater for Drive 2 (M = 27.03, SD = 8.28) than Drive 1 (M = 19.53, SD = 5.01). There was also a main effect of Stop, ($F(3, 26) = 52.47$, $p < .001$). As presented in Figure 40, the main effect of stop indicated that fuel economy increased across the 3 of the 4 stops. Fuel economy was significantly less during Stop 1 (M = 21.41, SD = 5.9) compared to Stops 2 (M = 25.41, SD = 8.4) and 3 (M = 27.6, SD = 8.4). Fuel efficiency during stop 2 was significantly less compared to Stop 3. However, Fuel efficiency during Stop 4 (M = 18.7, SD = 4.7) was significantly less compared to Stops 1, 2, and 3. The interaction between Stop and Drive was significant ($F(3, 78) = 10.49$, $p <.001$) and was due to relatively stable fuel economy within Drive 1 across the four stops as compared to the increasing fuel economy exhibited across stops within Drive 2. It should be noted that fuel economy increased for Stops 1 through 3 within Drives 1 and 2 and was most likely due to the ability of participants to gauge their performance against that of the lead vehicle as compared to Stop 4 in which participants did not have a comparison vehicle.

Across Stops 1 through 3, there was a main effect for Stop ($F(2, 52) = 36.01$, $p < .001$).Fuel economy during Stop 1 (M = 24.7,Sd = 5.8) was significantly less compared to Stops 2 (M = 30.4, SD = 8.4) and 3 (M = 32.3, SD = 8.2). Fuel economy during Stop 2 was significantly less compared to Stop 3. Although the interaction between Stop and Group was not significant there was a trend that suggested that fuel economy increased within Group 2 such that average fuel economy increased across Stops 1 through 3 when they used the FEDIC-FE. A similar trend was found for participants in Groups 1 and 3. Interestingly there appeared to be a slight difference between groups such that the apparent trend in fuel economy was greater for those that drove with FEDIC-FE. The main effects and interactions for fuel economy can be found in Figure 40.

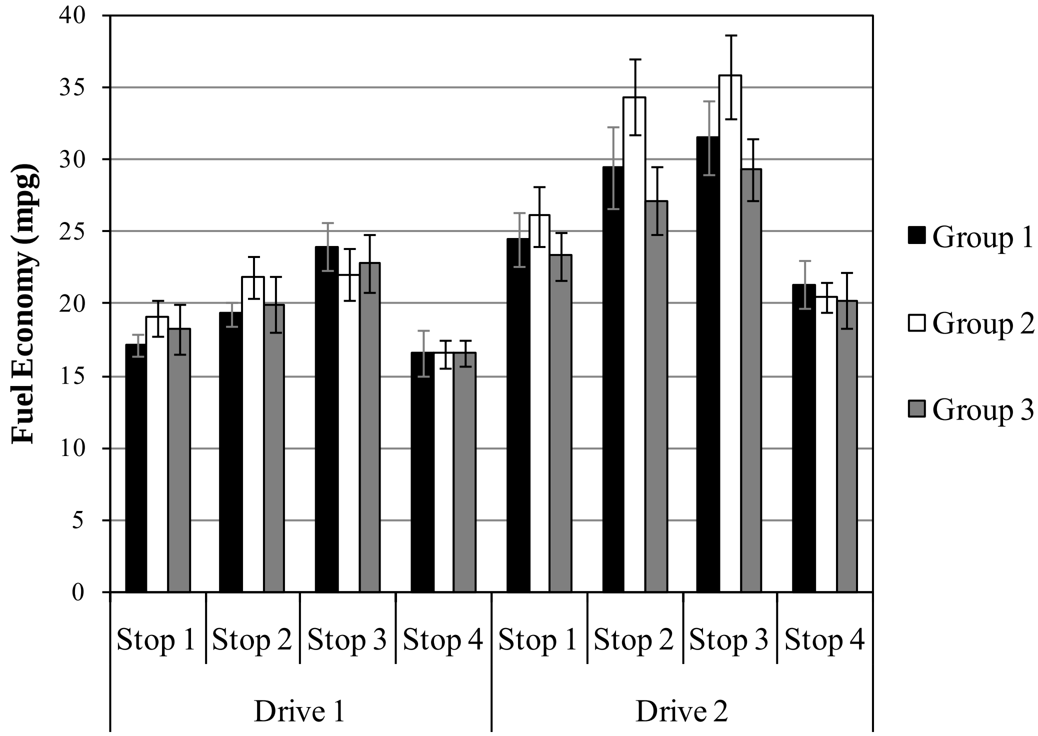


Figure 40. Fuel economy (average miles per gallon) during all four Stops of the SG scenario.

6.1.1.3.1 **Celeration x Stop**

Results indicated a main effect for Drive across all four stops for celeration, ($F(1, 26) = 69.09$, $p < .001$). As presented in Figure 41, celeration during Drive 1 (M = .23, SD = .05) was significantly higher than celeration during Drive 2 (M = .17, SD = .05). The main effect for Stop ($F(3, 78) = 28.10$, $p < .001$) indicated that celeration was significantly higher during Stop 4 (M = .23, SD = .06) when compared to Stop 1 (M = .20, SD = .06), Stop 2 (M =.18, SD = .05), and Stop 3 (M = .18, SD = .05). Celeration was significantly greater during stop 1 compared to stops 2 and 3. The difference in celeration between stop 2 and 3 was not significant. The interaction between Stop and Drive was significant ($F(6, 78) = 2.66$, $p \leq .05$) and suggested that the decrease in celeration that occurred after participants were asked to drive fuel efficiently during Drive 2 was likely a result of the significantly lower celeration during Stop 1, Stop 2, and Stop 3. The result that celeration increased in Drive 4 suggests the presence of the lead vehicle influenced driving during the SG scenario in such a way that celeration was dampened.

Across Stops 1 through 3 within Drive 2 there was a main effect of Stop, ($F(2, 52) = 7.55$, $p < .01$). Participant celeration during Stop 1 (M = .17, SD = .04) was significantly greater than Stops 2 (M = .15, SD = .04) and 3 (M = .15, SD = .04).

