# RANGE ANXIETY AND IMPACT AWARENESS IN ELECTRIC VEHICLES

Masters Thesis

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# INTRODUCTION

For over 50 years, car drivers have been presented with simplistic analog displays to provide them with information regarding their remaining fuel level. This gauge is typically broken into $1/4^{ths}$ and 1/8ths since this reading is volumetric. As of 2012, there are 121,440 gas station in the United States (US Census Bureau) and with such a prevalence of gas refueling stations, a vague feedback display for fuel levels is manageable. However, electric plug-in vehicles are recently gaining popularity and as of this time, there are only approximately 12,000 public charging stations available nationally for Plug-in Electric vehicles (PEVs). With a lack of charging stations relative to gas stations and an already limited range due to the current level of battery technology, range anxiety is a growing concern for vehicle operators and potential PEV buyers. This vehicle related anxiety reflects the uncertainty, stress, and lack of confidence in the vehicles ability to reach the desired destination(s) before completely running out of energy reserves.  It is often cited (Franke, 2012; Krems, 2010; Davies-Shawhyde, 2011; Nilsson, 2011) as an impediment for PEV adoption as well as a barrier for stress-free electric vehicle ownership. Alongside marketing, engineering, and energy consumption tips used to diminish this anxiety, many electric vehicles also contain a new form of ‘fuel’ gauge feedback. These new data visualization techniques are presumed to assist drivers in understanding the shift from an engine powered by gasoline to that of a battery powered, range limited electric vehicle.

This paper begins with a dive into the evolution of the vehicle-driver context and the fundamentals of vehicle-interface research as it relates to fuel efficiency, range awareness, and interface design. The identification of a current-day problem is isolated and elaborated in the Problem Statement section. A Review of Literature component will utilize the topmost influential articles that impacted the purpose, design, and implementation of the research carried out for this paper. This paper then lays out the hypotheses, method, procedure, and results of a traditional research report and culminates with a discussion and conclusion of what impact the results may have on further experimentation and design.

## BACKGROUND INFORMATION

When the first vehicles entered the consumer landscape in the early 1900s, the biggest difference in transportation was the range of freedom of mobility not previously met by horse drawn carriages. This freedom also meant a wide array of variables were added to the context of mobility in daily traveling. With the introduction of the Model T in America, personal vehicle ownership grew alongside new roads and fueling stations. The role of vehicle mobility grew drastically and the use of gasoline increased as well. Prior to the popularization of family owned automobiles, coal dominated the transportation fuel market via use in trains and boats.  While fuel cells (a.k.a. batteries) existed as early as 1839, filling an automobile with gas was the crucial new way to power America's new mode of transportation. Gas was relatively cheap and plentiful; a support structure could be set up quickly and in any town with the proper demand and thus the modern gas station was created.


*Figure 1* Very little variation over the years has gone into the general design for gas gauges and the feedback they give to a driver.

As fuel is a liquid and a tank reserve volumetric, translating the vehicles remaining fuel into a gauge was easy for drivers to respond to; half of a tank is 50% and a ¼ tank left gives you one fourth of the total range you can get from the full tank. The concept of 'full' and 'empty' is transparent and relevant in regards to tank contents. The idea that a lower needle means a low amount of fuel in the tank is consistent with a predetermined mental model. The result was a standard for gas reserve feedback that remained largely unchanged for 80 years.

## Problem Statement

With growing concerns over sustainability and fuel consumption, along with the natural consumer desire to save money, more attention is now given to driving behavior and how it affects the rate of fuel usage. Automakers have designed 'smart' interfaces to aide in fuel conserving driving styles, with an agreed upon consensus that in-vehicle system design highly impacts driver behavior and performance while driving (Medenica, 2012; Kyung, 2008). Particularly in electric vehicles, with a smaller total driving range before needing to recharge the battery pack, range anxiety has been documented as an impediment for plug-in electric vehicle (PEV) ownership. Driving a PEV is therefore a high stress context especially when congestion and road delays are at an all-time high. Regenerative breaking (power brought back to the battery via the braking system) and active battery displays give drivers live feedback of their fuel/battery resources in an effort to give more control back to the driver. Using *Figure* 2 as an example, as the driver accelerates the orange bar on the right moves upward representing an increasing wattage output by the batteries. When the driver releases the pedal/throttle and decreases acceleration, the orange bar moves downward into a 'negative' output zone, demonstrating the power gained back via regenerative braking.

Automakers assume this data visualization relieves range anxiety due to raised situational awareness for the driver and live feedback of driving habits. The problem is these displays have not been researched from in a cost-benefit analysis of their distraction and impact towards forcing driver behavior changes.  Many of these newer displays, such as the one shown in *figure 2* below, have design elements with huge novelty and learning curve implications for newer drivers. The goal of this study is to assess the balance of distraction and stress reducing qualities of an advanced, ecological range display in the context of route planning and resource management.


*Figure 2* Digital speedometers like the one above from *Mission Motorcycles* are increasingly common. The curved orange bar on the right denotes battery output; when acceleration increases the wattage output increase is show by the orange bar moving upward. When the driver decelerates the bar goes below ‘zero’ and represents regenerative energy.

## Traditional vehicle design guidelines

Most Human Factors driver-vehicle research has been done on anthropometric and situational awareness effects relating to cabin design; matching displays to human stature and data-visualization research regarding color coding, blinking, audio feedback, and other forms of vehicle-human communication. This has been the source for general ergonomic guidelines for human/vehicle interaction and physical control placement in vehicles (Kyung, 2008). Governmental agencies such as the National Highway Traffic Administration lay down a standard for what feedback must be present for various mechanical error codes (engine temperature, oil levels, engine malfunctions, etc.) as well as thresholds for distractibility, while issues such as optimal steering wheel height and the subtleties of icon design are undertaken by university professors and in-house industry researchers.

The guidelines that exist for passive displays state that automakers should use numeric displays for measureable data and pointer displays for hastening of reading quantifiable data (Green, 1988). Pointer displays work efficiently for a clearly understood volumetric measurement such as fuel, but visualizing a ¼ filled battery is not as easily grasped by vehicle operators. Small consumer electronics have used battery percentages for years and are the natural choice due to ease of scaling up to a larger battery capacity

## Gauge design & resource visualization

Standards for gauge design more or less follow the same principles of quickest glance time and gestalt principles – as noted by Dr. Green (*Figure 3a)*, "A commonly accepted human factors principle is that a collection of moving pointer displays should be arranged so their pointers are aligned when all displays are showing normal values [which] facilitates check reading" (Green, 1988, p. 57).

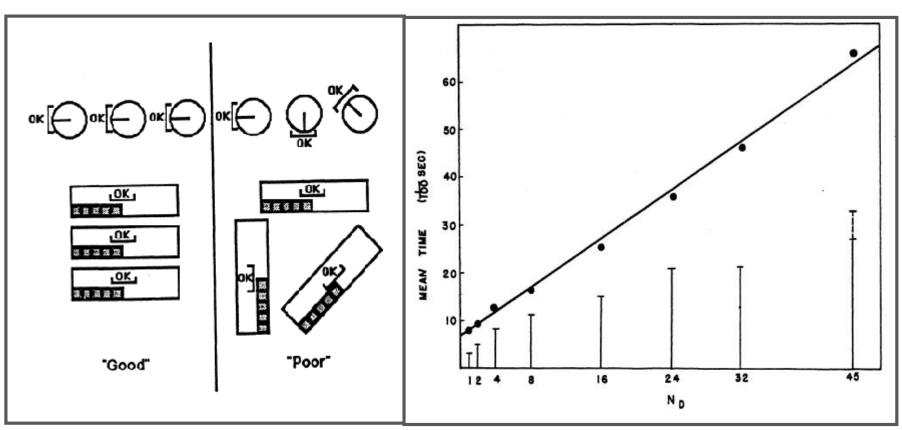



*Figure 3a)* Consistency with pointer placement is essential for mitigating confusion and errors. 3b) At the same time, limiting the amount of pointers is also important. Green, 1988

As shown above in *Figure 3b*, too many pointer displays is a consistent predictor of confusion and errors due to misreading the wrong gauge when requiring specific information also relayed via a pointer. The consensus among a plethora of research that Green synthesized is that exact pin-point data is better served with numeric labels and a pointer while ambiguous data is better displayed via a scaled range without incremental labels (Green, 1988). For instance, the feedback for engine temperature does not typically need to display the exact temperature so long as the driver knows that the engine warms up but does not go too close to extreme heat. Movement upwards on the gauge is enough to tell a driver that there is a coolant or transmission error. Further along in gauge design research, which component of the gauge does the movement has also been studied as far back as the early 1970s.

According to the experiments reviewed, moving pointer displays offer much better response time when the information required is precise rather than falling within a general range; however a stationary pointer with a moving scale is ideal when a specific baseline target is desired. *Figure 4* below depicts these design differences as tested in McCormick’s study on gauge movement and monitoring affect.

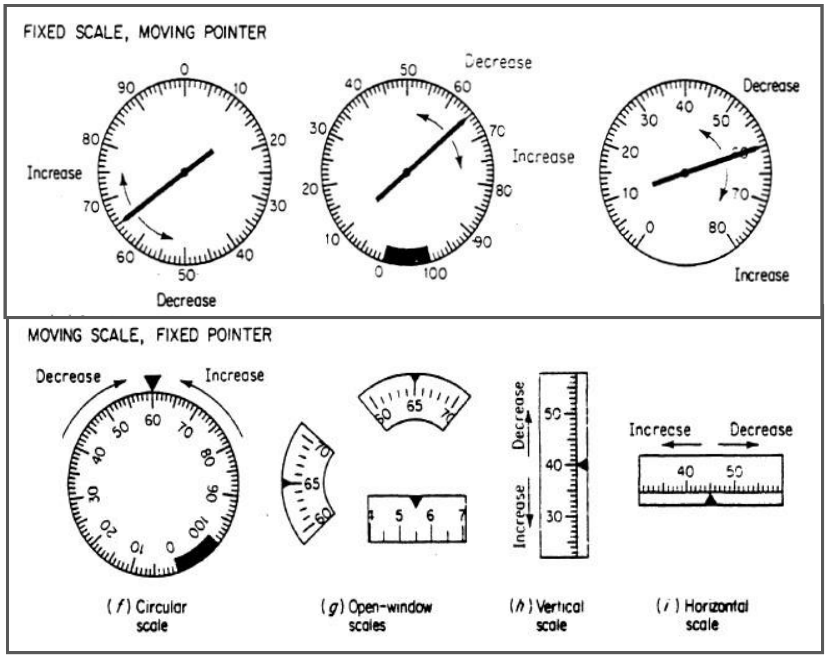



*Figure 4* In a fixed scale gauge, the pointer rotates while the measurement range is stationary. Moving scale gauge has a fixed pointer and the measurement range moves in relation to the pointer. *Source: McCormick (1970)*

According to the experiments reviewed, moving pointer displays offer much better response time when the information required is precise rather than falling within a general range; however a stationary pointer with a moving scale is ideal when a specific baseline target is desired. Moving scale gauges consistently resulted in a lower recall percentage score when displaying quantitative data and should therefore not be utilized when data-value memory is a priority. The main take away from gauge experiments is that different styles affect performance depending on the task context.

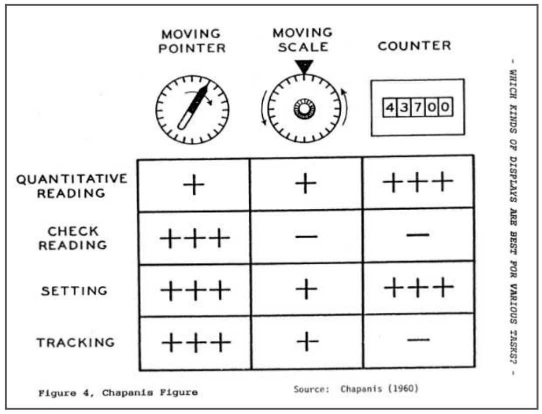



*Figure 5* A categorical guide for which type of gauge to use for certain tasks. Chapanis, 1960

Designers and engineers must assess the context in which a gauge will be used and what vital information is taken from it since “the choice of display depends upon what the viewer will be doing with the information” (Green, 1988, p. 14). Considering that displaying an active battery output and energy re-uptake is a fairly new type of feedback for most drivers, consideration for how these gauges are designed should not be overlooked. For such a lucrative dependency – energy to propel your vehicle – the existence of range anxiety is a clear indicator that a more informative, performance based visualization is needed for electric vehicle drivers. In order for automakers to combat range anxiety via a factor they can control, the display must contain “effective instruction on how to drive more efficiently and provide them useful reference point information” (Gonder, 2011, p. 21).

Object, Ecological, and Configural displays

Ecological and configural displays have had a good track-record of success in research investigating monitoring and vigilance in regards to raising accuracy and speed of comprehending changes in a system. An ecological display directly represents the relationship of controls and schematics of a system, while a configural display contains design elements that morph according to variations in corresponding system elements. Most often these changes are related to contours, arrangement, or color and have been shown to improve performance. Unfortunately, most of this research is done in the context of airline pilot cockpit displays or large scale energy facilities where the contexts are far removed from a consumer driving standpoint. There is certainly a stress context behind these experiments, but they have also been limited to display formats involving overall salience of characteristics, linearity of graphical elements syncing with system balance, and exploring the benefit advantage and whether they are due to code integration vs. emergent feature strength (Carswell, 1996). The salience of emergent features and how they interact with task type lend insights into what sort of display would be useful for electrical vehicle range awareness, especially when ordinal comparisons and conjunction identification are common tasks done in short attentional bursts.

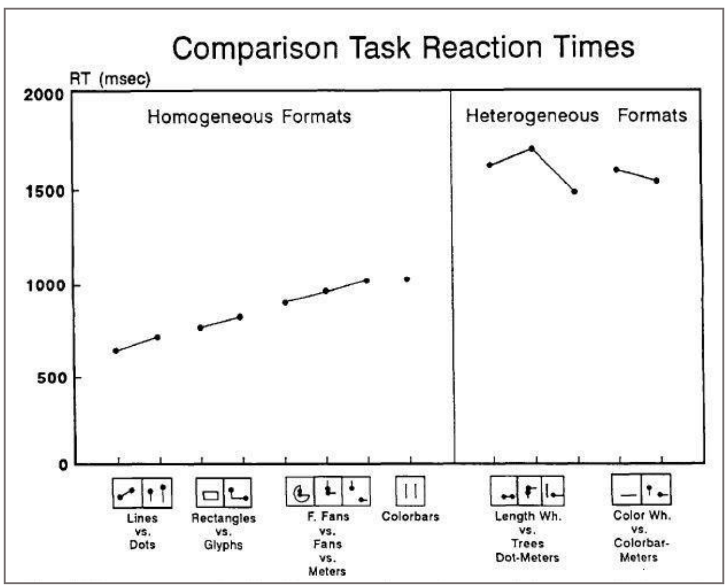



*Figure 6* Object displays proved a significant advantage due to emergent features when the coding integration was maintained by homogeneous signals. Carswell, 1996.

What Carswell and Wickens object display experiment reveals, shown in *figure 6* above, is an advantage towards strong emergent features when homogeneous coding integration is utilized by design features. Reactions times and error rate were lower when participants had to determine correct sequence among a digit pattern while aided by the object display.

In a similar study that tests salience in object displays, it was found that when the task goal is midpoint identification and distance monitoring that signal salience is largely determined by format type. The research, led by Jams Szalma (2011) was mainly focused on signal processing where system-status was indicated on a basis of linearity and dot arrangement. There is a huge implication subtly included in Szalma's study that many configural display studies and applications beforehand may have been held-back by inappropriate or understated salience levels. Vehicle interface design is a large area where there is a significant gap in object display research – this is most likely due to the assumption that in a vehicle there are not many instances in which the quick absorption of data is either a) the type of information feedback best supported by object displays or b) there is not a large enough spread of information types that would warrant the need for a condensed display feedback of energy usage.

## A new vehicle display paradigm

The difficulty in designing for in-vehicle display systems has increased steadily over the past twenty years as automakers race to include more features in low to high-end vehicles. Standards have now split into two main tiers: function specific guidelines are those human factors design considerations that are specific to the display(s), control interface, and system architecture used for a particular function. Integral guidelines are those that focus on human factors design considerations when two or more functions are used together in a partial or fully centralized display system. The growing trend is not only integrated functions requiring a modal selection and then adjustment alteration, but many cars now contain feedback and input on two separate screens.

