# USABILITY EVALUATION OF FUEL GAUGES FOR HYBRID ELECTRIC VEHICLES

A THESIS
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BY

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# Dedication

I dedicate this thesis to my mother and to nana, without whose love and encouragement I would not be here today.

# Abstract

This thesis describes a usability study designed to increase an automotive designer's understanding of how to design effective dual-fuel gauges for hybrid vehicles. Hybrid Electric Vehicles (HEVs) aim at reducing dependency on gasoline. While gasoline has one primary source, which is non-renewable, electricity comes from renewable as well as non-renewable sources of energy. As we begin to generate electricity more efficiently from newer power plants that are built using renewable energy, it is important that drivers of HEVs begin to reduce their dependency on gasoline and rely more on electricity for operating their vehicles. Hybrid fuel gauges have a role to play in the overall user experience and adoption of HEVs. When purchasing a car, people take into consideration how the instrument panel looks and how understandable it is (Green, 1984). Therefore, it is important that these gauges are effective in providing information on fuel levels so that it can be read quickly and accurately.

The goal of this work was to identify a class of gauges that support quick and accurate reading so that the driver can understand when to recharge the electric battery or refill the gas tank for efficient trip planning. A set of thirty-three hybrid gauge designs created by designers at General Motors was provided to the University of Minnesota team. The UMN team created four new gauge designs that were different from the ones created by the General Motors.  These were reduced to a set of nine gauges by the process of heuristic evaluation. A two-part usability study was conducted with sixty drivers. In the first part, drivers participated in a timed comprehension task in which they were made to view certain gauges and answer questions on them. This was followed by a subjective questionnaire in which participants were asked about their preferences for various gauges.

Vertically oriented bar gauges were found to be most effective. They elicited the highest accuracy rates and lowest response times compared to horizontally oriented bar gauges and circular gauges. Participants were able to process information in relative form (expressed in graphical or pictorial form) more easily and accurately than information in absolute form (expressed in numeric form). Familiar types of gauges, which appeal to participants, do not always contribute to better performance. Introducing new types of gauges requires more upfront marketing of their benefits (such as higher reading accuracy and speed).

A set of recommendations has been created for automotive designers on how to create effective hybrid fuel gauges. These recommendations are important in driving standardization of hybrid fuel gauges to help deliver a consistent user experience and to minimize confusion and user frustration. These gauges encourage fuel-efficient behavior by helping drivers reduce their dependency on gasoline, thereby reducing pollution from carbon dioxide emissions and ultimately resulting in a cleaner environment.

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# 1. Introduction

The goal of this thesis is to identify a class of hybrid fuel gauges that can be read accurately and quickly. Sixty drivers participated in a usability study that involved using a variety of hybrid fuel gauge designs and answering questions about fuel and mileage. In a dynamic environment such as that inside a moving vehicle, the accuracy and speed of reading vehicle related information is of prime importance. In Hybrid Electric Vehicles (HEVs) drivers must be able to accurately comprehend information related to the two energy sources. This allows drivers to plan trips more efficiently and reduce their dependency on gasoline for the operation of their vehicles.

More and more HEVs are being developed and brought to market with the end goal of reducing dependency on gasoline as a fuel source. The operation of hybrid vehicles is more complicated than that of conventional vehicles because of the introduction of a second fuel source. A clear understanding of how HEVs function can enable drivers to plan their trips so that they can rely more on the electric battery and less on gasoline. For those drivers who wish to operate their vehicles mostly on the electric battery, it becomes important for them to know exactly how far they can travel on the battery and when they need to recharge it. Well-designed fuel gauges that can be read easily and accurately, enable drivers to make well-informed decisions on trip planning.

A majority of the energy produced in the United States comes from non-renewable sources. According to the United States Energy Administration, in 2013, 87% of the electricity generated came from non-renewable sources such as coal, natural gas etc. However, as newer power plants are built using renewable energy sources like hydroelectric, biomass, geothermal, wind and solar, the generation of electricity will become more efficient.  While gasoline has one primary source, electricity comes from many sources, some non-renewable and some renewable. By driving HEVs today drivers are already reducing their dependency on gasoline.

According to the United States Department of Energy, each gallon of gasoline burnt creates twenty pounds of carbon dioxide ($CO_2$). An estimated 1.5 billion metric tons of greenhouse gases (GHGs) mostly in the form of carbon dioxide are released into the atmosphere annually. GHGs such as water vapor ($H_2O$), carbon dioxide ($CO_2$) and methane ($CH_4$) prevent or slow the loss of heat into space by absorbing or trapping energy. They make the Earth much warmer than it would otherwise be without the emission of GHGs. According to the United States Environmental Protection Agency, this has resulted in the "greenhouse effect" which is contributing to global climate change. Thus although their impact is limited today because we rely heavily on non-renewable energy sources and fossil fuels for the production of electricity, HEVs have the potential to have a tremendous impact on the environment in the future once the generation of electricity becomes more efficient.

A considerable amount of research has been conducted in the aviation and instrumentation industries to determine which types of gauges are optimal for different types of reading tasks. However, very few studies have investigated the design of fuel gauges for vehicles. At the time when this study was conducted (2007) there were no published studies in the literature that had investigated the design of hybrid fuel gauges (to the best of the author's knowledge). There were no recommendations available in the literature for automotive designers on how hybrid fuel gauges should be designed for optimal performance. These recommendations are important for driving the standardization of hybrid fuel gauges across various manufacturers.

In recent years there has been a societal shift towards leasing vehicles. Car manufacturers need to recognize this shift and standardize key elements of the dashboard such as fuel gauges in order to deliver a consistent user experience. Hybrid fuel gauge designs in HEVs need to be universally understandable and usable given their global user base. Advancements in display technologies are now making it possible for interface designers to explore gauge designs that are radically different from the conventional fuel gauge. Liquid Crystal Display (LCD) screens are being used in vehicle dashboards, which are allowing vehicle manufacturers to tout differentiation through interface design. In many new vehicles the fuel gauge is no longer a stand-alone component but is being integrated into a more complex interface. With such rapidly changing in-vehicle interfaces, it is becoming important to standardize a vital interface component, the fuel gauge. While it is important to every HEV manufacturer to develop unique driver interfaces as a means of differentiation, excessive variability in fuel gauge designs can lead to confusion, user frustration and in some case even abandonment of HEVs. This could have a significant impact on the consumption of gasoline. Standardization in design of hybrid fuel gauges will make it easier for drivers to easily transition from one HEV to another.

From the results of the usability study, it was found that vertically oriented bar gauges resulted in the highest reading accuracy and were read the fastest compared to other gauges. These gauges were designed so that the individual components were in close spatial proximity and also presented total range information in numerical form. Although subjects were seeking quantitative information from the hybrid fuel gauges (in terms of how much fuel is left and how many miles can be traveled) at a glance they were able to process relative information expressed in graphical or pictorial form more easily and accurately than absolute information expressed as numbers. Based on these findings it is recommended that hybrid fuel gauges be designed to include vertically oriented bars. Augmenting gauges with numerical information for the gas and battery individual ranges is optional but it is recommended for presenting the total or combined range. Both vertical bar gauge designs that elicited the highest reading accuracy and speed include individual components that have close spatial proximity. It is recommended that the gas and battery components should be designed to be in close spatial proximity, ideally with at least one shared border between the two components. Reducing spatial proximity of gas and battery components helps with the task of mental integration of information from two or more sources and reduces information access cost. It is hoped that the automotive design community adopts these recommendations made on the design of hybrid fuel gauges.

# 2. Background

**Types of Hybrid Electric Vehicles (HEVs) and their operation**

Vehicles that operate on dual energy sources, including a conventional or alternative fuel source and an electric battery are known as Hybrid Electric Vehicles (HEVs). The two types of Hybrid Electric Vehicles (HEVs) available in the market today are standard HEVs and Plug-in Hybrid Electric Vehicles (PHEVs). While both types of vehicles operate on gasoline and electric batteries, they are different in terms of how their electric batteries are recharged.

Standard HEVs use various technologies such as regenerative breaking and the internal combustion engine (ICE) to recharge their electric batteries. They convert the vehicle’s kinetic energy lost during breaking into electric energy, which gets stored in the battery. Additionally, the HEV uses an ICE with reduced size and power resulting in reduced inefficiencies from under-utilization. The ICE is off during idle states to reduce energy wastage. PHEVs have battery packs that can be recharged by plugging them into electric source outlets so PHEV owners can recharge the batteries conveniently at their own homes. As PHEVs use larger battery packs than the standard HEVs, they can be driven for longer distances (up to 40 miles) on electric batteries without using any gasoline as compared to standard HEVs.

**Operation of the PHEV developed by General Motors**

The hybrid vehicle under consideration in this thesis was a plug-in hybrid electric vehicle (PHEV) that operated on gasoline and an electric battery. The vehicle was designed to run on only one of these energy sources at a time.

The PHEV could travel a maximum of 40 miles in all-electric mode, operating on an electric battery that had been plugged in for eight hours. After the battery depleted completely, the vehicle would switch over to using gasoline for its operation. The vehicle could travel a maximum of 300 miles on a full tank of gas. It is important to note that the vehicle could be driven on gasoline only when the battery was depleted while driving, and if the driver chose not to recharge the battery. Drivers who commuted less than 40 miles each day could operate the vehicle on the electric battery alone. Drivers who commuted over 40 miles each day would benefit from reduced dependency on gasoline.

**Adoption of HEVs and incentives offered**

There is an increasing emphasis on the research and development of hybrid vehicles that operate on alternative energy sources. New vehicles are being developed by car manufacturers that provide better fuel economy than conventional gasoline based vehicles. There has been a strong drive in the United States to significantly reduce dependency on gasoline, thereby reducing pollution from carbon dioxide emissions resulting in a cleaner environment.

One of the initial challenges to the widespread adoption of hybrid vehicles was their cost. Hybrid vehicles were priced considerably higher than their conventional counterparts and it would take many years for an owner to offset the price differential through reduced fuel consumption. Over the last few years the cost of a hybrid vehicle has decreased. With gas price increases it is beginning to take hybrid car owners less time to make up the price difference.

The United States government has provided some tax credit incentives for owners of fuel-efficient vehicles. According to the United States Department of Energy, tax credits for diesel and hybrid vehicles are up to $3400 while tax credits for PHEVs are up to $7500. The minimum credit amount for a qualifying PHEV is $2500. However, once a minimum of 200,000 qualifying PHEVs have been sold by a manufacturer in the US in a calendar quarter, the tax credit will begin to be phased out in the second quarter following that calendar quarter. The credit is applicable to vehicles acquired after December 31, 2009. The vehicle must also meet certain criteria in order to qualify, such as having a plug-in electric drive motor that draws propulsion using a traction battery that has at least five kilowatt hours (kWh) of capacity. The use of an external source of energy to recharge the battery is another qualifier, and specified emission standards must be met in a vehicle with a gross weight rating of up to 14,000 pounds. It must also meet specified emission standards.

A number of other incentives are provided to owners of hybrid vehicles such as preferred parking spots and the ability to drive solo in High Occupancy Vehicle (HOV) lanes. By encouraging more and more people to purchase hybrid vehicles now when the cost is still relatively high, the goal of reducing dependency on gasoline as the fuel source may be realized.

# 3.Contributions

I conducted this thesis work as part of the team at the HumanFirst laboratory at the University of Minnesota (UMN). The team was provided with a set of thirty-three gauge designs developed by the General Motors design team (Appendix A). The UMN team generated four additional gauge designs (Appendix B). A heuristic evaluation was conducted on all designs resulting in a set of nine gauges that were used for testing in the usability study.

The team of human factors experts at UMN comprised of Nicholas Ward (principal investigator), Janet Creaser (co-investigator), Mick Rakauskas (human factors expert) and Esha Bhargava (research assistant). Each team member had a different contribution in this project.

The following are contributions of each team member in this project:

**Janet Creaser**:

- Was responsible for experimental design of the usability study and design of the subjective questionnaire.
- Was part of the four-person brainstorming team (UMN) that generated additional gauge designs
- Was part of the four-person team that conducted the heuristic evaluation of the gauge designs
- Was involved with the preliminary data analysis

**Esha Bhargava (author)**:

- Was part of the four-person team that conducted the heuristic evaluation of the gauge designs
- Was part of the four-person brainstorming team (UMN) that generated additional gauge designs
- Was responsible for running subjects through the usability study

- Conducted an in-depth data analysis including tests of significance
- Developed a set of recommendations based on results of the study to inform future gauge designs

**Nicholas Ward**:

- Was part of the four-person team that conducted the heuristic evaluation of the gauge designs
- Was part of the four-person brainstorming team (UMN) that generated additional gauge designs

**Mick Rakauskas**:

- Was part of the four-person team that conducted the heuristic evaluation of the gauge designs
- Was part of the four-person brainstorming team (UMN) that generated additional gauge designs

The outcomes resulting directly from my work on this project include:

- Data analysis
- An improved understanding of what features increase comprehension of dual-fuel gauges
- Recommendations for designers of fuel gauges in hybrid vehicles

# 4. Significance of this research

**Readable hybrid gauges**

More and more hybrid vehicles are being developed and brought to market. The operation of hybrid vehicles is different from that of conventional vehicles because of the introduction of a second fuel source. Plug-in hybrids get their fuel from gasoline and electric batteries, which are recharged from the power grid by plugging into an electric outlet. For those drivers who wish to operate their vehicles mostly on the electric battery, it becomes important for them to know exactly how far they can travel on the battery and when they need to recharge it. A second fuel source complicates the task of monitoring fuel levels. So it is important that hybrid fuel gauges are designed to be easy to comprehend. At the time when this study was conducted (2007) it was one of the first written to investigate hybrid fuel gauge designs. There were no recommendations available in literature for automotive designers on how best to design hybrid fuel gauges.

**Encouraging fuel-efficient behavior**

This study has helped identify a class of hybrid fuel gauges that can be read accurately and quickly. Based on findings from the study, a set of design recommendations has been created for automotive designers. These recommendations will help facilitate standardization of hybrid fuel gauge designs in this global industry. Standardization in design of hybrid fuel gauges will make it easier for drivers to make easy transitions from one HEV to another. A lack of standardized fuel gauge designs can complicate the task of planning trips, potentially resulting in user frustration and in some cases even abandonment of HEVs. This could have a significant impact on the consumption of gasoline.

**Shifting dependence on gasoline to electricity**

According to the United States Energy Administration, in 2013, 87% of the electricity generated came from non-renewable sources such as coal, natural gas etc. However, while gasoline has one primary source, electricity comes from many sources, some non-renewable such as coal, natural gas, and petroleum and some renewable such as hydroelectric, biomass, geothermal, wind and solar. As newer power plants are built using renewable energy, the generation of electricity will become more efficient. So as we begin to make more progress towards generating electricity from renewable energy sources, it is important that drivers of HEVs begin to reduce their dependency on gasoline and rely more on electricity for operating their vehicles. Hybrid fuel gauges have a role to play in the overall user experience and adoption of HEVs. The recommendations made in this thesis are important in driving standardization of hybrid fuel gauges.

There has also been a societal shift towards leasing vehicles in recent years. More and more people are opting to lease rather than buy vehicles as leasing has become considerably cheaper than buying. This shift has perhaps been driven by services like Spotify, Netflix, Zipcar, or Airbnb that give customers the flexibility to access their services without having to purchase the actual products. Car manufacturers need to recognize these shifts and standardize key elements of the dashboard such as fuel gauges. Gauges that are designed using these guidelines can help reduce the burden on drivers to adapt to hybrid fuel gauges each time they rent a HEV.  While it is important for every car manufacturer to develop unique driver interfaces as a means of differentiation, excessive variability in designs can lead to confusion and user frustration. Reducing or eliminating user frustration with these fuel gauges in hybrid vehicles is the first step towards increasing and sustaining the adoption of HEVs.

# 5. Literature Review

Many aspects of gauges have been investigated in the instrumentation and aviation literature. The goal of this literature review is to cover studies that have investigated the suitability of different types of displays for different reading tasks and studies that have investigated various aspects and considerations in display design. These include design considerations as well as considerations based on driver knowledge, behavior, expectations and attitudes.

Additionally, studies that have investigated interfaces and other tools that can influence driver behavior towards better fuel economy have been included in this review. Hybrid vehicles are designed with the goal of reducing driver dependency on gasoline. Driver behavior also plays an important role in achieving better fuel efficiency. Although the usability study in this thesis investigated the comprehensibility of hybrid gauge designs and not the impact of these designs on driving behavior, it is still of interest to understand how in-vehicle interfaces can be designed to encourage fuel-efficient driving behavior.

This literature review has been organized into the following four sub-sections:

**1. Suitability of different types of gauge designs for different reading tasks**

Studies conducted by Sleight (1948), Grether (1949), Thomas (1957), Graham (1956), Carveth and Adams (1964), Green (1984), Grether and Connell (1948) have evaluated the reading efficiency of various display formats and shapes for different reading tasks. Several authors like Baker and Grether (1954), Sanders and McCormick (1977), Heglin (1973) and Green (1988) have conducted comprehensive reviews of literature to develop a set of recommendations on types of gauges that are best suited for different types of reading tasks. These studies were most pertinent to this thesis.

**2. Other display design attributes that contribute to efficiency of reading (speed and accuracy)**

Studies that have looked at various display design attributes such as pointers, scales, markings, etc. and their impact on reading efficiency were also of interest to this thesis. Johnsgard (1953), Ross, Katchmar, Bell (1955), Dashevsky (1964), Green (1984) and Mital and Ramanan (1986), Green (1988) and Sanders and McCormick (1977) have provided recommendations on **pointer arrangements and orientations** for optimal reading efficiency. Kappauf and Smith (1950a,b) have investigated the effects of design attributes such as **spacing of graduation marks**, **graduation mark values, scale range**, **display size** and location of reading on circular displays. Whitehurst (1982), Grether and Williams (1949), Churchill (1956, 1959), Churchill (1960) have investigated various aspects of **pointer, scale and marker design**. As part of his study, Green (1984) has investigated various labeling schemes. Baker and Grether (1954), Sanders and McCormick (1977), Green (1984), Kurke (1956) and Heglin (1973) have discussed **color coding, contrast and color deficiencies** in people with reference to display design.

**3. Driver behaviors, expectations and attitudes to consider while designing fuel gauges**

Studies by Green (1984) and Brand (1990) have investigated driver behaviors, expectations, attitudes towards fuel gauges and also driver perceptions of automotive display systems.

**4. Influencing driver behavior towards better fuel economy**

Many studies have investigated ways to influence driver behavior towards achieving better fuel economy. Van der Voort etal. (2001), Jenness et al. (2009), Manser et al. (2010a,b,c), Graving etal.(2010) and Meschtscherjakov et al. (2009) have evaluated fuel economy interfaces for drivers. Gonder et al. (2011) have made recommendations on feedback mechanisms and techniques for increasing driver motivation to maximize fuel savings by changing driving behavior.

## 5.1. Suitability of different types of gauge designs for different reading tasks

### 5.1.1. Different types of reading tasks

In order to determine how best to present information in a fuel gauge, it is important to understand how drivers read and process the information from these gauges. Many studies have investigated the suitability of various types of gauges for the different types of reading tasks involved with dynamic displays. Sanders and McCormick (1977) describe four uses of information provided by dynamic displays: quantitative reading, qualitative reading, check reading and situation awareness. While quantitative reading involves reading of a precise numeric value, qualitative reading is used to obtain a trend or change in direction. Check reading is used to determine if a value is within a normal range or not. Situation awareness refers to perceiving elements in a volume of time and space, comprehending their meaning and using the information for projection of future element status. (Endsley,1988).

In both hybrid and conventional vehicles drivers seek information on how far they can travel or how many more gallons of fuel they have before the gas tank is empty. In the case of hybrid vehicles, drivers also look at the gauge to understand which fuel source the vehicle is operating on. They seek information on the balance of the two fuel sources and how far the vehicle can travel on each fuel source. Seeking this type of information involves qualitative and quantitative reading, but not check reading. Check reading is commonly done in aircrafts, where the pilot checks the airspeed indicator to see if a deviation has occurred from the null or normal position. This type of reading involves seeking binary

information, like whether the variable is in a normal position or not. This is not something that drivers engage in while reading fuel related information.
The fourth type of reading involved with dynamic displays is situation awareness. Endsley (1988) has discussed the application of situation awareness in a wide variety of environments with varying levels of complexity. Pilot performance in air-to-air combat and air traffic control depends upon situation awareness. Situation awareness is also highly applicable in the context of the operation of large complex systems. Examples are nuclear power plants and refineries that require up-to-date assessments of dynamic environments and the constant monitoring of several parameters and patterns to get an understanding of the system as a whole for decision-making. In terms of day-to-day activities such as driving, situation awareness can be applied to tactical-level tasks such as driving in heavy traffic. However situation awareness is not relevant to the simple task of monitoring fuel.

The task of reading a hybrid fuel gauge is more complex than check, qualitative or quantitative reading because it requires more mental processing of the information. A number of studies have looked into the suitability of various types of gauges for check, qualitative and quantitative reading tasks. It is important to note that the task of reading a hybrid fuel gauge is more complex than the tasks involved in these studies. These studies involve tasks that required participants to read the information presented and decide whether it is in or out of range or whether an increase or decrease had occurred from the previous or normal reading or to simply state the reading. The tasks involved in the usability study conducted by the author not only required participants to extract information on how much fuel was remaining, but also to determine whether it was possible to travel a certain distance on one fuel source after the other had depleted and whether it was possible to travel a certain distance with the total amount remaining in both fuel sources. These tasks require more mental processing of the information seen.

### 5.1.2. Inclusion and exclusion criteria for studies reviewed in this sub-section

At the time when the studies in this thesis were conducted (2007) there were no human factors studies in the literature that had investigated the design of fuel gauges for hybrid vehicles (to the best of the author's knowledge). The studies included in this sub-section are from the aviation, instrumentation and conventional automotive literature. These have been included as they have examined different types of gauges for the tasks of quantitative and qualitative reading, which are most relevant to the task of monitoring fuel in a hybrid fuel gauge. Studies that investigate gauges for check reading purposes have been excluded from this review, except for the study done by Grether and Connell (1948) that has investigated gauges for check and qualitative reading.

This section includes studies by Sleight (1948), Grether (1949), Thomas (1957), Graham (1956), and Carveth, Adams (1964) and Green (1984) that have investigated the suitability of different types of gauges for the task of quantitative reading. A study by Grether and Connell (1948) that has evaluated various gauges for qualitative reading tasks has also been included. Additionally, some authors such as Baker and Grether (1954), Sanders and McCormick (1977), Heglin (1973) and Green (1988) have provided recommendations on which gauges are best suited for the tasks of quantitative, qualitative and check reading based on a comprehensive review of literature. These papers have been reviewed in this section. Studies that investigated displays for situation awareness have been excluded from this review, since situation awareness is not relevant to the simple task of monitoring fuel.

### 5.1.3. Different types of displays

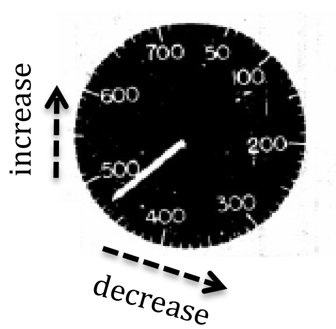
Various researchers have used a number of different terms in their studies with reference to gauges. These include displays, scales, indicators, principles of

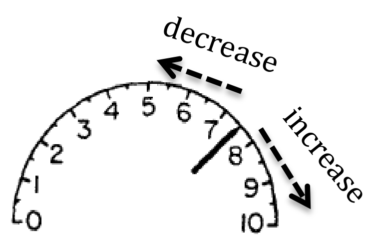
indication, gauges and displays. For the purpose of consistency the author will refer to these as displays or gauges in the remainder of this section.
It is helpful to review the different types of displays before discussing each of the studies. Baker and Grether (1954) describe two types of dynamic displays, pictorial and symbolic. Pictorial displays visually simulate the observation of the occurrence of the event. Symbolic displays do not have a pictorial representation of the conditions they present such as speed, fuel, heat, altitude etc. and are most commonly used. On the basis of their mechanisms, symbolic displays can be divided into three main categories: moving pointer and fixed scale, fixed pointer and moving scale and counters or numeric displays.

The following figure shows the different types of symbolic displays. Arrows have been added where applicable to show the direction of increase and decrease.