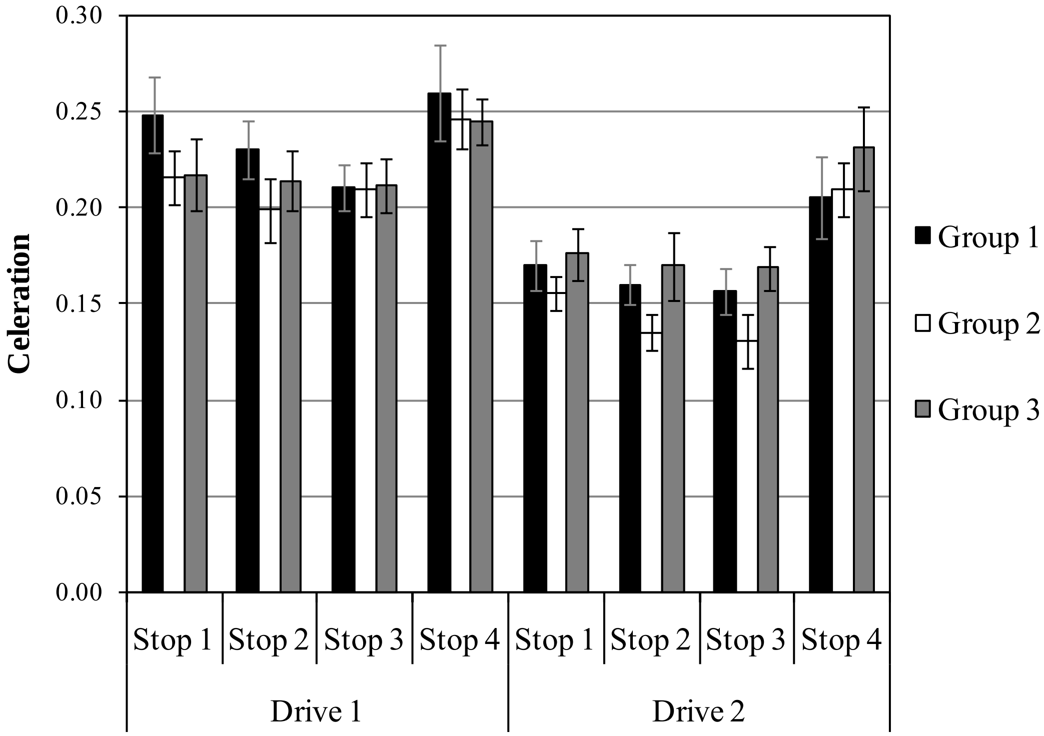


Figure 41. Average celeration during all four Stops of the SG scenario.

6.1.1.4 Effort

The results of the within-subjects tests indicated a significant difference for RSME between Drives 1 and 2 for Group 1. As presented in Figure 42, the significant difference within Group 1 ($t(9) = 2.64$, $p < .05$) was due to the higher RSME scores after Drive 2 ($M = 50$, $SD = 31$) as compared to after Drive 1 ($M = 41$, $SD = 26$).

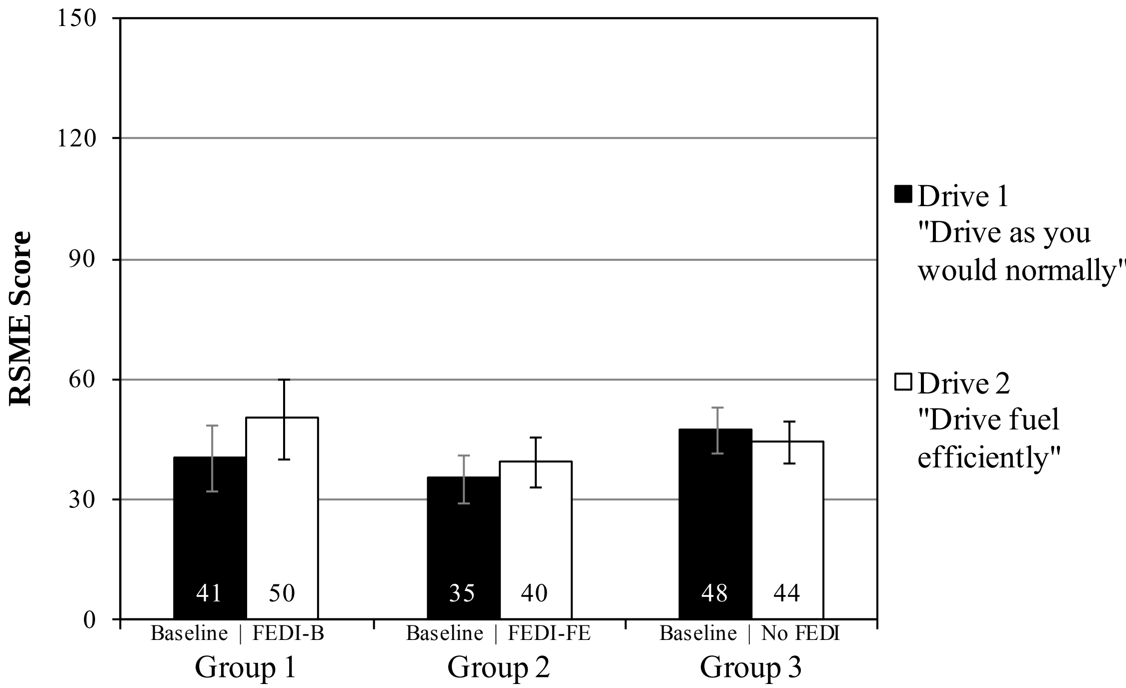


Figure 42. Rating scale mental effort scores Groups 1 through 3 for the SG scenario.

6.1.2 Free Drive (FD) Scenario

6.1.2.1 Fuel Economy

6.1.2.1.1 Fuel Economy

The within-subjects tests indicated significant differences in average fuel economy between Drives 1 and 2 for Groups 2 and 3. Figure 43 shows that the significant difference within Group 2 ($t(9) = 3.79$, $p <.01$, $d = 1.31$) was due to the greater average fuel economy exhibited by participants during Drive 2 ($M = 31.24$ mpg, $SD = 2.97$ mpg) as compared to Drive 1 ($M = 27.96$ mpg, $SD = 2.33$ mpg). The significant difference within Group 3 ($t(9) = 2.97$, $p < .05$, $d = .97$) was due to the greater fuel economy exhibited by participants during Drive 2 ($M = 30.16$ mpg, $SD = .986$ mpg) as compared to Drive 1($M = 28.97$ mpg, $SD = 1.42$ mpg).