This is troublesome and counterproductive to most standards, which have a “broad consensus that, apart from brief glances at mirrors or instrumentation, the driver's gaze should be


*Figure 7* The appearance of digital displays, with differently style graphics, digital numeric, and 3d visualizations is quite the departure from previous instrument cluster design conventions. *Source: Nissan Altra and Chevy Volt.*

directed towards the road scene” (Stevens, 2002, p. 23). Meanwhile, the DOT standards for physical controls primarily deal with maintaining an exclusive space for certain higher priority indicators and features, ensuring luminescence at night and/or while headlights are activated. Newer technology is increasingly entering a grey area due to touchscreen controls blended the lines between physical, interactive controls and passive monitor displays. Therefore, the ‘scope’ of the existing standard rarely covers all possibilities of the driving context. As noticed in the SAE Handbook, in regards to route guidance systems, “visual monitoring tasks …such as route following…voice-activated controls or passenger operation of controls are also excluded” from benchmarks regarding safe use (2004).

Battery technology & Regenerative braking

Regenerative braking is a technology that brings power back into the battery reserves from the brake pads as the vehicles slows down naturally rather than applying the brake pads. Battery depletion and power output, shown via an active battery display (ABD), does not translate well from previous models and guidelines of data visualization found in vehicle displays. Regenerative breaking in most electric vehicles is a visual monitoring task only, however higher end vehicle models are beginning to offer adjustable levels of regenerative breaking. Adjusting your regenerative braking to a higher level would cause your car to naturally slow down faster and gain more power back – with a reduced distance of ‘cruising’ smoothly.


*Figure 8, [From top left, clockwise] a)* The Nissan Leaf employs a circular array that contains four filled dots the move right for output and left when regenerative braking is activated. b) The Chevy Volt 'power flow' screen, c) The Lexus CT consumption screen showing regenerated power, d) the Kia Hybrid active regenerative braking graphic.

Never before has the consumption of fuel been given such transparent feedback in a vehicle setting – a transparency which directly impacts one of the largest issues in the minds if drivers following the turn of the 21st century: fuel efficiency. Although even in the instances in which "the perceived value of a fractional reduction in their fuel budget may be insufficient relative to such other influences" (Gonder, 2011, p. 19), a regenerative braking display may be one of the few areas automakers can impact the range anxiety phenomenon.

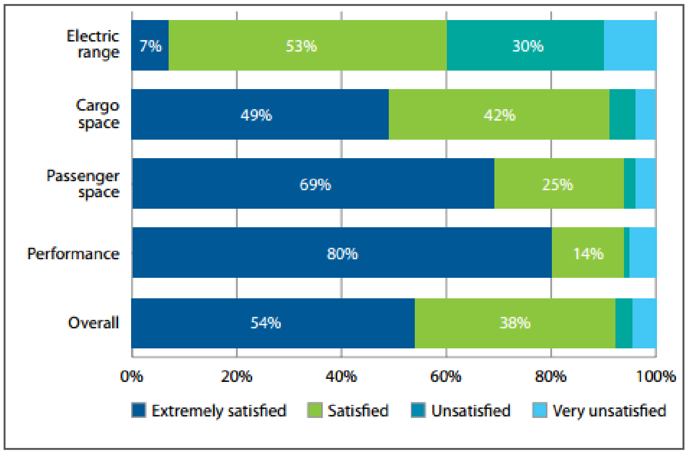
The inconsistency in these new display types is evident immediately – even though they all aim to inform the driver of the same attribute – the battery output of the vehicle and energy brought back in while 'cruising'. Consider the circular Nissan Leaf interface (*figure 8a)* where the circles move within larger circles, to the right when the drier accelerates and to the left when the gas pedal is released and regenerative braking begins. Another common graphic to use is an engine transferring power back to a battery symbol similar to *figure 8b* and *8d*. This feedback is not the same as a fuel gauge, which depletes in one direction, nor is it the same as a constantly moving RPM gauge which is not tied to fuel consumption or range in a direct manner. For these electrically propelled vehicles these new interfaces are the most relevant way to actively promote conscious driving changes with the emphasis of affecting total range. Since PHEVs can run in charge depleting (CD) and charge sustaining (CS) modes there is uncertainty as to how much travel will be completed in each mode due to the variety of possible vehicle designs, access to charging infrastructure, and charging behavior of vehicle drivers. As Franke points out, "Imagine an EV user whose goal is to have a comfortable and timely commute to work, when a traffic jam requires the driver to take a longer route and energy resources are already partially depleted" (2012, p. 4). A regenerative braking display is explicitly about putting control back in the driver's hands regarding the range of their vehicle. This emphasis on range being dependent on driving behavior is manifested in an awareness of driving habits not seen before the 21st century, partly due to gas conservation and energy conscious movements.

## New Driving Contexts and Range Anxiety

With a historically high national average of gas prices in 2008, prospective vehicle buyers cited fuel economy as one of the top considerations given when looking for a new vehicle (Consumer Reports, 2009). Not only is there a direct benefit for high fuel economy from an ongoing financial perspective, but consumer’s self-reported higher satisfaction ratings in scenarios when dealers provided support for adapting driving behaviors related to fuel consumption. There is also a political element to adopting a high MPG vehicle and even more-so adopting an EV that will never rely on ‘going to the pump’ and has a zero-emissions rating. Even with an inevitable dependence on the energy grid, “a transportation system that includes an increasing use of alternative fuels in vehicles could offer a number of solutions to global challenges such as climate change and oil dependency” (Bakker, 2011, p. 18). The downside to these alternative energy vehicles however, partnered by slow advances in battery technology, is low total range before requiring a recharge. It is clear then that when a vehicle is powered by electricity and in most cases has a lower total range than a gasoline powered vehicle, people view the energy resources differently. This led the EPA to introduce the MPGe measure in 2010 so that gas vehicles could be compared to alternative fuel or mixed fuel vehicles; the “e” in MPGe, literally meaning “equivalent”, “signifies the use of an energy-based, rather than volumetric or other fuel specific measurement” (Stillwater, 2011, p. 19). However, this metric is mainly used for standardizing the costs of the fueling methods and does not placate the concerns of those who view a limited range vehicle as inefficient regardless of the cost differences.

Limited range & Access to resources

One of the market positioning tactics used by automakers for their EV segment is to push a lower range as a reflection of the vehicles use as a supplementary vehicle for short, urban errands and for urban commuting consumers. Unfortunately, survey results (*figure 9*) consistently show that desired range is higher than the average consumer's actual commuting range per day.



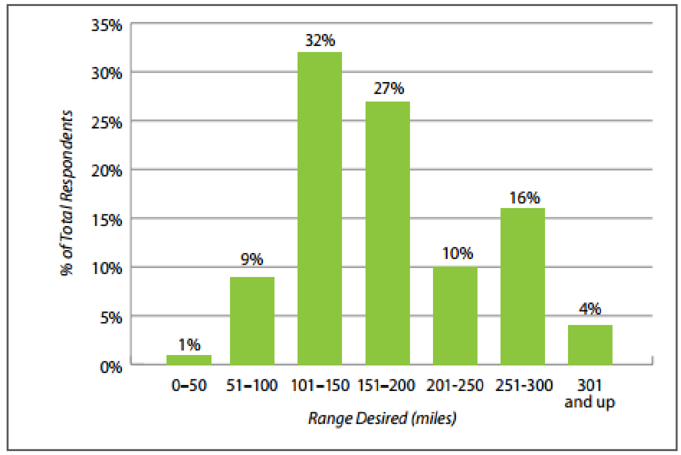




*Figure 9* A farther range is clearly the desired feature that users wish automakers of electric vehicles will improve upon. *Source: Center for Sustainable Energy, 2012 Survey results.*

This is an understandable position taken by consumers, whom for more than 50 years have gotten used to gas vehicles which get 250 or more miles per tan even when the MPG is low. The assumption that EVs will only be used for short distance trips is more of a symptom of the technology than an actual consumer behavior – people view mobility resources as something you cannot have too much of and a surplus is beneficial in fringe scenarios where a longer journey is necessary (Graham-Rowe, 2012). An approach to this conundrum has been the development of fast charging stations, "where a vehicle can be charged in only a few minutes to near full capacity" (Adler, 2013, p. 2).

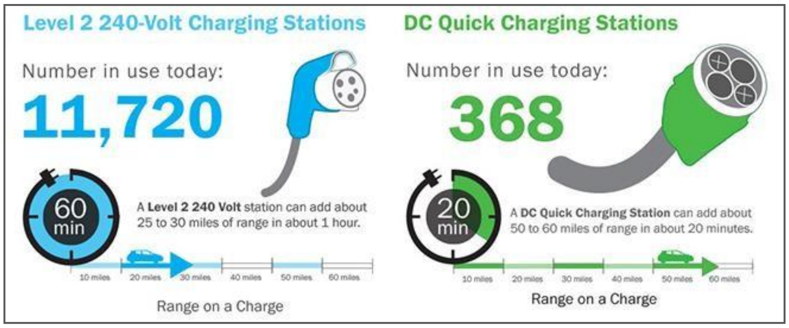



*Figure 10* The rise of charging stations is a typical balance of a chicken vs. egg market scenario; the popularity of PEVs is dependent on infrastructure, which is in turn regulated by popularity of PEVs. *Source: Center for Sustainable Energy*

Unfortunately the number of current public charging stations, as shown in *figure 10,* is still far behind the usual abundance of gas stations. Public infrastructure for electrical vehicles is essential for new adopters; "drivers gain confidence in venturing out with an electric vehicle as public stations are installed" (Bakker, 2011, p. 21) and counter the anxiety of low mobility resources. As described above, having a low remaining range for a certain journey can be conceived as having low mobility resources to reach personal goals or to meet external demands set by the environment (mobility needs). This imbalance between desired needs and resource availability bears similarities with common definitions of stress.

## Congestion, GPS, & route planning

The number of vehicles on the road has been steadily increasing since the 1950s, hitting a peak in 2009 at 254,212,610 registered passenger vehicles according to the US Department of Transportation. As more cars congest the roadways, this implies that more stress is put on attention requirements of drivers along with less ability for drivers to utilize 'cruise control;' stop and go fluctuations are naturally more common with higher levels of traffic. With the advent of GPS systems or GPS applications on more smartphones there has been a shift with how people plan out their daily routes or react to road delays.  Whereas before route planning was more linear and committed, people may now make last second changes in their route when delays are present due to the ability to rely on GPS. This is good for mitigating congestion at certain times, but ultimately bad for driver distraction. These driver controlled detours also make it difficult in managing a limited range vehicle, when the new course departs from a predetermined route. Drivers take unfamiliar routes which forces them to check their navigation screens more, rather than giving 100% attention to the road. Limiting distraction in a vehicle is thus even more important in today's evolving driving context.

## The Phenomenon of Range Anxiety

Even when 78% of driver's daily range needs are met by a PEV, consumers use range of an ICE vehicle as a primary anchor from which range is evaluated (Krems, 2010). This only leaves EV users the option of evaluating reduced range as either neutral or negative. Framing on losses is further reinforced by the fact that users originally expected to match the cycle range of the EV more accurately, and failure to achieve this typically has a sobering effect. Anxiety is then defined in a resource management context as feelings of unease, discomfort, and "a state of tension coupled with apprehension, worry, guilt, insecurity, and a constant need for reassurance" (Stranks & Dewis, 1986). This 'reassurance' is what automakers strive to provide with live output displays (regenerative braking feedback).

### Self-regulation & managing resources in high stress environment

While industry tends to focus on leveraging the cost-benefits of lower range electric vehicles by establishing MPGe and building more charging infrastructure, there has been some indication that the user interface itself can reduce some of this stress. Survey data (CSE) has shown that 80% of commuting daily distances would be met by even the lowest range vehicles and so consumer anxiety is thus discussed as 'sufficiency'. According to Franke, "A powerful predictor for range utilization appears to be low internal control beliefs in dealing with technology. The second-best predictor seems to be high impulsivity" (2013) which implies that an interface which empowers the user and calms their driving habits may raise confidence in range adequacy.

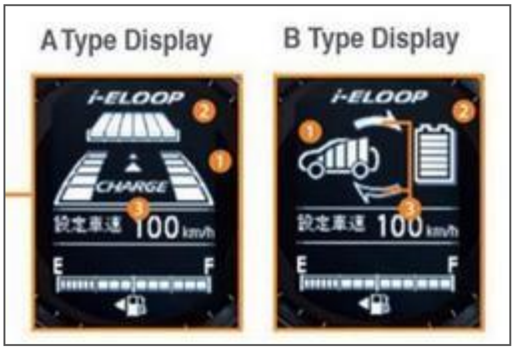



*Figure 11* 2014 Mazda 6 Sedan i-ELOOP system provides a visual feedback loop for alerting the driver when their driving style gains back energy via regenerative braking.

Integrative interface systems such as the above in *figure 11* have recently been put into vehicle displays and early research suggests that when people monitor their driving habits in a live MPG framework while driving, their fuel economy increases by as much as 5%. This live feedback use puts driver's in more control over their fuel than they have ever had, and "self-regulatory resources mediate the negative link between avoidance goals and subjective well-being" (Oertig, 2013, p. 365).

With resource control more transparent to the driver, considering the effectiveness of this transparency is vital. For different contexts and different experience levels, access to resource levels may be of negative consequence. Ability to mitigate anxiety due to resource loss depends greatly on coping mechanisms; generally "the loss of economic resources had a strong and mostly positive relationship to anxiety and anger" (Unal-Karaguven, 2009, p. 177) however the coping mechanism utilized was a consistent predictor for the onset of anger and anxiety. Not surprisingly, there is a learning curve when adapting to a new resource feedback system and "This process of change often entails overriding natural, habitual, or learned responses in order to guide psychological functioning in a different direction" (Baumeister &Vohs, 2007, p. 365). In an interesting finding that corroborates other EV infrastructure recommendations, coping methods for resource anxiety are best achieved with a communal support system and experience (*figure 12*).

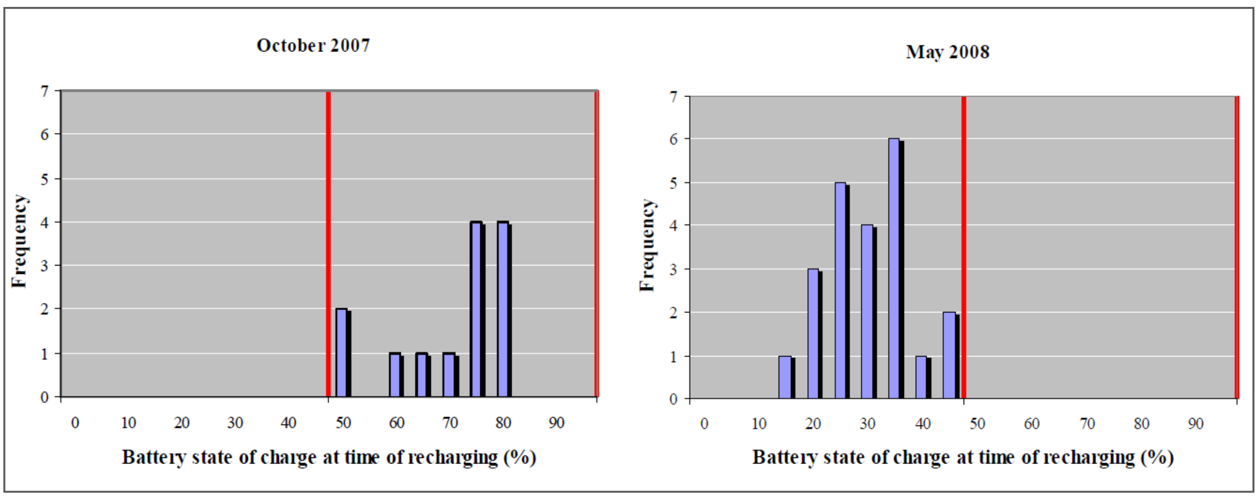



*Figure 12* As drivers become more aware of public charging stations, even if they are not utilized, their confidence regarding range is improved and manifests itself in a lower SOC when eventually charging. TEPCO presentation - Hiroyuki Aoki. Bakker, 2011.

## Confidence building with resource management

In a longitudinal study reviewed by Bakker (and represented in *figure 12* above), confidence building towards range was substantial after only one year of EV use when supported by growing infrastructure. Not too surprisingly as charging infrastructure increased the point of charge level that participants in a study charged their vehicle at decreased. This can easily be taken as a diminishing role of range anxiety in charging behavior brought forth by a growing confidence with range prior to charging. Not only is charging infrastructure seen as communal support, but well-designed displays are also seen as a communal effort by automakers to make driving more enjoyable. As Bakker states, “just knowing that the chargers were available made the drivers more comfortable driving further out” (Bakker, 2011, p. 53) and show great promise for mitigating range anxiety.