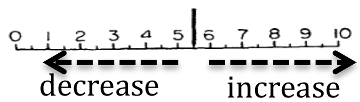
**Figure 5.1: Different types of displays (sources: Grether and Connell (1948) and Sleight (1948), Baker and Grether (1954))**

1. Moving pointer displays (circular, semi-circular, curved, vertical, horizontal)

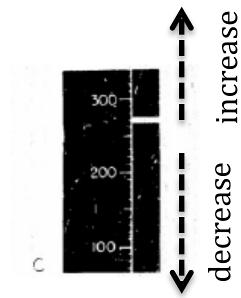



CIRCULAR SEMI-CIRCULAR CURVED

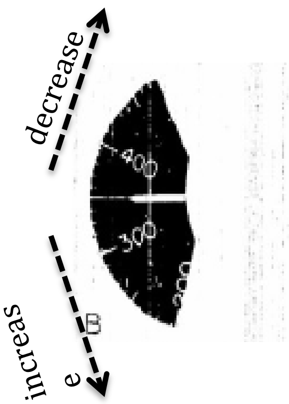



HORIZONTAL

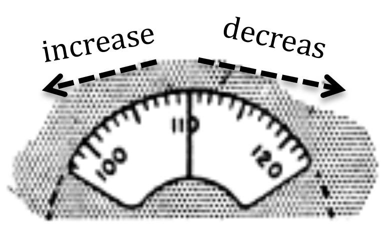



VERTICAL

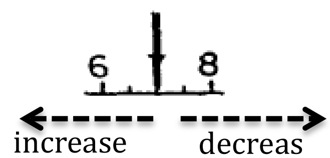
2. Moving scale displays (curved, open-window, vertical, horizontal, circular)



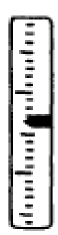

CURVED



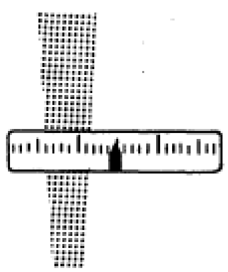

CURVED




OPEN-WINDOW



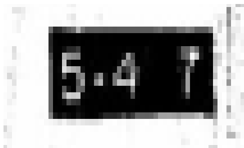
VERTICAL



HORIZONTAL


CIRCULAR

3. Counters or numeric displays



As the name suggests, in a moving pointer display the pointer physically moves along the scale to indicate a reading. These displays can be of various shapes (circular, linear, curved) and orientations (vertical, horizontal). A conventional gas gauge is an example of a moving pointer display.

In moving scale displays the pointer is fixed at a specific location while the scale moves behind it to indicate a reading. One example of a moving scale display inside vehicles is the control for interior temperature. A counter or numeric display presents a reading in the form of digits or numbers. Many vehicles have speedometers that are numeric displays.

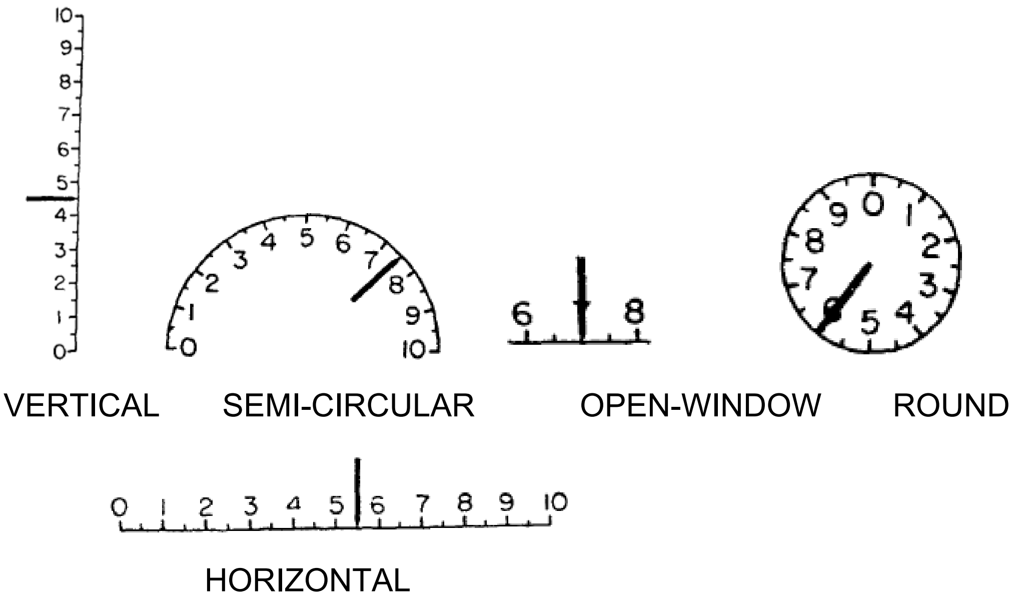
**5.1.4. Suitability of different displays for quantitative reading tasks**

Several empirical studies have been conducted to investigate the suitability of different types of gauges for the task of quantitative reading.

**SLEIGHT (1948)**

Sleight (1948) conducted a study with sixty male subjects to evaluate the relative legibility of five displays for the task of quantitative reading. Legibility was measured in terms of reading accuracy. Four of the five displays in the study were of the moving pointer type with different shapes and orientations- circular, semi-circular, horizontal and vertical. One display was of the fixed pointer type with an open-window. The five display types were identical in terms of size and style of numerals, marks and pointers, contrast, background brightness, background size and pointer positioning with respect to numerals and marks. They differed with respect to effective area due to variation in shape.

**Figure 5.2: Five display types used by Sleight (1948)**




A tachistoscope was used to present the displays to the subjects (one at a time) for a controlled exposure time. Subjects were asked to engage in quantitative reading of the display upon exposure. A preliminary experiment involving five subjects was conducted. Exposure times of 0.28, 0.20, 0.17, 0.14 and 0.12 seconds were used to determine at which of these times sufficient errors were committed by subjects. It was found that exposure speeds and subjects were not significant factors contributing to variance in data, but display type was clearly significant. Based on these results Sleight decided to conduct a further investigation.

For the main experiment involving sixty subjects an exposure time of 0.12 seconds was used as it was believed that for the simple task of display reading, a brief exposure would be needed in order to provide sufficient errors for differentiation between the displays. A total of 1020 readings were made on each of the five displays. The results of the experiment showed that the percentage of error for the open-window display was the lowest while it was highest for the vertical display. Sleight pointed out that there appeared to be a positive relationship between the effective area of a display and the amount of inaccuracy that came from reading it. The open-window display with the smallest effective area produced the least amount of errors while the vertical display (one of the two displays with the greatest effective area) produced the largest number of errors. In order of reading accuracy, the displays ranked as follows- open-window, circular, semi-circular, horizontal and vertical. Sleight concluded that for quantitative reading open-window displays are superior to moving pointer displays of various shapes (circular, semi-circular, vertical and horizontal) in terms of reading accuracy, and that reading accuracy has a positive correlation to the effective area of a display.

One critical weakness of this study is the very short and controlled exposure time of 0.12 seconds. It was selected because it was expected to elicit sufficient number of errors and hence sufficient amount of differentiation between the displays. Sleight does not state the practical relevance of the 0.12 second exposure time or the context in which these results may be applicable (aircrafts, vehicles etc.). This study only measures the reading accuracy and not response time. Response time measurements would have provided insights about how long subjects took to recall the image and process the information. This study also did not evaluate the numeric display for the purpose of quantitative reading even though it provides the most direct way to present quantity and often has an even smaller effective area compared to the open-window display. It would have been valuable to see how the numerical display compared with the open-window display in terms of reading accuracy. Sleight only stated that similar results could be expected for numerical displays due to the small effective area and the knowledge of where to look for the reading.

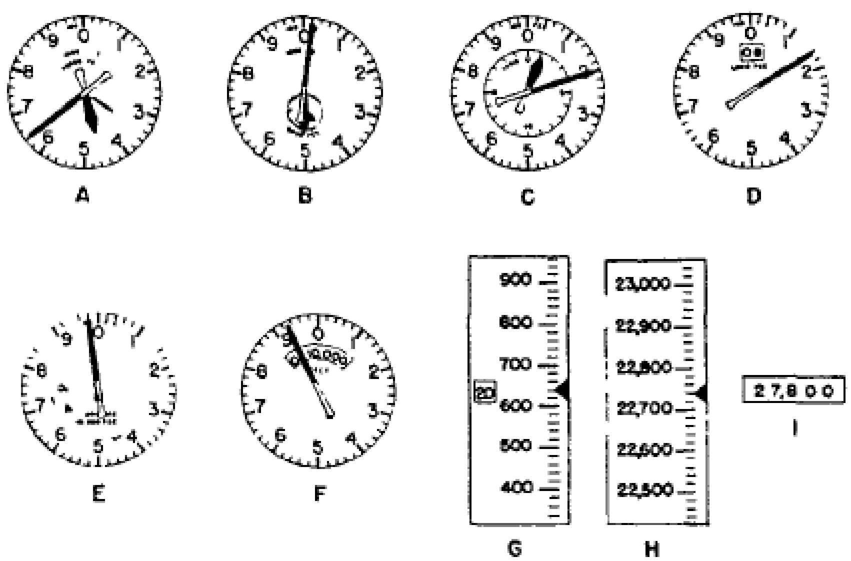
There is a possibility that the subjects were able to read the open-window display more accurately in the brief exposure time due to the nature of fixed pointer designs in which the pointer position is known. This made it easier for subjects to anticipate the position of the pointer in case of the open-window display but not in case of the other four displays that had moving pointers. Grether (1949) believes that the technique used by Sleight favored the fixed pointer indicators.

Sleight also does not explain why reading accuracy was poorer on the vertical display compared to the horizontal display even though the effective area covered by both is the same.  Perhaps this can be attributed to the fact that human eyes are located side-by-side resulting in a visual field that is horizontal (wider than taller). Under the constraint of a short exposure time, the speed of eye movements is based on ease of movement for which the horizontal direction is better than the vertical. This could be a possible explanation as to why the reading accuracy was better on the horizontal display compared to the vertical display even though both have the same effective area. Graham (1956) gave a similar explanation for the difference in reading accuracy between horizontal and vertical displays as found in her study.  Graham's study has been reviewed later in this section.

**GRETHER (1949)**

In a study conducted by Grether (1949), nine experimental displays were evaluated in terms of speed and accuracy for quantitative reading. Each display was a simulation of a long scale length altimeter. Long scale displays are those in which the readings can vary over a large range (0 to 100,000). The displays evaluated were of the following types- moving pointer fixed scale (display A, B, C, D), fixed pointer moving scale (display H), numerical display or direct reading counter (Display I) and some hybrid displays -moving pointer and moving scale (Display E), moving pointer with counter (Display F), fixed pointer moving scale with counter (Display G).  This study was of particular interest because some of the displays used combinations of mechanisms (such as two or three pointers, and pointer with numerical display) similar to the hybrid fuel gauge designs evaluated in the usability study. The task involved in this study was also similar in terms of complexity to the tasks involved in the usability study of the hybrid gauge designs. For displays A, B, C, D, E, F and G, subjects were required to combine information from multiple scales in order to determine the overall reading presented by the altimeter. The following figure shows the displays evaluated in Grether's study.

**Figure 5.3: The nine experimental displays evaluated in the study by Grether (1949)**




Display A was a simulated altimeter used almost universally in military and larger commercial aircrafts. It has three pointers of which the longest gives readings in hundreds of feet, the broad pointer gives readings in thousands of feet and the small pointer gives readings in ten-thousands of feet. Displays B and C are also simulations of the altimeter but not commonly used.

The single pointer in altimeter Display D gives readings in hundreds of feet. One revolution is made by the pointer for each 1000 feet change in altitude and multiples of 1000 feet are displayed on the numerical display inside the display. While Display E also uses one pointer, it has two displays rotating behind a window to indicate multiples of 1000 feet. In Display F, the pointer makes one revolution to cover an entire altitude range.  The whole range is displayed in the window (0-1000 ft, 0-10,000 ft, 0-100,000 ft). Displays G and H are similar in that they represent a vertical moving scale. Display G also has a numerical display that presents multiples of 1000 feet. Lastly, Display I is a numerical display which was included by Grether due to its simplicity in that it doesn't require any interpretation time.

A total of ninety-seven USAF pilots and seventy-nine college men with no aircrew experience participated in the study. Each subject was presented with a booklet for each of the nine altimeter displays that contained twelve different settings for each display. The order of presentation was counterbalanced for learning effects. Subjects were required to write down the reading presented by each setting. So the time taken to read Display I which was a numerical display would represent only the time required in copying a reading and no interpretation time. Each subject's completion time was recorded on his booklet (it is not clear if this was done by a study moderator or the subject himself). The interpretation time for each display from the study for Displays A to H was obtained by subtracting the average time for Display I from the average time for each of the other displays. The results showed that the **numerical display (Display I) had the fastest response time and highest response accuracy of all displays,** indicating it would be the best display for quantitative reading. However it would be inferior to a moving pointer display for the tasks of check reading and qualitative reading. **The findings showed that the displays that were read the fastest were also read most accurately**. Thus speed and accuracy of reading are **positively correlated so that an improvement in reading speed can be expected to result in improved accuracy.**

In comparing the data from pilots (experienced users) with the data from the college students (inexperienced users) the results were found to be very similar indicating that **experience was of relatively low importance** in this study. Also there was positive correlation between speed and accuracy of individuals for all displays indicating that **individuals who read the indicators most rapidly also read them most accurately.**

An important finding from this study was that the two fixed pointer Displays G and H showed no superiority to the comparable moving pointer Display D. This is noteworthy because it contradicts the finding from Sleight's (1948) study in which the open-window display (with moving scale) was found to be superior to moving pointer displays for quantitative reading. Grether attributes this discrepancy in findings to the fact that Sleight used a tachistoscopic method with a very small exposure time of 0.12 seconds. Controlling the exposure time restricted the number of visual fixations and the exposure time of 0.12 seconds did not allow subjects to change the preparatory eye fixation. Thus the technique favored the fixed pointer indicator because subjects could anticipate where to look.
The results show that the combination of indications from two or more pointers or from a pointer and rotating sub-displays was a relatively difficult task that could lead to reading errors. Perhaps supplementing such displays with numerical displays may be helpful in facilitating faster and more accurate reading. This finding is relevant to the set of hybrid fuel gauges evaluated in this thesis because many of these displays also required drivers to mentally integrate readings from two pointer type displays. Some of the hybrid fuel gauges have similar design elements to the displays in this study.

**THOMAS (1957)**

Thomas (1957) conducted a study to shed some light on the contradictory findings from Sleight (1948) and Grether's (1949) studies. In Sleight's tachistoscopic study, the open window fixed pointer display elicited the highest reading accuracy, while in Grether's study (test booklet method) with no controlled exposure time, fixed pointer displays did not show any superiority over moving pointer displays. In fact the numerical display elicited highest response speed and accuracy for quantitative reading. Grether pointed out that the use of a very short exposure time (0.12 seconds) by Sleight favored the open window display. It did not allow a change in the eye fixation because of which subjects could anticipate the pointer position on the open window display in which the pointer is fixed.

Thomas evaluated the effect of different exposure times on display legibility. He used miniature versions of the same five displays used by Sleight with the assumption that due to the small size of these displays the different number of eye fixations required for the different display types would no longer be important. The diameter of the circular display in Sleight's experiment was 2.5 inches where as the diameter of the circular display in Thomas's study was 7/8 inch. The other displays were drawn in proportion. Another difference was the scale length, 0 to 10 used by Sleight compared to 0 to 6 used by Thomas.
A total of eighty subjects participated in the study, of which sixty-three were men and seventeen were women. They were divided into four groups of twenty subjects each. Each group was presented with the displays for different exposure times of 0.50 seconds, 0.10 seconds, 0.04 seconds and 0.02 seconds. It is not clear from the paper as to why these specific exposure times were selected and why Thomas did not use the 0.12-second exposure time that Sleight used in his study. Subjects were required to provide readings (quantitative) after each presentation. This was a between-subjects study for exposure time in that each subject viewed nine settings of each of the five displays, but only for one of the exposure times. The order of presentation of the five displays was randomized.

When the data for all exposure times was considered together, the **horizontal display elicited highest reading accuracy followed by the circular, vertical, open-window and semi-circular displays**. When the data for each exposure time was looked at separately, the open-window display ranked second best in terms of reading accuracy at exposure times of 0.50 seconds and 0.10 seconds. However the open-window display ranked fifth at exposure times 0.40 seconds and 0.20 seconds. In summary, the order of the displays for reading accuracy when the data was looked at separately for each exposure time was as follows:

**Table 5.1: Display rankings in terms of reading accuracy from Thomas's (1957) study**

Exposure times

| | 0.50 sec | 0.10 sec | 0.40 sec | 0.20 sec | Collectively (all exposure times considered) |
|---|---|---|---|---|---|
| Rank 1 (highest reading accuracy) | Horizontal | Horizontal | Horizontal | Horizontal | Horizontal |
| Rank 2 | Open-window | Open-window | Circular | Circular | Circular |
| Rank 3 | Vertical | Vertical | Vertical | Vertical | Vertical |
| Rank 4 | Circular | Circular | Semi-circular | Semi-circular | Open-window |
| Rank 5 (lowest reading accuracy) | Semi-circular | Semi-circular | Open-window | Open-window | Semi-circular |

At 0.10 exposure time, which is closest to the 0.12-second exposure time used by Sleight (1948), the open-window display ranked second in terms of reading accuracy. This showed that when eye fixations were minimized, as is the case with miniature displays, the open-window display was no longer the most accurately read. These findings validated Grether's argument that the 0.12-second exposure time used by Sleight favored the open-window display.

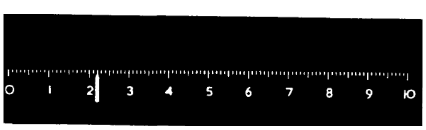
The data also showed a tendency for reading accuracy to be higher at certain reference points. Reference points are those that have a tendency to be more easily recognized. For the circular display this was seen at the 12, 3, 6 and 9 o'clock positions, for the semi-circular at the 9, 12 and 3 o'clock positions and for the horizontal and vertical displays at the two end points and the center. For the open-window display all points are equally easy to detect. The data validated Thomas's prediction that **reading errors would be evenly spread out on the open-window display**.

The results showed that **shape as well as exposure time are significant in determining the reading accuracy of a display**. The study uncovered a fundamental problem with the tachistoscopic method of evaluating displays. In this method the exposure time is pre-selected by the experimenter and this influences the performance of the displays. **These findings validated the method used for the timed comprehension task in the author's study in which the subjects controlled the exposure time for each gauge. This eliminated the effect of pre-selected exposure time on reading speed and accuracy**.

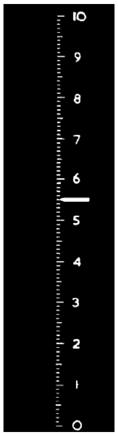
**GRAHAM (1956)**

Graham (1956) conducted a study with 60 male subjects to compare three displays (horizontal, vertical and circular) in terms of reading speed and accuracy for the task of quantitative reading. All three displays were of the moving pointer fixed scale type. The scales on the displays ranged from 1 to 10 and were considered as being made up of five segments (0-2, 2-4, 4-6, 6-8, 8-10). Intervals between scale markings were the same on all three displays.

**Figure 5.4: The three displays used in Graham's (1956) study**




HORIZONTAL





VERTICAL CIRCULAR

The study was designed such that each subject made two quantitative readings in each scale segment for each of the three displays. Although the apparatus used was a camera fitted with a counter, the study was similar in nature to a tachistoscopic study in that an exposure time of 0.5 seconds was selected for the presentation of each display. Each subject was allowed 8 seconds to write down the reading. A total of thirty readings were made by each subject. Before the study, practice trials involving the same three displays were given to the subjects.

The results from the study showed **highest reading accuracy for the horizontal display, followed by the circular and vertical displays**. Reading **errors were significantly greater on the vertical display** than the other two displays. While the differences between the horizontal and circular displays were attributed to chance, Graham attributed the difference in reading accuracy between horizontal and vertical scales to the shape of the visual field and mechanics of eye movement. The linear displays subtended an angle of approximately 10 degrees at the eye. However, since the angle subtended by the foveal vision is only about 3 degrees, during short exposure times reading accuracy depends on how quickly eye movements can be made. Horizontal eye movements are the fastest while vertical ones are the slowest. An interesting finding was that the tendency to make mistakes was significantly greater at the ends of the displays (0-2 and 8-10 segments) rather than in the middle segments

(2-4, 4-6 and 6-8). This was true for the horizontal, vertical as well as circular displays. While this was expected for the two linear displays, it was unexpected for the circular one because of its shape and smaller size relative to the linear displays. Graham did not provide an explanation as to why reading errors were highest in the 0-2 and 8-10 segments of the circular display. A closer look at the data showed that the top segment (8 - 10) of the vertical display had the highest number of reading errors than any other segment on the three displays.

**Table 5.2: Number of errors for each scale type by scale segment (Graham, 1956)**

The Total Error Score for Each Segment of the Three Displays

| | Scale | | | |
|---|---|---|---|---|
| Major Segment | Hori-zontal | Ver-tical | Cir-cular | Total Error |
| 0–2 | 80 | 72 | 78 | 230 |
| 2–4 | 33 | 58 | 38 | 129 |
| 4–6 | 44 | 48 | 40 | 132 |
| 6–8 | 18 | 64 | 41 | 123 |
| 8–10 | 53 | 123 | 64 | 240 |
| Total error | 228 | 365 | 261 | 854 |

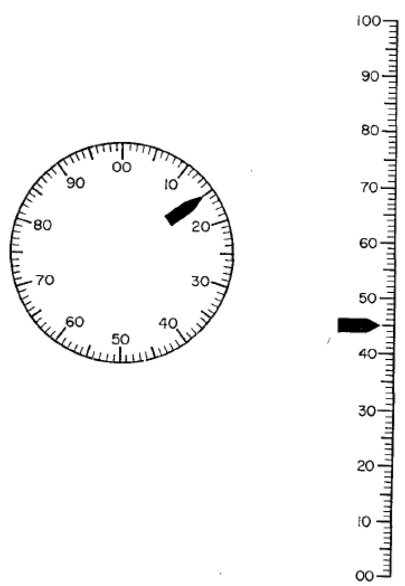
One weakness of this study is that although Graham stated that the goal of the study was to evaluate the speed and accuracy of reading the three scales, no measurements were reported in this paper for reading speed (in terms of time taken to write down the reading). There is no explanation on the practical significance of the 0.5-second exposure time. It is not clear as to how this exposure time relates to display reading tasks in the industry (vehicles or aircrafts) so as to get a better sense for its applicability in the real world. Graham stated that the exposure time was selected on the basis on a pilot experiment. The details of which are not stated in this paper, nor have references been provided.

**CARVETH AND ADAMS (1964)**

Carveth and Adams (1964) conducted a study to evaluate the effect of practice on the efficiency of quantitative reading for circular and linear displays. They stated that two types of variables determine reading speed and accuracy: task-centered and man-centered. While task-centered variables include display size, type, illumination etc., man-centered variables include fatigue, practice etc. The independent variables in this study were display type, exposure time and practice.

Two displays (vertical and circular) were evaluated for two exposure times (500 and 100 milliseconds). Both displays were of the moving pointer fixed scale type. The scale length on each display was 0 to 100 with major divisions for every 10 units.

**Figure 5.5: vertical and circular displays used by Carveth and Adams (1964)**



A projector fitted with a shutter was used as a tachistoscopic device for group presentations. A total of ninety-nine slides were presented for each exposure time. One display was presented on each slide. The hypothesis was that practice might influence the differences in reading performance for two displays at the two exposure times.

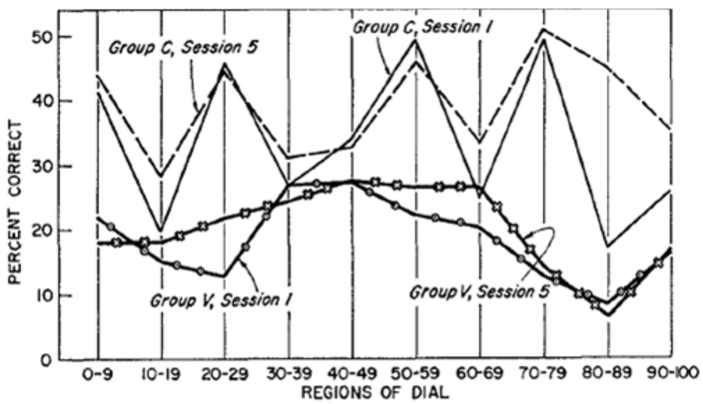
A study was conducted using twenty-two male subjects who were divided into two groups of eleven each. One group read the circular display while the other group read the vertical display. All subjects in a group were tested simultaneously. The exposure time was a within-group variable, so each group viewed half the presented displays at exposure time 100 milliseconds and the other half of presented displays at exposure time 500 milliseconds. Each subject group went through five sessions to allow extensive practice. During each session ninety-nine slides were shown for each of the two exposure times with the order of the two exposure times reversed for each subsequent session. Reading accuracy was measured in terms of percent correct. The degree or amount of error was also calculated from the data.