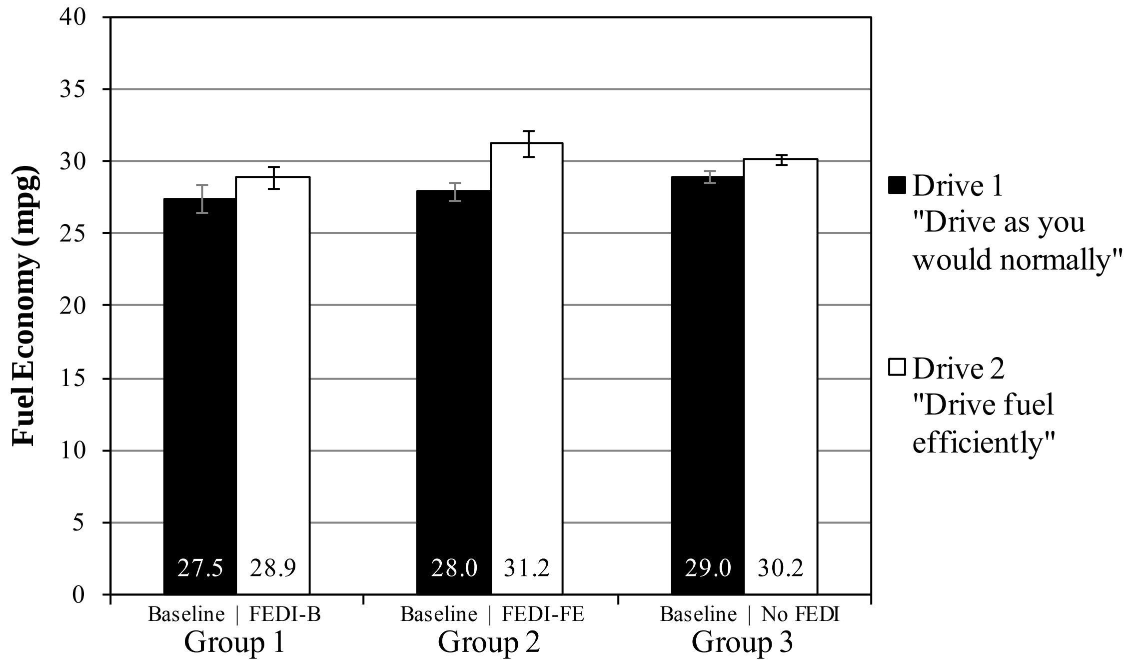


Figure 43. Average Fuel Economy (mpg) during the FD scenario.

6.1.2.1.2 Celeration

The within-subjects tests indicated significant differences in average celeration between Drives 1 and 2 for Groups 1 and 3. Figure 44 shows that the significant difference within Group 1 ($t(9) = 2.76$, $p < .05$, $d = .75$) was due to the greater celeration exhibited by participants during Drive 1 ($M = .02$, $SD = .02$) as compared to Drive 2 ($M = .01$, $SD = .01$). The significant difference within Group 3 ($t(9) = 2.72$, $p < .05$, $d = .46$) was due to the greater celeration exhibited by participants during Drive 1 ($M = .013$, $SD = .008$) as compared to Drive 2 ($M = .009$, $SD = .006$).

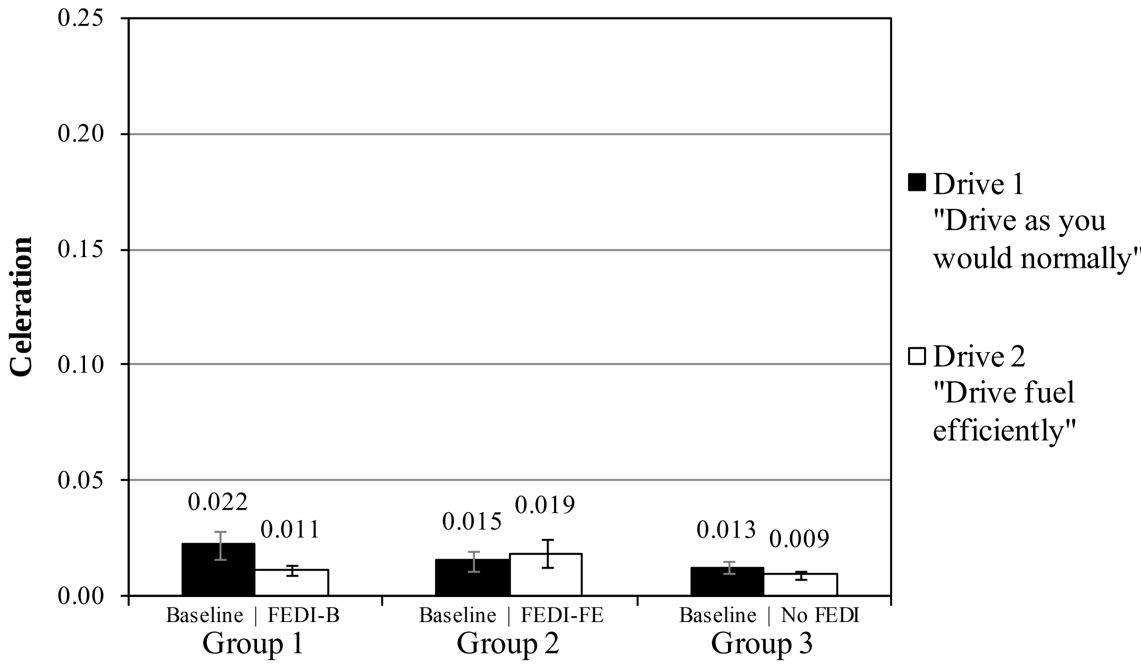


Figure 44. Celeration during the FD scenario.

6.1.2.2 Safety

6.1.2.2.1 **Steering Entropy (SEnt)**

The within-subjects tests indicated significant differences in average SEnt between Drives 1 and 2 for Groups 1 and 2. Figure 45 shows that the significant difference within Group 1 ($t(9) = 3.28$, $p < .01$, $d = .74$) was due to the greater SEnt exhibited by participants during Drive 1 ($M = .40$, $SD = .014$) as compared to Drive 2 ($M = .39$, $SD = .014$). The significant difference within Group 2 ($t(9) = 3.79$, $p < .001$, $d = 1.88$) was due to the greater SEnt exhibited by drivers during Drive 1 ($M = .39$, $SD = .009$) as compared to Drive 2 ($M = .38$, $SD = .007$).

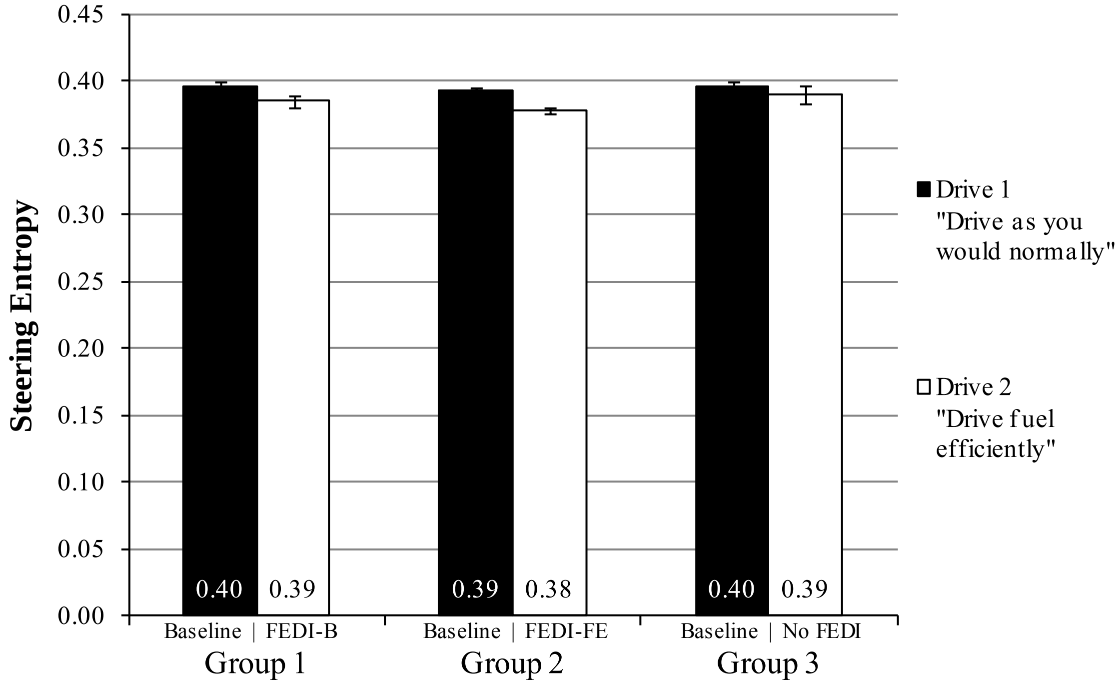


Figure 45. Average Steering Entropy during the FD scenario.