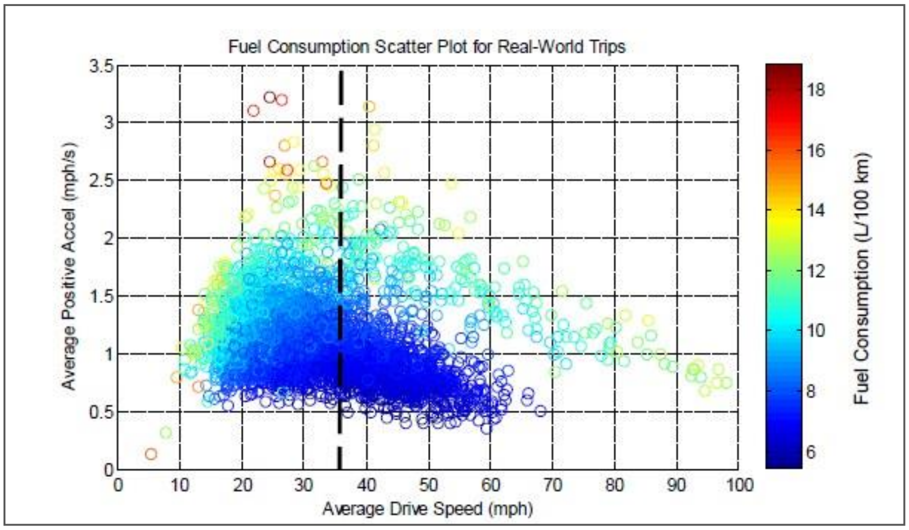



*Figure 13* As Regenerative braking is most efficient at moderate cruising speeds, the more often a driver maintains a good driving speed the more often they see energy regained by the vehicle. Ultimately, this will give them a more positive view of their current energy resource. NREL, 2013.

The context of a regenerative braking interface with a resource management model for electric vehicle usage is to approach the interface as one component of a larger support structure. The presumed mindset behind the function of these displays is that by shifting driving style (*figure 13*) towards the point of lowest consumption, the buffer between appraised range sufficiency and instances of charging will grow as an attribute of lower range anxiety.

Unfortunately, the possible distraction caused by these newer interfaces has not been researched fully.

Distraction as a cognitive impairment

The primary reason why a live battery feedback interface would differ from other gauges and in-vehicle system monitoring is due to its implication with immediate fuel consumption and resource allocation. In a UC Davis PHEV experiment, Stillwater (2011) examined the terminology usage difference between Prius drivers that had an on-board feedback system versus those that checked vehicle statistics on a computer outside of the vehicle. She found that in the onboard display group distraction, confusion, and time pressure was mentioned significantly more in follow up interviews.  Other research has shown consensus that on-board systems greatly increase awareness but with the side-effect of an additional display that increases ‘time-off-road’ time via eye glances (Graham-Rowe, 2012). A paradox may be created where distraction from these energy saving displays may actually hamper longer term resource management. Even in instances where the majority of factors are controlled, “resource loss remained as an important predictor of anxiety and anger” (Unal-Karaguven, 2009, p. 189). This research along with others support the Relative Time-Sharing model and Attentional Resource Model for working memory resources being diverted from time planning activities (Matthews, 2012). Mitigating distraction when these live displays are used is not only important for increasing their effectiveness at route planning but also for increasing safety.

The following literature review begins with one of the central studies in formulating which elements of an object display affects changes in monitoring performance. Articles concerning principles and conventions of vehicle interfaces are also reviewed for a groundwork of ‘best-practices’, and a handful of recent articles exploring ‘range anxiety’ and electric-vehicle usage are used as a jumping point for the researcher’s experimental design.

## REVIEW OF LITERATURE

### A) Ecological and Configural Displays

#### “Mixing and Matching Lower-Level Codes for Object Displays: Evidence for Two Sources of Proximity Compatibility.”

Carswell and Wicken’s explore how the concept of Object displays intersect with design patterns that fall in line with the proximity compatibility principle. Specifically, they wanted to investigate whether previous researched advantages of object displays are due to the low-level coding of individual system integration or the emergent features reflected in an object display design when two codes interact. Considering that “the integration demands of the task should always drive the visual configuration chosen by the display designer” (Carswell, 1996, p. 1), the processing of coding thresholds and their integration with design variables may impact human performance results more-so than the design itself – this is an area of research Carswell and Wickens acknowledge has been neglected. Studies that fail to show advantageous results have been most helpful in identifying this paradigm; why would one object display fail while a similar one succeeds? Context may not be the only answer and recently more researchers have explored issues of signal salience, noting that “the lower-level codes of the object displays used in many studies may simply be less discriminable or salient than those used for the separable displays with which they are compared” (Bennet, 1992). It is not surprising that there is controversy surrounding the efficacy of object display use and the research team for this study executed two experiments with the intent of isolating what factors lead to the most expedient performance enhancements when utilizing object displays.

Both experiments contain sets of homogenous and heterogeneous displays that contain mixed or matched codes. This paradigm arises from the researcher’s assumption of fewer emergent features from mixed lower-level codes while display designs with matched codes will naturally illustrate more emergent features. Before the experiment trials, each participant was able to view a ‘correct’ or normal sequence of digits that would determine judgment on an ordinal comparison. These sequences would determine whether the correct variable was greater than the comparison variable and “assuming that only two values are presented, the subject must clearly use both information sources to determine which value is greater” (Carswell, 1996, p. 5).

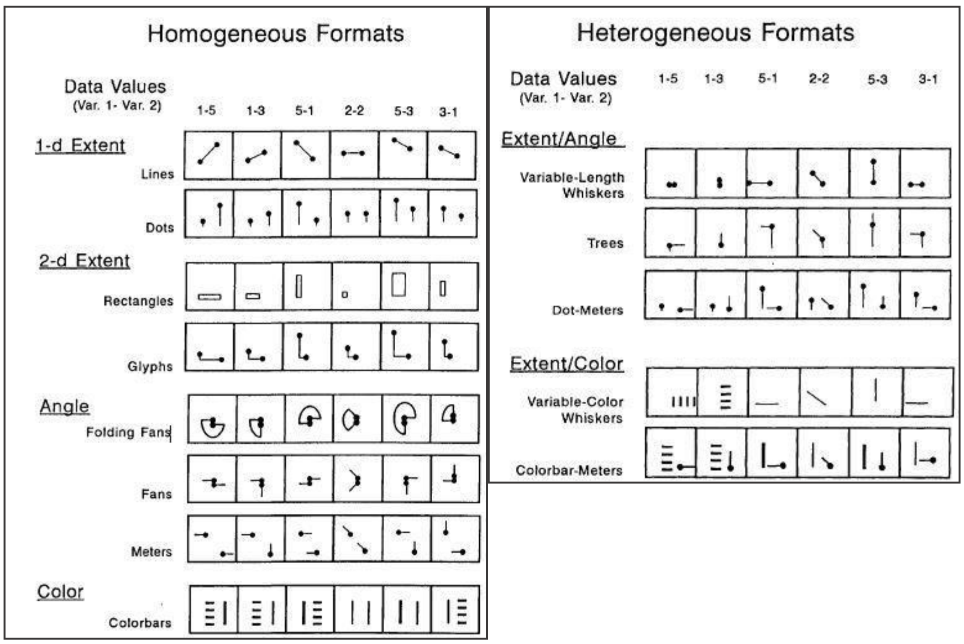



*Figure 14* A different format was chosen for each trial – in total, eight homogeneous and five heterogeneous formats. These were paired with the digit sequence to determine if ordinal decisions were aided by emergent features or by code integration levels (matched or mixed). Carswell, 1996.

Multiple trials were run and for each trial one of the above formats in *figure 14* was presented alongside the six-digit sequence with the object display design with the purpose ‘aiding’ in the decision for normality or abnormality. Homogeneity was supported by eight of the thirteen formats and in these formats there is a common baseline that determines the arrangement of the design dynamics. The format most relevant to the driving interface paradigm tested in the later experiment of this research paper is the 2-d rectangular extent. Height of the rectangle correlated to variable 1 while width correlated to variable 2. The intervals match the baseline set by the other homogenous formats and this integration is similar to displays researched by Barnett & Wickens (1988), Bennett et aI. (1993), Goldsmith & Schvaneveldt (1984), and Wickens & Andre (1990) in medical and process control settings.

If the researcher's earlier assumptions held true regarding emergent feature strength, "an advantage for homogeneous displays should dominate differences among the various formats" (Carswell, 1996, p. 4). In the results of the comparison tasks, this held true, thus revealing strength of emergent features when utilized in homogeneous formats. The conclusion then is that object displays with clear emergent features may not have nearly as much advantage in mixed-coding scenarios as they do when matched codes are used to integrate design features.

The second experiment departed from a comparison task and investigated which format type was best utilized in the case of conjunction value identification – that is, do the values of two variables or data points fall within their anticipated range. For these scenarios the resulting performance indicated that heterogeneous formats are actually more useful for conjunction recognition of range values met. This implies that in these situations where a target or ordinal decision is not needed but a range validation is required, mixed codes may facilitate processing of the original values and codes themselves.

The pattern of these models fits the proposed design methodology explored for vehicle interfaces – determining which peripheral or vehicle attribute is impacting driving range the most is a mixed-factor integration of variables. There is indeed the need to compare on an ordinal level, but with a polygon object display the original values would be preserved while also putting forth a set baseline of an acceptable growth range. As the discussion section of Carswell and Wicken's research explains (in the case of preserving raw values), "display manipulations that serve to facilitate the identification of each of the "raw" values (and which serve to eliminate potentially irrelevant or distracting information) may be most effective" (Carswell, 1996, p. 20).

"The Employment of an Iterative Design Process to Develop a Pulmonary Graphical Display."

Watcher et al., 2003 discuss the slight differences between configural displays and ecological displays, focusing first on their difference with handling emerging features. Both types of display map parameters of a system to a graphical display – a configural display utilizes design attributes that accentuate the shift in levels of emergent features. An ecological display directly represents the relationship of controls and schematics of a system. For the study carried out by Watcher's team, a large emphasis was placed on testing iterations of a configural display in order to maximize intuitiveness. Their designs for a pulmonary pump display combined configural and ecological with the goal of maximum intuitiveness without sacrificing simplicity. The difficulty is this hybrid approach with a goal of simplicity is maintain consistent meaningful representation of the changing data. For the experimental iterations, the team tested static images with participants and “a confusion matrix compared the designer's intended answer with the subject's chosen answer.”

The design and test iteration cycle continued until a threshold of % success was reached for variable mapping scores and a diagnostic meaning test score. The two tests used on participants effectively measured the impact of the reference frame – the indication of the initial baseline and the salience of the change when the impact source has fluctuated. This reference frame is indicated by a distortion of the original shape. Given the limitations of the iterative cycle for this experiment (static, printed images), there was significant promise that training time would decrease with these display designs along with increased accuracy due to learned pattern recognition. However, the limitation is also anchored by the need for clinical meaning to reliably show similar results and it is unclear at the time of the study how real-time data would change the animations and therefore change the results.

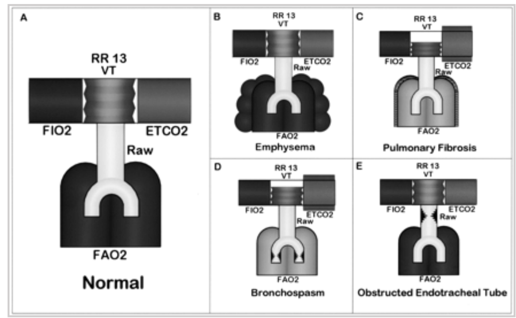



*Figure 15* Pulmonary Configural Display. The above is a configural display that uses the shape and schematics of a lung valve to communicate changes and issues in the relevant organic area when an alert event is triggered. Watcher, *2003.*

“Workload and stress in vigilance: the impact of display format and task type.”

James Szalma set up a study to investigate the effect of salience differences within well-mapped object displays and whether the changes impact stress, workload, and vigilance. In a configural display, design elements change according to changes in corresponding system elements. Most often these changes are related to contours, arrangement, or color and have been shown to improve performance. However there have not been many experiments within a subset of display types to assess the outer-bounds of salience strength and the effect of different salience levels. Ninety-six participants were split into six conditions - three bar chart displays split across two task types. The levels of the task type were individual variable monitoring and a midpoint identification for isolating data averages. Groups were distributed randomly but maintained an even gender distribution between the conditions.

The displays were rapidly, at under 3 seconds per display or approximately 26 graphs per minute. When a critical signal appeared, participants had to respond with a keyboard click and if they were too late or too early their response was marked as a false alarm.

The emergent feature for these displays was largely based on linearity – when the system was in balance or all thresholds at expected level the bars or area of the graph lined up evenly. Violations of the linearity pointed to an imbalance in the system. The configural display variance had an effect on performance with identifying midpoint values but not on the monitoring task. There was no effect on stress across either of the task types. These effects correspond to a decline in performance of 26% for monitoring and 19% for identification.

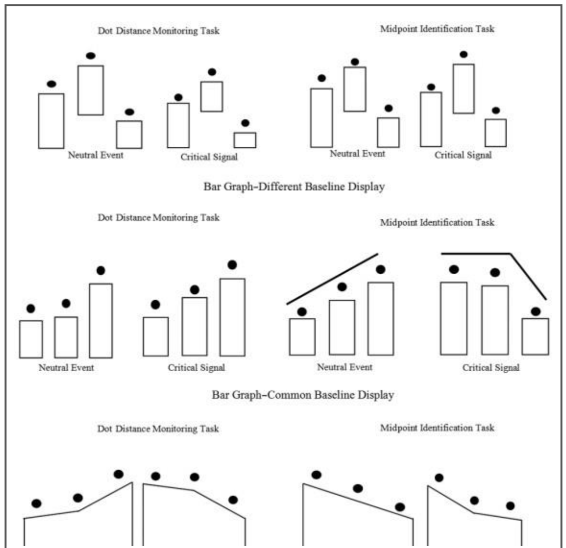



*Figure 16* Configural Display Salience. Six display types split into 2 groups - Monitoring and Identification task - used to isolate any effect of variable salience on performance, stress, workload, and vigilance. Szalma, *2011*.

Differences between displays were substantially smaller in the dot distance monitoring task than in the midpoint identification task, suggesting that the efficacy of configural displays is only of value when salience is strong enough between impact types and graphical format. Perceived workload effects were influenced by display format and by task type but did not interact across the two conditions. There is a huge implication subtly included in Szalma's study that many configural display studies and applications beforehand may have been held-back by inappropriate or understated salience levels.

B) Guidelines and driving interfaces

“Suggested Human Factors Design Guidelines for Driver Information Systems.”

Under contract from the Department of Transportation, this committee aggregated guidelines from various sources to create a compendium of standards for in-vehicle interface systems. The goal was to not only establish the standards, but to lay the groundwork for testing the ease of use and safety of the interfaces these guidelines would be used for. The researchers also strived to predict how, when following their standards, drivers would react when using these in-vehicle systems. Five systems were selected and prototypes of these displays were given to people to determine whether they understood the features or not. Alternatives to these displays were then compared in a more controlled setting to determine response time, performance, frequency of errors, etc. The results are not the main focus of these guidelines, which are in separate papers – rather the guidelines in this report feed from those separate studies. This committee thus divided up a hierarchy of standards in order to frame how guidelines should be used: General guidelines, function specific guidelines and integral guidelines. Within those three layers are guidelines for physically controllable controls, visual monitoring displays, auditory feedback features, and integration guidelines. The guidelines that are most applicable to range indicator research fall under visual monitoring guidelines and integrated functions. These guidelines are also very informative in pointing out areas where standards have not been made for newer technology, and the researchers conclude with the advice that the “DOT should contract for the development of pre-production interfaces relating to topic areas where the guidelines are weak.” Research papers that discover holes in existing standards are sometimes more valuable than those that explore the current conventions – this paper clearly shows a wide gap in standards for many different areas of the human-vehicle interface development arena.

“Information visualizations for knowledge acquisition: The impact of dimensionality and color coding.”

Keller, et al addressed the trend in software development of an increased use of information visualizations that use three spatial dimensions to visualize data. While three dimensional (3D) representation has proven to help users in find information and apply where necessary, the research team brings to light the areas where this application has not yet been tested. Their research aims to test whether 3D representation aides in the memorization and understanding of a data set or relevant information. Theories of computational efficiency, cognitive load, working memory models, and of multimedia learning are cited as a premise to which 3D representations have previously aided the processing theory of users. The experiment focused on an assessment of whether visualizations helped foster knowledge at a higher rate than text-based information display. 100 students were used and the Independent variable was type of display: spreadsheet or one of four types of dimensional information displays. Of the four alternative representations, there was a monochrome option for 2D and 3D and a polychrome for 2D and 3D. The subject material referenced construction sites and labeled metrics such as size of the project and current progress of the construction. Compared to a spreadsheet format, it was found that 2D and 3D visualizations both increased knowledge acquisition. The 2D format actually had a slightly increased rate of acquisition over 3D models and polychrome formats affected performance slightly as well when compared to monochromatic representations.