The results of the study showed that for **both exposure times the circular display elicited significantly greater reading accuracy than the vertical display**. It was found that within each subject group, reading accuracy was significantly affected by exposure time. The **100 milliseconds exposure time elicited significantly poorer reading accuracy (per cent correct) for both circular and vertical displays for all five sessions**.

With regard to practice effects, only one statistically significant practice effect was found for the circular display at the 100 milliseconds exposure time. The circular display showed only a slight change with practice while the vertical display showed no practice effect. When the circular display was divided into 90 degree quadrants (0-25, 26-50, 51-75, 76-100), it was found that there was a tendency for the reading accuracy to be low at about the middle of each quadrant irrespective of exposure time. This effect was more pronounced in the first session compared to the last session. Carveth and Adams suggested that **minor practice effect occurred in the middle of these quadrants where subjects**

**experienced most difficulty in reading.** This tendency was not observed for the vertical display.

**Figure 5.6: Graph showing percent correct for 10 unit regions of circular (group C subjects) and vertical displays (group V subjects) for sessions 1 and 5 (Carveth and Adams, 1964)**




When the data was analyzed in terms of amount or degree of error (unit deviations from correct reading) it was found that at each of the two exposure times (overall for five sessions) the vertical display elicited a significantly greater degree of reading error compared to the circular display. No significant practice effects were found for the amount of error for either display.

Carveth and Adams do not explain why 100 milliseconds and 500 milliseconds were used as exposure times in this study. There is no explanation of the practical significance of these times and their applications in industry. The exposure time was a within-group variable, so each group viewed half the presented displays at exposure time 100 milliseconds and half at exposure time 500 milliseconds. Also, half the subjects viewed the circular display only and the other half viewed the vertical display only. Since type of display was a between-group variable it is difficult to be sure whether the differences found are due to the two different groups of subjects. A within-subject design in which both groups of subjects were shown both displays for both exposure times would have been preferable. It would have been interesting to investigate whether practice effects could be seen across gender. The study involved only male participants so this was not possible. Another shortcoming of this study is that although the goal of the study was to investigate efficiency of reading, no measurements were made on reading speed.

In conclusion, the study showed that the **circular display elicited significantly greater reading accuracy than the vertical display** for both exposure times. Practice effects for reading accuracy were minimal for both displays. The vertical display elicited a significantly greater degree of reading error compared to the circular display. No significant practice effects were found for the amount of error for either display. Although practice was not used as a variable in the author's study, many of the hybrid fuel gauge designs evaluated in the usability study are circular and vertical.

**GREEN (1984)**

Green (1984) conducted a study with sixty-six drivers to investigate display formats for automotive fuel gauges and to evaluate drivers' understanding and knowledge of instrument panel displays for vehicles. The study investigated topics like what types of display formats (digital or moving pointer fixed scale type) are best for presenting fuel level and engine parameters, should the choice of a display format depend on the parameter being presented (example, fuel level, engine temperature etc), how much does color coding help in the understanding of engine displays, the benefits of color coding compared with benefits of pointer alignment for grouping of gauges, the labeling of display scales and the driver's understanding of numeric fuel displays. The study also investigated how much drivers knew about their cars. Based on the results on this study, Green provided recommendations on various aspects of display design for conventional vehicles. In this sub-section of the literature review, only findings related to various display formats for presenting fuel and engine parameters will be discussed. Green's recommendations on other aspects of display design (such as color coding, scale labeling etc.) and on driver understanding of their cars will be discussed in the next two sections of this literature review.

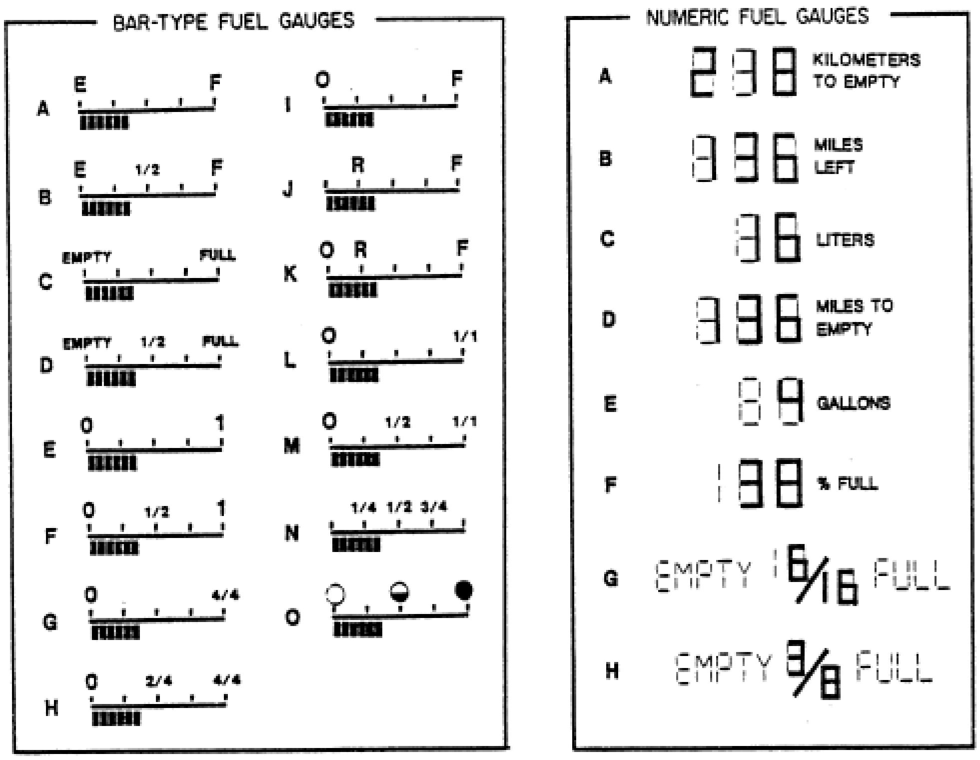
The study involved licensed drivers between the ages of 18 to 78 years. Thirty-six were men and thirty were women. Subjects were divided into four groups based on age (under 40 and 40 and over) and gender (male, female). Participants were made to perform three main tasks.

**Task 1:** Subjects were asked questions about their cars on fuel capacity, normal engine temperature etc. in order to learn about how well drivers understood their cars. The results of this task are discussed in section 4.3.

**Task 2:** The subjects' comprehension of designs for fuel, oil, temperature and electrical system gauges was tested. Participants were shown slides of instrument panels while they were seated in a driver's seat of a test mock-up. Each person was read one of three scenarios: local, moderate distance or long distance trip and then was shown slides of various instrument panels. Subjects were instructed to state if each display reading was high, low, OK or if they were unsure of the answer. For example, the speed may have been too high, engine temperature may have been too low, etc. Essentially, subjects were engaging in quantitative reading and then doing some additional mental processing to determine whether they could make the trip based on the reading. This task was similar to the timed comprehension task in the author's study.

Subjects were also given a list of potential actions that could be taken and were asked to state what they would do if the reading was not OK. Some of the actions were, "ignore it", "speed up", "slow down", "keep checking to see if it gets worse", "stop at the next service station" or "treat it as a special case". Subjects were also encouraged to write actions in their own words if they preferred. Next, subjects were asked to rank order the designs observed from the most to least understandable. They were shown eight basic designs for the numbered gauges, fifteen for the bar type fuel gauges and eight numeric fuel gauges.

**Figure 5.7: Twenty-three fuel gauges examined by Green (1984)**




**Task 3**: Lastly, subjects were asked three trick questions to highlight the discrepancy in the knowledge of ordinary drivers and that of automotive designers. The results of this task are discussed in section 4.3.

A total of one hundred forty test slides of instrument clusters were used for the study. Additionally, two practice slides and one focus slide were shown. The test slides were randomly divided into two groups of seventy slides, each of which seen by roughly half of subjects. Each slide comprised of five elements: a turn signal indicator, six indicator lights, a digital speedometer, a fuel gauge and the “other” gauges. These “other” gauges were either for oil (level or pressure), temperature and electrical systems (current or voltage) or were labeled with numbers (1,2,3) for three non-specific systems. The independent variables explored were display format (digital or analog), parameters presented (oil, pressure, voltage or current, engine temperature), units system (English or metric), color-coding (present or absent) and scale labeling (single letters, short abbreviations, full names). The numbered gauges used in the study were designed to assess the effects of scale labeling (OK, normal, norm and !), color coding and pointer alignment. The following table shows the various combinations used.

**Figure 5.8: Gauge combinations for numbered (hypothetical) gauges Green (1984)**

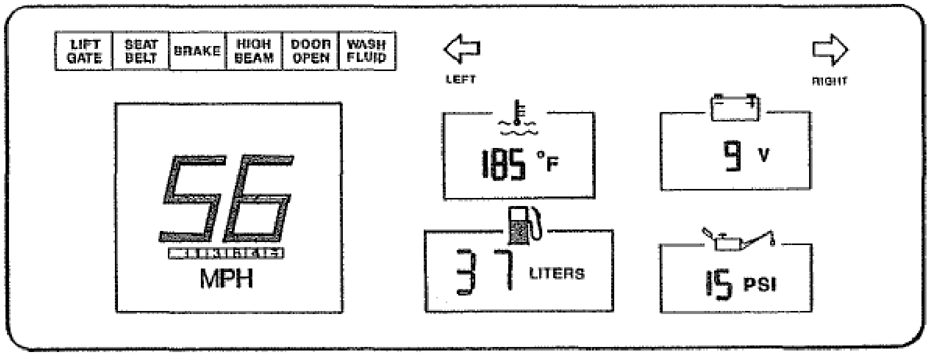
Numbered (hypothetical) Gauge Combinations

| Color Coding | Reading Condition | GROUPING: Separated — Label: ! | Norm | OK | Normal | Grouped & Aligned — Label: ! | Norm | OK | Normal |
|---|---|---|---|---|---|---|---|---|---|
| No Coding | OK | ✓ | ✓ | ✓ | ✓ | | | | |
| No Coding | Not OK | (1) | (2) | (3) | (1) | (2) | (3) | (1) | (2) |
| Color Coded (red/green) | OK | | | | | | | | |
| Color Coded (red/green) | Not OK | (1) | (2) | (3) | (1) | (2) | (3) | (1) | (2) |

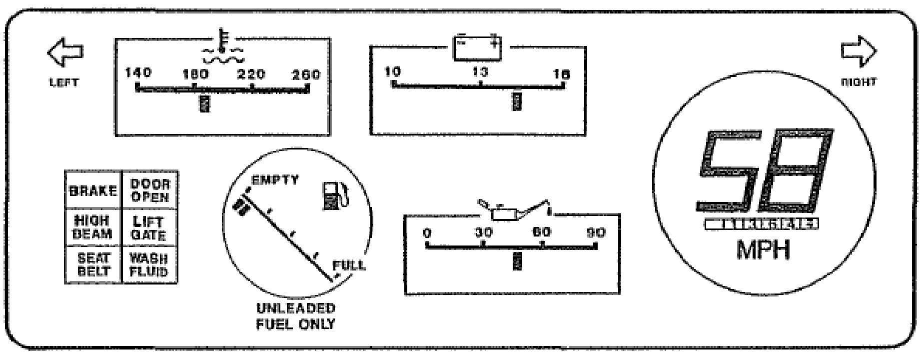
() = which gauge is not OK

✓=repeated

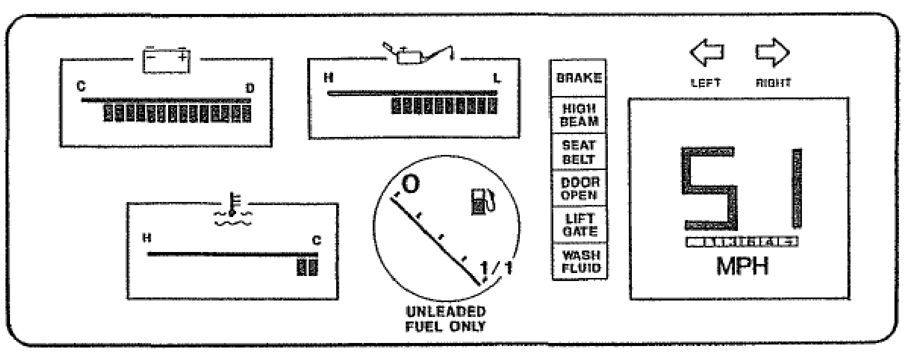
**Figure 5.9: Instrument panels used by Green (1984)**



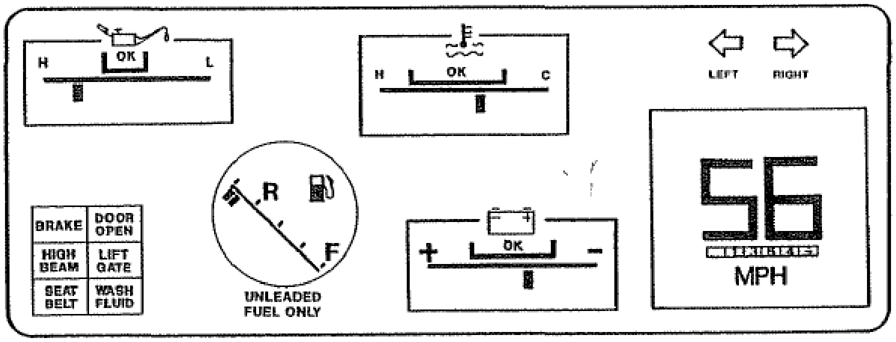

Cluster with all numeric gauges (class A1)



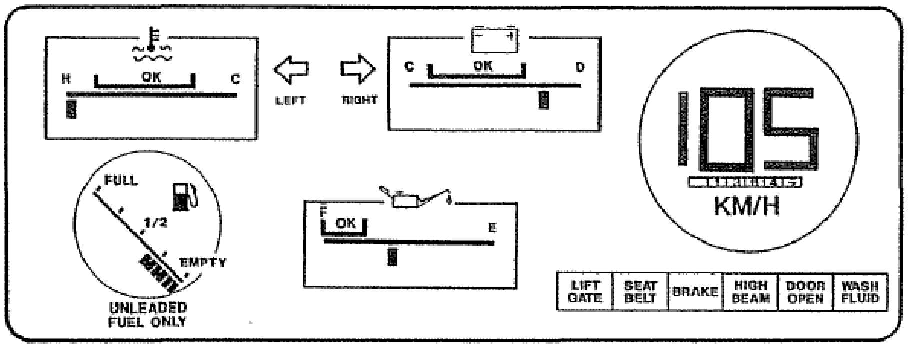

Cluster with plain bar-type displays (class B1)



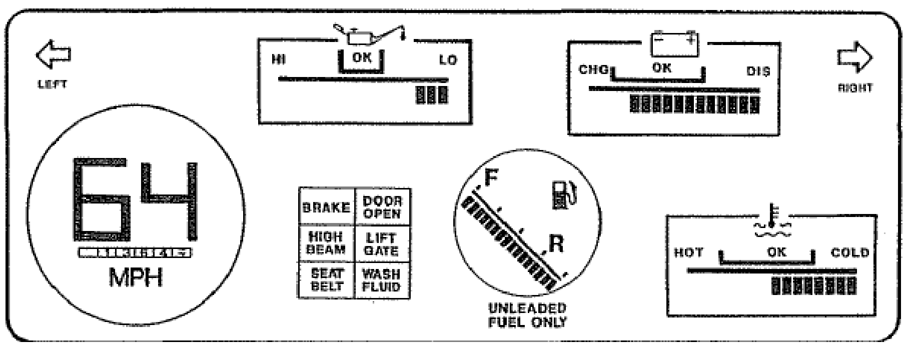

Cluster with plain bar-type displays (class B2)



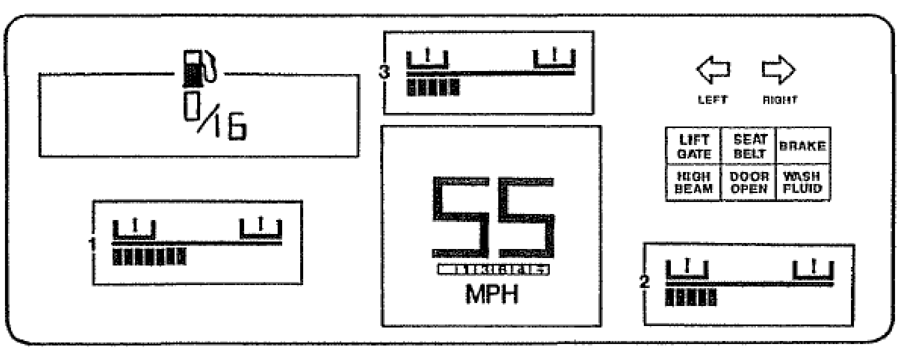

Cluster with zone-coded bar displays (class C2)



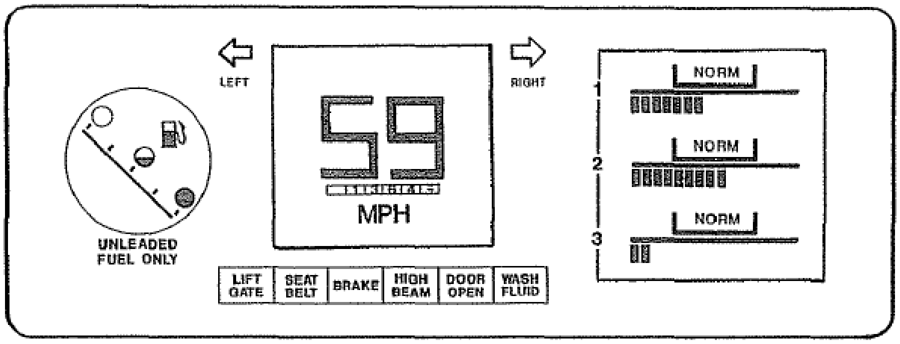

Cluster with zone-coded bar displays (class C3)




Cluster with zone-coded bar displays (class D1)




Cluster with numbered gauges (separated and not coded)




Cluster with numbered gauges (grouped and color coded)

There were one hundred forty unique fuel gauge reading combinations with twenty-three different labeling schemes (fifteen for bar type displays, eight for numeric displays). These labeling schemes included words (empty, full), letters (E, F), others forms like ¼'s and R (reserve, refill, refuel) and pictorial elements (moons). Some prototypes for the bar displays had a 45-degree sloping line such that the end of the scale associated with full was ambiguous. This was done to force subjects to pay attention to labels. For numeric displays fuel level was presented in volume, distance to empty (both units systems) and fraction percentage full. The twenty-three different fuel gauge designs that Green examined were numeric and moving pointer (bar) displays. The pointer was either white or color-coded (red or green). Moving pointer displays were segmented and a reading could be indicated by illuminating one or more segments.

The results of task 2 showed that the reading performance with digital fuel displays was inferior to that with bar-type displays. Drivers made more errors while reading digital displays compared to analog displays for fuel and engine gauges. Green recommended that **analog displays be used with numeric displays and used as redundant sources**. This was because drivers wanted to know information like whether things were changing state, how rapidly that was occurring, what was in a normal state and what was not. Green stated that this type of information is best presented by analog displays.

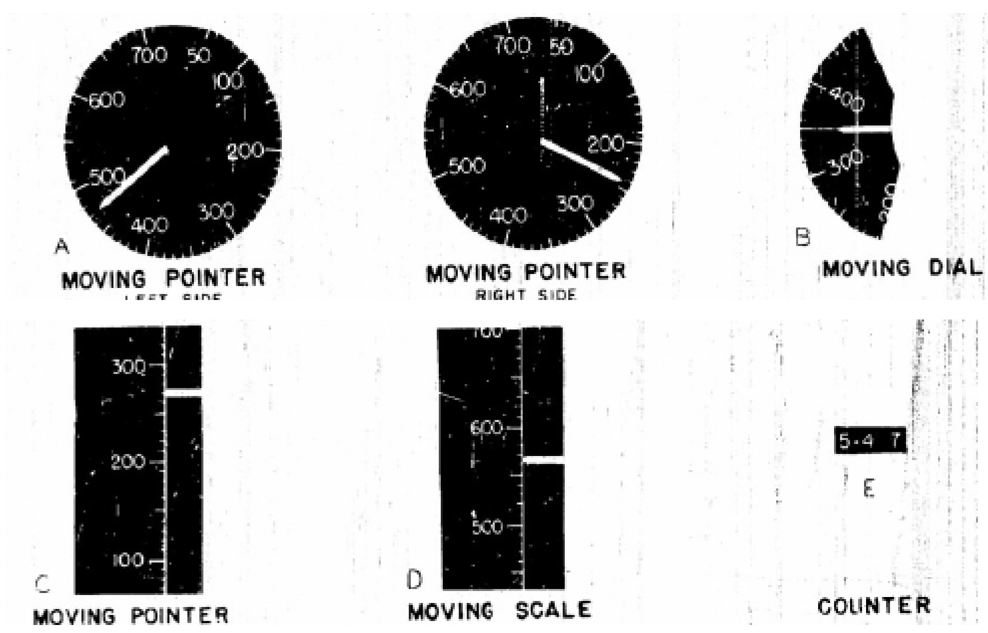
### 5.1.5. Suitability of different displays for qualitative reading tasks

Some empirical studies have investigated the suitability of different types of gauges for the task of qualitative reading.

**GRETHER AND CONNELL (1948)**

One study conducted by Grether and Connell (1948) evaluated the suitability of five display designs (which they refer to as principles of instrument indication) for the purpose of check and qualitative reading tasks. The instrument was an airspeed indicator. The following five displays were tested- a rotating pointer, a rotating display, a moving pointer on a linear scale, a moving linear scale and a direct reading counter.

**Figure 5.10: Five displays evaluated in the study by Grether and Connell (1948)**




Three experiments were conducted. The simulated instruments were presented to the subject using an apparatus that had a shutter-like shade. The opening of the shade started a clock that stopped once the subject had responded. The dependent variables measured were the response time and accuracy. In the first experiment, twenty male subjects evaluated the response time and accuracy of qualitative reading for the five displays. Each subject responded 480 times to each display type. The second experiment also evaluated the five displays but for a simple check reading task. While in the first experiment the subjects were required to determine whether the reading had increased or decreased from the previous one (qualitative reading), in the second experiment subjects were only required to determine whether or not a change had occurred since the last reading (check reading). Another difference in the two experiments was in the movement of a three-way toggle switch in response to the display presented. In the first experiment subjects were instructed to push the handle upward if the instrument reading had increased, to the right if it had not changed and downward if it had decreased beyond a desired and previously presented reading. The second experiment was different in that subjects were instructed to move the switch left to indicate the presented reading was same as previous and to move switch to right to indicate the presented reading was different from previous and desired reading. Response time was measured from the time the display was presented to the time the switch was pushed. Each subject was given few practice trials before the actual experiment.

The results of the first experiment showed that the **moving pointer and fixed scale displays had the shortest response times and fewest errors for the task of qualitative reading**. **Counters were almost equally** good. Moving scale and fixed pointer displays were the worst. From the results of the second experiment it was also found that **moving pointer displays and counters were superior to moving scale displays for check reading**. Direct reading counters were again found to be equal to moving pointer displays. The fixed pointer displays (B and D) showed poorer results indicating that subjects found it easier to detect displacement of a pointer compared to the displacement of a scale. One of the most interesting findings from the first experiment was the fact that the **right side of a circular display with a rotating pointer elicited a slower response from subjects compared to the left side**. Grether and Connell attributed this difference to the experimental procedure where on the right side of the display an increase was indicated by a downward deviation of the pointer for which the subject was required to make an opposite movement on the toggle switch (upward). Whereas on the left half of the display an increase was indicated by the upward deviation of the pointer and required an upward movement on the toggle switch. In light of this finding the procedure for the second experiment was modified such that only two of the response switch positions were used as described above. From the results of the second experiment it was evident that this simplification in the required movement of the toggle switch resulted in faster response times. This finding is particularly noteworthy for **gauges or instrument displays on which the operator is required to make manual controls**.