6.1.2.2.2 Pedal Entropy (PEnt)

The within-subjects tests indicated significant differences in average PEnt between Drives 1 and 2 for Groups 2 and 3. Figure 46 shows that the significant difference within Group 2 ($t(9) = 2.96$, $p < .05$, $d = .33$) was due to the greater PEnt exhibited by participants during Drive 1 ($M = .50$, $SD = .04$) as compared to Drive 2 ($M = .48$, $SD = .07$). The significant difference within Group 3 ($t(9) = 2.39$, $p < .05$, $d = .51$) was due to the greater PEnt exhibited by participants during Drive 2 ($M = .52$, $SD = .03$) as compared to Drive 1 ($M = .49$, $SD = .06$).

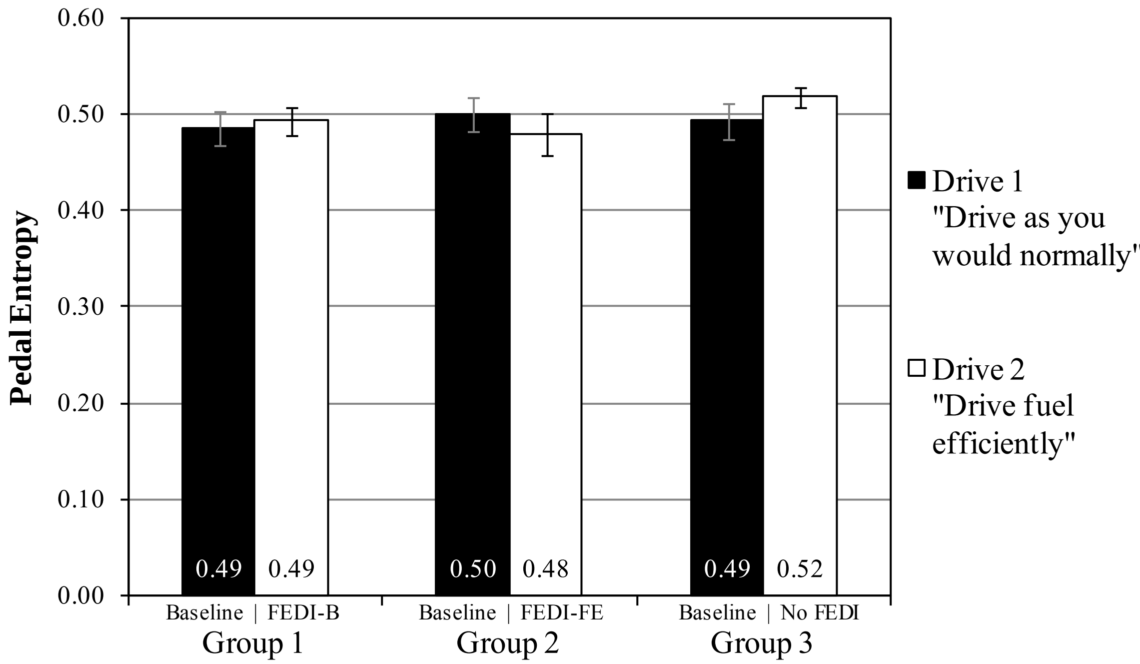


Figure 46. Average Pedal Entropy during the FD scenario.

6.1.2.2.3 Eye Glance Frequency (EGF)

The results of the within-subjects tests indicated a significant difference for average EGF between Drives 1 and 2 for Group 2. Figure 47 shows that the significant difference within Group 2 ($t(9) = 4.80$, $p \leq .001$) was due to the greater EGF exhibited by participants during Drive 2 ($M = 83$, $SD = 38.6$) as compared to drive 1($M = 40$, $SD = 23.9$).

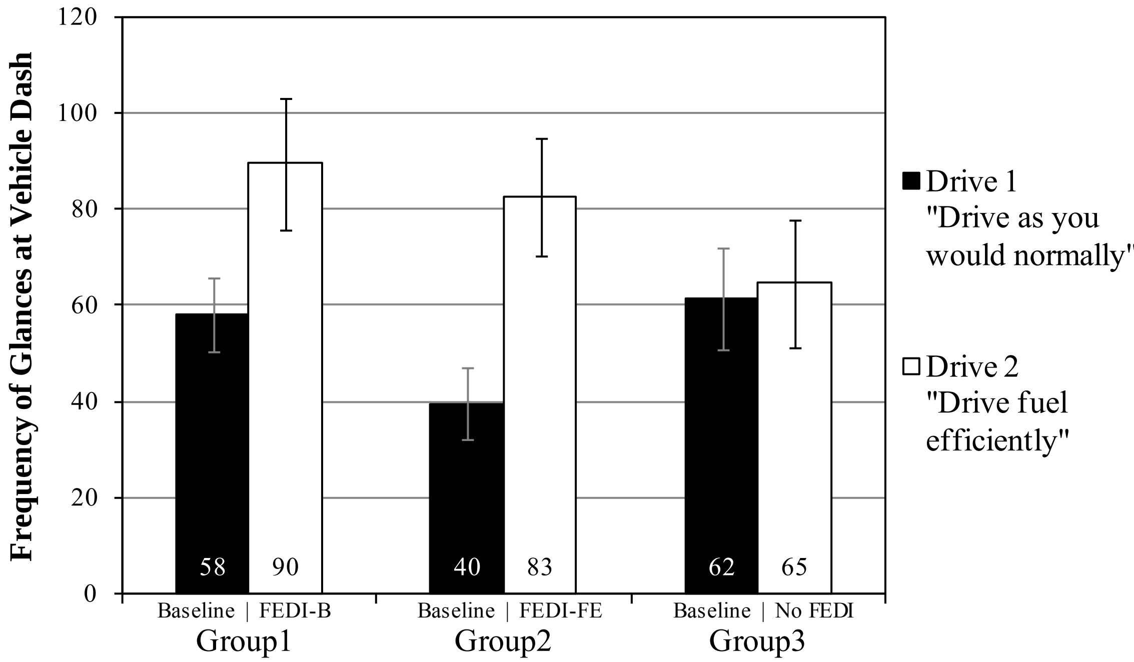


Figure 47. Average eye glance frequency for all three groups during the FD scenario.