"Cross-correlation based performance measures for characterizing the influence of in-vehicle interfaces on driving and cognitive workload."

The doctoral dissertation by Medenica is a mass compilation and analysis of research practices, tendencies, performance measures, and performance scales used in the context of driving related investigations. Of most interest is the investigator's groundwork for a new performance measure to assess the cause of a specific in-vehicle interaction. The assumption, or premise of his argument is that existing 'average based performance measures' portray the driving experience as a whole rather and this subtle overgeneralization may overlook localized changes in a driving scenario. A statistical model was created to 'extract' the relevant change based on interaction; 'Cross-correlation' is used to detect similarities between two scenarios, and the rate over time used to discern where the change occurred and how much of it was due to a precise interaction. The statistical model was then tested with four different studies; a map based navigation system, interacting with mobile radios, speech accuracy with a voice activated interface, and the effect of map based devices on visual attention. The outcome of the individual studies are less relevant for range indication research. However, the ability to deduct meaning from cognitive load measures and how they correlate with physiological metrics, visual distraction measures, and subjective workload measure will be of great use to further statistical analysis in driving related research.

"Design guidelines for safety of in-vehicle information systems."

Another set of guidelines, this report was constructed with the intention of being a more usable, straight forward synthesis of existing in-vehicle system guidelines. While the brunt of the report are standards for issues such as placement, hierarchy, luminescence, and accessibility of certain features, these guidelines are pulled from other research that sets groundwork standards based on efficiency, workload, and driver performance on differentiated system designs. The section on visual displays is of most applicability to range indicator research, specifically on the standards of symbols and graphics, screen image stability, and image blinking. All standards related to visual displays are consistent with the principle that the less fluctuation within the display the better. Higher rates of blinking and or flickering raise occurrence of distraction rather than inducing a quick, rapid check for information. These guidelines seem to be a huge area where active range indicators would not fulfill existing standards. Other than the tachometer and speedometer, visual display systems are recommended to keep their dynamic displaying at a minimum.

"Human Factors and Gauge Design: A Literature Review"

Dr. Paul Green's holistic analysis of gauge research covers existing literature as far back as 1940 up until the late 1980s. These studies are pulled from human factors literature and from industry sponsored automotive literature and applications. Green's review aims to answer which types of displays are best for which tasks, proper use of pointer displays, proper gauge scaling, color coding scales, and the overall design of pointers and gauges. The review does not asses research limited to vehicles, but also calls upon gauge research related to airplane cockpits and larger machine systems. Response time and error rates are some of the more common measurements used to determine which types of gauges are better for which tasks. In one of the studies 'display accuracy' was tested via participant responses to the precise number the display was trying to communicate. Some displays tend to show the measurement on a rounded glass shield above the apparatus; however across the three different display types tested ‘display accuracy’ did not have a large effect on performance. Research was also done on the effect of gauge type on short term memory. The example used is when someone is interrupted after looking at a telephone number they may forget the number even after such a brief interruption. In an automotive context, this problem is present when people may end up forgetting information displayed on the instrument panel. Multiple charts and guides are presented for when to use which gauge for which type of task – quantitative reading, check reading, setting, or a tracking task. Error rates (accuracy) for the gauge types are not as relevant to range anxiety research due no significant consequence of misreading battery output. However, speed of recognition and recall rate are of great importance for the assessment of battery output gauges. The conclusion for a lot of the tasks regarding dynamic gauges (that change direction frequently) was that “the pointer location for the moving pointer display provided cues that were useful to viewers” (p. 43).

C) Range Anxiety and PEV Contexts

“Impact of Observed Travel and Charging Behavior, Simulated Workplace Charging Infrastructure, and Vehicle Design on PHEV Utility Factors (UF), Total Charge Depleting (CD) Driving and Time of Day (TOD) Grid Demand: Scenarios Based on Consumers' Use of A Plug-in Hybrid Electric Vehicle (PHEV) Conversion”

With the advancement of battery driven vehicles automakers have implemented different ‘driving modes’ which affect fuel efficiency and driving performance. Designers have made assumptions as to how these features will impact driving habits along with charging frequency of PEV owners. To date, analysts have made assumptions as to the design of PHEVs (Plug-in Hybrid Electric Vehicles) that will be purchased, and the travel and charging behavior of the future users. Furthermore, since PHEVs can run in charge depleting (CD) and charge sustaining (CS) modes there is uncertainty as to how much travel will be completed in each mode due to the variety of possible vehicle designs, access to charging infrastructure, and travel and charging behavior of PHEV users. Davies-Shawhyde approached his research with the intention of lessening the uncertainty with how the presence of these different modes affected user charging and driving behavior, as well as typical mileage traveled in each mode. As a launching point, Davies-Shawhyde goes over the existing research on PEV usage and charging tendencies in

PEVs with only one standard driving mode. The rest is a mixture of survey results and electrical power grid analysis to assess charging habits of workplace vs. household charging. The conclusion is that workplace charging provides larger percentage benefits for shorter CD ranges. After the trial period for this observation, participants whose grid profiles and driving amounts were previously analyzed answered a questionnaire. This questionnaire allowed the participants to 'design' their own PHEV based on the metrics they desired. The results maintain that workplace and public charging infrastructure raise the acceptance of CD modes due to the ability to charge in short bursts to regain levels of energy consistently, rather than fully depleting fuel reserves and charging the complete tank all at once.

"Mainstream consumers driving plug- in battery- electric and plug- in hybrid electric cars: A qualitative analysis of responses and evaluations."

Graham-Rowe's team of researchers seek to appraise user's perspective towards several types of electrically driven vehicles.  The classification differences they offer for electric vehicles is slightly different than other categorical evaluations. Battery-electric vehicles (BEVs) have an all-electric drivetrain powered by electricity, plug-in hybrid electric vehicle (PHEV), and range-extended electric vehicle (REEV). REEVs are those vehicles that primarily use power from a battery system, however the battery can be recharged via a built in ICE that is powered by gasoline. REEV generally have a much longer total range ability than other forms of purely electric vehicles. A mixed-form interview was used to gauge consumer's views towards electric vehicles following a seven day trial period of EV use. The participants were all current drivers of gasoline vehicles; there were 40 of them and the main criteria was whether they were the main decision maker regarding vehicle purchases within their household. A BEV was given to twenty participants during the trial period and another twenty were given then PHEV. Expected vehicle range along with charging procedures and monitoring range was discussed prior to the seven day period. Responses and comments were funneled into six different categories for assessment: (1) cost minimization; (2) vehicle confidence; (3) vehicle adaptation demands; (4) environmental beliefs; (5) impression management; and (6) the perception that EVs are currently a 'work in progress'. One of the feedback points emphasizes the difference between ICE and PEV interfaces: ''[It was] a little bit, not only confusing but quite off-putting because you kind of found yourself driving along looking at it because of what it was doing. [. . .] At the end of the day, you don't really need to know it. It makes no difference to you whatsoever because it cuts in and charges it as and when it chooses to'' (P24, PHEV). The view that electric vehicles are still an ongoing development and are not yet in their prime, along with the differentiated feedback towards PEV interfaces and adaptation controls, illustrates the necessity for more research and applied design in this area.

"Experiencing range in an electric vehicle: Understanding psychological barriers."

In this study led yet again by Franke, psychological barriers towards EV purchasing due to range 'sufficiency' were examined. Forty electric vehicles were given out to drivers for testing over a 6-month period. This is one of the longest periods of a testing phase for EV research when the vehicle is not owned or leased by the driver prior to the study. What Franke *et al* hoped to find were other psychological barriers, not just anxiety or fear. They achieved this by combining four different paradigms of range measurement; cycle range, competent range, performant range, and comfortable range. Comfortable range is the one that is most focused on in their research.

Descriptive statistics for comfortable range variables.

| Variable | *M* | *SD* |
|---|---|---|
| Safety buffer | 19.23 | 13.02 |
| Range comfort zone | 78.27 | 10.11 |
| Range threat appraisal | 3.33 | 1.07 |
| Comfortable trip distance | 120.41 | 16.93 |

*Note*: All variables are in km except for range threat appraisal (scale value on a 6-point scale).

*Figure 17* Psychological Barriers to Low Range Vehicle. Franke creates a baseline with which automakers can approach consumer attitude and needs when it comes to adopting a low range vehicle. Franke, et al, *2005*

Questionnaires were used to measure the participant's feelings towards "mobility, acceptance, charging, range issues, and personal variables" in order to measure the conceptual magnitudes of range experience, range satisfaction and concerns, and how certain personality traits buffered range anxiety via various coping mechanisms. Most participants believed they could adapt to the new range limitations. There was a significant affect between personality traits and stated comfortable range, highlighting that there are other avenues through which range sufficiency appraisal can be enhanced.

"Electric vehicle: The phenomenon of range anxiety."

The Elvire project is a European co-op organization and this review is a summary of literature and approaches regarding range anxiety. The purpose of the review was to overview what has been researched regarding range anxiety as well as put forth the current market trends towards combatting range anxiety. The article's rudimentary approach, starting out with physiological definitions of anxiety and contexts of dealing with consumer based stresses, helps to narrow down what other researchers mean when they mention range anxiety. Subjective, physiological, and behavioral sub systems are all considered when approaching range anxiety. A chart is also offered by Nilsson showing all the differently worded definitions of range anxiety by researchers. These are then synthesized into four main branches of range anxiety stress. Anxiety towards future scenarios, worry over that scenario, worry of not being able to solve the problem when it emerges, and the worry of being stranded due to that problem. A very skeleton approach towards range anxiety, but it helps demonstrate that the problem is not range of the vehicle but of the anxiety itself. Strategies are then put forth for how automakers and researchers alike have combatted range anxiety: Giving suggestions on driving habits to increase range, eco modes, more transparency about range information, awarding smart driving behavior, utilizing certain features during charging, warning indicators, etc. The research review actually finishes with reviewing the methods out there to measure range anxiety. Nilsson's examination is an excellent article to manage which area of investigation to narrow in on depending on what aspect of range anxiety is being researched.

"Contesting Range Anxiety: The Role of EV Charging Infrastructure in the Transportation Transition."

This analytical report compiled by Jorrit J. Bakker for a Master's dissertation was also framed as a pivotal recommendation for the Netherland's transportation council. The main goal of the paper is to examine the role of electric vehicle infrastructure as a crux of a larger, holistic transportation transition. Essentially, 'how important is state supported charging infrastructure for electric vehicles when attempting to transition to a more sustainable, eco-friendly transportation culture. Bakker systematically evaluates the current development plans of the state commissions, what is required for an overall ‘regime’ change in infrastructure and what components have already been deployed, and finally what aspects of EV infrastructure affects other attributes of the entire transportation network. Chapter 4 and 5 are most relevant to range anxiety, noting the psychological effects of a dual home and public charging infrastructure. Confidence building via infrastructure building is the main take away of this report. A huge component of this conclusion was a study that demonstrated how “just knowing that the chargers were available made the drivers more comfortable driving further out” even when the chargers were not used.

“Comprehending consumption: The behavioral basis and implementation of driver feedback for reducing vehicle energy use. University of California, Davis; Transportation Technology and Policy.”

Stillwater’s dissertation is a large-scale look at fuel consumption in vehicles and how live-feedback can increase fuel efficiency. The first two chapters of her dissertation argue why the current MPG metric is flawed and why a new measure is necessary and also contains a review of behavioral theories for why and how drivers plan and interact inside their vehicles. The main component of the dissertation is a field study on energy information feedback. The vehicles used are 12 Prius vehicles that have been converted from hybrids to plug-in hybrids for battery charging. Along with the original driver information display already built in to the Prius, participants were directed to a website where they could view a log of data regarding their vehicles performance, comparisons of various trips, and energy usage. 98 participants were used and each one had a vehicle for four to six weeks. The difference between groups was the length of time during the trial in which they had access to the in depth driving information via the website or the live-action Prius display.

| Theme | Total Mentions of Theme | | Proportion of Respondents Who Mentioned Theme | |
|---|---|---|---|---|
| | OEM Display | Web-Based | OEM Display | Web-Based |
| Changing driving behavior | 39 | 2 | 40% | 2% |
| Strong emotional reaction | 16 | 2 | 16% | 2% |
| Experimentation for it's own sake | 18 | 5 | 18% | 5% |
| Personal goals or competition | 27 | 4 | 28% | 4% |
| Extension to other areas | 16 | 2 | 16% | 2% |
| Purely descriptive interest | 20 | 19 | 20% | 19% |
| Novelty wearing off | 13 | 13 | 13% | 13% |
| Distraction | 21 | 3 | 21% | 3% |
| Confusion | 25 | 2 | 26% | 2% |
| Too much effort needed | 2 | 19 | 2% | 19% |
| Time pressure | 14 | 0 | 14% | 0% |
| Traffic pressure | 14 | 0 | 14% | 0% |
| Additional guidance desired | 12 | 16 | 12% | 16% |
| Total number of Mentions | 324 | | | |
| Total Respondents (n) | 98 | | | |

*Figure 18* Information Feedback: Live vs. Passive Data. Verbal analysis was applied to investigate how the presence of energy usage information affected drivers who had an onboard display versus those that looked up their driving habits at a computer. Stillwater, 2011

Participant statements during post-trial interviews were used to assess the difference of impact between the OEM display and access to the website. Both conditions had a large impact on the emotional connection and reactions towards such a fuel efficient vehicle, however it is clear from the findings that active feedback in the vehicle itself had a much higher impact on self-assessed driving habits. Extremely relevant and important though, is that in the OEM condition, distraction, confusion, and time pressure is also mentioned significantly more.

Having summarized the backdrop of vehicle evolution, the stepping-stones to the modern day range anxiety phenomenon, and the review of the relevant experimental pieces that would justify a new EV interface paradigm, an ethnographic deep-dive and experimental design were created to support several design iterations for an Object Display.

## IMPORTANCE OF STUDY

Further research is required for the topic of resource data visualization in a vehicle context under the premise that existing standards are based on *suggestions* and *guidelines* for broad instrumentation and are not specified for live feedback of energy consumption. New PEV systems that have smart, adaptive fuel consumption and ‘eco-modes’ change ecology of vehicle habituation, behavior, and context. People approach electric vehicle range differently than gas vehicles, even with newer higher-range electric vehicles. The ability for more information to have a *negative* effect on anxiety is worthy of study considering the increase of in-vehicle dynamic displays and their influence on situational awareness. Maximizing battery/fuel efficiency is a well-established parameter of modern driving habits (Davies-Shawhyde, 2011) and these feedback systems are typically present with the implication of range extension in a PEV system. Their distractibility/efficiency trade-off has never before been examined and the following study wishes to analyze the effectiveness of these ‘in the moment’ feedback displays on ‘smart’ route completion.

Many questions arise due to the implementation of these new interfaces; most relevant to the sales of these vehicles for automakers would be which form of data visualization raises the apparent level of range sufficiency in an electric vehicle. For an engineer and standards expertise, the most immediate may be an information architecture question: *Where does range* *indication belong in an information cluster?* Closer to a psychological attributive question, one may ask what sort of numerical/graphical representation eases anxiety and maintains high levels of situational awareness? Or at what point do too many attributes/elements increase anxiety rather than decrease anxiety? What this research aims to answer is whether displaying active output/regenerative energy of a battery changes behavior and driving approach more than certain displays with a goal oriented, directive approach.

## METHOD

Research methodology involved contextual inquiry and ethnographic interviews for the first part of the study. Newer vehicles have evolved to contain dynamic displays for fuel and power output. Particularly in electric vehicles, with a smaller total driving range before needing to recharge the battery pack, range anxiety has been explored as an impediment for plug-in electric vehicle (PEV) ownership. PEV drivers tend to monitor driving behavior due to this decreased total range and also tend to be the same consumers attempting to lower their overall energy usage. Driving a PEV is therefore a high stress context especially when congestion and road delays are at an all-time high. To combat this automakers have implemented regenerative breaking (power brought back to the battery via the braking system) and active battery displays that give drivers live feedback of their battery output/re-uptake. The ethnographic inquiry aspect of this study will be split between a brief pre-survey and a one-hour interview containing questions regarding range anxiety, driver attitude, desired vehicle information, and current EV interface design qualities. Two designs were then drafted utilizing the feedback from the participants to maximize value and need-relevance. Twenty-six newly recruited participants then partook in part two of the study, a driving simulator task. During these tasks the fabricated display designs were shown incrementally to participants while navigating two different maps. The new design interfaces will be compared to a ‘standard’ display that constantly shows battery percent, total estimated range in miles, and a KW output graph. Participant reactions and reception of the different display types were recorded along with awareness of comparative impact, attentional load, ranking speed, helpfulness and energy communication ratings, and their awareness of remaining ‘range’ throughout the driving scenarios.