The third experiment was conducted to further investigate the moving pointer and moving scale displays with a focus on display quadrant and direction of response switch motion being used. Subjects were divided into four groups. Each group moved the toggle switch in one of the four directions- up, down, left or right in response to a display reading that was too high. The results of the experiment showed that the **moving pointer display took less time to read and was read more accurately than the moving scale display**. Also, the performance of the subjects in terms of speed and response accuracy was substantially superior when the switch and pointer movement coincided compared to when the movements of the switch and pointer were not aligned. There was a tendency for shorter response times and fewer errors in the 9 and 12 o'clock areas of the display. However there was no clear evidence to indicate that any one quadrant was superior over the others.

A weakness of this study is that this was not a pure within-subjects design. In a within-subjects design each participant sees all of the indicators presented and goes through all test conditions. In this study a total of 20 male subjects participated in the first experiment. The second experiment was also conducted with 20 male subjects 16 of which had participated in the first experiment. In the third experiment the participants were 20 males subjects of whom only 13 had participated in both earlier experiments. So only 65% of the subjects consistently participated in all three experiments. It would have been interesting to see results from those 13 subjects. The study was also conducted with only male subjects, so any differences in performance due to gender were not investigated.

This study showed that for the tasks of qualitative reading (determining an increase or decrease) and check reading (whether or not there is a change) the **circular moving pointer display followed by the counter elicited the fastest and most accurate responses compared to the moving scale displays (arc shaped and vertical) and the vertical moving pointer display**. These results are relevant to the author's studies as they provide empirical evidence on the types of display formats that are superior for the purpose of qualitative reading which drivers are expected to engage in while reading hybrid fuel gauges.

### 5.1.6. Recommendations on displays for various reading tasks based on comprehensive literature reviews

Several authors like Baker and Grether (1954), Sanders and McCormick (1977), Heglin (1973) and Green (1988) have conducted comprehensive reviews of literature to develop a set of recommendations on types of gauges that are best suited for different types of reading tasks.

#### BAKER AND GRETHER (1954)

Baker and Grether (1954) emphasize the importance of considering the ways in which a display will be used. Based on a literature review, they developed a summary of the advantages and disadvantages of three types of displays (moving pointer, moving scale and counter) for different methods of use (quantitative reading, qualitative and check reading, setting and tracking). Since setting and tracking refer to the control of instrument settings they are out of the scope of this thesis.

**Display formats for quantitative, qualitative and check reading**

The following table summarizes the recommendations made by Baker and Grether based on their literature review.

**Table 5.3: Baker and Grether's (1954) table of recommended displays for different reading tasks**

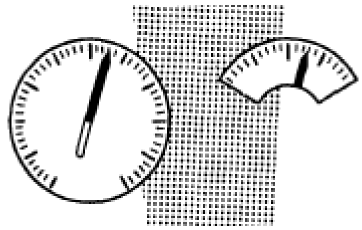
| METHOD OF USE | MOVING POINTER | MOVING SCALE | COUNTER |
|---|---|---|---|
| 1. Quantitative Reading. | Fair | Fair | Good<br>Minimum time and error in obtaining exact numerical value. |
| 2. Qualitative and Check Reading | Good<br>Location of pointer easily detected. Numbers and scale need not be read. Change in position easily detected. | Poor<br>Difficult to judge direction and magnitude of deviation without reading numbers and scale. | Poor<br>Numbers must be read. Position changes not easily detected. |
| 3. Setting | Good<br>Simple and direct relation of pointer motion to motion of setting knob. Pointer position change aids monitoring. | Fair<br>Somewhat ambiguous relation to motion of setting knob. No pointer position change to aid monitoring. Not readable during rapid setting. | Good<br>Most accurate monitoring of numerical setting. Relation to motion of setting knob less direct than for moving pointer. Not readable during rapid setting. |
| 4. Tracking | Good<br>Pointer position readily monitored and controlled. Most simple relation to manual control motion. | Fair<br>No pointer position changes to aid monitoring. Somewhat ambiguous relation to control motion. Not readable during rapid changes. | Poor<br>No gross position changes to aid monitoring. Ambiguous relation to control motion. Not readable during rapid changes. |
| Comments | Requires greatest exposed and illuminated area on panel. Scale length limited unless multiple pointers are used. | Offers saving of panel space. Only small section of scale need be exposed and illuminated. Long scale possible by use of tape. | Most economical of space and illuminated area. Scale length limited only by number of counter drums. |

Based on recommendations in the table, direct reading counters are most suited for quantitative reading. In Grether's (1949) study, the direct reading counter had the fastest response time and highest response accuracy of all designs. However, the applicability of these counters is limited to when only a numeric value is desired. As the task of reading a hybrid fuel gauge is complex requiring qualitative and quantitative reading the use of a counter alone would not be suitable. The advantages of the counter suggest that it may be a useful supplement to indicators that are well suited for qualitative and check reading. For qualitative and check reading where it is important to easily locate the pointer, Baker and Grether recommend the use of a moving pointer display. The advantage of a moving pointer over a moving scale for qualitative and check reading is that numbers and scale need not be read. In moving scale displays judging the direction and amount of deviation becomes difficult without reading numbers and scale.

One of the disadvantages of the moving pointer display is that the scale length is limited to the area available. To overcome this multiple pointers may be used. Another disadvantage of the moving pointer display is that it requires the most area on a panel compared to the moving scale indicator and the counter. On the other hand, moving scale displays require much less space. Additionally, on mechanical moving scale displays a long scale may be used because tape can be wrapped behind the exposed portion of the display. While this was certainly an important advantage when Baker and Grether developed these recommendations, it is not necessarily an advantage in present day where electronic display technologies are becoming more common than mechanical indicators. Counters require the least amount of space on a panel. The paper states one of their disadvantages as the scale length being limited by the number of counter drums. This also assumes a mechanical construction of these counters, which is not necessarily a requirement in present day but rather an option. More and more vehicle manufacturers are using or beginning to use advanced electronic displays (such as LCD screens) in the vehicle dashboard.

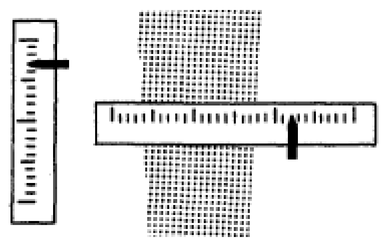
**Variations in display designs**

The paper also compared the variations in display designs in each category of displays. The findings and recommendations made by Baker and Grether are summarized below.



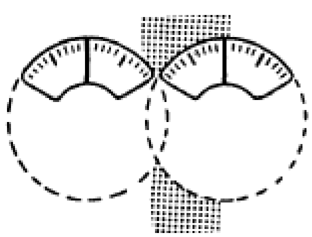
Moving pointer- circular and curved scales

While the longer pointer and rotational movement on the circular and curved scales are both considered to facilitate check and qualitative reading, the circular scale allows for maximum exposed scale length. The circular scale is preferred over the curved scale for a majority of



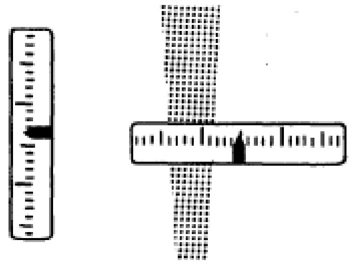
Moving pointer- vertical and horizontal straight scales

The vertical and horizontal moving pointer straight scales have a shorter pointer and lack angular movement. These features make them less favorable for check reading.



Moving scale- circular and curved scale

The partially exposed scale was generally recommended due to its ability to cover a large range of values in the limited panel space. Displays with the full scale exposed were recommended for instruments where tracking was necessary. Baker and Grether describe moving scales as being "poor" for qualitative and check reading and "fair" for



Moving scale- vertical and horizontal straight scales

A moving scale behind an open window may be a moving straight scale, drum or tape. While moving scale designs were not recommended for general use, moving tape designs were recommended as being suitable for quantitative reading of a large range of values.

**HEGLIN (1973)**

Heglin (1973) also made recommendations on considerations for selecting analog displays. He suggested that when an exact quantity is to be displayed with no need for interpolation between numbers or for an indication of direction or rate, a digital counter is preferred. This is because it allows only one number to be seen at a time thus reducing the likelihood of reading errors. When an approximate quantity is to be displayed such as for qualitative check reading, moving pointer fixed scale displays are preferred. The general position of the pointer in such displays gives a rapid clue to the quantity and relative rate of change. It is also recommended that if several displays are to be read rapidly then their pointers should be aligned at 9 o'clock for normal conditions. Heglin also suggested that when scale expansion is necessary, a pointer and an adjacent counter would be best.

Heglin developed a checklist for a good visual display. The first two criteria are of primary importance to this thesis. The first is whether a display can be read quickly in the manner required (check, qualitative or quantitative reading) and the second is whether a display can be read accurately within the needs of the reader (preferably no more accurately). In many of the studies included in this literature review at least one of the two (reading accuracy and speed) have been used as the main measures based on which displays have been evaluated. In the study conducted by the author response accuracy and response time have been used to evaluate the hybrid fuel gauge designs. Some of the other considerations on Heglin's checklist relevant to this thesis are whether or not the design excludes features that are likely to cause ambiguity or gross reading errors, whether or not changes in the reading are easy to detect, whether or not the information provided is in the most meaningful form requiring minimum translation to other units, whether or not the instrument is distinguishable from other displays and whether or not the operator can be easily aware of an inoperative condition. Heglin's checklist also mentions another relevant consideration, which is whether or not the illumination level of the instrument is satisfactory under all considerations of expected operation. While illumination is an important consideration, the evaluation of the hybrid fuel gauge designs for illumination was outside the scope of this thesis. Such an evaluation would require a prototype that can be placed inside the dashboard of the vehicle and the testing of the prototype under conditions of day and night. Additionally, the consideration for ease of detecting an inoperative condition was also outside the scope of this thesis.

**SANDERS AND MCCORMICK (1977)**

Sanders and McCormick (1977) have discussed some of the advantages of different display types in their book chapter on visual displays. They emphasize that the choice of display must be based on a thorough understanding of the nature of the task for which they must be used. They state that counters or digital displays are generally superior to analog displays (circular, horizontal and vertical) for quantitative reading when a precise numeric value is required and when the values presented by the counter remain long enough to be read. The fixed scale moving pointer display (analog) is advantageous over counters when values are likely to change frequently. They allow the reader to have more time to read. They are also useful for qualitative reading where it is important to observe rate or direction of change in reading. In general moving pointers and fixed scales displays are superior to displays with moving scales and fixed pointers. However one of their limitations is that when the range of values to be presented is very large it becomes difficult to present on a relatively small scale. In such situations the open-window (moving scale fixed pointer) displays have advantages in that they occupy a small amount of space. The non-relevant section of the mechanical scale can be wound behind the panel face. These recommendations are in agreement with those made by Baker and Grether (1954) who also recommend the use of counters for quantitative reading and moving pointer displays for qualitative and check reading.

**GREEN (1988)**

Green (1988) conducted an extensive literature review on human factors studies with a goal of providing information for automotive designers and engineers on display design. This paper is unique in that it discusses the applications of findings from instrumentation as well as automotive literature for design of automotive gauges. While many topics of interest are discussed in this paper, only findings related to display types and their applications for reading tasks will be discussed in this section. Additional findings related to pointer alignment, scale markings etc. are discussed in section 4.2 of the literature review. Green discussed findings of various researchers with regard to understanding what type of displays are best for various tasks. He concluded that the choice of the best display depends on how it will be used and to some degree on how well the design follows acceptable human factors practice. If the purpose of reading a display is to determine an exact value then a numeric display should be used. If the purpose of reading is to check whether a display or a group of displays are within certain bounds then a moving pointer display is most suitable. In general, moving scale displays are preferred in only a few situations. In terms of shape, Green concluded that for moving pointer displays, the preferences in the order of most to least preferable are: circular scales, horizontal scales and vertical scales. The reason for this is the shape of the visual field, which is more horizontal than it is vertical and the likely distance of the pointer tip from a fixation point.

### 5.1.7. Summary of recommendations on displays for different reading tasks

In conclusion, it was found that certain types of displays were preferable and better suited for different types of reading.

#### Check reading tasks

Overall, a majority of the researchers **recommend the use of moving pointer fixed scale displays** for check reading (Grether and Connell (1948), Grether (1949), Baker and Grether (1954), Heglin (1973), Green (1988).

#### Qualitative reading tasks

For the purpose of qualitative reading, **moving pointer fixed scales are most suitable**. In terms of which shape is preferred for qualitative reading, there is no conclusive answer from the literature review. Grether and Connell (1948) found the moving pointer on a linear scale to be preferable. Baker and Grether (1954) recommended circular moving pointer displays over curved scale displays for qualitative and check reading. Vertical and horizontal scales are less favorable for qualitative reading. Green (1984) compared bar-type (linear scale) moving pointer displays with numeric displays for a qualitative reading task and found that the bar-type display was superior.

#### Quantitative reading tasks

For quantitative reading, **many researchers recommend the use of direct reading counters** (Grether (1949), Baker and Grether (1954), Sanders and McCormick (1977), Heglin (1973), Green (1988)).

Some exceptions were found because some studies did not include counters in the set of displays evaluated for quantitative reading. Sleight (1948) found the open-window display (moving scale fixed pointer) to be superior while Thomas (1957) found the horizontal display (moving pointer fixed scale) to be most suitable. Additionally, Carveth and Adams (1964) found the circular display (moving pointer fixed scale) to be superior over the vertical display with moving pointer. These discrepancies can be attributed to the fact that in each study a different set of displays was evaluated. Sometimes only moving pointer displays were investigated while in some cases the direct reading counter was not evaluated. Another reason for these differences in findings is the experimental method used. Many studies used a tachistoscopic method of evaluation and used different exposure times. Thomas (1957) found that shape as well as exposure time are significant in determining the reading accuracy of a display. Another exception worth noting is **Green's (1984) study which found digital displays to be inferior to bar-type displays**. This one is of particular interest to this thesis because it was an empirical study that evaluated automotive gauges.

### 5.2. Other display design attributes that contribute to efficiency of reading (speed and accuracy)

The last section reviewed studies that have investigated the effect of **display formats** (moving pointer fixed scale, moving scale fixed pointer, direct reading counter), **display shapes** (circular, semi-circular, linear, curved) and **display orientations** (vertical, horizontal) on reading efficiency based on different reading tasks. In this section of the literature review, studies that investigate other display design attributes that can influence speed and accuracy of reading will be discussed.

#### 5.2.1 Inclusion criteria for studies reviewed in this sub-section

Many authors have investigated a number of different display attributes and their effects on reading efficiency. Studies with findings that were related to the design attributes such as **size, scale, markings, color, spacing and pointers** were included.

Studies by Johnsgard (1953), Ross, Katchmar, Bell (1955), Dashevsky (1964), Green (1984) and Mital and Ramanan (1986) have investigated the effects of **pointer arrangements and orientations** (and other various design attributes) on the speed and accuracy of reading. Additionally, Green (1988), Sanders and McCormick (1977) have made recommendations on pointer arrangements based on comprehensive reviews of literature. Although many of these studies were conducted for check reading tasks, they explore the arrangements of two or more displays, similar to many of the hybrid gauge designs in this thesis. These studies have been included.

Studies by Kappauf and Smith (1950a,b) have been included. These studies have investigated the effects of design attributes such as **spacing of graduation marks**, **graduation mark values, scale range**, **display size** and location of reading on circular displays.

A number of studies have explored the effects of various design attributes on interpolation, which is a form of quantitative reading. It involves the estimation of specific values between markers when the scale design is such that not all scale units have markers (Sanders and McCormick, 1977). Interpolation was directly not involved in the timed comprehension task in this usability study because subjects were not asked what the reading was, but were asked to estimate if they could travel a certain distance. However, these studies were included because their findings are still relevant to the design of display attributes like circular dial diameter, length of scale unit, marker width, pointer design, location of scale numbers, scale orientation, numerical progression etc. Whitehurst (1982) has investigated design attributes like **clutter, length of scale unit, marker width, pointer design, location of scale numbers, scale orientation and numerical**

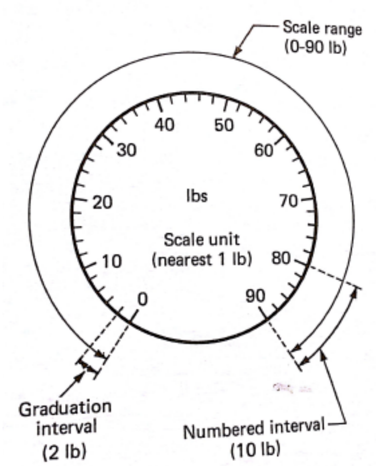
**progression**. Grether and Williams (1949) have investigated the effect of **circular dial diameter, angular separation of scale divisions** and **display lighting (day vs. night) conditions** on the accuracy of interpolation of pointer position. Churchill (1956, 1959) investigated the effect of design attributes like **interval length and pointer clearance** on the speed and accuracy of interpolating to tenths of a scale interval. Churchill (1960) also investigated the effects of **pointer width and scale mark width** on the accuracy of interpolation with different interval lengths.

A number of studies have also investigated the effect of color and contrast on the speed and accuracy of reading. Baker and Grether (1954), Sanders and McCormick (1977) and Green (1984) have discussed the use of **color-coding** in displays. Kurke (1956) has studied the effect of **contrast** on display reading efficiency. Heglin (1973) has discussed the use of color for displays in terms of **color-deficiencies** in people.

### 5.2.2 Various display attributes

This next sub-section reviews studies that investigate various other attributes and features of displays in terms of their effect on reading accuracy. It is worth discussing what some of these features mean before discussing the studies. Some of the main terms used for display features that will be discussed in subsequent sections are: scale range, length of scale unit, numeric progression, numbered interval, graduation interval, interpolation required, use of scale markers, marker width (thickness in inches) and pointer width (thickness in inches), design of pointers and location of the scale numbers. Some of these are self-explanatory (marker width and pointer width). The following display shows a number of the attributes discussed here.

**Figure 5.11: Basic components of a display (Sanders and McCormick, 1977)**




**Scale range:** Sanders and McCormick (1977) define scale range as the difference in numerical value between the highest and lowest values on the scale (whether numbered or not).  With reference to the above display, scale range is 0 to 90 lbs.

**Numbered interval or interval length or scale interval length** is the difference in numerical value between adjacent numbers on a scale. For the above display, the numbered interval is 10 lbs.

**Graduation interval** is the difference in numerical value between the smallest scale markers. The graduation interval for the above display is 2 lbs.

**Scale unit** is the smallest unit to which the scale is to be read. This may or may not be the same as the graduation interval. In the above display the graduation interval corresponds to 2 lbs; however a reader may be required to read the scale for a 1 lb measurement (scale unit).

**Numeric progression** refers to the numbering of the major scale markers. The scale below is design such that the numeric progression is by 10s (0, 10, 20….).

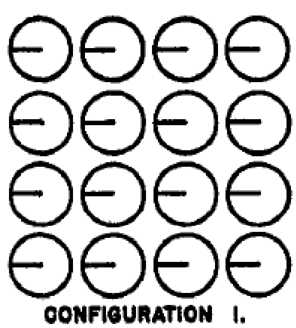
**Length of scale unit** represents the numeric value that is the smallest unit to be read. For example if a display is to be read to the nearest 5 lbs and the scale is designed such that 0.05 inches on the scale represents 5 lbs then the length of the scale unit is 0.05 inches.

### 5.2.3 Effect of pointer arrangement and orientation on efficiency of different reading tasks

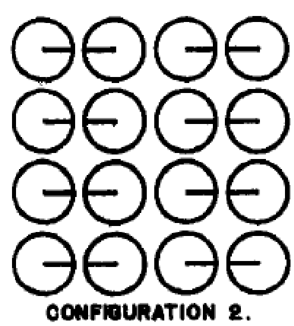
**JOHNSGARD (1953)**

Johnsgard (1953) conducted a study to evaluate the rotating or moving pointer type indicator for check reading to determine which type of pointer pattern (symmetry, alignment or sub-groups) would facilitate highest speed and accuracy of check reading. Four sixteen-display panels were used as stimuli in the study. Each of these four had different pointer patterns and was referred to as a configuration. The null hypothesis was that all four configurations would facilitate check reading equally. The following four configurations were used in the study.

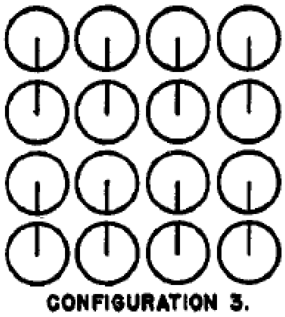
**Figure 5.12: Four configurations showing pointers in the normal or correct position used in Johnsgard's (1953) study.**

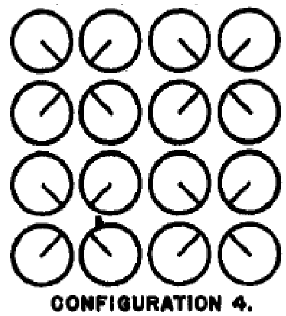



Pointer alignment at 9 o'clock position




Pointer symmetry (horizontal orientation)




Pointer symmetry (vertical orientation)          Pointer sub-groups

Configuration 1 (C1) represents pointer alignment at the 9 o'clock position, configuration 2 (C2) represents pointer symmetry in the horizontal orientation, configuration 3 (C3) represents pointer symmetry in the vertical orientation and configuration 4 (C4) represents a pointer sub-group pattern. For each configuration nineteen stimulus panels were prepared. One of the panels showed the pointers in a null position. The other eighteen stimulus panels were divided into six blocks containing three panels each. Panels in the first block had one deviating pointer, panels in the second block had two deviating pointers and so on such that for the sixth block the panels had six deviating pointers. The displays within a particular panel with deviating pointers were selected randomly and the deviation of the pointer was also random. The deviation was within the range of minimum 15 degrees to a maximum of 180 degrees from the null pointer position.

This was a tachistoscopic study in which the stimulus materials were projected on to a screen. Two subjects were tested simultaneously. Each panel was presented for an exposure time of 0.5 seconds. Johnsgard stated this was the average fixation time for pilots while flying. A total of forty-eight male subjects were tested. Each subject was provided with response sheets containing seventy-two sixteen-display panels on which he was required to check the appropriate display or displays that corresponded to the ones with deviating pointers on the test panel.

The order of stimulus presentation was randomized to eliminate practice effect. The results showed that C3 (pointer symmetry in vertical orientation) was superior to the other configurations for check reading purposes in terms of the number of correct responses. Thus the null hypothesis that all configurations would facilitate check reading equally was rejected. Configuration C3 was followed by C2, then C1 and lastly C4 in terms of correct responses. Configurations C2 (pointer symmetry in horizontal orientation) and C1 (pointer alignment at 9 o'clock position) were similar in performance. Configuration C4 with pointer sub-groups had twice the number of errors as configuration C1 with pointer alignment (9 o'clock position). Thus the configurations evaluated in this study with pointer symmetry (C2, C3) and pointer alignment (C1) were superior to the configuration with pointer sub-groups (C4). Based on an observation of increase in mean score for correct responses between the first configuration presented and the last configuration presented, Johnsgard concluded that a transfer effect existed between configurations.

The following table summarizes the mean scores for correct responses for forty-eight subjects. Each subject was exposed to sixty-three deviating pointers, based on which the percentage of error has been calculated by the author for each configuration.