6.1.2.3 Effort

The results of the within-subjects tests indicated a significant difference for RSME between Drives 1 and 2 for Group 1. Figure 48 shows that the significant difference within Group 1 (t(9) = 2.95, p <.05) was due to the higher RSME scores by participants after Drive 2 (M = 49, SD = 24) as compared to after Drive 1(M = 33, SD = 14).

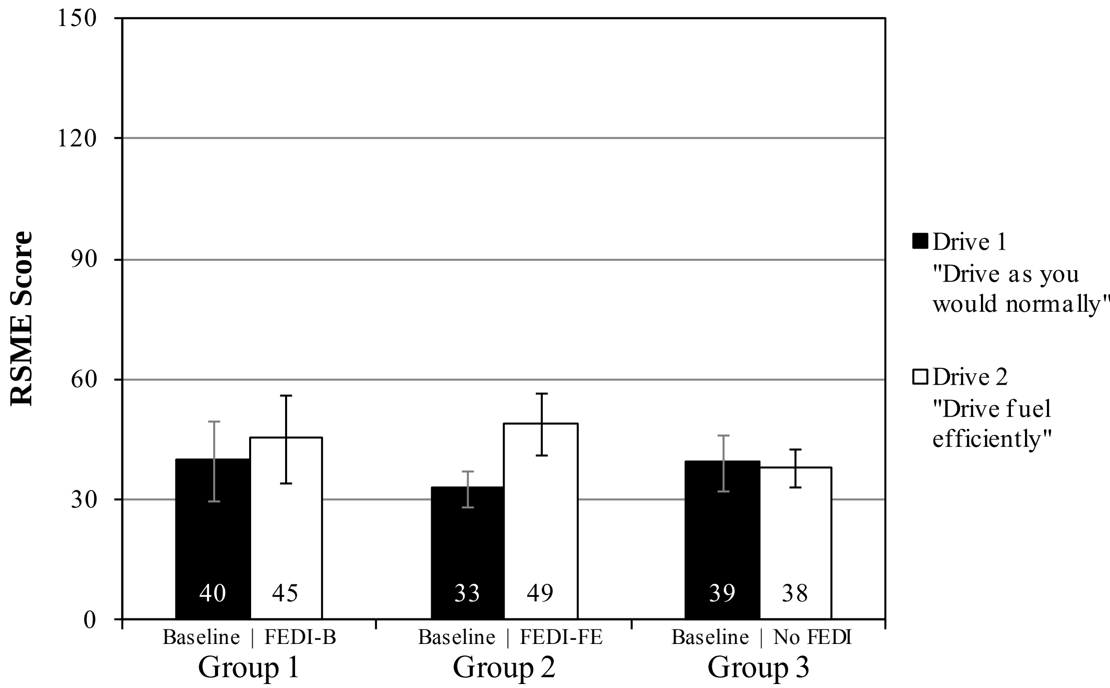


Figure 48. Average rating of mental effort during the FD scenario.

6.1.3 Car Following (CF) Scenario

6.1.3.1 Fuel Economy

6.1.3.1.1 **Celeration**

The within-subjects tests indicated significant differences in average celeration between Drives 1 and 2 for Groups 1 and 3. Figure 49 shows that the significant difference within Group 1 ($t(9) = 4.16$, $p < .01$, $d = 1.07$) was due to the greater celeration exhibited by participants during Drive 1 ($M = .05$, $SD = .02$) as compared to Drive 2 ($M = .03$, $SD = .02$). The significant difference within Group 3 ($t(9) = 3.32$, $p < .01$, $d = 1.11$) was due to the greater celeration exhibited by participants during Drive 1 ($M = .04$, $SD = .02$) as compared to Drive 2 ($M = .02$, $SD = .01$).

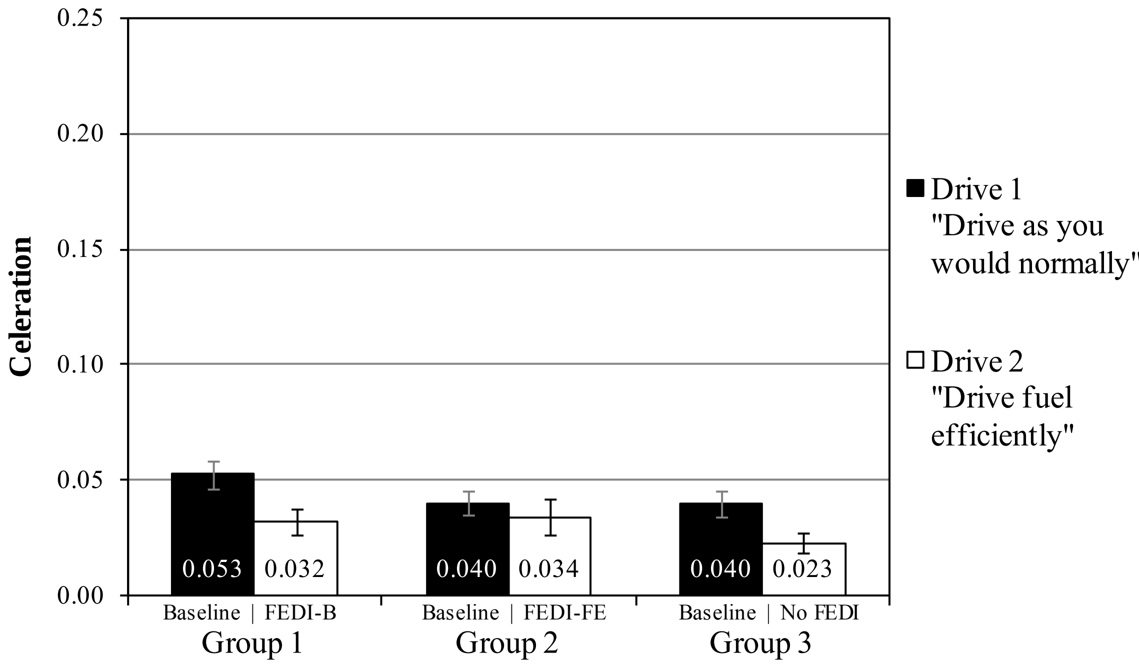


Figure 49. Average Celeration during the CF scenario.

6.1.3.1.2 Coherence

Data from seven participants were excluded from the coherence analysis (and from amplification and delay) because of low sample rates during their drives (i.e., following distance was too great to calculate coherence). The within-subjects tests indicated significant differences in average coherence between Drive 1 and 2 for Groups 1, 2, and 3. Figure 50 shows that the significant difference within Group 1 ($t(7) = 2.79$, $p < .05$, $d = 1.20$) was due to the greater average coherence exhibited by participants during Drive 1 ($M = .74$, $SD = .16$) as compared to Drive 2 ($M = .56$, $SD = .14$). The significant difference within Group 2 ($t(5) = 3.85$, $p < .05$, $d = 1.87$) was due to the greater coherence exhibited by participants during Drive 1 ($M = .75$, $SD = .13$) as compared to Drive 2 ($M = .46$, $SD = .18$). The significant difference within Group 3 ($t(8) = 3.4$, $p < .01$, $d = 1.29$) was due to the greater coherence exhibited by participants during Drive 1 ($M = .65$, $SD = .19$) as compared to Drive 2 ($M = .41$, $SD = .19$).