## Ethnographic Investigation

Ten electric vehicle owners were interviewed to assess driver mentality and resource needs in limited range scenarios. Requirement was ownership of total plug-in electric vehicle, no gas-electric hybrids. The vehicles represented were the Nissan Leaf, Toyota Rav4-EV, Ford Focus EV, Fiat 500e, and Smart FourTwo. Comprehensive interview questions and output can be found in the Appendix (*F*). Interview sessions lasted on average for 45 minutes – typically interviews were carried out in the subject’s home without entry into the vehicle, though several participants were open to answering questions while showing the various UI elements of their vehicle.

The purpose of these interviews were to gather generative data towards formulating a relevant design scope. Despite the experimental panel consisting of non-EV owners, it is essential to focus design implementations on realistic standards and contextual needs. Average subject age was 39 – not too far from the general trend that those who can afford the early adoption price tag of electric vehicles are slightly more established and middle aged. For most owners, the electric vehicle was supplemented by a gas vehicle for longer distance road trips and emergency circumstances. Three of the ten interviewees had two electric vehicles. The two tables (*table 1 and table 2*) below summarize the output and qualitative feedback supplied during the interviews.

| Age | Vehicle /range | Daily miles | Charging | Motivation | Range anxiety | Range mentality |
|---|---|---|---|---|---|---|
| 47 | Ford Focus EV, ~85 | 20 | Home only | Cost, environment | Very relaxed, such limited use. Only worries in extreme circumstances. | Miles left, cost |
| 52 | Nissan Leaf, ~75 | 25 | Work | Through work, cost, ease of use | Slight, due to battery degradation. Worries when can't charge at work. | Charging station proximity, battery percentage |
| 42 | Fiat 500e, ~90 | 40 | Work, school | Cost, trendy, size, efficiency | Check range frequently due to interest. Worries when 50%-60% | Miles, but sees prediction as flexible so falls back to percentage. Sees full charge as cost. 2 hours charging = 1 dollar. |
| 38 | Toyota Rav4-EV, ~105 | 45 | Home only usually | Environment, cost | Determined by access to known charging stations, but also ~50% starts checking more. | Percentage, knows miles are fleeting prediction and his driving style changes. |
| 55 | Nissan Leaf, ~95 | 25 | Home, work | Carpool lane, cost, trendy | No worries after first month...but does notice faster depletion when carrying others. Checks more often at 70% or less. | Miles & time needed to recharge. |
| 45 | Nissan Leaf, ~100 | 50 | Work, home | Environment, cost, proximity to charging | Depends on familiarity with route, but 55% | Somewhere in between miles and battery percentage…tries calculating true difference depending on driving style. |
| 57 | Ford Focus EV, ~80 | 25 | Home | Rebate/cost, environment | 50% range…or typically after 20 or so miles of driving | Familiar with Watt conversions so trying to use that recently, but typically just the miles |

| | | | | | | |
|---|---|---|---|---|---|---|
| 32 | Smart FourTwo, ~65 | 20 | Work, home, errands | Ease of use, parking, cost, quiet | Low, due to such restricted use | Miles. |
| 25 | Fiat 500e, ~100 | 25 | Work, home, errands, dealer station | Cost, environment, trend | Seems to have constant anxiety – even when at 100% drives very slowly. Focuses on conservation constantly. | Cost is a big topic he always compares to, yet very zoned in on increasing range via slow driving |

*Table 1* - Output table from ten ethnographic interviews

| Interviewee | Design Needs |
|---|---|
| 1 | More intuitive graphics, for long-term data.<br>Too many subpages in display, needs to be updated<br>Show isolated peripheral power.  Graph in current vehicle too squished. |
| 2 | Regen showed miles gained, GPS better synced to battery availability. Separated miles lost for peripherals, show difference…maybe clear graph with short-term use?  She never uses web portal. |
| 3 | Vehicle had more mode types or cleared feedback on what mode types mean…impact of switching modes |
| 4 | Peripheral power use should not hide the math for her, what does Ac use? Does some of the route math but would like some sort of overlay map? |
| 5 | Energy usage was displayed a bit more graphically…or comparatively…not just as kWh or MPGe…compare beginning of trip vs. end of trip. |
| 6 | GPS tied to range somehow…or that it showed 'surplus' or risk of running out based on route. |
| 7 | Range shown more graphically, maybe depleting bar. Something to help out communicate what battery percent means but not as…simple as number only. |

| | |
|---|---|
| 8 | Vehicle has very little information of trip power usage, regenerative amount over time, air conditioning power usage. Some sort of route entry, GPS. |
| 9 | He had supercharger capabilities, isolated peripherals, native GPS, different power modes, trip usage not as text based |

*Table 2* – EV owners revealed desires based on smart interfaces that reduced their need to calculate and elements that increased peripheral and traffic situational awareness related to range awareness.

## Ethnographic Inferences

Of notable discussion throughout almost all of the interview sessions was the ability, or lack-thereof, of their vehicles' interface to show them a breakdown in range impact per vehicle peripheral or driving behavior components. Rather, most of their vehicles only showed an impact on the total predicted range and forced the driver to do the math. Five of the interviewees also expressed interest in showing a more detailed rating of their regenerated power, despite most understanding that acceleration and deceleration is largely impacted by traffic pace and out of their control. From the robust qualitative feedback given, it was determined that the best paradigm to test in a lab setting for an EV interface would be between a traditional graphics presentation versus an object/ecological display. Both of these would be showing impact of their driving, peripheral power, and contextual influence showing isolated impact in miles.

## Design Progression

Following the ethnographic sessions and a robust support via previous research, a decision was reached to investigate how an analog display revealing peripheral and driving condition impacts would perform alongside an object display showing the same range impacts. Twenty participants were tested over a span of three pilot tests implemented to improve iterations. These pilot tests were helpful in isolating testing variables and forming an ideal balance of a design that would fall between what an experienced EV owner would recognize and what would be acceptable for those unfamiliar with EVs to understand with minimal initial exposure. Below are several of the main outcomes of the iterations, with the final testing stimuli presented with the hypotheses.

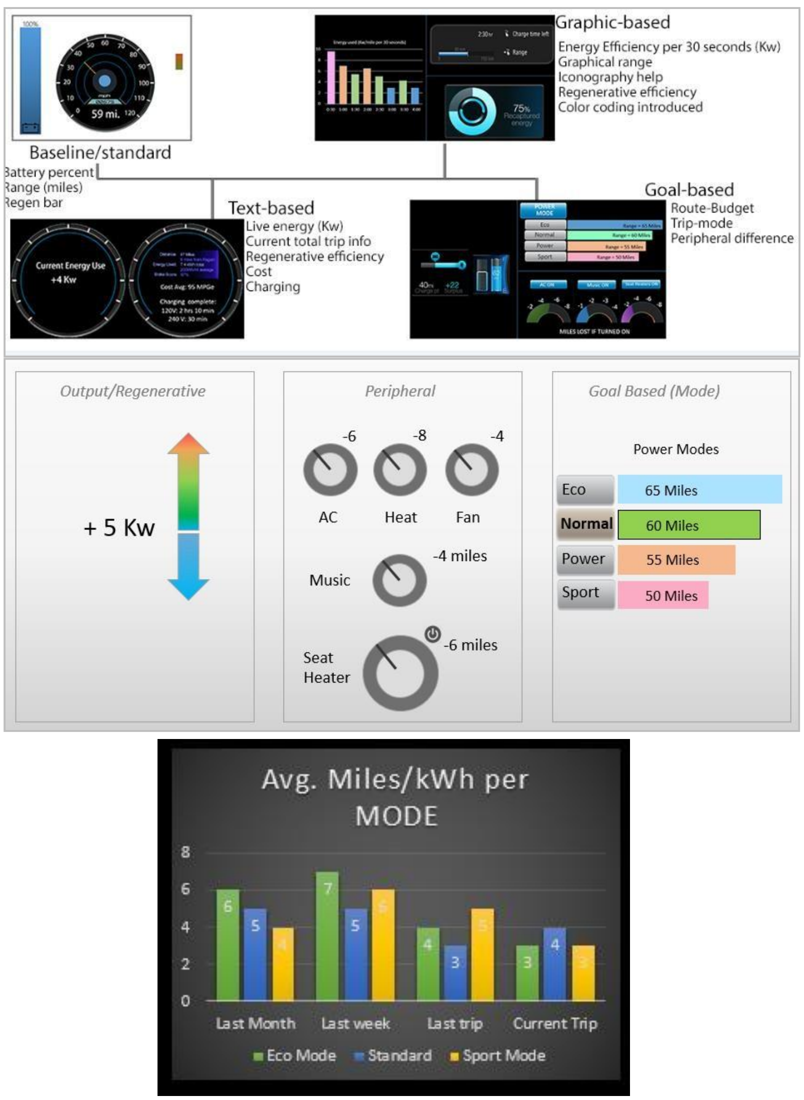



*Figure 19* Several display options explored following the ethnographic interviews, borrowing common themes desired from the PEV drivers such as peripheral impact, driving style, regenerative performance, and long term vs. short term consumption.

# HYPOTHESIS

Following the pilot sessions, two different display configurations were finalized using input from the EV users and minimizing extraneous variables throughout the pilot trials. These static displays were then tested in conjunction with a driving simulator task. The goal of this study was to explore which type of display presentation allows quicker and clearer digestion and accurate comprehension of impact on range in miles. Any possible attentional difference or helpfulness value will also be assessed. The effect of these displays on ratings of range sufficiency is also of interest. Lastly, the researcher will investigate whether any differences between the two display types change over time across a second driving session due to increased familiarity and exposure.

## Null Hypotheses

*No effect on performance score of top impact between the two display types*
$H_{0:}$ There will be no difference in impact comprehension between the two display types.

*No effect on performance score of ranking the impacts between the two display types*
$H_{0:}$ There will be no difference between display types on the speed of ranking attribute impact.

*No effect on participant ratings of display qualities between the two display types*
$H_{0:}$ Attentional load, helpfulness ratings, and effect on range awareness will not change depending on the type of display shown during the driving tasks.

*No difference of any main effects based on display type between the two driving scenarios*
$H_{0:}$ No interaction will occur between type of display shown and exposure over time and across the two driving scenarios.

## Alternate Hypotheses

$H_{1:}$ There will be a significant difference in impact comprehension between display types.

$H_{2:}$ There will be significant difference between display types on the speed of ranking attribute impact.

$H_{3:}$ Attentional load, helpfulness ratings, and effect on range awareness will be significantly different depending on the type of display shown during the driving tasks.

$H_4$: An interaction will occur between type of display shown and exposure over time and across the two driving scenarios.

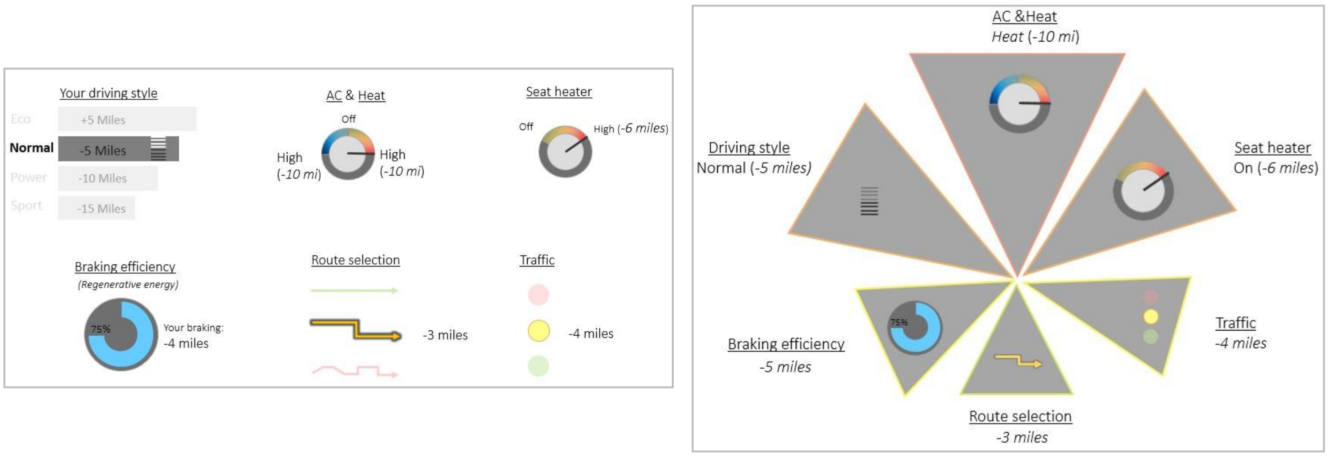



*Figure 20* The final two displays. a) Analog Impact Display and the b) Object Display. Participants were primed and given a brief explanation of the impact features with versions of these designs with all impact peripherals at 0 (neutral).

## DESIGN

The experimental model implemented for the driving simulator task was a *within-subjects* factorial of display type and exposure over time (correlated with decreasing range).

| | (IV) Display type | |
|---|---|---|
| (IV) Driving Scenario & range | (*Level*) Analog Impact Display | (*Level*) Object Impact Display |
| (*Level*) Open map, range drops from 60 to 45 miles | n = 26 | n = 26 |
| (*Level*) Guided task, range drops from 45 miles to 25 miles | n = 26 | n = 26 |

*Table 3* All participants participated in both driving scenarios and were exposed to both display types.

The independent variable for this experiment was type of display design shown; the levels of this variable are (a) Analog Impact Display and (b) Object Impact Display. The dependent variables are impact comprehension, speed of digestion, error difference, attentional ease rating, helpfulness rating, and range awareness affect rating.

Each participant performed both route types and viewed both display types within each route. In both conditions the standard display (displaying battery percentage and 'remaining' range) was shown constantly, dropping one percent and one mile every 60 seconds. Carryover effects were controlled via randomization of the order in which the experimental displays were shown. Displays were shown at a set time increment at 2 minutes into the route for 5 minutes each. The standard display was positioned directly under the simulator monitor similar to a tachometer placement while the secondary displays were immediately to the right of the driving window. Probing questions regarding the attribute impact, attentional load, helpfulness, and ease of understanding were asked at set increments as well. Range sufficiency and driving awareness questions were asked between the routes after seeing both displays. In between the routes there was also time to discuss the displays and gain qualitative feedback on their influence.

The above design was chosen with the goal of answering the following questions - a) What is the effect of different display types on energy awareness and vehicle awareness? b) Is there any difference of this effect over time with increased familiarity? c) What attributes of 'smart' interfaces are actually helpful and valuable to a PEV driver?

Ultimately, my interpretation will assess if an Object display increases the speed and accuracy in which drivers can assess the impact level of various driving attributes on energy conservation.

## Participants, Apparatus, and Instrumentation

Ten participants were involved in the contextual inquiry portion of the study. Twenty-six additional participants were recruited for the driving simulator tasks following display design fabrication. An online randomizing tool was used in conjunction with a simple numbering paradigm, *INITIALS12*, to determine order in which the displays were shown. Demographic and driving attitude data were collected prior to the driving session to assess any experiential bias or correlation with EV experience. No participants for the driving simulator tasks owned an fully electric vehicle and only three of the twenty six had regularly drove any sort of hybrid vehicle.

A pre-survey regarding PEV ownership and usage was administered upon initial email or phone communication. Only those owning or frequently driving PEVs were recruited for the contextual inquiry phase. Data collection during this phase consisted of surveys, interviews, experimental observations, and voice recording - as well as possible design sketches aided by the interviewees. For the simulator component there was a pre-survey for the participants regarding driving habits and knowledge about PEVs. Along with driving simulator software run by a laptop and monitor, the simulator tasks utilized in-task questions, video recordings, a tablet for display design presenting, and a driving simulator steering wheel. Motion capture software was applied to recorded videos of participants post-experiment to assess dwelling time on the secondary displays. There was be one video camera – attached directly to the monitor pointing directly at the participants face. *Figures 18-22* below cover the physical experimental setup along with the relevant stimuli.

*Figure 18* The setup; Driving simulator window, standard display in front of steering wheel, secondary displays, tablet for entering probe answers and scales, and a phone for stopwatch & timing.