**Table 5.4: mean scores for correct responses for 48 subjects (Johnsgard, 1953)**

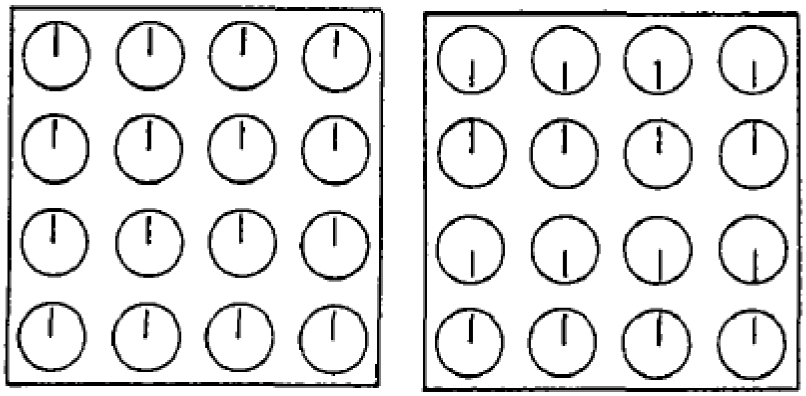
| Configuration | Mean score (correct responses) | % error |
|---|---|---|
| 1 | 30.19 | 52.07 |
| 2 | 31.46 | 50.06 |
| 3 | 34.48 | 45.26 |
| 4 | 17.54 | 72.15 |
| | | |

There are some concerns with Johnsgard's study. It can be seen from the above table that overall the percentage of reading errors made by the participants was quite high (45% and higher). To some degree, the high number of reading errors can be attributed to the short exposure time used in the study. Johnsgard stated in the paper that the exposure time of 0.5 seconds was the average fixation time for pilots while flying. He referenced an unpublished Master's thesis by Johnson (1950) as a source for this information. The author was unable to find this document. If this is indeed a valid assumption, then that would imply that the four configurations explored in his study were not suitable for check reading particularly in airplanes where such high reading errors could have fatal implications. There were other variables in the study that have not been evaluated such as the effect of the amount of pointer deviation from null position and the number of deviating pointers on reading accuracy.

### ROSS, KATCHMAR AND BELL (1955)

In another study Ross, Katchmar and Bell (1955) evaluated the difference between uniform and symmetrical pointer alignment for check reading purposes. They also assessed the effects of practice on reading accuracy for these two alignments. A total of twenty-four subjects (eighteen male and six female) participated in two studies. Subjects were randomly divided into two groups, A and B. Each group consisted of three female subjects. Each group was tested separately. Each subject was provided with a test booklet containing sixty-nine sixteen-dial panels to record his or her responses. Subjects were instructed to determine which (if any) of the dials had a pointer pointing in a different direction from other pointers when a panel was presented. On each presentation for one of the dials the pointer deviated by ninety degrees from the general direction. Sixteen single pointer dials arranged in a four-by-four pattern were mounted on a plywood block. Three configurations of dial arrangement were used. In the first configuration (C1) all pointers were aligned at the 12 o'clock position, in the second configuration (C2) the pointers were opposing each other at the 6 and 12 o’clock positions and in the third configuration (C3) all pointers were aligned at the 6 o’clock position. The configurations were projected on to a white screen. The exposure time for each projection was 0.33 seconds.

**Figure 5.13: Two of the three configurations used in this study by Ross, Katchmar and Bell (1955)**



Configuration 1 Configuration 2

In each test session two of the three configurations were used. Each session involved thirty-two presentations of one configuration followed by thirty-two presentations of the other configuration, so that each of the sixteen dials in a configuration was shown twice with deviations (once to the right and second time to the left). Two types of errors were found in the data. One type of error was observed when a subject could not identify which dial was “different” (positional errors). The second type of error was observed when a subject could not identify the direction of pointer deviation (directional error). The first experiment involved configurations one and two. The two groups of subjects were presented with the two configurations in opposite orders. The results indicated that configuration two (pointer symmetry) was more difficult (at least initially) compared to configuration one (pointer alignment) during the early stages of practice.

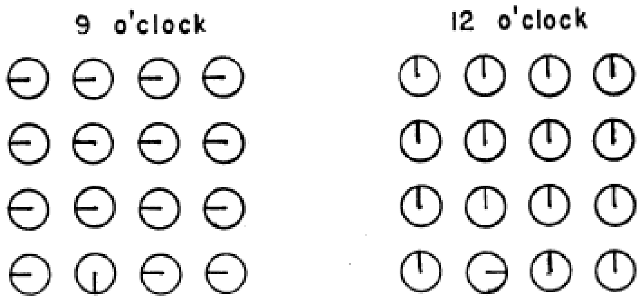
A second follow-up experiment was conducted to verify the results of the first experiment with a uniform pointer alignment configuration (at 6 o’clock) and to determine the effects of further practice. Each group was given two test sessions, a week apart. The experiment involved configurations two and three. Like in the first experiment, the two groups were presented with two configurations in opposite order. For both configurations it was found that the differences in mean for positional and directional errors in session were very small indicating that both configurations were equally effective.

The results of these studies show that for check reading purposes, pointer symmetry is equally effective as uniform pointer alignment after extended practice. Contrary to Johngard's (1953) finding that pointer symmetry may be superior to uniform alignment, the results of this study favor uniform alignment. Ross, Katchmar and Bell attribute this difference to the different exposure times between Johngard's study and theirs. While Johnsgard's study used an exposure time of 0.5 seconds, their studies used an exposure time of 0.33 seconds due to their belief that differences between the configurations would be revealed under more demanding circumstances.  It was also found that transfer effects from pointer symmetry to uniform alignment were greater than transfer effects from uniform alignment to pointer symmetry. This was indicated by the greater reduction in mean positional and directional errors when the order of presentation was C2 first and C1 second.

**DASHEVSKY (1964)**

Dashevsky (1964) conducted two studies to determine other ways of arranging multiple dials for check reading so as to increase the probability of detecting errors. In the first experiment, two configurations were evaluated, one with pointer alignment at the 9 o'clock position and another with pointer alignment at the 12 o'clock position.  These were evaluated in two positions with respect to the subject (directly in front and to the side). The reason for this was to investigate if there were differences in eye movement between the display and work surface for the two positions and whether eye movements were more natural in certain conditions. It was hypothesized that the 9 o'clock pointer position would prove to be superior when the display was by the subject's side while the 12 o'clock pointer position would be superior when the display was in front of the subject.

**Figure 5.14: Configurations used in experiment 1 by Dashevsky (1964)**




A total of twenty-five male subjects participated in the first experiment. Cards simulating the four-by-four display configurations were projected on to a screen. Subjects were instructed to indicate whether all pointers were aligned and which was the deviant dial if a dial was not aligned. Subjects were run in three groups of eight to ten each. For the side presentation subjects turned their chairs ninety degrees such that half the subjects had the display to their right and half had it to their left. Twenty cards were presented sequentially for 0.5 seconds each for each of the four conditions: 9 o'clock front, 9 o'clock side, 12 o'clock front and 12 o'clock side. Ten of the twenty cards contained one non-aligned dial. The order of presenting cards within a set and the order of presenting sets were randomized. Errors were defined as missing a deviation and reporting one for a null display. Identifying a wrong dial as one with a deviation was considered a half error. The results of the first experiment showed that there were no significant differences between the 9 and 12 o'clock positions of pointer alignment. There were also no significant differences between the frontal and peripheral modes of presentation.

In the second experiment Dashevsky evaluated the three modes of display alignment; the first according to Johnsgard's (1953) method and the second similar to Johnsgard's method but rotated 45 degrees for a possibly more natural configuration and the third according to Gestalt theory principles of good form and closure.

**Figure 5.15: Dial configurations used in experiment 2 by Dashevsky (1964)**

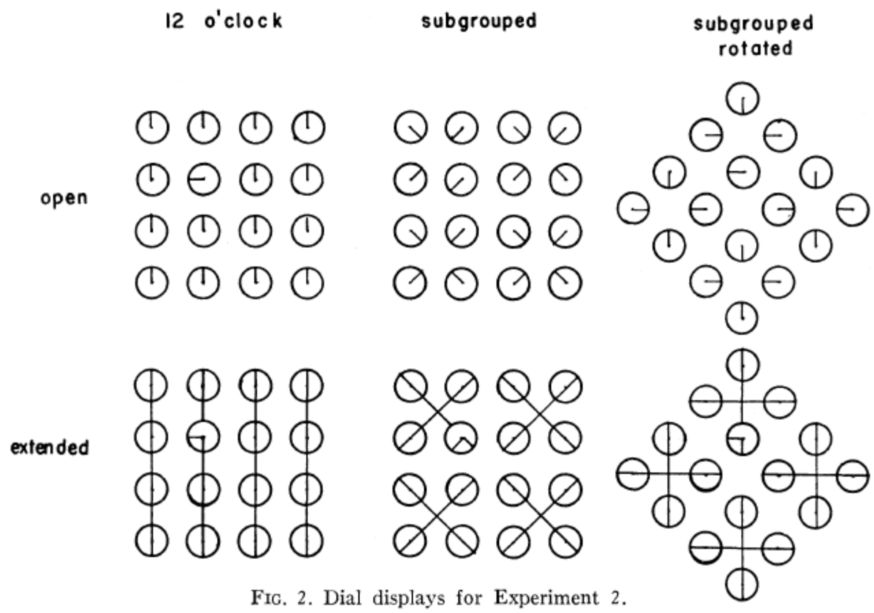



FIG. 2. Dial displays for Experiment 2.

A total of eighteen subjects participated in experiment two, some of which had also participated in experiment one.  From the dial configurations shown above it can be seen that the main variable studied was the continuing lines between the dials that were extensions of the pointers in null position.

There were a few differences in the conditions between experiment one and experiment two. Fifteen of twenty cards had one deviant dial. In addition to 90 and 270-degree deviations, a 180-degree deviation was also used.  Only gross errors were scored (no half errors). Each card was presented for 0.5 seconds.

The results showed that by extending pointers errors for all modes of patterning were reduced by almost 85%. The 12 o'clock position elicited fewer errors than the sub-grouped and sub-grouped rotated modes. Also, rotating the sub-grouped display resulted in an increase in number of errors made.

Dashevsky (1964) concluded that for a four-by-four matrix of dials, there seemed to be no consistent difference between the 9 and 12 o'clock positions of pointer alignment. Frontal and peripheral positions of the subject did not seem to have any interactions with the 9 and 12 o'clock positions of pointer alignment. Extending of lines made by pointers can greatly reduce errors since single deviant pointers appear as breaks in a line.

**GREEN (1984)**

Green (1984) conducted a study with sixty-six drivers to investigate display formats for automotive fuel gauges and to evaluate their understanding and knowledge of instrument panel displays for vehicles. The study has been described in detail in section 4.1.4. In his study, Green found that there were benefits in the grouping of gauges with their pointers aligned. It was found that this grouping reduced error rates by 5%. When indicating normal conditions the pointers of the engine gauges should be aligned.

**MITAL AND RAMANAN (1986)**

Mital and Ramanan (1986) conducted a tachistoscopic study to evaluate the influence of design attributes like pointer position, percentage of deviant dials and background color on the accuracy of check reading. Additionally, they investigated the effect of operator sex and exposure time as well. While previous studies have investigated pointer position, Mital and Ramanan claim they were the first to study the influence of factors such as exposure time, background color of the dial and percentage of deviant dials present on the accuracy of check reading. They hypothesized that these factors would have a strong influence on check reading. A total of fifty subjects (twenty-eight males and twenty-two females) participated in the study. Extended pointer dials were used in this study based on Dashevsky's finding that they lead to superior performance. A randomized complete block factorial design with blocking on subjects was used. Exposure times investigated were 0.25, 0.50 and 0.75 seconds. Pointer positions at 9 and 12 o'clock were evaluated to determine which one was superior. In order to determine performance changes with the number of deviant dials, the percentage of deviant dials (1%, 2% and 3%) was evaluated. The study also investigated background color of dials (black dials on white background vs. white dials on black background). A total of thirty-six combinations were presented to each subject (three exposure times, two pointer positions, three percentages of deviant dials and two background colors). The presentation order was randomized for each subject. Ninety slides were shown for each combination; thus each combination had a total of one thousand four hundred forty dials (ninety slides with sixteen dials per slide). Each slide had at most one deviant dial. There were fifteen slides with a deviant dial for the 1% deviant dial condition (0.01 X 1440 = 15), twenty-nine slides for the 2% deviant dial condition and forty-four slides for the 3% deviant dial condition.

**Figure 5.16: Dials used by Mital and Ramanan (1986) in their study**

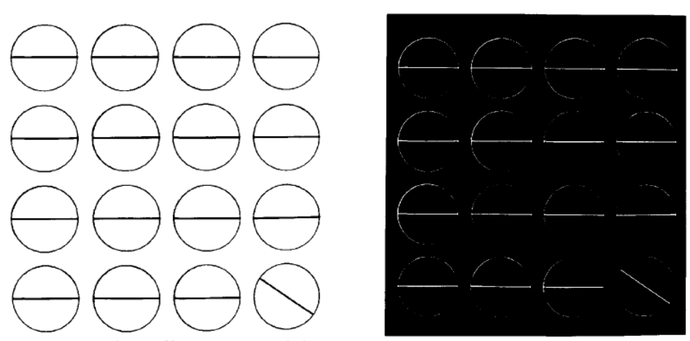


Figure 1. *4 × 4 cluster of black instrument dials on white background.*

Figure 2. *4 × 4 cluster of white instrument dials on black background.*

The results of the study showed that males made 36% less errors than females. This finding could not be explained by Mital and Ramanan as there were no procedural differences nor were there any large differences between the subjects in terms of experience, training or age. The effects of exposure time and background color were highly significant. Pointer position and percentage of deviant dials had no effect on efficiency of check reading. It was also seen that as exposure time increased the number of errors made decreased. It was concluded that the accuracy of check reading is a function of viewing time with fewer errors being made with a relatively long exposure time. Interestingly, performance differences between males and females became insignificant at the exposure time of 0.75 seconds. It was observed that in general, fewer errors were made with black dials and pointers on white backgrounds than with white dials and pointers on black backgrounds, but this trend changed for the exposure time of 0.75 seconds. At this exposure time the performance of subjects was better with the black background. Although theoretically both combinations have the same contrast and should not elicit such performance differences, this was not the case. Mital and Ramanan concluded that the selection of background color was important for check reading and that depending on the routine exposure time either a black or white background should be selected. Both 9 and 12 o'clock positions did not elicit any performance differences between males and females. The 12 o'clock position is recommended since subjects expressed a preference for that position.

**GREEN (1988)**

Based on an extensive literature review that included the studies discussed above and additional ones, Green (1988) concluded that pointer alignment facilitates check reading of displays. It was found that there was no single best position for pointer alignment for check reading. However, the cardinal clock positions of 3, 6, 9 and 12 o'clock were superior to other pointer arrangements (sub-groups etc.). The extension of pointers to cover the entire dial face also facilitated check reading. In terms of providing extension lines for pointers it was not found to improve performance in well practiced tasks. Green stated that this feature could be helpful but it lacked experimental validation. Most of the studies examined the issue of pointer alignment for circular moving pointer dials. Although it is believed that the findings from circular dials can be applied to linear scales, there is no experimental evidence to support this. Green also stated that while there are few cars with sixteen dials to show engine performance, these principles of pointer alignment are applicable even with two gauges.

**SANDERS AND MCCORMICK (1977)**

Sanders and McCormick (1977) stated that with round instruments, in the normal position pointers should be aligned at the 9 o'clock or possibly the 12 o'clock position. They explained that the advantage of such alignment is based on gestalt theory, which describes the human tendency to perceive complex configurations as complete entities. Thus any feature that is "at odds" with the configuration can be detected immediately.

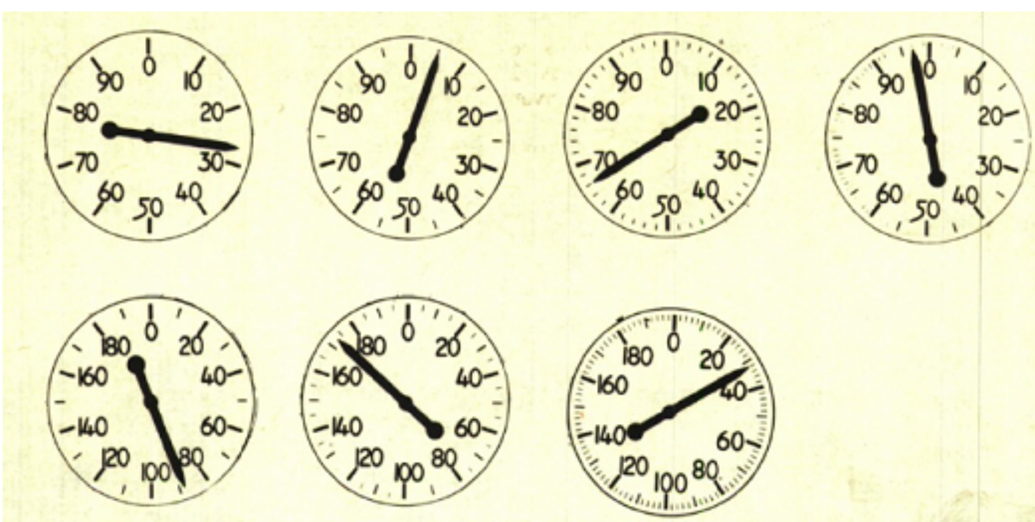
### 5.2.4 Effects of spacing of graduation marks, graduation mark values, scale range, display size and location of reading on circular displays

**KAPPAUF AND SMITH (1950a)**

Kappauf and Smith (1950a) investigated the relative difficulty of quantitative reading in different portions or sections of linearly graduated circular dials. Two studies were conducted. In the first study eight subjects were tasked with reading seven types of dials in one hundred different pointer positions. In the second study twenty subjects were tasked with reading fifteen different types of scales. A total of forty-five thousand readings were involved in the two experiments combined.

In the first experiment, each subject was exposed to twelve identically designed dials on each stimulus card presented. The central ten were test dials. Of the seven different dial designs, four were 0-to-100 dials and three were 0-to-200 dials. The dials were graduated at every ten units, every five units and every two units.  There were two dial sizes: 2.8 inches diameter and 1.4 inches diameter. A total of one thousand four hundred test dials were involved: one hundred for each type and size of dial. In each tenth of the dial a set of ten distributed readings was developed. The settings were distributed systematically on each dial so that the frequency of occurrence for settings would be balanced within successive dial tenths. Eighty stimulus cards (four types of scale, two sizes of dials and ten cards for each type/size combination) for 0-to-100 dials were divided into two balanced decks of forty cards each. Similar test decks were prepared from sixty 0-to-200 dial cards. Subjects were instructed to read dials as rapidly as possible and to make each reading to the nearest unit.

**Figure 5.17: Circular dials used in the first experiment by Kappauf and Smith (1950a). These are negatives of those actually read in the experiment.**



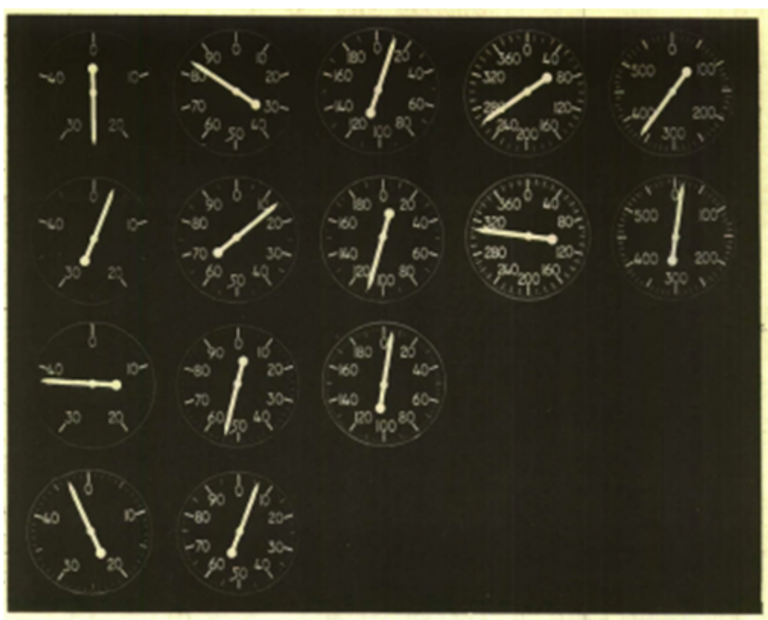
The purpose of the second study was to collect supplementary evidence on the sector question (does the sector have an effect on reading errors?). Twenty subjects made readings on fifteen different types of dials. The experiment method was similar to that of the first experiment. An important difference was that the sectors within which the pointer settings were balanced in final digit distribution were not as small as dial tenths. Fifteen dial designs were used with dials scaled from 0 to 50, 0 to 100, 0 to 200, 0 to 400 and 0 to 600. They were graduated by ten unit intervals, by five unit steps, by two unit steps or single units. The diameter sizes were also the same as the dials in the first experiment (1.4 and 2.8 inches).

Kappauf and Smith (1950a) define **local scale errors** as errors of one and two units and **systematic errors** as errors of 5 units or more. **Reversal errors** are defined as the errors of reading a scale in the wrong direction from a numbered graduation. The data from the study showed no evidence indicating that local scale reading errors (errors of one or two units) were more likely in one part of the dial versus another. It was found that systematic errors (of five or more units) were made with greater frequency on the right half of the dials than on the left half of the dials. The most clearly identified systematic error was the one where values reported were too large by ten units. Although reversal errors (in which the scale is read in the wrong direction from a numbered graduation) were rare it was found that reversal errors occurred dominantly on the right half of the 0-to-50 and 0-to-100 dials.  These have been attributed to the fact that on the right half of clockwise dials, the values increase downward, which is opposite to that of conventional scales in which the values increase upward. Kappauf and Smith recommend that all other things being equal, **circular dials with low scale value ranges and numbered by tens should be oriented such that the region of the scale where the most frequent or critical quantitative readings are to be made appears on the left half of the dial**.

**KAPPAUF AND SMITH (1950b)**

In another study conducted by Kappauf and Smith (1950b) they evaluated the influence of spacing of graduation marks, graduation mark values, scale range and dial size on reading times and dial reading errors. The study involved twenty subjects who were tasked with reading dials on cards with twelve dials each. Dials evaluated had scale ranges of 0 to 50, 0 to 100, 0 to 200, 0 to 400 and 0 to 600 units and graduations by tens, fives, twos and ones. A total of thirty-four thousand, four hundred readings were made. The study apparatus and procedure was similar to the one used by Kappauf and Smith in the previous study (1950a). The diameter sizes for the dials were 1.4 and 2.8 inches.

**Figure 5.18: Dials used by Kappauf and Smith (1950b). These are negatives of the dials actually read in the experiment.**



Kappauf and Smith (1950a) define **local scale errors** as errors of one and two units and **systematic errors** as errors of five units or more. The results showed that for quantitative reading, **local or small errors vary significantly with the interval size and graduation scheme**. It was found that the thickness of the graduation mark was a secondary factor on which the precision of reading depended. The frequency of large errors and reading times varied critically with scale range but was influenced less by dial size or by the graduation schemes used in this study. The study also provided evidence that accuracy of visual interpolation in tenths is optimal when scale interval length is about 0.5 inches or less (for reading distances of 24 to 30 inches but may hold for shorter distances such as 12 inches). It applies to scales where marks are 0.015 inches in stroke thickness.

**5.2.5 Effects of numeric progression, scale markers, graduation length, dial diameter, pointer clearance and other design attributes on interpolation**

Interpolation is a form of quantitative reading. It involves the estimation of specific values between markers when the scale design is such that not all scale units have markers (Sanders and McCormick, 1977). Another term used for interpolation is "rounding". When reading quantitative scales a number of design factors can influence the accuracy of interpolation and hence affect reading time and accuracy.

A number of studies have investigated the effects of various design attributes like clutter, scale unit length, marker width, pointer design, location of scale numbers, scale orientation, numerical progression, interval length, labeling schemes, pointer clearance, pointer width, circular dial diameter, angular separation of scale divisions and display lighting on the speed and accuracy of interpolation.

**WHITEHURST (1982)**

Whitehurst (1982) conducted two experiments with a goal of determining the influence of eight independent variables on speed and accuracy of reading for moving pointer fixed scale displays. The eight variables investigated were clutter, whether or not interpolation was involved, length of scale unit, marker width, pointer design, location of scale numbers, scale orientation and numerical progression. The importance of this study is that it provides guidance on which variables are most influential on reading accuracy.

Screening designs were used in the experiments. Simon (1977) describes screening designs as systematic data collection plans that are useful for identifying important factors and their effects. Screening designs have advantages over traditional experiments in that they allow factors to be ordered according to size of their effects and for discovery of interactions among the factors within the same experiment. Thus instead of having to conduct three or four experiments with replicated designs and collecting redundant information as is the case with traditional experiments, screening designs allow a number of factors to be examined with minimum redundancy, maximum amount of information and relatively few observations.

The first experiment involved two screening designs and the eight variables mentioned earlier. A total of sixteen subjects (twelve females and four males) participated and six females and two males were assigned to each design. Each screening tested sixteen out of two hundred fifty-six total possible combinations. Each subject was tested for each of the sixteen conditions. In the first experiment sixty-four black-on-white displays were presented, thirty-two for each of the two screening designs. In the second experiment sixty-four white-on-black displays were presented.