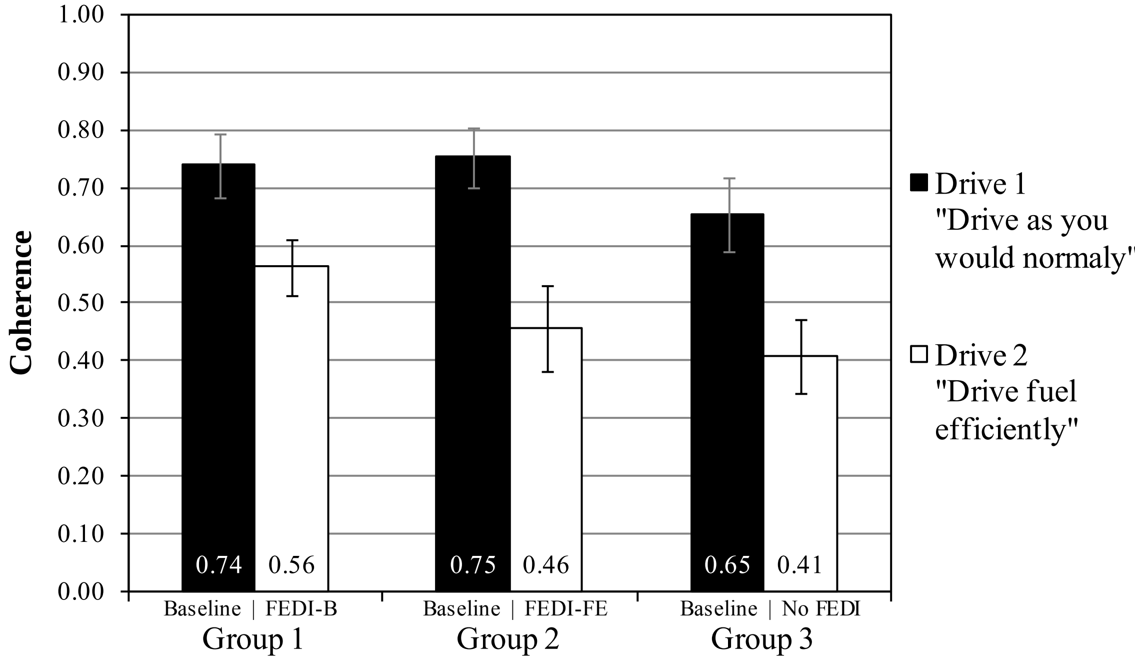


Figure 50. Coherence scores for Groups 1 through 3 for the CF scenario.

6.1.3.1.3 Amplification (Modulus)

Data from seven participants were excluded from the amplification analysis (and from coherence and delay) because of low sample rates during their drives (i.e., following distance was too great to calculate coherence). The within-subjects tests indicated significant differences in average modulus between Drive 1 and Drive 2 for Groups 1 and 3. Figure 51 shows that the significant difference within Group 1 ($t(7) = 3.46$ $p < .05$, $d = 1.24$) was due to the greater modulus exhibited by participants during Drive 1 ($M = .62$, $SD = .22$) as compared to Drive 2 ($M = .37$, $SD = .18$). The significant difference within Group 3 ($t(8) = 3.23$, $p < .05$, $d = 1.09$) was due the greater modulus exhibited during Drive 1($M = .50$, $SD = .25$) compared to Drive 2 ($M = .26$, $SD = .17$).

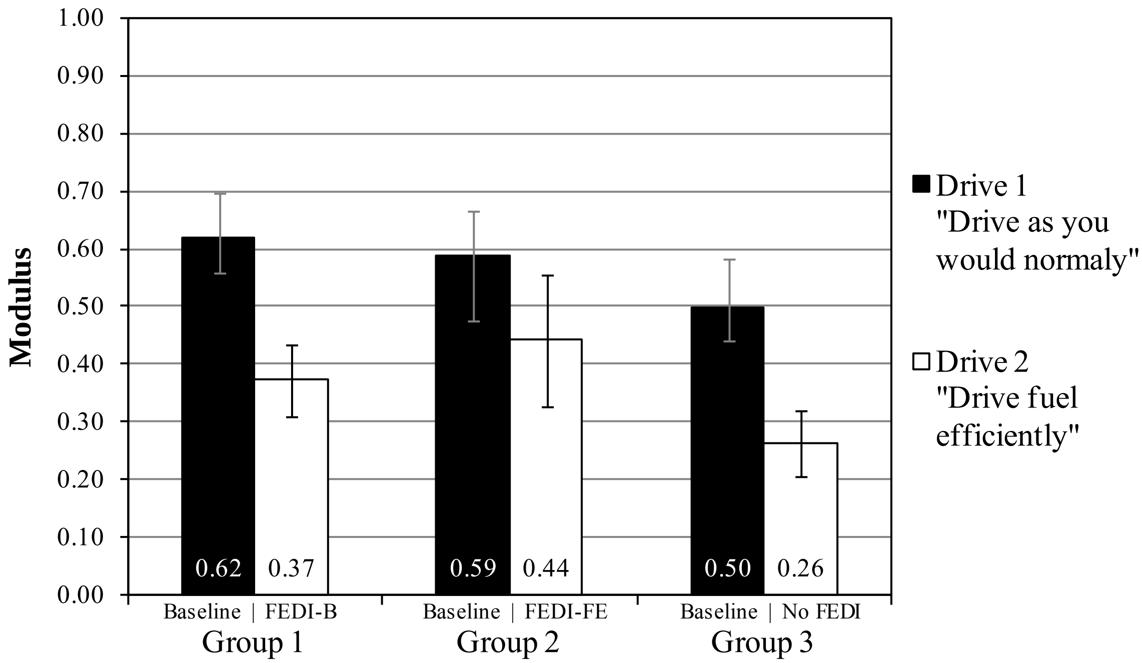


Figure 51. Average Modulus during the CF scenario.

6.1.3.2 Safety

6.1.3.2.1 **Minimum Time-to-Contact (TTC Min)**

The within-subjects tests indicated significant differences in average TTC Min between Drive 1 and 2 for Groups 1 and 2. Figure 52 shows that the significant difference within Group 1 ($t(9) = 4.23$, $p < .01$, $d = 1.47$) was due to the greater TTC min exhibited by participants during Drive 1 ($M = 4.99$ s, $SD = 3.52$ s) as compared to Drive 2 ($M = 1.18$ s, $SD = 1.04$ s).The significant difference within Group 2 ($t(9) = 3.78$, $p < .01$, $d = 1.36$) was due to the greater TTC Min exhibited by participants during Drive 1 ($M = 6.51$ s, $SD = 4.47$ s) as compared to Drive 2 ($M = 1.83$ s, $SD = 1.90$ s).