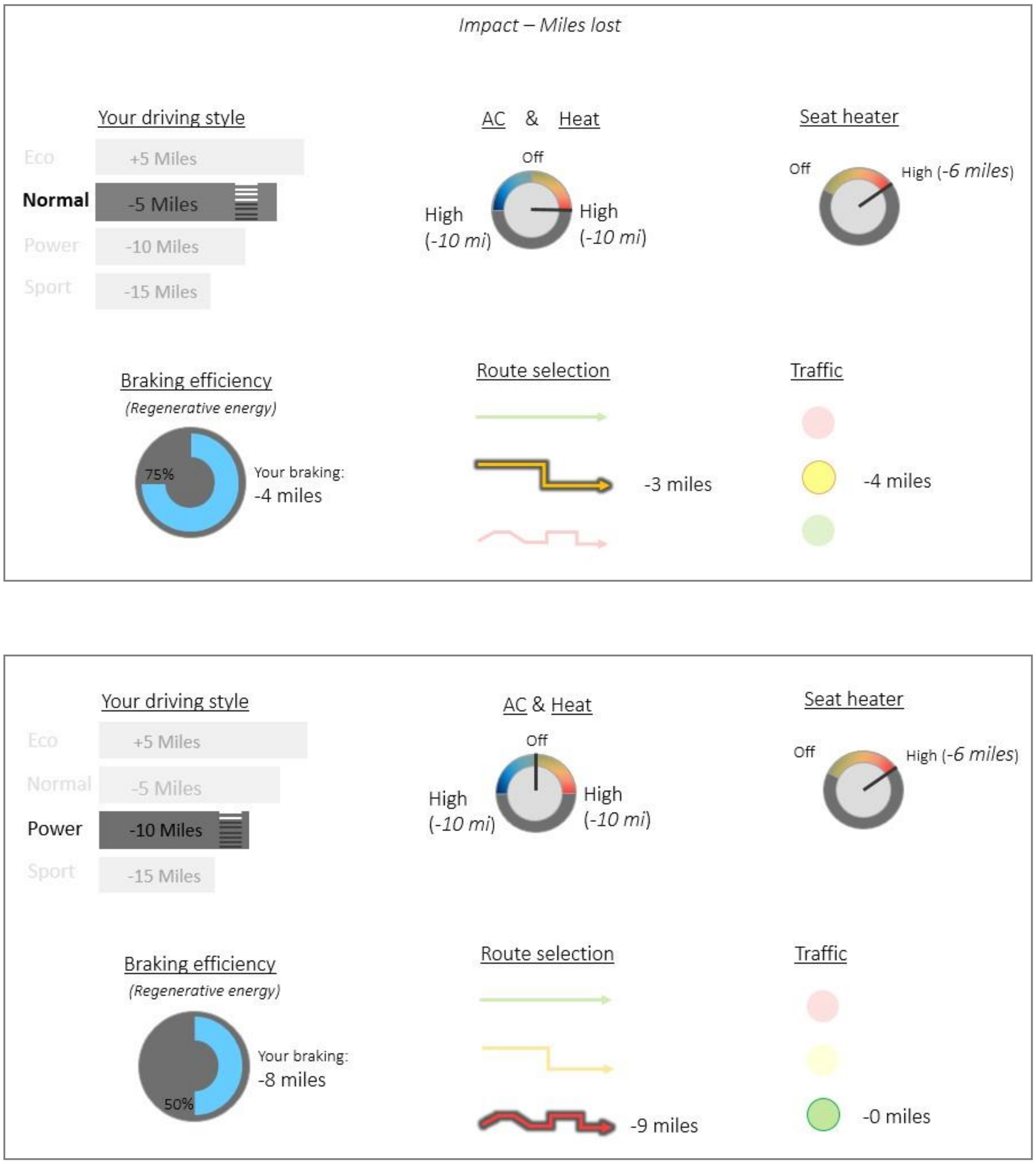



*Figure 19* The 'Regular Impact Display' showing impact of vehicle attributes on available range in miles during the two driving scenarios.

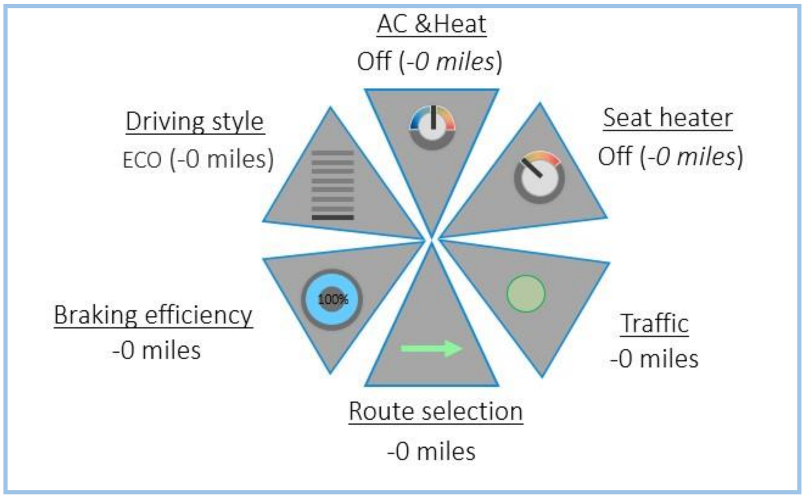



*Figure 20* The 'Object Impact Display' as shown during a preview explanation on what the most optimal driving representation would be shown as.

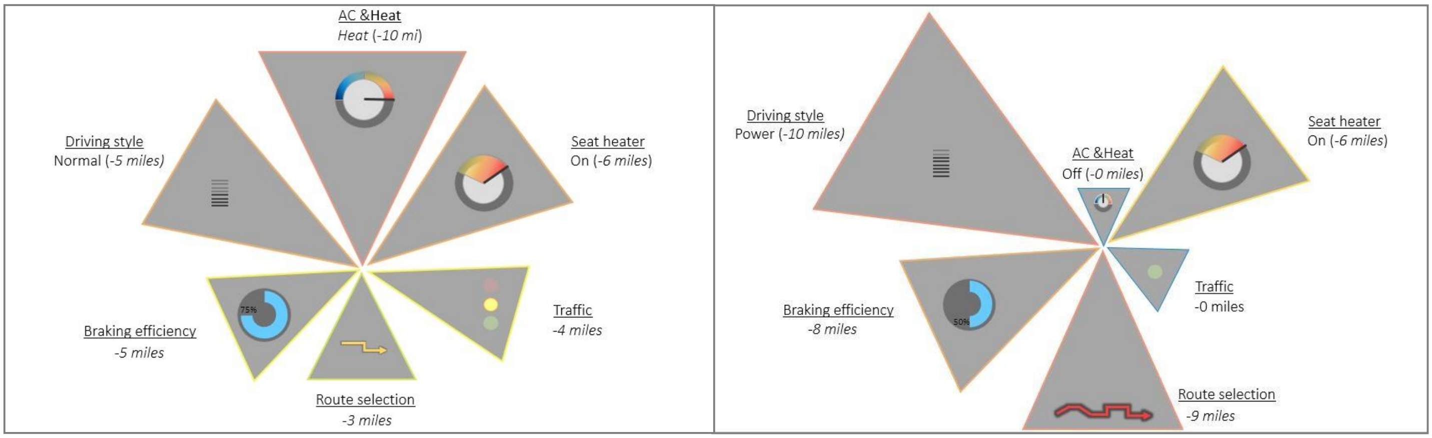



*Figure 21* The 'Object Impact Display' as shown during the driving scenarios – one separate representation for each driving scenario with impacts that match the 'Regular Impact Display'.

Procedure & Protocol

Upon entry to the lab participants signed-in, were given a consent form, and given a briefing of the study's general subject matter along with a description of regenerative braking and EV range/battery context. A one page survey was given asking questions regarding their driving habits and familiarity with electric vehicles. During this initial survey they were given a participant ID that was used to track all of the digital data entries done by the researcher. Following the survey, a technical explanation of newer, smart interfaces in PEVs was outlined again, this time verbally, for the participants to gain some more context without revealing the displays.

For the first 5 minutes participants were able to have a 'free explore' session with the driving simulator in order to familiarize themselves with the steering wheel, pedals, and overall handling of the virtual vehicle. Once they were ready to begin the official task, recording devices were turned on and they were told that the virtual vehicle has a limited range that will not replenish at any time throughout the two driving scenarios. They were told that the simulator will turn off once their range depletes. It was stressed that their primary attention should of course be on the road, but to treat the standard and secondary displays as they would normally their fuel gauge if they only had several gallons left in their vehicle.

Questions regarding 'range sufficiency' and comparisons between the displays were asked via a digital survey immediately following each driving session and will allow for the researcher to prepare for the next task. The participants were asked the same in-task questions during the subsequent driving scenario as well as the same post-driving survey following the second scenario.  After the participant completed all route types and filled the last set of questions, they had several minutes to sit with all of the display designs and fill out questions and comments regarding their preference of design attributes. For more information on the protocol script & flow, see APPENDIX B-F.

## Analysis of Data

This project utilized both quantitative and qualitative data collection tools, but was rooted in a qualitative approach that recognizes the importance of positioning the research within a particular social, cultural, and historical context. Therefore close precision with interpretation of both qualitative feedback and quantitative measures were of utmost concern. The dependent variables are impact comprehension, speed of ranking, error difference, ranking accuracy, dwelling time, attentional ease rating, helpfulness rating, and range awareness affect rating.

# RESULTS

Combined scores *from both driving scenarios* are presented initially below in *tables 4* and *5* and reflect the primary data analysis. Combined scores were prioritized to focus on identifying display type advantages with a larger *power* and to reduce familiarity affects. The tables are divided by the variable context – the first table (4) contains the variables independent from participant feedback or self-reporting, while the second table (*5*) are scores self-rated by the participants themselves. A Repeated Measures ANOVA was run for all variables along with a *t-Test* for redundancy confirmation. To assess any significant interactions when accounting for the familiarity gained between driving scenarios, the Repeated Measures ANOVA was run alongside a *paired t-Test* in order to isolate the influence of the scenario conditions.

Core Performance Measures

The primary analysis includes a total of 52 trials across 26 participants. The core performance measures were four qualitative nominal measures regarding the participant's comprehension of how the display was communicating range impact.

*Core Performance Measures*

| | Impact Error | Dwelling time | Ranking Accuracy | Ranking Speed |
|---|---|---|---|---|
| Regular | .48 | 3 sec. | .55 | 10.2 sec. |
| Object | .21 | 2.8 sec. | .8 | 8 sec. |

*Table 4* Quantitative data reflecting average participant score for the dependent values of a) Top impact identification error, b) Avg. dwelling time, C) Accuracy of impact ranking, and D) Speed of ranking impacts. All results above are averages with combined data from both driving scenarios.

*Impact Correctness and Ranking Accuracy* both reflect how well the participants comprehended the ability of the display in regards to communicating which attribute or peripheral of their vehicle was impacting their available range in miles the most, along with how subsequent impacts relate. There was a clear advantage from the Object Display in communicating top impact: For the Regular display, 25 out of the 52 driving sessions the participant guessed the incorrect top impact while regular display was shown, which translates to an error rate of 48%. However, when the Object Display was shown 11 out of 52 responses were incorrect, an error rate of 21%. *Ranking Accuracy* was a percentage of how many ranked positions the participant got correct when answering which attribute affected their available range in miles, from least to most. There were six attributes to rank and participant's rankings were scored x/6 depending on which attributes they rated in the correct spot. Display type had a statistically significant effect on '*Ranking Accuracy*' for the impact of the various attributes, F(1,

50) = 15.53, p < .05. As *table 4* reflects, the Regular Display produced a 55% ranking accuracy while the Object Display was met with an 80% accuracy average.

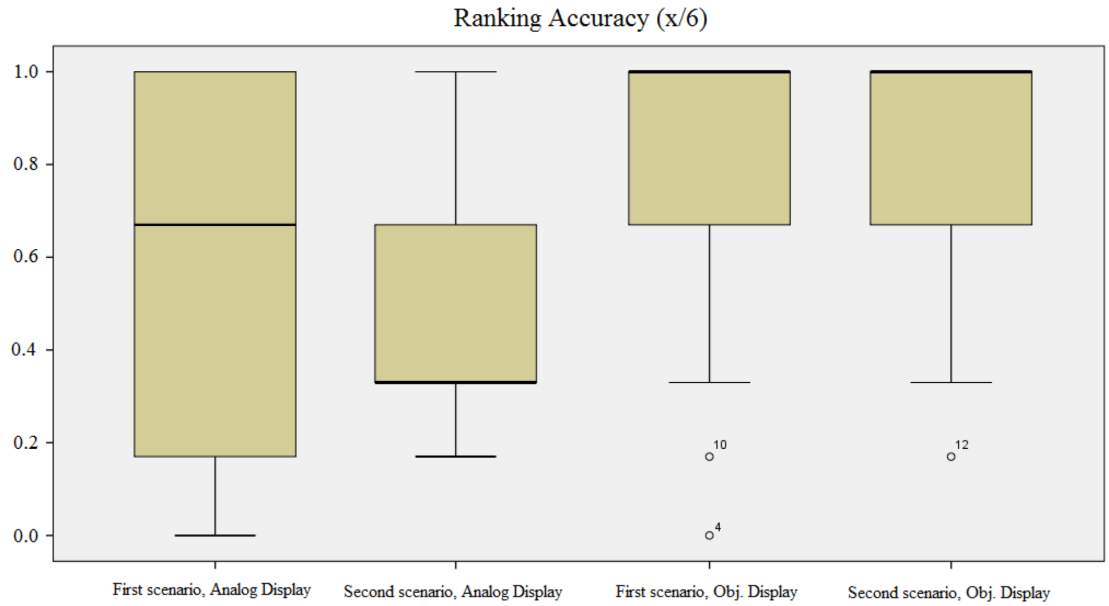



*Figure 22* Ranking accuracy, split according to the driving scenario and display type. Ranking accuracy dropped in the second scenario with the analog display, despite familiarity and assumptions of a learning curve. Ranking accuracy held constant across both scenarios for the object display with three outliers below 33%.

The time to produce the ranking was calculated as well, regardless of correctness or not. The timer began as soon as the researcher finished the question and ended when the last rank was given by the participant.

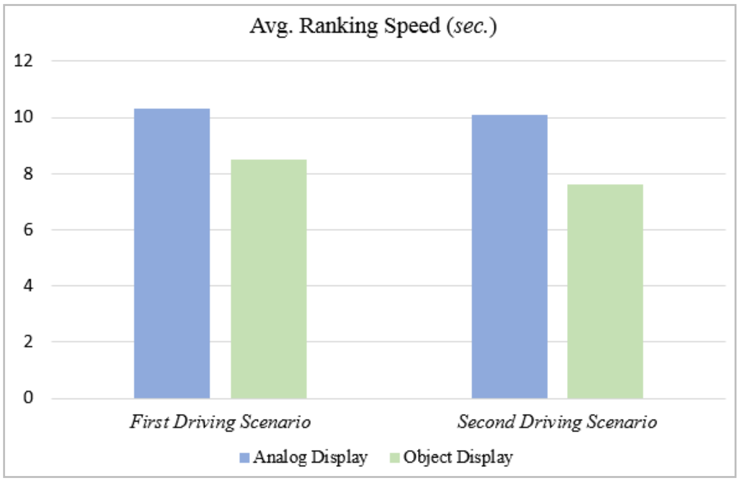



*Figure 23 Average* speed of ranking was consistently slower for the Analog Display. There was a slight reduction in the speed to rank all of the attributes as participants became more familiar with the Object Display.

Display type had a statistically significant effect on '*Speed of Ranking*' for ranking the attributes impact from least to greatest, $F(1, 50) = 49.685$, $p < .05$. Participants, on average, ranked the Regular Display attributes 2.2 seconds slower than the Object Display attributes.

*Dwelling Time* was not found to be statistically significant, $F(1, 50) = .91$, $p = .34$, when combined across driving scenarios, however it was statistically significant when isolating the second driving task, $F(1, 25) = 24$, $p < .05$. This is deliberated further in the discussion section.