**Figure 5.19: Four displays used in Whitehurst's (1982) study**

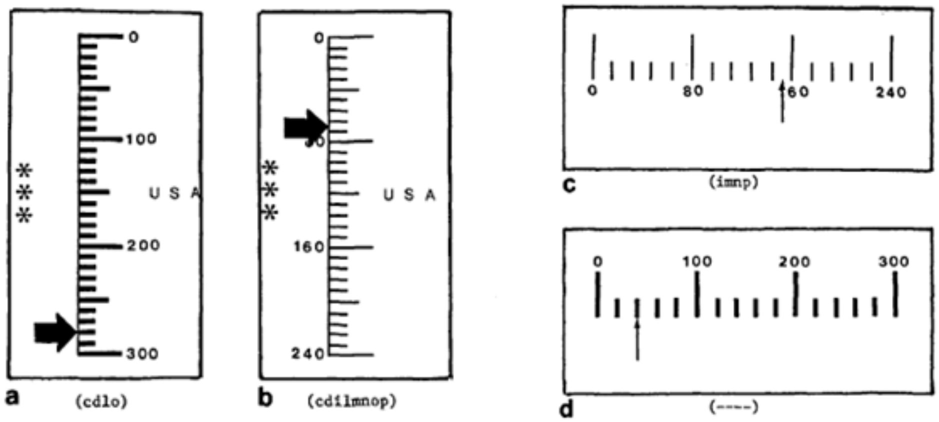



**Table 5.5: The two levels of the independent variables used by Whitehurst (1982)**

Independent Variables and Levels

| | Level | |
|---|---|---|
| *Independent Variable* | + | − |
| Clutter | Yes | No |
| Pointer Design (width) | 6.4 mm | 0.8 mm |
| Interpolation | Yes | No |
| Scale Unit Length | 3.2 mm | 6.4 mm |
| Marker Width | 0.8 mm | 1.6 mm |
| Scale Number Location | In | Out |
| Scale Orientation | Vertical | Horizontal |
| Numerical Progression | 8 or 16 | 10 or 20 |

Each of the eight independent variables was tested at two levels, which were determined from previous studies and could be presented on real displays. It was expected that the plus level of each variable would require longer response times and lead to more errors compared to the minus level.

Four displays were evaluated in the experiment, all of which were linear or rectangular. The displays differed in the amount of clutter presented to the participants. Response time and errors were the two main dependent variables. Subjects were also asked about their preference for black-on-white versus white-on-black displays.

The results of the two experiments showed that the independent variables of numerical progression, interpolation and scale unit length were of most importance. Numerical progression was found to be statistically significant across displays and screening designs and accounted for a large share of the time and error data variance. It was also found that **scales with numeric progression in tens or twenties were read faster and with fewer errors than those with increments of eight or sixteen**. Interpolation and scale unit length accounted for less of the time and error data variance but were also found to be significant. **Displays were read faster and with fewer errors when interpolation was not required and when scale markers were widely spaced**. While there was no significant difference between mean times for black-on-white and white-on-black displays, subjects made significantly more errors when reading black-on-white displays. However, black-on-white displays were preferred by majority of the subjects. Whitehurst states that this was possibly because the overall luminance was greater for these compared to white-on-black displays. The contrast of the light scale and pointer against the dark dial face was greater for the white-on-black displays than it was for the black-on-white displays. Whitehurst states this as a possible explanation for why subjects were able to read more accurately on white-on-black displays.

**GRETHER AND WILLIAMS (1949)**

Grether and Williams (1949) conducted a study with eighty male subjects to evaluate the effect of circular dial diameter, angular separation of scale divisions and lighting (day vs. night) conditions on the accuracy of interpolation of pointer position. A set sixteen simulated instrument dials covering a range from zero to fifty units was prepared. The dials varied in diameter sizes (1, 1 7/8, 2 ¾ and 4 inches). For each dial size four different graduation intervals were used. These were defined in terms of the angular separation between scale marks as five, ten, twenty and forty degrees. Graduation marks were at the zero, ten, twenty, thirty, forty and fifty positions with numerals at zero and fifty only.

Four groups of twenty subjects each were tested on four dials, one of each diameter and one of each graduation interval. Half of the twenty subjects were tested in simulated day conditions and the other half were tested in simulated night conditions. A total of two hundred readings were obtained on each of the sixteen dials for each lighting condition. Subject responses were obtained in the form of error and response time data.

The results showed that as the **graduation interval increased up to approximately 0.5 inches the relative interpolation error decreased**. At higher intervals the interpolation error was nearly constant. For the two different lighting conditions, the **accuracy of interpolation was independent of the lighting except for the most closely spaced divisions**. Although the measurements made for the response time were crude, it was concluded that the **speed of dial reading was not systematically related to the dial diameter or angular spacing of scale marks**.

**CHURCHILL (1956)**

Churchill (1956) investigated the effect of interval length and pointer clearance on the speed and accuracy of interpolating to tenths of a scale interval. The study used single-scale intervals to eliminate the effects of scale reading. Six scale intervals of 0.25, 0.50, 0.75, 1.0, 1.5 and 2.0 inches were used in the study. A formal definition of scale interval length was not provided. The author believes that by scale interval lengths Churchill is referring to the distance in numeric value between adjacent numbers on the scale. The pointer tip was 0.03 inches thick and could be adjusted to achieve clearances of 0, 0.125, 0.25, 0.50, 1.0 and 2.0 inches between the pointer tip and the scale reference line. The displays were viewed through an aperture. Between the aperture and the display was a shutter. In the first part of the experiment the shutter was closed when the subject pressed a micro switch while in the second part, a timer controlled the shutter such that the display was exposed for 0.3 seconds. Nine interpolated pointer positions were presented twice under each of the thirty-six conditions. A total of ten subjects participated in the experiment. Each subject was presented with the six scale intervals in random order and for each interval the six pointer clearances were also presented in random order. Thus each subject observed thirty-six conditions and made one hundred eighty readings for each condition under speed and accuracy instructions. Viewing distance was a constant twenty-eight inches.

The results showed that there was a significant decrease in errors and reading time as the pointer clearance was reduced from 2.0 to 0.125 inches. There was also a significant decrease in errors and reading time as the scale-interval length was increased from 0.25 to 1.5 inches. These results are true for both situations where the subject controlled the exposure of the display as well as for the 0.3 second exposure time. It was also observed that there was a tendency toward increased errors on any scale interval that was preceded (in terms of presentation order) by a shorter scale interval. There was also a relationship between interval length and direction of errors. On short scale intervals (less than two inches) and pointer clearances, majority of errors tended to be toward interval extremes. On long scale intervals (two inches and above) and for the pointer clearances, a majority of the errors were towards the midpoint. It appeared that 1.0 inch was the transition point for both scale interval length and pointer clearance.

**CHURCHILL (1959)**

Churchill (1959) conducted two studies to determine the optimal scale interval length for interpolating in tenths and the effect of viewing distance on this optimal interval length. The first study involved seven horizontal scale intervals of 0.25, 0.5, 0.75, 1.0, 1.5, 2.0 and 3.0 inches. Two numeral markings were made above the scale; zero at the extreme left of the interval and ten to the extreme right. The clearance between the pointer tip and the horizontal scale line was 0.125 inches. Three viewing distances of 28, 56 and 84 inches were used in the study. The study was conducted with twenty-four subjects. An exposure time of 0.5 seconds was used with an inter-exposure time of 4 seconds for the subject's response. At each viewing distance for each of the seven scale intervals, eighteen settings were presented (two at each pointer position from one to nine in random order). For the distances of 56 and 84 inches the 0.25 inches scale interval was not presented as interpolating from shorter scale intervals at longer viewing distances was considered to be difficult. The results of the study showed that a scale interval length of 1.0–1.5 inches resulted in the least number of interpolation errors irrespective of the viewing distance. Also based on the findings it was concluded that the law of the visual angle did not apply to the displays and conditions used in this study. The law states that an increase or decrease in viewing distance should be accompanied by a proportional increase or decrease in display dimensions so as to maintain a constant visual angle.

In the second study, the dimensions of line thickness, pointer and numeral size (kept constant in the first study) were kept proportional to the variations in scale interval length. Thus the dimensions subtended the same visual angles at different viewing distances. The projection apparatus allowed variations in interval length to be accompanied by proportional variations in the dimensions of all component parts. The study was conducted with five subjects who were presented with nine combinations of interval length and viewing distance (0.5 and 1.5 inch intervals at twenty-eight inches viewing distance, 0.5, 1.0 and 3.0 inch intervals at fifty-six inches, and 0.5, 1.5 and 4.5 inches at eighty-four inches viewing distance). Exposure time was 0.25 seconds with inter-exposure time of four seconds for the subject's response. The intervals were selected to allow a comparison of two interval lengths (0.5, 1.5 inches) and two visual angles (approximately one and three degrees) at the three viewing distances. The test was repeated one week later. It was found that for the smaller visual angle of one degree, as viewing distance was increased the number of errors decreased. However for the larger visual angle of three degrees, the number of errors decreased as the viewing distance was decreased. The 1.5 inch interval was found to be optimal at all three viewing distances even though it subtended a one degree angle at a viewing distance of eighty-four inches and three degree angle at a viewing distance of twenty-eight inches.

**CHURCHILL (1960)**

In a subsequent study, Churchill (1960) investigated the effects of pointer width and scale mark width on the accuracy of interpolation with different interval lengths. A preliminary experiment was conducted with five subjects to investigate the effect of the ratio of pointer width to scale unit width on accuracy of interpolation and on scale interval length. The experiment involved three different displays. One had a 0.5 inch interval and 1.0 scale unit wide pointer. A second display had a 1.5 inch interval with 1.0 scale unit wide pointer. A third display had a 1.5 inch interval with a 0.33 scale unit wide pointer. It was found that the increase in pointer width from the 0.33 scale unit to a 1.0 scale unit on the 1.5 inch interval resulted in the reduction of errors from 25.6% to 14.4%. The increase in interval length from 0.5 inch to 1.5 inch with a 1.0 scale unit wide pointer resulted in very little error reduction. In the main study, Churchill investigated the effect of pointer width and scale mark width on accuracy of interpolation in tenths for scale intervals of different lengths with ten female subjects. Displays with three different interval lengths (0.5, 1.5 and 3.0 inches), three pointer widths (0.25, 1.0 and 4.0 scale units) and two scale mark widths (0.25 and 1.0 scale units) were evaluated. These eighteen conditions were tested at viewing distances of twenty-eight and fifty-six inches. The results showed that a pointer width of one scale unit (which ranged from 0.0125 to 0.30 inches in thickness) elicits greater accuracy than a pointer of narrower or wider width. It was also seen that the accuracy of interpolation was increased when this optimal pointer width (1 scale unit) was combined with a scale mark width of 1.0 scale unit. These results are different from those found by Kappauf and Smith (1950b) who stated that the accuracy of interpolation is optimal for scales with a mark thickness of 0.015 inches. It is important to note that Kappauf and Smith evaluated circular displays while Churchill evaluated displays consisting of one horizontal interval. It was also found that pointer width had some effect on optimal interval length. Interpolation was equally accurate on the 0.5 inch interval with a one unit pointer width as on the 1.5 or 3.0 inch interval with 0.25 or 4.0 unit pointer width. Churchill also noted that at the twenty-eight inches viewing distance, accuracy was greater on the 1.5 inch interval while for the fifty-six inches viewing distance it was greater for the 3.0 inch interval. Contrary to Churchill's previous study (1959) viewing distance may have an effect on optimal interval length.

**GREEN (1984)**

As part of his study Green (1984) investigated various labeling schemes for displays. The experimental method and the other results from his study have been described earlier in section 4.1.4. The results showed that in terms of scale labeling, drivers understood all of the existing labeling schemes for analog fuel displays but had varying levels of difficulty in understanding digital fuel displays. It was interesting to find that drivers ranked the scale labeled "E- ½ -F" as most informative. Gauge designs with letters "0-F", "0-R-F","R-F" were ranked as least informative. There was some confusion with the labeling schemes used in the study using the letter "R" ("R-F", "0-R-F"). Subjects did not know what "R" meant (reserve, refill or refuel). Also it was found that the acceptable range on a gauge should be labeled "normal". The next preferable labeling option after "normal" is "norm" followed by "ok" even though this requires minimum space. It was also found that participants were confused about where the "empty" indication was for the multiple segments bar type displays. This was because no segments were on in this condition. It is suggested that the displays should use the word "empty" or have a circled "E" or low fuel indication marks. Some drivers were unsure whether fuel remaining or fuel consumed was being shown. Green recommended that the labels “gallons left” and “liters left” should be considered. It was also found that there were differences in rankings based on age. Young drivers ranked the design that used “miles to empty” as number one and older drivers ranked designs that used “gallons”. Green suggested the use of “gallons left” as the label. In general drivers ranked English units to be more understandable than metric units and Green recommended that metric units not be used in instrument panels for the American market.

Another important recommendation is that bar type scales should be labeled such that an increase is reflected by up and to the right. Reversed scales led to an increased number of reading errors. One other noteworthy finding was that some drivers misunderstood large numbers often assuming that a decimal point was missing. This was because for seven-segment numeric displays, there is a space to the left of the digit “1” which caused these errors. Green recommended that for seven-segment displays the decimal point should be shown in order to minimize this error.

### 5.2.6. Effects of color on speed and accuracy of reading

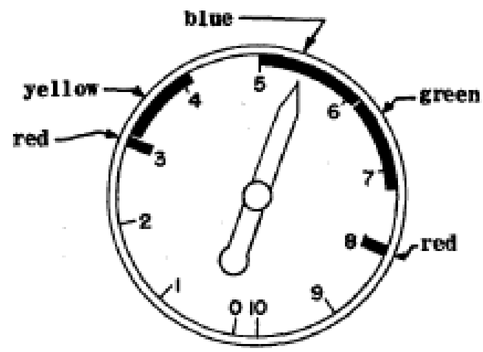
A number of studies have investigated the effects of color-coding and contrast on the reading efficiency of displays. Kurke (1956) and Green (1984) have conducted empirical studies on color while the other authors (Baker and Grether (1954), Heglin (1973) and Sanders and McCormick (1977)) have provided recommendations based on comprehensive literature reviews.

### BAKER AND GRETHER (1954)

Baker and Grether (1954) have discussed the use of color-coding to represent different operating conditions on a display. They recommend that color-coding should not be used if the instrument is to be illuminated with a colored light such as red as colors are not distinguishable when illuminated by colored sources.

**Figure 5.20: Example showing the use of color-coding in displays (Baker and Grether, 1954)**

| Color | Condition |
|---|---|
| red............ | danger |
| yellow......... | caution |
| green.......... | desirable – auto rich |
| blue........... | desirable – auto lean |
| no marking..... | inefficient |




Baker and Grether also discussed some of the implications of selecting certain colors on people with significantly reduced abilities to distinguish color differences. While 6% of the healthy male population has reduced abilities for color differentiation only 0.003% of the population is completely color blind (only see various shades of gray). Even so, it is important to understand these deficiencies and design displays to accommodate the needs of this population. Four colors are considered ideal for color-coding because color deficient individuals can also recognize them easily. These **colors are black, white, yellow and blue**. There are additional colors that are considered to be least confusing for individuals with normal and color defective vision. These are red, orange, purple, gray and buff. In terms of the ability to recognize colors correctly it was found that red and green signal lights are rarely interchanged.

**KURKE (1956)**

Kurke (1956) evaluated a dial design for reading speed and accuracy for the purpose of check reading. The design is unique in that when the indicator is pointing to a section of the dial indicating caution or danger then a high contrast wedge appears on the dial. This wedge is not present when the machine is operating within safe and normal limits. The design is based on the principle that visual perception and interpretation of high contrast figures of known symbolism is easier than the reading a scale. Changes in shape, area, hue and brilliance are likely to attract the eye of the reader.

A total of thirty-three males subjects participated in the study. They were required to engage in card sorting. Four decks of fifty index cards were prepared. Three of the decks (named A, B and C) had dial faces drawn on the cards. Each dial was two inches in diameter and numbered clockwise from 0 to 10 along the periphery at 22.5 degree intervals with 0 at the 12 o'clock position. The dial indicator was drawn to point to the numbers from 0 to 10 and also to 0.5, 1.5, 8.5 and 9.5 positions. Thirty of the cards in decks A, B, C were designed so that the indicator pointed to a number between and including 0.5 and 8.5 which represented "safe and normal" operation. Twenty of the remaining cards had dials with indicators pointing to numbers in the 0 to 1 and 9 to 10 intervals representing "red line" operation. The designs described above for fifty cards were included in deck A. In deck B, red line areas were marked with red edging along the dial periphery between 0 to 1 and 9 to 10. In other respects this deck was identical to deck A. In deck C, safe and normal operation was indicated in the same manner as in deck A (with only the pointer and number shown). A red wedge that appeared on the dial face indicated red line operation. The size of the wedge was directly proportional to the amount of deviation from the "safe and normal" operation. Deck D was different from the other three decks. It comprised of fifty consecutively numbered cards, with the numbers appearing at the top of the cards. Twenty of the cards were numbered in red and the remaining thirty cards were numbered in black. Each of these cards had a two inch circle in the center. Twenty of these circles were filled in black and the remaining thirty had empty circles. Each subject was instructed to turn the cards over one by one and separate them according to a criterion into two piles. In a practice session deck D was first sorted on the basis of number color and then on the basis of whether or not the circles were filled. Time and error scores were measured. The decks A, B, C were sorted to separate displays with “safe and normal” operation from “red line" displays. The order of presentation for decks A, B, and C was randomized. Lastly, Deck D was sorted again on the basis of circles.

The data showed that the thirty-three subjects made only one error out of one thousand six hundred fifty trials on deck C, eighteen errors out of one thousand six hundred fifty trials on deck B and thirty-nine errors out of one thousand six hundred fifty trials on deck A. It was observed that red lining a dial to indicate caution or danger is significantly better than no line indication when reading errors or reading time (reading time isolated from associated motor activity) are being considered. Thus, the **dial design with the wedge was found to be significantly more efficient than the other two dial designs** possibly due to the fact that a simpler form of visual discrimination was required for reading it.

**Figure 5.21: Decks used in Kurke's study (1956)**

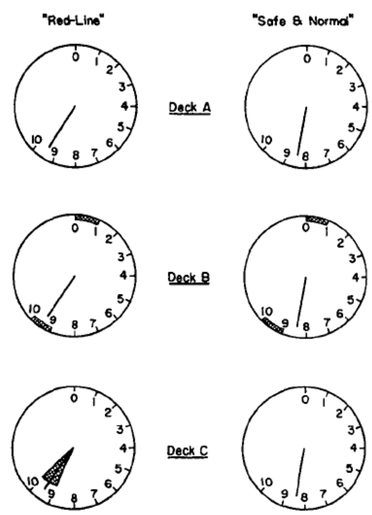



FIG. 2. The appearance of decks *A*, *B*, and *C* showing "Safe and Normal" and "Red-line" displays.

**HEGLIN (1973)**

Heglin (1973) has discussed the use of color for displays and color-deficiencies in people. He states that color deficiency is almost always hereditary, present in about eight percent of the male population and rarely affects females. The most

**common form of color deficiency is for red and green**. Monochromatic vision, which is the ability to only see in shades of gray, is extremely rare.

**GREEN (1984)**

In his study Green (1984) investigated how much of an effect color-coding had on driver understanding of engine displays. The experimental method and the other results from his study have been described earlier in section 4.1.4. The results showed that with respect to color-coding, subjects ranked colored-coded displays as more understandable than non color-coded ones. It was also found that the color-coding factor was more important to subjects than the scale label. Based on this finding Green recommended that **gauge segments should be color-coded**. Bar type gauge segments should change color as engine parameters go from normal to abnormal states in order to reduce reading errors.

**SANDERS and MCCORMICK (1977)**

Sanders and McCormick also recommend the use of color to differentiate between the different zones on a scale.

## 5.3. Driver behaviors, expectations and attitudes to consider while designing fuel gauges

### 5.3.1 Inclusion criteria for studies reviewed in this sub-section

Any studies that have been conducted to understand how well drivers know their cars and have investigated any driver behaviors, expectations and attitudes that that should be taken into consideration in the design of fuel gauges have been included. Studies on driver perceptions of in-vehicle display systems and their expectations from these systems have also been included.

### 5.3.2 Driver knowledge, behaviors, expectations and attitudes

**GREEN (1984)**

In his study, Green (1984) investigated driver knowledge of their cars. Subjects were asked questions related to fuel capacity, normal engine temperature and other engine parameters. Overall, it was found that driver knowledge of their vehicles was incomplete. Drivers were asked the following two questions about the fuel systems in their vehicles: “when your gas tank is full how much does it hold?” and “what level does your gas gauge usually show when you decide it is time to fill up?” It was found that drivers knew how many gallons of fuel their cars could hold. This led Green to conclude that a digital fuel gauge showing level in gallons could be meaningful for drivers. Also, the most common response to the question of what level is shown by the fuel gauge when the drivers decide to refuel was ¼ tank.

In the last part of the study (task 3) subjects were asked three trick questions. “How often should the muffler bearings be lubricated?” “Where does one add exhaust fluid?” “How often should the air in your tires should be changed?” From the results of the three trick questions it was found that 15% of the participants thought these were legitimate questions. These questions were successful in highlighting the differences between what ordinary drivers know and what automotive designers know. Green recommended that while designing information systems for drivers it is important that messages presented are understandable by the most naïve drivers and can also provide secondary or more technical information for advanced or more informed drivers.

### 5.3.3 Driver perceptions of in-vehicle display systems

**BRAND (1990)**

Brand (1990) investigated driver perceptions of safety of display systems in automobiles and how they can be made easier to use. This was done using depth group interviews. This is a technique that involves about ten people talking with a highly trained moderator. The moderator always challenges the first response to a question so that the participant is forced to prove the statement. In this technique the moderator always assumes that the first response to a question is not the real answer.

The study aimed at gathering actual consumer feedback on their experiences with display systems and gathering their reactions to future developments. The information collected would be used to determine broadly what forms these new systems should take. Four depth group interviews involving ten participants each were conducted in two cities (Los Angeles and Stamford). The discussion guide used for the interview sessions included topics such as background information on vehicles, features in their cars, general attitudes toward sophisticated systems in their vehicles, automotive gauges and warning systems, entertainment systems, vehicle monitoring systems, touch screens and trip computers, cell phones, citizen band radios, navigational systems and road hazard monitoring systems. The discussion was geared toward understanding driver attitudes toward these systems, their usage, perceived advantages and disadvantages and participants' recommendations for making them more useful, safe and user friendly. The subject groups consisted of older (50+ years) and younger drivers (21-35 years, 36 – 50 years). All of the participants drove regularly in heavy traffic and owned a variety of vehicles ranging from BMWs to Jeep Cherokees, Oldsmobile Cutlass Supremes, Nissan Maximas, Cadillacs and Corvettes. While feedback was obtained on several different topics, only the ones of most interest to the author's thesis are discussed here. With respect to gauges and warning lights, some participants expressed concern that having too many dials on the dashboard was confusing and cluttered. They referred to warning lights as “idiot lights” that flashed on only when it was too late to address a problem and when the problem had already reached a state of emergency. Often times they did not know what the problem was. Participants also expressed an uncertainty in terms of how to act when a warning light came on or a gauge went into the red. Specifically, they had questions on whether they needed to go to the nearest service station immediately or if they could wait to go to the service station of their choice.

They expressed a desire for the systems to provide early warnings of potential problems and for the indication of urgency level and the required action when an early warning is given. A secondary warning indicating greater urgency should appear as a different message or a different colored light. Participants also wanted a combination of gauge and warning lights for vital functions like engine temperature, gasoline level and oil pressure with the warning light being used to draw attention to the gauge in case of a problem. The concerns around gauges and warning lights were interesting as they represented some of the day-to-day challenges that these drivers faced in their cars. Their recommendations were also very pragmatic in nature. Participants wanted to be alerted early enough so that they could take preventive measures. They wanted to be informed about the specific nature of the problem and what course of action to take. This was particularly important to have for the vehicle systems that affect the vehicle’s ability to operate. It was also interesting to note that participants expressed frustration at the lack of consistency in vehicle systems and interfaces between vehicles. Those who switched between cars frequently were challenged with having to remember where the controls were and how they operated. They expressed a desire for more consistency in the location and types of controls in cars.