The One-way ANOVA indicated that Drive 2 TTC Min differed significantly as a function of Group ($F(2,19) = 15.00$, $p <.001$). Follow-up Tukey paired comparisons indicated that Group 3 had significantly greater mean TTC Min ($M = 7.8$ s, $SD = 4.69$ s) compared to Group 1 ($M = 1.18$ s, $SD = 1.04$ s) and Group 2 ($M = 1.83$ s, $SD = 1.9$ s).

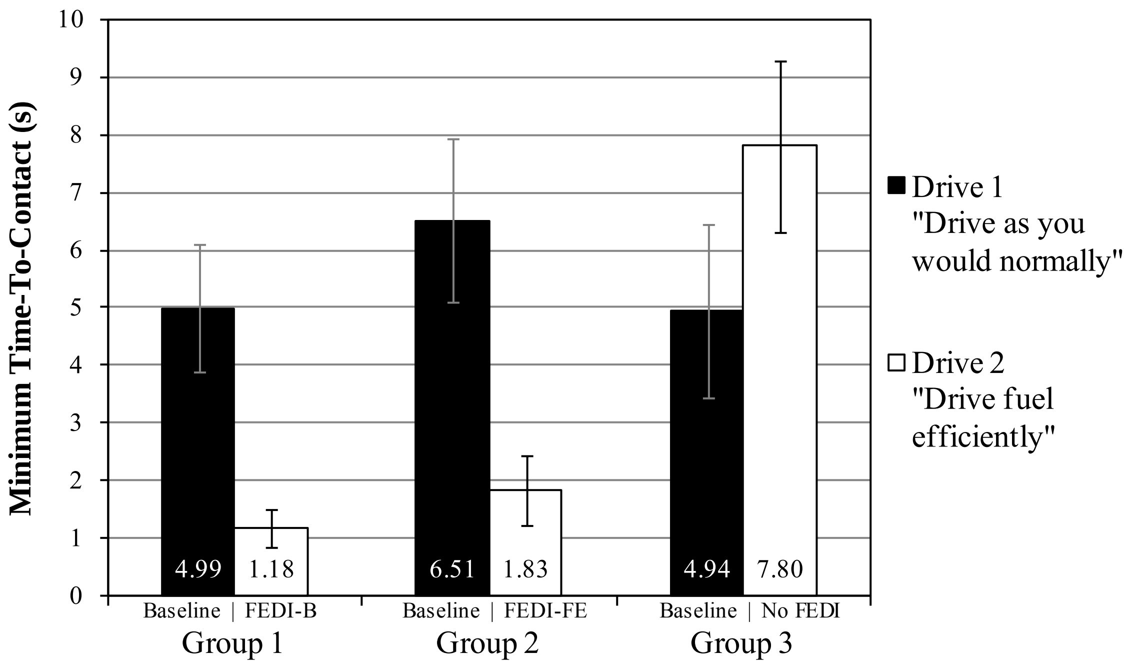


Figure 52. Average Minimum Time-to-Contact (s) during the CF scenario.

6.1.3.2.2 **Eye Glance Frequency**

The within-subjects tests indicated significant differences in EGF between Drive 1 and 2 for Groups 1 and 2. Figure 53 shows that the significant difference within Group 1 ($t(8) = 4.61$, $p < .01$) was due to the greater EGF exhibited by participants during Drive 2 ($M = 60$, $SD = 25.5$) as compared to Drive 1 ($M = 17$, $SD = 12.4$). The significant difference within Group 2 (9) = 3.03, $p < .05$) was due to the greater EGF exhibited by participants during drive 2 ($M = 49$, $SD = 28.5$) compared to Drive 1 ($M = 26$, $SD = 20.7$).

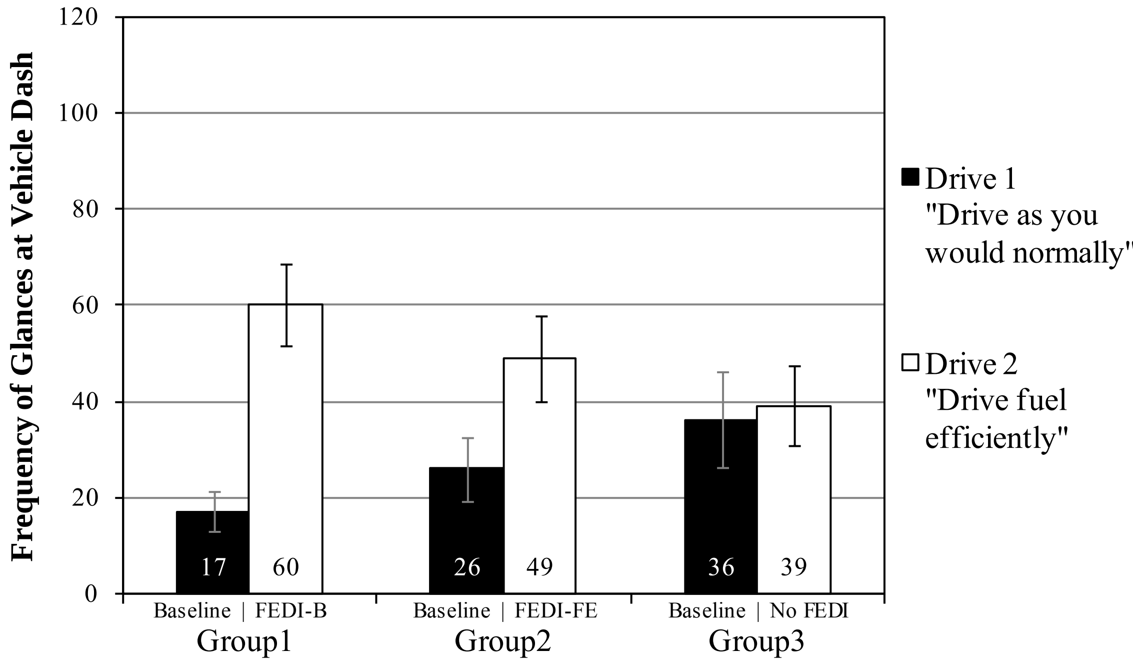


Figure 53. Average Frequency of Glances at Vehicle Dash during the CF scenario.

6.1.4 Usability Comparisons

6.1.4.1 Usability Scale (Usefulness & Satisfying Scores)

Average usefulness and satisfaction ratings between the FEDIC-B and FEDIC-FE were not significant, both $p > .05$. However, as shown in Figure 54, participants from the simulator study tended to provide higher usefulness ratings for FEDIC-B and FEDIC-FE compared to the usefulness ratings provided by the participants from the usability study for the top four recommended CS: CS02, SC03, CS05 and SC06. In addition, Figure 54 indicates that FEDIC-B received the highest rating for satisfaction compared to all other FEDICs. These results suggest that employing a FEDIC within a driving context may have led to a greater understanding of the FEDIC by allowing participants the opportunity to match FEDIC information to their own driving performance.