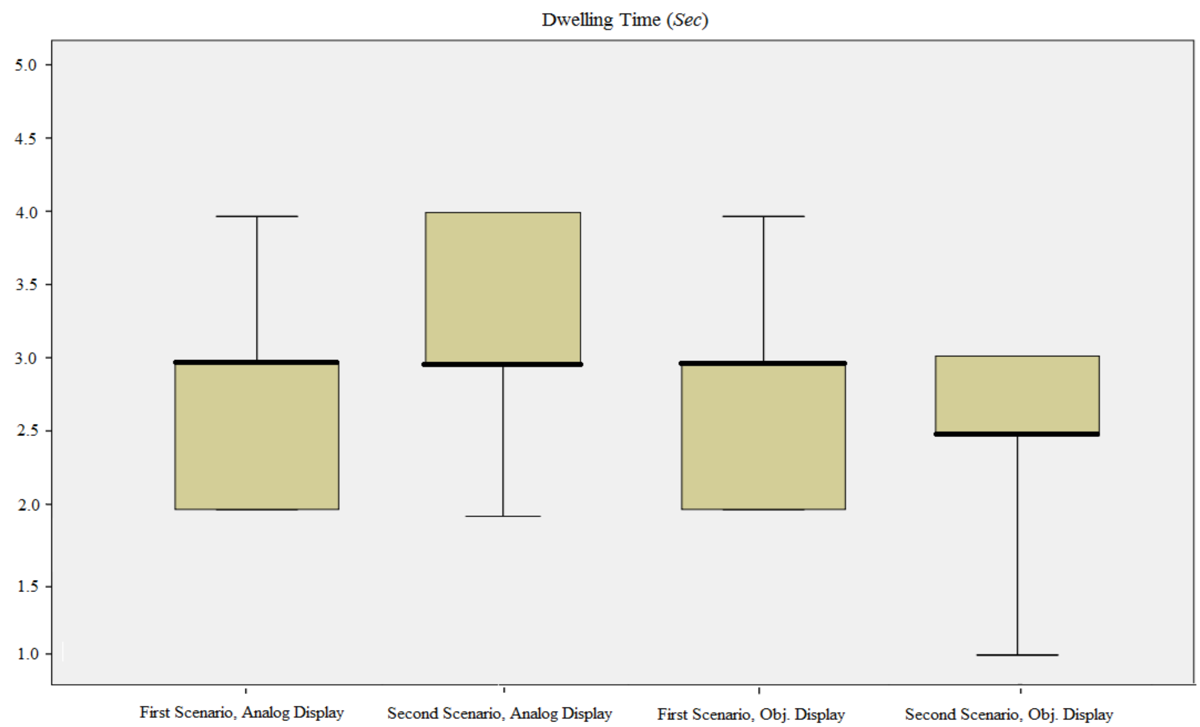



*Figure 24* Dwelling time held pretty constant regardless of the display type, though the slight dip in the second scenario average for the Object Display may imply a quick learning curve in noticing the emergent feature and increased comprehension.

## Self-Reported Rating of Displays

Self-reported ratings were verbally given by the participants on 7-point Likert scales according to their own assessment. All scales were anchored negatively on the minimum 1-value and positively at the maximum 7-value.

Combined Scenario Scores

| *Ratings are x/7* | Attentional load | Awareness | Helpfulness |
|---|---|---|---|
| Regular | 3.5 | 4.2 | 4 |
| Object | 4.5 | 3.3 | 4.9 |

*Table 5* Quantitative data reflecting average participant self- response for the dependent values of a) Attentional load, b) Range awareness, and C) Helpfulness of display communication. All results above are averages with combined data from both driving scenarios.

Prompted by the researcher, participants gave their feedback on the *difficulty of splitting their attention* between the road and the secondary displays, how much the secondary displays increased their *range awareness*, and how *helpful* the secondary displays were in regards to communicating the impacted range.

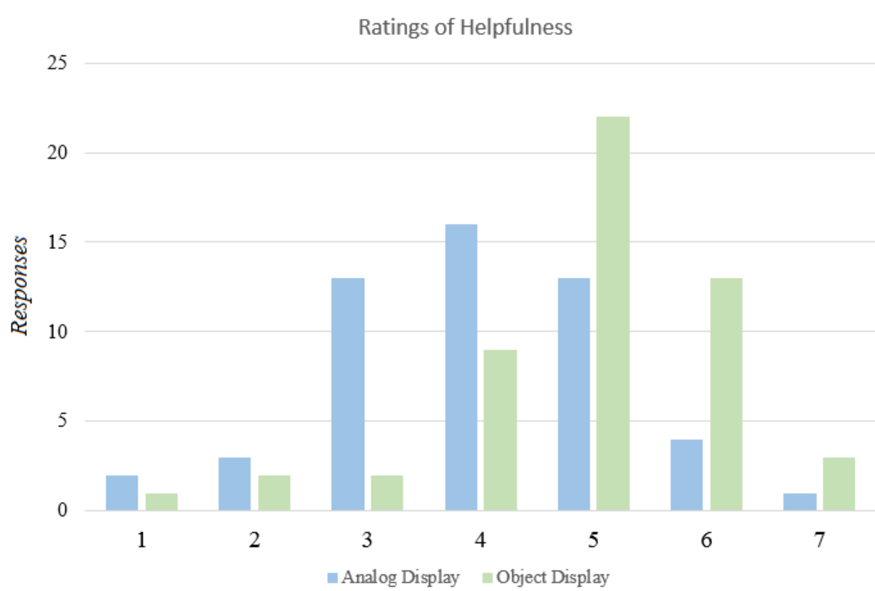



*Figure 25* While the Object Display did not necessarily raise the participant's awareness of overall range limitations or how driving differed in an electric vehicle, the Object Display still maintened a greater helpfulness in the ability to communicate attribute impact.

On the matter of *attentional load*, there was a statistically significant effect on participant ratings of their ease of splitting attention, $F(1, 50) = 20.27$, $p < .05$. It is assumed that a high level of participant doubt regarding the impact comparison lead to the need for a closer examination of the regular display, and thus higher attentional demand. Despite the Object display being a novel concept for the participants, the exaggeration and focus on the emergent features limited the need for any closer inspection across the six impacts. This paradigm correlates well with the interaction of driving scenario and dwelling time, which will be discussed further in the discussion section.

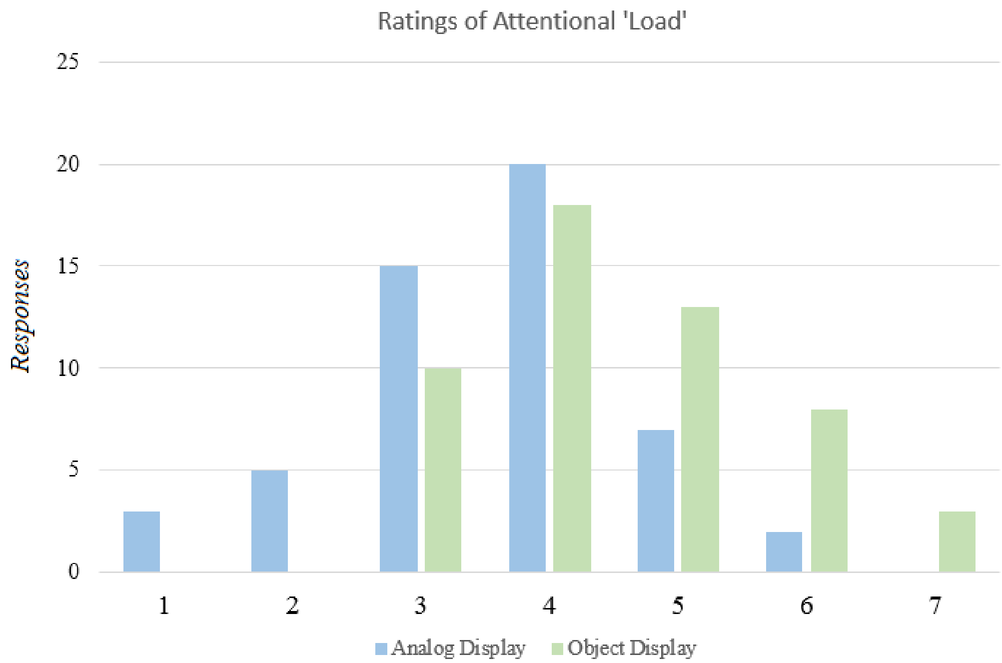



*Figure 25* Participants rated how difficult it was to split their attention between the simulator road and the display. There was some overlap, but a clear trend towards the Object Display carrying slightly less of an attentional load.

Although splitting attention and identifying the comparable impacts was easier and quicker with the Object display, the Regular display had an overall higher rating for its ability to raise range awareness. Once again, it is presumed that this may be due to the Regular display requiring a closer examination and thus the overall sentiment that more specific range evaluations were being communicated by that display type. Regardless, Display type had a statistically significant effect on ratings of effectiveness of the displays towards raising range awareness, $F(1, 50) = 9.51$, $p < .05$. When the self-reported probe was framed as *helpfulness* however, there was a statistically significant effect on ratings of helpfulness in regards to communicating energy usage, $F(1, 50) = 14.35$, $p < .05$ in favor of the Object display. This can be tied to the nature and objective of the study – the participants were primed towards the objective of isolating and determining the top impact, to which they would justifiably approach *helpfulness* in terms of which display helped them achieve this objective best. The limitations of these self-reported ratings is discussed further in the discussion sections along with their implications for further study.

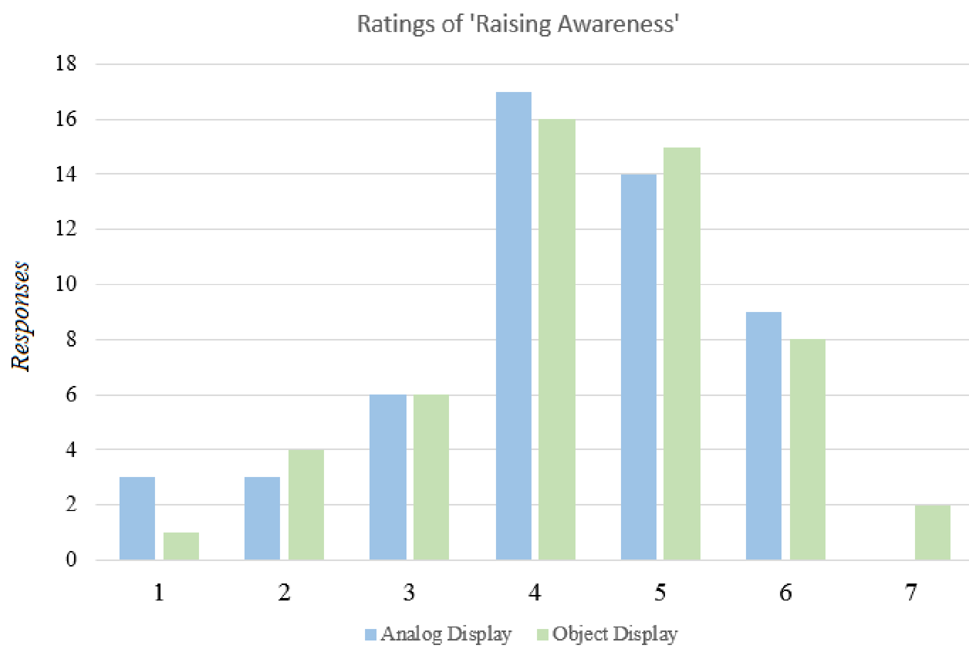



*Figure 26* Almost identical ratings were given for the ability of the displays towards raising the participant's awareness in overall range communication and range limitations.

## Interaction across Driving Scenarios

With the decision to run a within-subject design for the driving scenario and display type variables, the primary analysis was with combined scores using a total of 52 trials across 26 participants. However, the research was still concerned with what effect increased exposure across time and among increased driving comfort may have had on the impression of the two display types. For this interaction, a two-tailed paired *t*-test was conducted to measure difference between the correlated measures. Below in *Table* 6 are the group means for three of the researcher measured scores split between the first and second driving scenarios.

| | *Scenario* | Dwelling time | Ranking Accuracy | Ranking Speed |
|---|---|---|---|---|
| Regular | *First* | 2.9 sec | .64 | 10.3 sec |
| | *Second* | 3.1 sec | .47 | 10.1 sec |
| Object | *First* | 2.9 | .76 | 8.5 sec |
| | *Second* | 2.2 | .84 | 7.6 sec |

*Table 6* The group means for the quantitative display scores of a) Dwelling time, b) Ranking accuracy, and c) Ranking speed.

There was not a significant difference in the *Ranking accuracy* scores for the Regular display across driving scenario 1 (M=.64, SD=.38) and driving scenario 2 (M=.47, SD=.32); t(50)=1.34, p = .19 in spite of such a large group means difference, the within group variance of the regular display was quite large.


*Figure 27* Despite a lack of significance, the focus on emergent features isolate the valuable material whereas numerical identification in the analog display introduces potential distractor information. The Object Display showed great promise in increasing the ability to rank range impact attributes.

For the Object display, There was not a significant difference in the scores across driving scenario 1 (M=.76, SD=.32) and driving scenario 2 (M=.84, SD=.23); t(50)=.99, p = .32. However, it is noticeable in this regard that the Object display had far less within-group variance and was trending towards and increased accuracy whereas the Regular display decreased in accuracy further into the driving scenario.

*Ranking speed* held incredibly constant for the Regular display across both scenarios, with only a .2 second avg. difference. In one of the more significant inferential findings, *ranking speed* for the Object display had a significant difference in the scores across driving scenario 1 (M=8.5, SD=1.2) and driving scenario 2 (M=7.6, SD=1.5); t(50)=2.25, p < .05. The incredibly similar variance within the Object display scenarios may certainly be attributed to a similar dwelling pattern noticed by the researcher. This ultimately led to a consistent shortening of dwelling time needed when assessing the impacts once a familiarity was gained with the display type. The learnability implication of shaved seconds between driving scenarios along with the overall *ranking speed* difference between the Regular display and the Object display shows hopeful promise for this type of display in the impact comparison context. For *dwelling time*, although the second driving scenario impacts were clearly difficult for participants to compare via the Regular display looking at multiple measurements, for the Object display the *dwelling time* also decreased whereas there was actually an increase for the Regular display. *Dwelling time* saw a significant difference in the scores across driving scenario 1 (M=2.9, SD=.8) and driving scenario 2 (M=2.2, SD=.6); t(50)=3, p < .05, which was once again supported by a very tightly consistent within-group variance across both driving scenarios.

Thoughts from the crowd

In order to continue the participant design atmosphere, the session concluded with the opportunity for direct qualitative feedback from the novice participants. They were asked about which attributes were vital pieces of information vs. attributes that seemed useless – this difference seemed to be more personally preferential with answers across the board. However, when asked which display overall was more helpful, here are some of the responses that represent the overarching sentiment (Display 2 was the number given to the Object display, regardless of order presented):

*“I liked the second display [Object Display] because it was graphically easier to overview. With the flower-form, it was easy to see what I could change the most to save energy. The first display was more difficult to understand and overview while driving.”*

*“Display 2 [Object Display] using different sized triangles helped to see which thing was impacting my mileage the most”*

*“I liked the graphic design of display 2 [Object Display] - it made it easy to read and understand my ‘dashboard’.”*

*“The images and shapes on the display 2 [Object Display] design rather than having to look at specific numbers”*

*“When they were closer together in display 2 [Object Display] and divided up into sections my eyes could find the answers easier and the information quicker.”*

*“For display 2 [Object Display], it was easier for the eye to catch as everything was bunched up into a single focus, rather than the other display where everything was spread out, making me spend more time trying to look at each individual attribute.”*

*“The parts that got bigger were helpful in display 2 [Object Display].”*

*“Display 2 [Object Display] was easy to read because it was visually increasing. The triangles were easy to understand.”*

*“Display 2 [Object Display] was best because your eyes were centered in one spot and not searching all over a big area”*

*“The quick glance was much easier to read on the flower designed display [2] [Object Display] because the shapes were easier to visualize very quickly.”*

*“Display 2 [Object Display] was helpful because it had the visual with the different sized triangles which corresponded to the amount of energy used.”*

# DISCUSSION

The set of dependent measures and the performance findings utilized allow the researcher to reject H0; there was clearly a difference in comprehension between the two display types. Similarly, speed of ranking and the ranking impact accuracy are the two most glaring differences between the effects of using the Object display. There is still room for interpretation as to how much insight the self-reported measures can actually help us learn to assess driver reaction to this new interface paradigm. For the hypothesis of an interaction between driving scenarios, the results do seem to imply a quick learning curve for the Object Display while comprehension of the Analog display is stagnant and independent of familiarity.

Remarkably, this was one of the first public research studies to test an object display within the PEV, limited range driving context. Understanding of how this study can be positioned in the volumes of vehicle interface research precedes any conclusion of significant impact. No one single interface design change or research finding is going to shake the foundation of vehicle safety research; which is why it is of even greater importance to support electric vehicle performance research before the industry sprints forward with new developments to capture market share and allure. Regardless of where the manufacturing and marketing decisions of current PEV distributers proceed, this study was a first step-in-the door comparative and causal analysis of an object display and its efficacy in ordinal impact evaluations in a driving context.

The findings support previous work that identified “Anxiety[‘s] negative effect on processing efficiency, as indicated by the longer dart times, lower response rates on the secondary task, increases in invested mental and physical effort, and changes in gaze behavior with anxiety. Finally, the dual task resulted in a greater investment of mental effort" (Nibbeling, p. 432, 2012). With an undeniable trend in manufacturer's inclusion of multiple screens, performance transparency, driving modes, and emphasis on fuel efficiency within the vehicle cockpit space, there is no doubt that this study and further studies of its kind offer value to driving safety research. Any move taken to reduce the mental load during multi-lateral processing will reduce the learning curve for young drivers and new EV drivers. Using graphs and simplistic emergent features "has also been verified by recent studies of process control graphics (Buttigieg & Sanderson, 1991) and statistical graphics" (Carswell, p. 12, 1996).