### 5.4. Influencing driver behavior towards better fuel economy

Several researchers have evaluated various fuel economy support tools to understand their effects on driver behavior and on reducing fuel consumption. The following section is a review of research done on tools and interfaces designed to communicate fuel economy information with a goal of changing driving behavior to maximize fuel efficiency.

#### 5.4.1. Definition of fuel economy and other related terms

**Fuel economy** is defined as the number of miles that a vehicle can travel on one gallon of gasoline. For conventional vehicles it is represented in miles per gallon (MPG). The United States Department of Energy states that for electric vehicles it is represented in miles per gallon equivalent (MPGe) where 33.7 KW-hrs is equivalent to 1 gallon of gasoline. For a hybrid electric vehicle that operates on two fuel sources, fuel economy is measured in terms of MPGe when the vehicle is operating on battery and in terms of MPG when it is operating on gasoline.

**Fuel efficiency** refers to how effectively a vehicle consumes fuel. Thus, vehicles that provide the highest fuel economy are also the most fuel-efficient. Fuel-efficient vehicles also contribute toward the larger goal of reducing dependence on petroleum as a fuel source. According to the United States Department of Energy, in the United States, out of about 19 million barrels of oil consumed per day, two-third is consumed for transportation. Thus, fuel-efficient vehicles can play an important role in helping reduce this consumption. Fuel-efficient vehicles also help reduce the contributions of carbon dioxide and other greenhouse gases. Therefore, they are important players in helping reduce global climate change.

In recent years, many researchers have published literature on driver interfaces that encourage fuel-efficient driving behaviors to help obtain better fuel economy. Several different terms have been used in literature to describe various fuel economy and fuel efficiency support tools. Jenness et al. (2009) describe a **Fuel Economy Driver Interface (FEDI)** as one that presents drivers with information on fuel usage or efficiency. While some of these interfaces present fuel economy information in absolute form such as in miles per gallon (MPG) others provide this information in relative form such as with alerts that appear when fuel economy is poor. In some vehicles drivers have the flexibility to choose the type of fuel economy related information that they want to have displayed. In their study, Manser et al. (2010a) refer to such types of tools as **Fuel Economy Driver Interface Concepts (FEDICs).** Graving et al (2010) refer to displays that present fuel efficiency information as **Fuel Economy Displays (FEDs).**

### 5.4.2. Factors affecting fuel economy

Hybrid and electric vehicles offer much higher fuel economy than conventional gasoline vehicles. According to the United States Department of Energy, in a 2014 ranking of the most fuel-efficient vehicles, the highest fuel economy in terms of combined MPGe is achieved by the all-electric vehicles 2014 BMW i3 EV (124 MPGe), 2014 Chevrolet Spark EV (119 MPGe) and the 2014 Honda Fit EV (118 MPGe).

In addition to vehicle technology fuel economy depends on driving behaviors to a great extent. Drivers need to be sufficiently informed and motivated to change driving behaviors. Factors such as aggressive driving (hard acceleration and breaking) and excessive idling particularly in stop-and-go traffic can lower fuel economy. Some of these driving behaviors also affect driver safety.  From this perspective, there is a strong need to provide feedback to drivers on how their driving behaviors affect fuel economy of the car and develop solutions that encourage fuel-efficient driving behaviors.

### 5.4.3. Inclusion criteria for studies reviewed in this sub-section

Van der Voort et al. (2001), Jenness et al. (2009), Manser et al. (2010 a,b,c), Graving et al.(2010) and Meschtscherjakov et al. (2009) have evaluated fuel economy interfaces for drivers. It was of interest to understand which designs and features were successful in contributing to fuel-efficient behaviors. These studies have been included. Additionally, studies that have made recommendations on feedback mechanisms and techniques for increasing driver motivation to maximize fuel savings by changing driving behavior are of interest to this thesis. One such study by Gonder et al. (2011) has been included.

### 5.4.4. Feedback mechanisms on efficient driving techniques

#### GONDER ET AL. (2011)

A study by Gonder et al. (2011) showed that if efficient driving behaviors are adopted then fuel savings of 20% could be achieved for aggressively driven trips. They recommend feedback mechanisms that provide drivers with effective instructions on how to drive more efficiently and to provide drivers with useful reference point information such as current fuel economy, acceleration rate, vehicle speed etc. Some of the recommended techniques for increasing driver motivation to maximize fuel savings by changing driving behavior include driver training and incentive programs (for drivers of commercial vehicles) and insurance company collaboration to implement usage-based insurance (for drivers of personal vehicles). Gonder et al. also recommend the inclusion of safety and convenience features into the vehicle such as lane keep assist, adaptive cruise control and “green driving assist” in which the vehicle intelligently selects optimal speeds and acceleration and deceleration rates. Another recommended approach is to incorporate driving efficiency reference information in to status gauges such as the speedometer, tachometer etc.

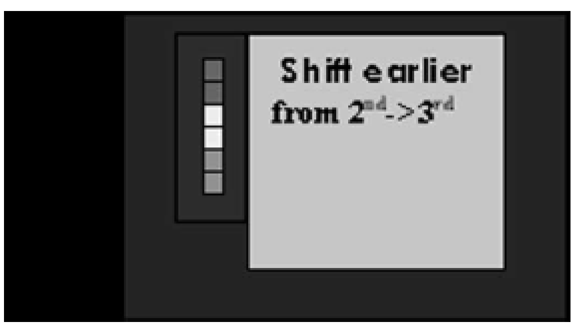
### 5.4.5. Evaluation of fuel economy interfaces and support tools

**VAN DER VOORT ET AL. (2001)**

Van der Voort et al. (2001) designed a fuel efficiency support tool that provided the driver with clear, accurate and non-contradictory information. The tool was designed to take into account the context that the vehicle was in and to work in both urban and non-urban environments.

Two Human Machine Interfaces (HMIs) were designed as part of this tool. These interfaces presented the driver with advice in visual form on a screen. The two HMIs differed in terms of the amount of advice presented: advice and extended advice. An example of advice is "shift earlier" while the corresponding extended advice is "shift earlier from 2nd to 3rd gear". In addition to text-based advice the HMI provided an indication of the extent of deviation between actual and optimal driving behavior using green, orange and red LEDs.

**Figure 5.22: Human machine interface showing extended advice part of study by Van der Voort et al. (2001)**




The fuel efficiency support tool was evaluated in a driving simulator study with eighty-eight male participants who were divided equally into the four groups of control group, existing group, advice group and extended advice group. Each participant drove six runs through urban, sub-urban and highway environments. The first run consisted of normal driving and the second run involved driving as fuel-efficiently as possible while keeping trip time constant. In runs three, four, five and six participants were also asked to drive as fuel-efficiently as possible, but with the support tool assigned to their corresponding groups. The existing group drove with an existing support tool while the advice and extended advice groups drove with the corresponding versions of the new support tool. The control group received no feedback during the experiment.

During the first two runs no differences in fuel economy were found between the four groups. Drivers presented with the extended advice obtained an average fuel reduction of 16% compared with their consumption during normal driving. The maximum reduction in fuel consumption was observed for the urban driving compared with rural and highway driving. This was attributed to an adjusted gear-changing behavior during acceleration in the more complex urban environment with higher traffic volumes. Van der Voort et al. inferred that it is best to present the driver with detailed advice. This study found that using the fuel-efficiency tool, drivers improved fuel consumption significantly resulting in substantial savings in fuel.

**JENNESS ET AL. (2009)**

Jenness et al. (2009) conducted a study that comprised of two tasks. The first task involved an extensive review of Fuel Economy Driver Interfaces (FEDIs) that were being used in vehicles or were being proposed. The main goals were to identify features of these FEDIs and past and current trends in FEDIs. In the second task, the researchers conducted focus groups with drivers from the general public and owners of vehicles with FEDIs. The purpose of the focus groups was to collect information on driving habits and opinions about FEDI designs. Through the focus groups Jenness et al. sought opinions on the usefulness and potential for distraction of various FEDIs.

The review of FEDI designs included solutions that have existed in vehicles for decades. More recently, these designs have become more prevalent and complex. The review showed that there are a variety of FEDIs. Some provide numerical information while others may include analog or digital gauges, bar charts or illuminator lamps. With the increasing use of LCD screens inside vehicles, FEDIs have started taking new forms. In some cases FEDIs include vehicle-adaptive features. These are features that can influence vehicle performance when fuel-inefficient driving behaviors are detected. The review also found that the most commonly seen quantitative measures of fuel economy were average fuel economy (mpg) since last fueling event, average fuel economy for the current trip, instantaneous fuel economy (current fuel usage rate in mpg), historical fuel economy (mpg for past 30 minutes of driving shown for each minute) and forward-looking estimates of fuel economy (miles to empty).

In the second task, a total of four focus groups were conducted. The first two groups comprised of drivers from the general public while the other two groups comprised of owners of conventional or hybrid vehicles with fuel economy interfaces

The topics covered in the focus groups were: the impact of large changes in gas prices on driving habits, knowledge and use of information displays in their vehicles including FEDIs if present, driving behaviors that may affect fuel economy, frequency of engaging in potentially dangerous driving maneuvers, personal motivations related to driving, reactions to a range of fuel economy display designs and desire to have fuel economy displays in their next vehicles they purchase. There was a clear difference in motivations while driving between participants from groups one and two and those from groups three and four. Hybrid vehicle owners rated reducing negative environmental impacts of driving, getting the best possible fuel efficiency, and reducing fuel costs as more important than owners of conventional vehicles.

The findings from the focus groups showed that participants in groups one and two (comprising of drivers from the general public) were resistant to additional information displays in their vehicles. Concerns were expressed on the impact of FEDIs on driver distraction and interference of vehicle–adaptive features (such as the eco pedal) with the driver in case of emergency situations. In addition to safety related concerns, participants in groups one and two also believed that the costs of these FEDIs would outweigh the benefits. These participants wanted to see a minimal amount of fuel economy information on their in-vehicle displays.

In contrast to the feedback from groups one and two, participants from groups three and four (owners of vehicles with FEDIs) expressed an interest in fuel economy information- particularly in downloading driving data for later viewing and analysis. These drivers had a more positive attitude towards FEDIs.  Overall, participants from all groups wanted to know the effect of FEDIs on potential fuel savings. There was interest in a concept that could provide individualized feedback and make recommendations on specific steps to improve fuel efficiency.

Participants were also shown nine different FEDI concepts representing the range of current and upcoming FEDI displays and technologies. It was found that drivers who owned vehicles with FEDIs had more positive attitudes and opinions about them. Certain features such as color changes in response to fuel economy and basic and text gauges were generally well received. Other features like instantaneous fuel economy displays, complex graphical designs like energy flow diagrams and fuel economy history bar charts and game-like displays received mixed feedback. Vehicle adaptive technology was not viewed favorably due to concerns of losing control in dangerous situations. Game-like displays that used growing plants were also not well received. It is not clear why. However, the researchers recommended the exploration of other feedback structures that minimize driver distraction and make the displays more meaningful and rewarding.

There was also interest in post-drive reporting technology to evaluate driving performance and in the social and comparative aspects of the technology. The conclusion was that acceptance of FEDI concepts is a matter of personal preference. Drivers who owned vehicles with FEDIs and drivers who are concerned about fuel economy may be interested in FEDIs with options and extensive features to improve fuel economy. The findings from this study were used along with accepted human factors principles to develop interface recommendations for FEDIs. It was found that some of the concepts presented to participants stood out as favorites and were considered to be promising for future considerations. These included simple, qualitative, color-coded indication of current fuel economy, post-drive reporting, feedback and social comparison, and text and analog gauge displays.

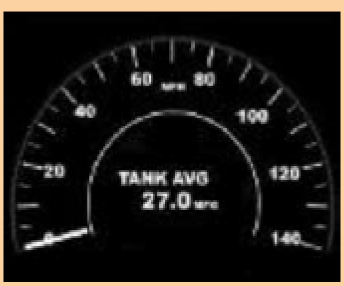
**MANSER ET AL. (2010b)**

Manser et al. (2010b) conducted a study to identify Fuel Economy Driver Interface Concept (FEDIC) designs and their characteristics that facilitated changes in driving behavior that result in improved fuel economy. The study also aimed at identifying best practices for FEDI designs that would meet driver needs and minimize potential for distractions.

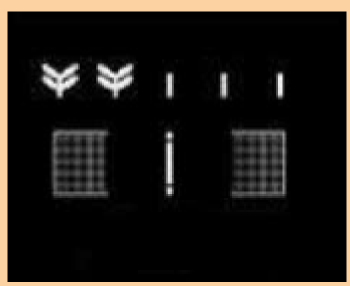
The study comprised of two tasks. The first task (Manser et al., 2010a) involved concept development while the second task involved refinement and testing of the concepts. The second task was conducted in two phases. The first phase (Manser et al., 2010b) involved usability evaluation of the FEDICs while the second phase involved a simulator based evaluation of driver behavior associated with using a FEDIC (Manser et al., 2010c).

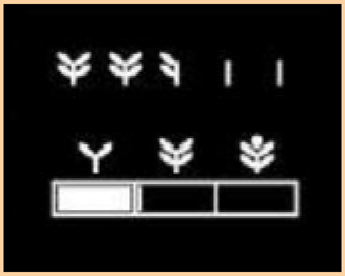
The goal of the usability study was to narrow down the range of FEDIC designs so that the most usable concepts would be tested in the simulator study. A total of seven prototypes FEDI component sets (FEDIC-CS) were created based on an analysis of user needs. Each set comprised of two components and two different types of fuel economy information (instantaneous, trip or average fuel economy). An initial comprehension task was conducted to determine user understanding of the component sets after a short exposure. The designs that elicited good performance were considered to be simple and straightforward, involving minimum driver distraction. A subsequent fuel economy comprehension task was conducted to determine if users were able to accurately understand how changes in the state of component sets related to fuel economy. The designs that elicited good performance were considered to have understandable and "differentiable" component sets (CS) states implying that for these designs drivers would be able to easily detect fuel-inefficient driving. General usability measures involved understanding participants' reactions to various CS in terms of their usefulness and user satisfaction.

**Figure 5.23: Set of seven FEDI-CS evaluated in the usability study by Manser et al. (2010b)**

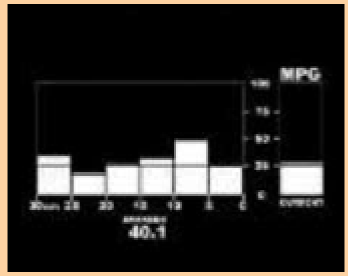


CS01: Intensity-changing light + Text MPG

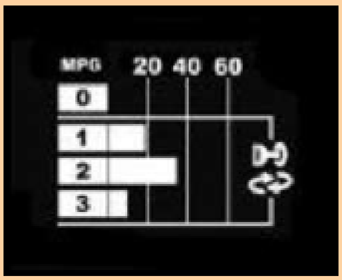

CS02: Representative picture + Acceleration/Declaration Bar



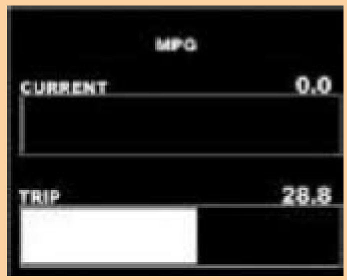
CS03: Representative picture + Horizontal MPG Bar



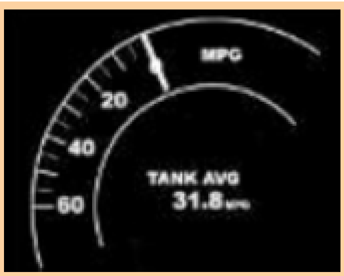

CS04: Vertical Graph of Instantaneous + Trip MPG




CS05: Horizontal Graph of Trip + Horizontal Graph of Average MPG




CS06: Horizontal Graph of Instantaneous + Trip




CS07: Leftward Dial + Text MPG

More details on the functioning of each of the FEDI-CS can be found in Manser et al. (2010a). The results of the usability study showed that CS02 had the highest percentage of correct answers when participants were asked to determine whether the display indicated they were driving fuel-efficiently. Thus, **presenting instantaneous fuel economy information in the form of a horizontal bar component and presenting trip fuel economy information as a representational picture display component resulted in the highest accuracy**. Also, CS02, CS05 and CS03 had higher participant ratings than

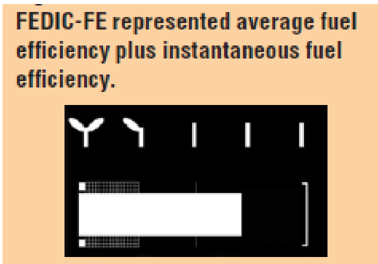
CS01, CS06 and CS07 in terms of usefulness and satisfaction. These components contained overall average fuel economy information in the form of display components (graphical, not text) which suggested that participants found this type of information more satisfying and useful than information presented by the other CS designs. The results of the usability study showed that horizontal bars or horizontal designs that included simple representations of fuel economy information were most usable.

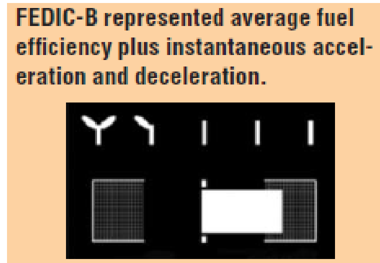
Components consisting of horizontal bars with overlaid references (CS02, CS05 and CS03) were found to have higher acceptance compared with bars with no overlaid references (CS06). Overlaying references likely provided participants with useful cues. There was subjective preference for symbolic forms over text for representation of fuel economy information. It was also found that text representation could improve user comprehension when text was combined with component features. The study also suggested that presenting information directly related to driving behavior (acceleration) may be equally useful as presenting fuel economy information.

**MANSER ET AL. (2010c)**

Based on the findings of the usability study Manser et al conducted a simulator study using two of the component sets to evaluate driving behavior and potential for driver distraction. The following two FEDICs were selected for evaluation in a driving simulator. In both concepts, fuel-efficient driving behavior resulted in an increase in the number of “leaves” while inefficient driving resulted in a decrease in the number of “leaves”. While FEDIC-FE showed instantaneous fuel efficiency, FEDIC-B showed instantaneous acceleration and deceleration.

**Figure 5.24: The two FEDICs evaluated in the simulator study by Manser et al. (2010c)**




Thirty drivers participated in the study. The study involved three different driving scenarios that were simulated to evaluate the FEDICs. These were: stop-and-go (urban setting with multiple stops), free driving (traffic-free highway) and car following (in a highway setting). Each participant drove through each scenario twice. In the first drive participants were instructed to drive normally. In the second drive, participants were divided into three groups of ten each and were instructed to drive in a fuel-efficient manner. One group viewed FEDIC-FE, the second group viewed FEDIC-B and the third group drove without any FEDIC. The results showed that for the stop-and-go scenario, there was a 41% increase in average fuel economy during drive two (driving in a fuel-efficient manner). The highest fuel economy was observed for FEDIC-FE. In the stop-and-go scenario participants drove most fuel-efficiently when presented with information on fuel economy (FEDIC-FE) rather than when presented with information about acceleration (FEDIC-B) or with no FEDIC. It was found that instructing participants to drive fuel-efficiently alone resulted in significant improvements in fuel economy. Driving behavior with FEDIC-B during drive two resulted in a similar increase in fuel economy as that obtained when participants drove with no FEDIC. Drivers also tended to make more glances away from the road when FEDICs were used. This indicates there may be safety implications to using these types of displays.

### GRAVING ET AL. (2010)

Graving et al. (2010) investigated the extent of reduction in fuel consumption when drivers were provided with a Fuel Economy Display (FED). A simulator study was conducted with twenty-eight drivers (fourteen males, fourteen females). Participants were asked to complete a baseline drive (drive one) and a subsequent drive in which they were instructed to drive as fuel-efficiently as possible (drive two). For drive two each participant was assigned to one of three groups. Group one drove with an acceleration FED (showing how acceleration affected fuel economy), group two drove with a FED that showed instantaneous fuel economy in MPG and group three drove without a display (control group). The results showed that male participants in group one showed significantly greater change in fuel consumption compared with male participants in groups two and three. Male drivers who drove with the acceleration FED were found to greatly reduce fuel consumption.  For female drivers there were no significant differences between the three groups. However, during drive two female drivers were able to reduce their fuel consumption to a greater extent than male drivers. Female drivers reduced fuel consumption independent of whether a FED was present or not. Male drivers who drove without a FED did not reduce fuel consumption. The study concluded that **female drivers can reduce their fuel consumption by carrying out latent driving strategies while male drivers may require a visual representation of the effect of their driving behavior on fuel consumption**.

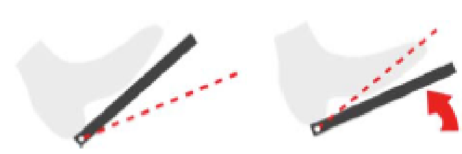
### MESCHTSCHERJAKOV ET AL. (2009)

One study conducted by Meschtscherjakov et al. (2009) involved an online survey which evaluated the user acceptance of various fuel economy interfaces. The survey also investigated whether other factors like driver properties and expectations influenced user acceptance. Fifty-seven participants (thirty-one females and twenty-six males) participated in the study. Five interfaces that support economic driving behavior were determined from literature.

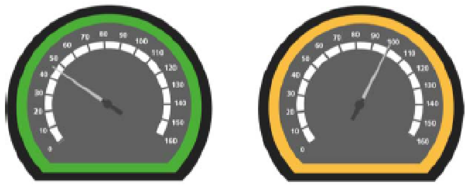
The five interfaces evaluated were: automatic eco system (EcoMatic), eco accelerator pedal (EcoPedal), Eco speedometer (EcoSpeedometer), Eco display (EcoDisplay) and Eco advisor (EcoAdvisor). The EcoMatic is a fully automated in-car appliance that can be manually activated and deactivated by pushing a button. It supports fuel-efficient driving by adjusting various parameters in the car (climate control etc.). This tool shows the amount of saved fuel at the end of each trip on a display. It aims at persuading drivers to use it by showing them benefits in terms of fuel savings. The EcoPedal works as a traditional accelerator pedal except that it pushes back against the driver's foot when wasteful acceleration is detected. Thus it aims at changing driver behavior by providing feedback at the right moment (before acceleration) along with a plan (accelerator pedal). The EcoSpeedometer provides visual feedback on whether a driver is driving fuel-efficiently at the moment or not in the form of a green or orange light around the speedometer. Green indicates fuel-efficient driving while orange indicates inefficient driving behaviors. The EcoDisplay presents feedback to the driver in the form of leaves that grow in number with fuel-efficient driving and decrease with inefficient driving. It presents an EcoScore at the end of each trip along with mileage and average fuel consumption information. The EcoAdvisor verbally presented a hint before a trip or during driving at appropriate moments.

**Figure 5.25: Tools evaluated by Meschtscherjakov et al. (2009)**

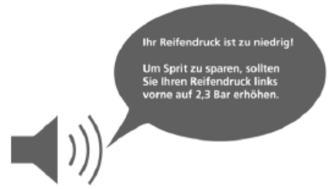

EcoMatic



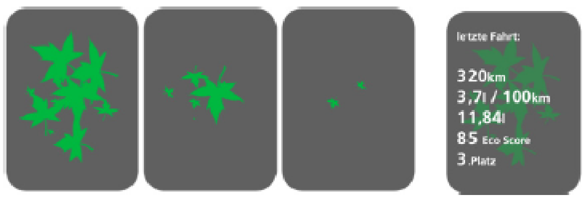
EcoPedal



EcoSpeedometer




EcoAdvisor




EcoDisplay

The EcoMatic, EcoSpeedometer, EcoDisplay and the EcoAdvisor were rated positively for user acceptance, behavioral intention to use, perceived usefulness and perceived ease of use. The EcoPedal was rated negatively for behavioral intention to use and perceived usefulness. For the EcoPedal, the behavioral intention to use and perceived usefulness were rated negatively by participants. Ratings for the EcoSpeedometer were the highest followed by ratings for EcoMatic. While the EcoDisplay and EcoAdvisor were rated similarly on perceived usefulness and ease of use, the EcoDisplay was rated higher than the EcoAdvisor on intention to use. The EcoPedal had the lowest ratings for intention to use and perceived usefulnesses even though it's ratings on perceived ease of use were high. Participants considered it to be easy to use but would not use it. Overall rankings of the different systems showed that the EcoSpeedometer was ranked as best and the EcoPedal was ranked as worst. The ranking for the EcoAdvisor was similar to that of the EcoPedal.