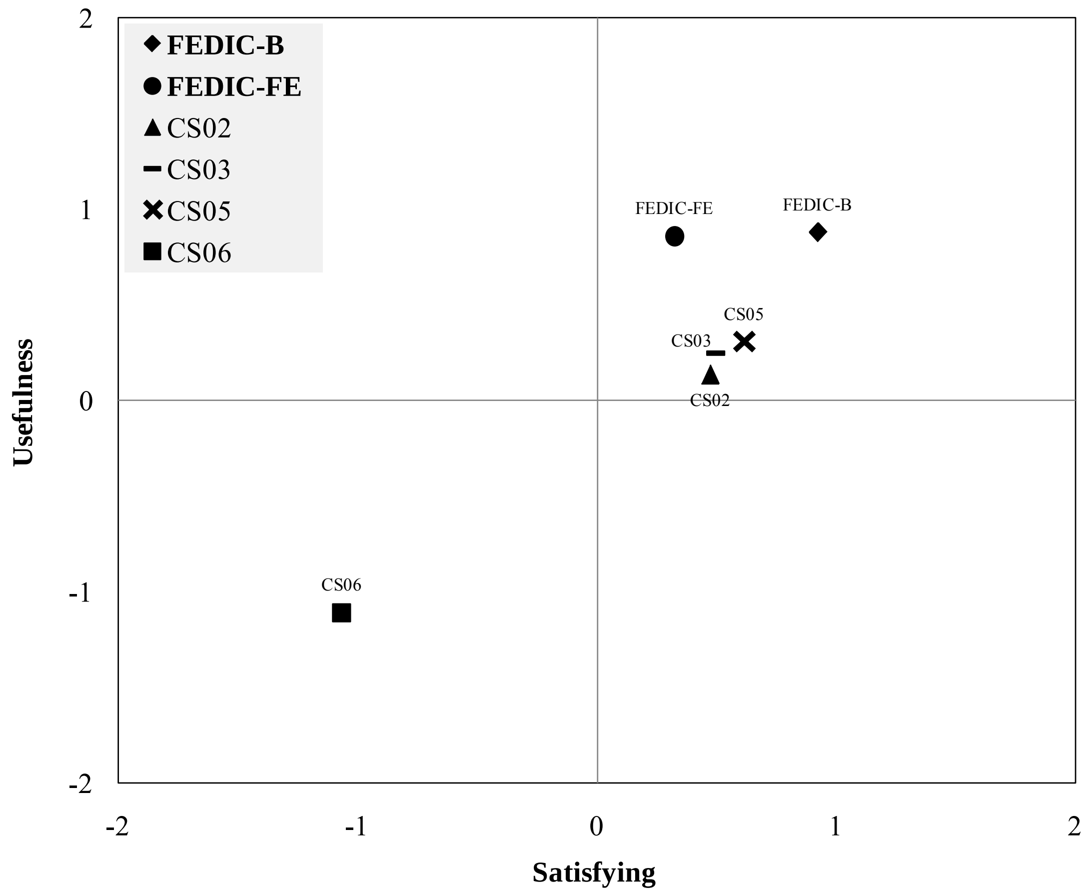


Figure 54. Usability scale usefulness and satisfying ratings for FEDIC-B and FEDIC-FE during the simulation study and the top 4 recommended FEDIC CS from the usability study.

6.1.4.2 Trust Questionnaire

There were no significant differences between the FEDIC-B and FEDIC-FE in terms of performance, process, foundation, or purpose constructs from the trust questionnaire, all $p > .05$ (Figure 55). However, the consistently high trust ratings across all constructs suggests that participants found both FEDICs to perform consistently, to be relatively comprehensible, and have to have obvious intentions.

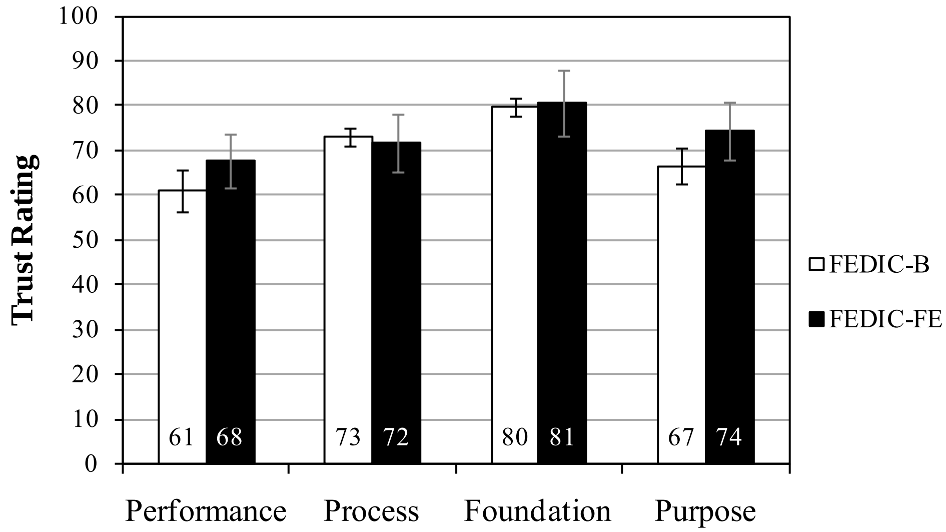


Figure 55. Mean Trust Rating for the four trust dimensions by FEDIC.

6.1.4.3 The Post Experiment Usability Survey

There was a significant difference in responses to FEDIC-B compared to FEDIC-FE when asked, “Having tried it, do you think this FEDIC had any benefits for you as a driver?”, $\chi^2(2) = 6.52$, $p < 0.05$. Participants that drove with FEDIC-FE reported a higher rating for major benefits while participants that drove with FEDIC-B reported more minor benefits (see Table 15).

74% (14 of 19) of the respondents reported having minor or major problems with both FEDICs, although only one participant reported having a major problem (FEDIC-B group). Participants’ follow-up responses indicated their issues were related to the potential distraction that a new interface might cause while driving and not any particular element of the FEDIC designs. 74% (14 of 19) of the respondents reported that “yes” they would include their FEDIC if it were offered for free in their vehicle while only one person (FEDIC-B group) reported that “no” they would not have it included if offered for free. 79% (15 of 19) of the respondents reported that “yes”, having a FEDIC like the one they used would motivate them to drive more fuel efficiently. Only one person (FEDIC-B group) reported that “no” it would not. 89% (17 of 19) of the respondents reported that if added to the cost of the vehicle, they would only be willing to pay less than \$500 for the FEDIC system; 14 of these respondents only reported a willingness to pay if it was less than \$100.

Table 15. Frequency of responses when asked whether the FEDIC had a benefit for the participants.

Any benefit for you?	FEDIC-B	FEDIC-FE
No benefits	0	1
Minor benefits	7	2
Major benefits	2	7

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