Carrying out ethnographic interviews earlier in the research and development phase allowed for creation from a cleaner slate and provided advantages in the ability to design for current 'elite' users and novice users alike.This step in the research process cannot be overstated enough. The creation of a believable display, formed from existing frameworks of knowledge is supported by previous work as well, which "showed that a display that incorporated reference frames enabled anesthesiologists to perform a task more accurately…subjects were able to perform better with the ecological displays compared with the alpha-numeric display due to the presence of boundary information indicating normal ranges of parameters" (Watcher, p. 366, 2003). The ability to mold the display upon contextual use- patterns supports "a temporal scanning pattern" in which drivers can engage in "directly compensating for the type of separation with which they have been presented" (Burns, p.127, 1997).

The analysis of these results were assessed via an objective oriented perspective – impact comparison, attentional load, and speed of ranking were identified as a trifecta priority for examining novice learnability and error reduction likelihood.  First and foremost, the clear increase in top impact identification accuracy is over-simplistic yet also key to understanding user needs. The 27% error rate difference (48% to 21%) between the Regular and Object display is not any implication that such an error may lead to a dead battery prior to charging, so much as it is implied that the more difficult it is to identify the largest impact, the higher the increase will be for attentional load when the driver may be motivated towards extra gazing instances at the display (double-checking effect). Despite the end-measures being communicated as quantitative findings, there is a deep abstraction at play when “self-regulation temporarily diminishes the amount of strength or energy available for subsequent acts of self-regulation” (Oertig, p. 366, 2012). During the experiment sessions, participants were clearly reacting to the Object Display as a new paradigm, as expected, and the dependent variable measures aimed to strip away at any need to worry about the previous experience brought to the study via existing driving behaviors. The data from the pre-survey collections confirms the assumption that, among those tested, there was no correlation between driving attitudes and the performance results.

The overall accuracy of ranking the impacts along with the speed of this ranking highlight the potential for improvement and learnability of object displays. Rapidly improving battery technology and the increasing use of low-energy peripherals may, in the future, marginalize this transparent impact use-case, however there will always be room for ways to mitigate attentional load when imposing any sort of ordinal comparison or energy feedback analysis on the operator of a vehicle. Similar “benefits previously obtained with heterogeneous displays for nonmetric multicue probability judgments…gives credence to the idea that proximity advantages have multiple determinants.” (Carswell, p. 17, 1996).

The ability to quickly rank six separate peripherals was done accurately at a much higher percentage with an Object display than the Regular, analog type display. Furthermore, as the novelty effect of the Object display wore off the speed of this ranking improved greatly when presented with the object display. In fact, it is assumed that most of the delay in ranking the impact through the Object display were mostly due to impact assignment rather than actually assessing the differences between the impact amounts. While the salience of the emergent features in the Object Display seemed to meet an acceptable threshold, “the lower-level codes of the object displays used in many studies may simply be less discriminable or salient than those used for the separable displays with which they are compared” (Bennet, 1992). The findings of this research, at the very least, demonstrate a sound execution of an Object Display in a driving scenario for which this is clearly significant performance differences due to the design elements themselves.

Utilizing conventional icons and a more appropriate stylistic contrast could further the speed of ranking even further, whereas for the Regular display the minimum ranking speed will always be impeded by nature of the display arrangement into segregated components and relying on numerical identification, rather than geometric identification.

The learnability of the Object display shows great promise, and it is further inferred that the only reason for the non-significant dwelling time difference for the first driving scenario is due to the appeal of such a new display type for the younger, more novice drivers. Despite the departure from conventional interface familiarity, the Object display was self-rated by the participant sample as maintaining easier attentional splitting and as more helpful towards the objective. The higher rating score towards *raising range awareness* was likely due to the framing of the objective as well as the instinctual need to assess the impact amounts when assessing the impact differences, whereas for the Object display the participants began relying on the emergent features of the triangular display rather than calculating via the impact amounts.

Limitations & Constraints

There are important limitations for what can be inferred from this study, mostly that “the subject's actions could be expected to be directed towards diagnosing the fault, and no longer demonstrating general monitoring behavior” (Burns, p. 119, 2000). While there is no doubt that an object display offers several benefits in ordinal comparisons, this study was limited via the nature of its methodology, fidelity of the designs, and the participant sample. The methodology, a within-subjects 2x2 design was chosen largely to maximize participant exposure for *both* designs and for ease of recruitment time and cost. It is unknown what causal effects would be brought out by conducting a between-subjects design focused more on performance comparison across two groups of participants. Similarly, the actual driving performance was completely ignored in this study, due to the costs and development time of a dependable driving simulator which would sync properly with actually transmitting vehicle feedback to a secondary display. Unfortunately, due to the restrictions in using a driving simulator, it is true that the typical self-regulation implicit in driving a vehicle was not fully present. However, this goes both ways in the sense that experienced EV drivers also learn very quickly how to mitigate any mathematical calculations needed to ascertain behavior benefits. Slower speed, stable acceleration, and peripherals set to ‘OFF’ is an easier to learn approach than assessing numerical impact across all energy costing attributes.

The stimulus design and driving simulator selection was largely driven by time and costs, as well as technical feasibility. As for the sample itself, novice drivers with no PEV experience was the target for the sample and was easily recruited, however it is completely unknown how a more diverse, experienced driver sample would react to such a newer display type. As for the statistical analysis itself, one must use caution when drawing from self-reported measures (*attentional load, helpfulness, and awareness*) however there is litte reason to doubt the internal validity of the dependent variables and their usage considering the objective of the study. The skewing of the accuracy score, however, may very well be due to an accuracy score truncated from a range of only x/6, leading to a wide distribution between .0 to 1.0. This research certainly paves the way for further research investigating the use of an Object display in a driving context.

## Further Research

The slightly understated conclusion from these results is that, while the Object Display supported the monitoring of impact thresholds better, the traditional numerical approach of the Analog Display may teach drivers more about peripheral impact on energy consumption. This is especially true once you move towards the acceptance that driving simulator studies are inherently limited in their contextual scheme, given the complicated nature of driving a vehicle. The intuitiveness of this Object Display design may change when the image is animated with real-time data, while the testing described in this report used static images using power-point, and the impact values were only changed between driving scenarios.

Before the contextual scheme is elevated to a more realistic driving simulator and ultimately tested in a moving vehicle, further research is needed at raising the fidelity and feedback mechanism of the display concept itself. An experiment using a live Object Display that changes incrementally at a much frequent rate is crucial to supporting the credibility of these findings.

As was pointed out by Burns, “One of the most interesting aspects of this research is that it shows clearly how people adapt to different display environments. Different displays do more than support user performance, but they have an impact on how those users approach their work”

(2000). The research findings do not change the fact that once activated, the nature of this display may be very different when given moving parts. For instance, the changing shape of emergent features may be too distracting compared to numerical counters or analog dials. The majority of vehicle interface features that move to market must undergo vigorous cost-analysis benefits of distraction and added value. Therefore, a well thought-out study testing the distraction potential of a moving Object Display will determine movement forward for this type of paradigm.

## CONCLUSION

Public research moves slower than recent advances in consumer technology. It is only fitting that while the primary researcher may be hesitant to conclude any industry changes or significant suppositions from this body of work, at the same time manufacturers and designers have already gone full speed-ahead with newer designs in an effort to compete and differentiate from the competition. It is therefore an obligation to point out the clear areas that any sort of shift in display paradigms may be advantageous. Combining the ethnographic feedback and the participant results, it is clear that the current display standards, while following their own conventions and antiquated standards, leave room for improvement.

The Object display accomplished the objective of impact identification and ranking speed significantly better than participants could with the Regular analogy type display. It is not so far off that the same sort of display that has been tested and used in power plants and other industrial factories could be used to an advantage in vehicle displays. Considering the phenomenon of Range Anxiety, any easy access to transparency can almost always make a driver feel more in control, and therefore more comfortable with the operation of a limited range vehicle.

Using an object display with embellished, clearly-affected emergent features when energy or performance feedback veers away from the baseline, while implying any sort of comparison, would increase the accuracy of such comparisons while also speeding up the potential ranking of the parameters. Potential areas of use include on-board GPS maps when displaying potential routes or even when pushing certain driving mode options to a technically oblivious vehicle operator. The error rate variance across the two display types along with the speed of ranking significance are not to be overlooked, especially when error frequency and seconds of distraction can mean the difference of life or death while operating a vehicle when that specific error leads to distraction.

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# APPENDIX

## i. IRB Approval

SAN JOSÉ STATE UNIVERSITY

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To: Aaron Ackerman

From: Pamela Stacks, Ph.D.
Associate Vice President
Graduate Studies and Research

Pamela C Stacks

Date: February 19, 2014

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"Range anxiety in electric vehicles: Live feedback of battery consumption"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the confidentiality of the subjects' identity when they participate in your research project, and with regard to all data that may be collected from the subjects. The approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Dr. Pamela Stacks, Ph.D. immediately. Injury includes but is not limited to bodily harm, psychological trauma, and release of potentially damaging personal information. This approval for the human subject's portion of your project is in effect for one year, and data collection beyond February 19, 2015 requires an extension request.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services that the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2427.

Protocol # S1402017

cc. Anthony Andre 0085

A. Interview questions for EV owners

1. What is your current electric vehicle that you own or drive regularly?

2. How long have you owned your electric vehicle?

3. What were the main factors in adopting an electric vehicle rather than continuing with a gas vehicle?

4. How many miles do you drive your PEV per day?

5. What is your total ‘average’ vehicle range, fully charged -> 0%?

6. Do you typically charge your vehicle more at home, work, or while doing errands?

7. How often do you find yourself worrying about running out of ‘juice’ while driving?

8. At what threshold of remaining range do you typically find yourself worrying about finding a charging spot?

9. Tell me about your vehicle’s existing interface design….

10. What information does your dashboard tell you that is different from previous gas vehicles you have driven?

11. How does your interface show energy consumption information?

12. Does your interface let you know about any energy usage separate from acceleration related consumption?

13. Does your interface show you any long term vs. short term information?

14. What information do you feel impacts your driving behavior most?

15. What aspect is most helpful in alerting you to energy consumption and charging importance?

16. Is there information you wish your car notified you about?

17. While driving, do you think of fuel consumption in terms of range, cost of charge, or efficiency more?

18. Have you noticed any change in your driving style since switching from a gas vehicle to electric?

B. Consent Form

Agreement to Participate in Research
Responsible Investigator(s): Aaron Ackerman, San Jose State University Graduate Student
Title of Study: Range Anxiety in Electric Vehicles

You have been asked to participate in a research study investigating vehicle interfaces.

1. You will be videotaped and recording devices will be taped to your skin on the trapezius muscle to record muscle activity. If there is excessive hair at these sites, it may be shaved with a new disposable razor. You will be asked to perform some brief maximal muscular contractions to calibrate the measurements from the EMG device. You will be asked to perform tasks on a driving simulator with the presence of a new interface. The research session will take approximately 1 hour.
2. Potential risks due to participation in this research study include cuts to your skin from shaving and/or muscular strain do to steering wheel/pedal operation.
3. While there are no direct benefits to participating in this research study, this research will contribute to the general understanding of vehicle interface design.
4. Although the results of this study may be published, no information that could identify you will be included. All individualized data collected during the research study will be stored in a password protected account accessible only to the primary investigator. All video images of you will deleted upon completion of the data analysis. No video images of you will be published nor disseminated.
5. Compensation for participating in this research study will be provided by the Principle Investigator in the form of an Amazon gift card.
6. Questions about this research may be addressed to Aaron Ackerman at aaron.ackerman@ymail.com. Complaints about this research may be presented to Dr. Louis Freund, Director, Graduate Program in Human Factors and Ergonomics, Department of Industrial and Systems Engineering, San Jose State University, at (408) 924-3890. Questions about a research subject's rights or research-related injury may be presented to Pamela Stacks, Ph.D., Associate Vice President, Graduate Studies and Research, at (408) 924-2427.
7. No service of any kind, to which you are otherwise entitled, will be lost or jeopardized if you choose not to participate in the study.
8. Your consent is being given voluntarily. You may refuse to participate in the entire study or in any part of the study. You have the right to not answer questions you do not wish to answer. If you decide to participate in the study, you are free to withdraw at any time without any negative effect on your relations with San Jose State University.
9. At the time that you sign this consent form, you will receive a copy of it for your records, signed and dated by the investigator.

- The signature of a subject on this document indicates agreement to participate in the study.
- The signature of a researcher on this document indicates agreement to include the above named subject in the research and attestation that the subject has been fully informed of his or her rights.

________________________________________________________

Participant's Signature Date

________________________________________________________

Investigator's Signature Date

C. Briefing

"Newer electric vehicles that run on an electric battery with no gas have limited range. On a full charge, they may get between 30 miles to 180 miles before needing to be plugged in and recharged. One of the ways of extending vehicle range is through smart interfaces that show drivers how much energy they are using and what they can do to control their consumption. You will be using a driving simulator and an energy consumption interface will be shown to you while operating the simulator."

D. Pre-Survey

1. Please rate your familiarity with plug-in electric vehicles, battery technology and charging

1-------------2-------------3-------------4-------------5-------------6-------------7

Completely Unfamiliar    Read about it    very interested    Highly involved

2. Please rate your ability to plan logistics, routes, or other driving related activities

1-------------2-------------3-------------4-------------5-------------6-------------7

Dependent on tech/others    amateur at best    fairly competent    Expert

3. Do you own an electric vehicle?
☐Yes
☐No

Check all that apply
- ☐Nissan Leaf
- ☐Smart Car
- ☐Fiat
- ☐Scion
- ☐Chevy Spark
- ☐Ford Focus EV
- ☐Honda Fit EV
- ☐Tesla Model S
- ☐Other: ______________________

3b. What is the maximum range of your electric vehicle before needing a recharge?

__________________________________________________

4. Does your ability to plan change when tasked with high stress problems?

☐ Yes ☐ No

If yes, please explain:

______________________________________________________________________

______________________________________________________________________

______

5. How would you characterize your driving attitude? (Choose at least 3)

| | | | |
|---|---|---|---|
| ] Relaxed | ☐ Aware | ☐ [illegible] | ☐ Alert |
| ] Angry | ☐ Cruising | ☐ [illegible] | ☐ Happy |
| ] Joyful | ☐ Defensive | ☐ [illegible] | ☐ Aggressive |
| ] Peaceful | ☐ Stressed | ☐ Precise | ☐ Thoughtful |

6. How many miles do you drive in a typical day?

____________________________________________________________

7. How does your driving style change when in heavy traffic?

____________________________________________________________

8. What is your necessary atmosphere level when you plan your daily tasks?

1--------------2--------------3--------------4--------------5--------------6--------------7

| quiet and completely focused | low music/chatter accepted | Loud music, heavy talking okay |
|---|---|---|

E. <u>In-task Questions</u>

1. Based on the secondary display what driving or car parameter should you change to have the greatest impact on increasing your range?"
Were they correct?

- ○ Correct
- ○ Wrong

2. (Miles impact difference from most valuable <-> their answer)

3. Please rank the attributes of your vehicle, from least to greatest, on their impact of your available range in miles

4. How would you rate the helpfulness of the secondary display in terms of communicating the your energy usage? 1 - very unhelpful and 7 - very helpful?

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Very unhelpful | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Very helpful |

5. How would you rate the ease of splitting your attention between the the road and the secondary display? 1-7, 1 being very difficult and 7 being very easy?

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Very difficult | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Very easy |

6. How would you rate this secondary display in terms of raising your range awareness? 1 being very ineffective and 7 being very effective?

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Very ineffective | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Very effective |

7. Without taking your eyes off the road, what is the estimated range left on your vehicle?
(input difference)

F. Between Scenario Questions

1. What is your confidence level in an energy impact display's ability to relieve any stress related to range anxiety?

- Very doubtful
- Doubtful
- Neutral
- Confident
- Very confident

2. How frequently did you check your battery percentage or worry about your remaining range during the driving session?

- Not at all
- Rarely
- Sometimes
- Frequently
- Constantly

3. Was there any noticeable difference in your driving style due to having limited range?

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| No change | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Significant Change |

4. Would a limited range vehicle be sufficient for your typical daily commute?

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Absolutely Not | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Definitely Yes |

5. In regards to display 1, how would you rate its helpfulness compared to the standard display?

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Very worthless | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Very valuable |

6. In regards to the display 2, how would you rate its helpfulness compared to the standard display?

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Very worthless | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Very valuable |

7. Which specific parts of any of the display designs were most helpful?

8. Which specific parts of any of the display designs contained vital information?

9. Which specific parts of any of the display designs do you feel were useless?

10. Which specific parts of any of the display designs do you feel were unclear?