Systems with tactile and/or auditory feedback were found to be disturbing to participants. Interestingly, in the study by Van der Voort et al. (2001) the interface presenting extended advice in text-based form resulted in considerable reduction in fuel consumption. This validates that drivers are open to advice in text-based and visual forms rather than in the form of auditory feedback.

# 6. Hybrid fuel gauge designs

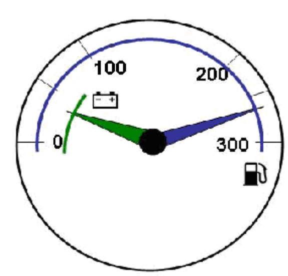
The following section describes the working and attributes of the thirty-three gauge designs developed by the team of designers at General Motors (GM) and the four gauge designs created by the team of human factors experts at the HumanFIRST laboratory at the University of Minnesota (UMN).

## 6.1. Gauge designs provided by General Motors

The thirty-three designs created by the GM design team incorporated various design attributes that were explored in varying levels. These were shape, orientation, use of relative and absolute information, spatial proximity of individual components, format, direction of fuel depletion, scale markings, range labels, color and placement of icons. The thirty-three designs do not systematically explore each possible variation of each attribute, but incorporate various permutations and combinations. **Shape and orientation were of primary interest** to this study. It was also of interest to understand how the use of relative and absolute information and the spatial proximity of the individual gas and battery components influence gauge comprehension.

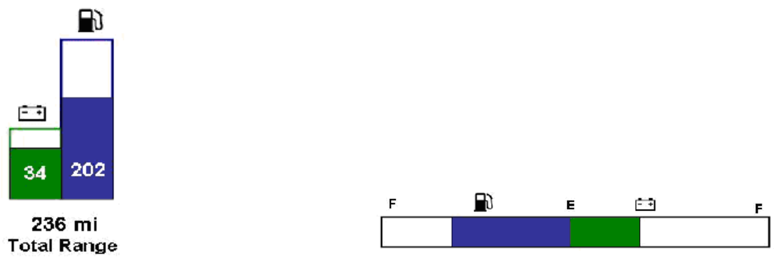
The design attributes have been discussed below.

**1.Shape:** Bars and circles were the two main shapes explored by the designers at GM. They created twenty-one bar gauges and only eleven circular gauges. Bar gauges offer the benefit of space saving as they take up less space on the dashboard compared to circular gauges.

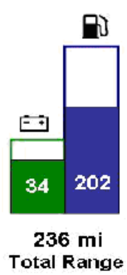
Example of a bar and circular gauge created by the GM design team

**2. Orientation:** Out of the twenty-one bar gauges created, nine were oriented horizontally and twelve were oriented vertically.

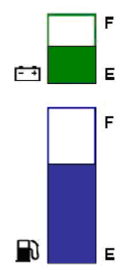



Example of a vertically and horizontally oriented bar gauge created by the GM design team

**3. Use of relative and absolute information:** Relative information refers to information that is presented in a graphic or pictorial form. Absolute information refers to information that is presented in numeric form. A majority of the gauges were designed to present range information in relative (graphic or pictorial) form. Only thirteen of the thirty-three gauges presented either individual or total range information in absolute (numeric) form.

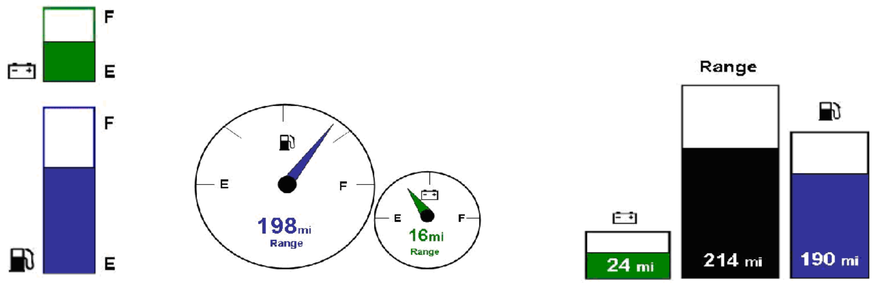



Information in absolute form

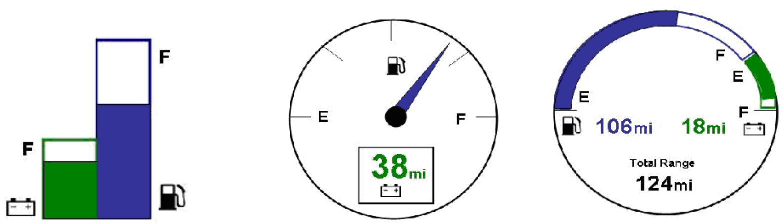



Information in relative form

**4. Spatial proximity of individual components:** Only four gauges were designed such that their individual gas and battery components were either not in close spatial proximity or the components did not share a border. In majority of the gauge designs the individual components were either stacked on top of another, placed side-by-side, placed one inside the other or integrated into one single circular dial resulting in close spatial proximity. According to Wickens and Carswell (1995) if a task requires mental integration then the close spatial proximity of the two information sources is helpful and it results in low information access cost (Wickens, 2003).




Examples of gauges with spatially separate individual components



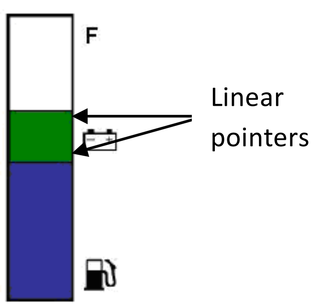

Examples of gauges with spatially close individual components

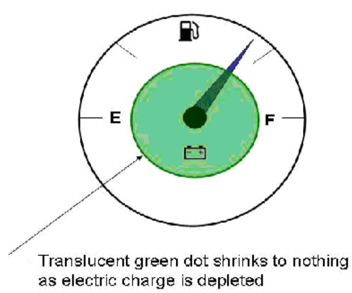
The four design attributes discussed above were of primary interest in the usability study. The gauge designs also had other design attributes that are discussed below.

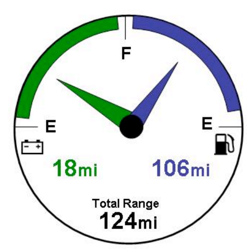
**5. Format:** The gauge designs were of three formats: moving pointer with fixed scale, moving scale with fixed pointer and numerical. Out of the thirty-three gauge designs, thirty-one were of the moving pointer with fixed scale format. One gauge was of the moving scale with fixed pointer format and one was a purely numeric or digital gauge (also known as a counter).

Moving pointer fixed scale gauges are generally preferred over moving scale fixed pointer gauges (Sanders and McCormick (1977)). One major advantage of moving pointer gauges over fixed pointer gauges is that numbers and scale don't need to be read. The general position of the pointer quickly provides an indication of the quantity and relative rate of change. In moving scale gauges judging the direction and amount of deviation becomes difficult without reading numbers and scale.

One disadvantage of the moving pointer gauge is that it requires the most area on a panel compared to the moving scale gauge and the counter. Another disadvantage of the moving pointer gauge is that the scale length is limited to the area available. In order to overcome this, multiple pointers may need to be used which could lead to clutter.  Many authors have found the moving pointer fixed scale format to be most suitable for the task of qualitative reading (Grether and Connell (1948), Grether (1949), Baker and Grether (1954), Sanders and McCormick (1977).

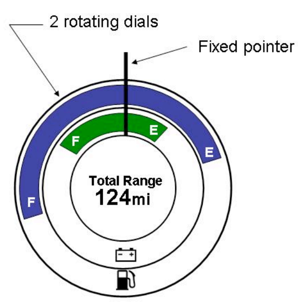


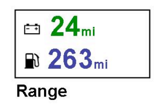




Moving linear pointer Moving radial pointer Moving needle pointer

Examples of fixed scale moving pointer gauges incorporating different types of pointers

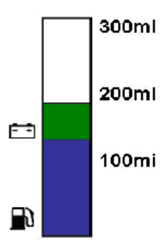


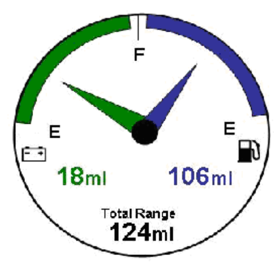

Moving scale fixed pointer gauge    Numerical gauge

**6. Direction of fuel depletion:** Some of the thirty-three hybrid fuel gauges were designed such that the fuel in their individual gas and battery components depleted in the same direction. In some gauges the direction of fuel depletion for the gas and battery components was opposite.

In horizontal gauges the direction of depletion was either from left to right or from right to left. In vertical gauges it was from top to bottom. Circular gauges used clockwise as well as counter-clockwise directions of fuel depletion.

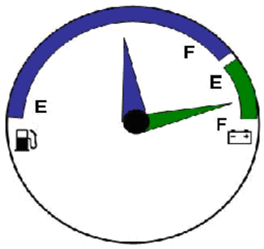


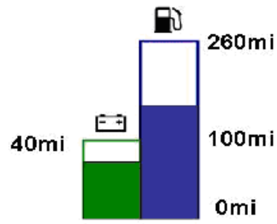





Top to bottom    left to right/ right to left    counter-clockwise/ clockwise

**7. Range labels used:** Some gauge designs used alphabetic labels such as “E-F”, some used numeric labels such as “40 mi” while a few designs did not use any range labels.

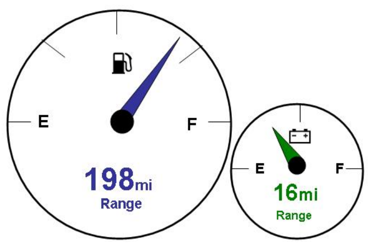


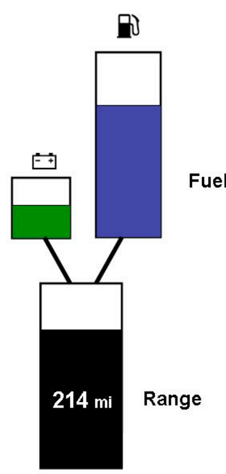


E-F range labels | Numeric range labels | No range labels

**8. Scale markings:** Scale markings have been used in some hybrid fuel gauge designs representing various fuel levels (full, 75%, half, 25% and empty). Most gauges have markings for at least the full and empty levels. A few designs did not use any scale markings at all.

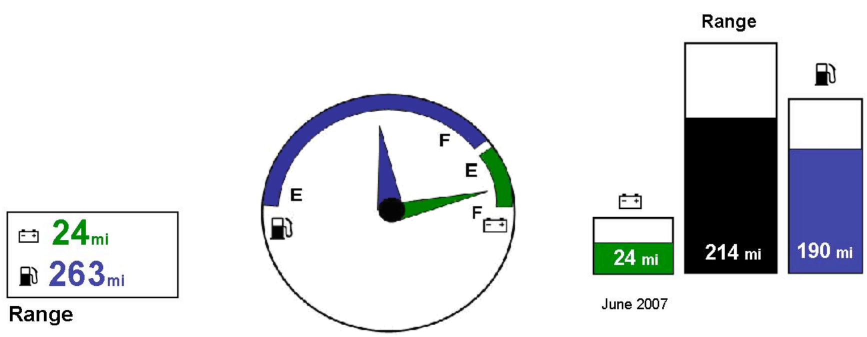



Example of a gauge with scale markings

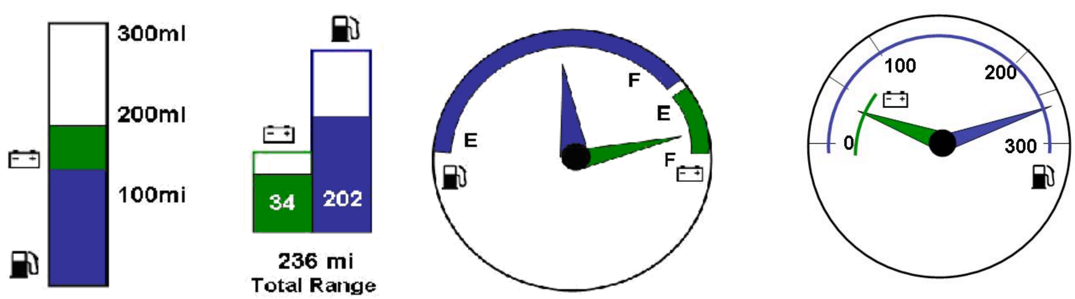

Examples of gauges with no scale markings

**9. Color:** The hybrid fuel gauges were designed to consistently use blue to represent gas, green to represent battery and black to represent the "total" component. In some gauges color has been used to fill in the bar or circular component up to the point representing the current fuel level. In other gauges components like needle pointers, scales, text and numbers are color-coded according to the type of component.




Examples of the different ways in which colors were used in gauges

**10. Placement of icons:** All gauge designs incorporate icons for gas tank and electric battery with variations on their placement.



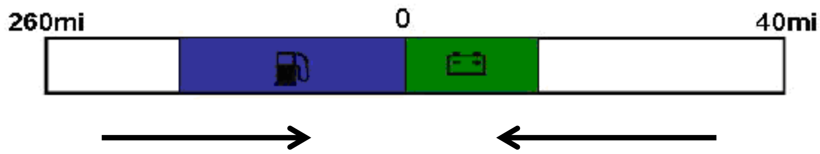

Examples of variations in placement of icons

### 6.1.1 Working of the gauges provided by General Motors

The following subsection describes the working of each of the thirty-three gauge designs. Bar gauges have been described first, followed by circular gauges and then numerical gauges.

#### A. Bar gauges

**Gauge 1:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

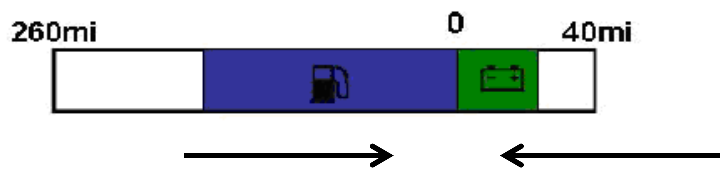
This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue (left side) and the battery component is completely filled with green (right side). As the battery begins to deplete, the green area begins to shrink towards the center of the gauge near the “0” mark. Similarly, as the gas begins to deplete the blue area begins to shrink towards the center of the gauge near the “0” mark. It is important to note that the colored regions for gas and battery components shrink in opposite directions (gas- from left to right, battery- from right to left)

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Horizontal orientation
- Equal area for gas and battery components
- Gas and battery components are in close spatial proximity
- Empty point is common for gas and battery, represented by “0”

- Labeling scheme is numerical (260 mi- 0- 40 mi)
- Gas and battery component pointers moving in opposite directions to each other. Depletion of gas level takes place from left to right and depletion for battery takes place from right to left.
- Gas and battery icons are located inside the gauge

**Gauge 2:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

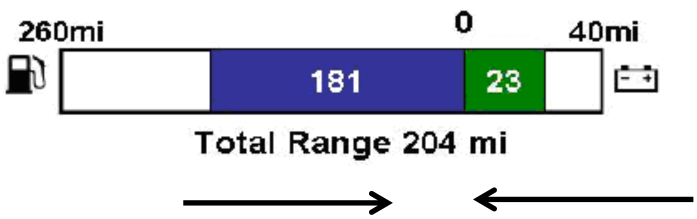
This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue (left side) and the battery component is completely filled with green (right side). As the battery begins to deplete, the green area begins to shrink towards the center of the gauge near the “0” mark. Similarly, as the gas begins to deplete the blue area begins to shrink towards the center of the gauge near the “0” mark. It is important to note that the colored regions for gas and battery components shrink in opposite directions (gas- from left to right, battery- from right to left).

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Horizontal orientation
- Size of gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source
- Gas and battery components are in close spatial proximity
- Empty point is common, represented by “0”

- Labeling scheme is numerical (260 mi- 0- 40 mi)
- Gas and battery component pointers moving in opposite directions to each other. Depletion of gas level takes place from left to right and depletion for battery takes place from right to left.
- Gas and battery icons are located inside the gauge

**Gauge 3:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

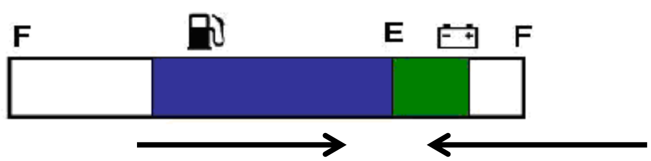
This gauge is a combination of moving pointer and numeric displays. It is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete, the green area begins to shrink towards the center of the gauge near the “0” mark. Similarly as the gas begins to deplete the blue area begins to shrink towards the center of the gauge near the “0” mark. It is important to note that the colored regions for gas and battery components shrink in opposite directions (gas- from left to right, battery- from right to left). Additionally, the number of miles that can be travelled on each fuel source (individual range) is displayed inside each gauge component in numeric form. The gauge also presents the total range in numeric form, which is the total number of miles that can be travelled on both fuel sources combined.

**Interesting attributes:**

- Linear moving pointer with fixed scale

- Horizontal orientation
- Size of gas and battery components proportional to the number of miles that the vehicle can travel on each fuel source
- Gas and battery components are in close spatial proximity
- Empty point is common, represented by “0”
- Labeling scheme is numerical (260 mi- 0- 40 mi)
- Individual ranges are displayed in absolute or numeric form inside each component
- Total range is displayed in absolute or numeric form
- Gas and battery component pointers moving in opposite directions to each other. Depletion of gas level takes place from left to right and depletion for battery takes place from right to left.
- Gas and battery icons are located outside the gauge to the left and right extremes

**Gauge 4:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

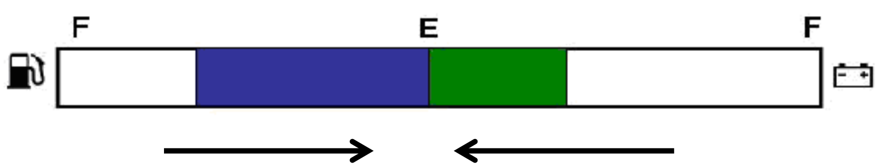
**Working:**

This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards the center of the gauge near the “E” mark. Similarly, as the gas begins to deplete the blue area begins to shrink towards the center of the gauge near the “E” mark. It is important to note that the colored regions for gas and battery components shrink in opposite directions (gas- from left to right, battery- from right to left).

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Horizontal orientation
- Size of gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source.
- Gas and battery components are in close spatial proximity
- Empty point is common, represented by “E”
- Labeling scheme is F-E-F
- Individual and total range information is not presented in numerical form
- Gas and battery component pointers moving in opposite directions to each other. Depletion of gas level takes place from left to right and depletion for battery takes place from right to left.
- Gas and battery icons are located above each individual gauge component

**Gauge 5:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

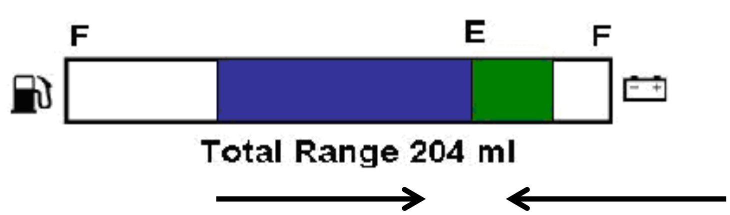
This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards the center of the gauge near the

"E" mark. Similarly, as the gas begins to deplete the blue area begins to shrink towards the center of the gauge near the "E" mark. It is important to note that the colored regions for gas and battery components shrink in opposite directions (gas- from left to right, battery- from right to left).

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Horizontal orientation
- Equal area for gas and battery components
- Gas and battery components are in close spatial proximity
- Empty point is common, represented by "E"
- Labeling scheme is F-E-F
- Individual and total range information is not presented in numerical form
- Gas and battery component pointers moving in opposite directions to each other. Depletion of gas level takes place from left to right and depletion for battery takes place from right to left.
- Gas and battery icons are located outside the gauge to the left and right extremes

**<u>Gauge 6:</u>**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

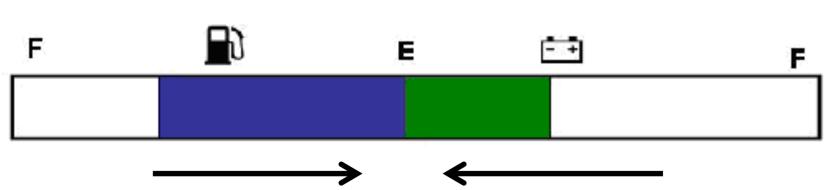
**Working:**

This gauge is a combination of moving pointer and numeric displays. It is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards the center of the gauge near the “E” mark. Similarly, as the gas begins to deplete the blue area begins to shrink towards the center of the gauge near the “E” mark. It is important to note that the colored regions for gas and battery components shrink in opposite directions (gas- from left to right, battery- from right to left). The total range is presented in numerical form.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Horizontal orientation
- Size of gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source.
- Gas and battery components are in close spatial proximity
- Empty point is common, represented by “E”
- Labeling scheme is F-E-F
- Total range information is presented in absolute or numerical form
- Gas and battery component pointers moving in opposite directions to each other. Depletion of gas level takes place from left to right and depletion for battery takes place from right to left.
- Gas and battery icons are located outside the gauge to the left and right extremes

<u>**Gauge 7:**</u>



Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

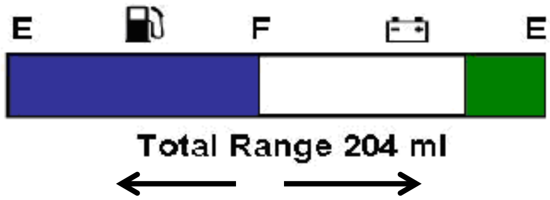
**Working:**

This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards the center of the gauge near the "E" mark. Similarly, as the gas begins to deplete the blue area begins to shrink towards the center of the gauge near the "E" mark. It is important to note that the colored regions for gas and battery components shrink in opposite directions (gas- from left to right, battery- from right to left).

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Horizontal orientation
- Equal area for gas and battery components
- Gas and battery components are in close spatial proximity
- Empty point is common, represented by "E"
- Labeling scheme is F-E-F
- Individual and total range information is not presented in numerical form
- Gas and battery component pointers moving in opposite directions to each other. Depletion of gas level takes place from left to right and depletion for battery takes place from right to left.
- Gas and battery icons are located above each individual gauge component

**Gauge 8:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

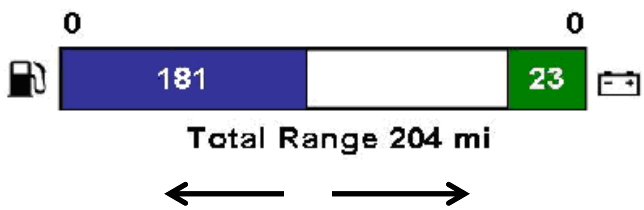
This gauge is a combination of moving pointer and numeric displays. It is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards the right of the gauge near the “E” mark. Similarly, as the gas begins to deplete the blue area begins to shrink towards the left of the gauge near the “E” mark. It is important to note that the colored regions for gas and battery components shrink in opposite directions (gas- from right to left, battery- from left to right). The total range, is presented in numerical form.

**Interesting attributes:**

- Linear moving pointer with moving
- Horizontal orientation
- Equal area for gas and battery components
- Gas and battery components are in close spatial proximity
- Full point is common, represented by “F”
- Labeling scheme is E-F-E
- Total range information is presented in absolute or numerical form
- Gas and battery component pointers moving in opposite directions to each other. Depletion of gas level takes place from left to right and depletion for battery takes place from right to left.

- Gas and battery icons are located above each individual gauge component

**Gauge 9:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

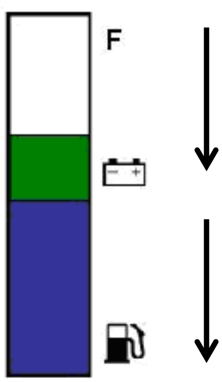
This gauge is a combination of moving pointer and numeric displays. It is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards the right of the gauge near the “0” mark. Similarly, as the gas begins to deplete the blue area begins to shrink towards the left of the gauge near the “0” mark. It is important to note that the colored regions for gas and battery components shrink in opposite directions (gas- from right to left, battery- from left to right). The individual range is presented in numerical form inside each gauge components. The total range is also presented in numerical form.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Horizontal orientation
- Equal area for gas and battery components
- Gas and battery components are in close spatial proximity

- Full point is common (located in the middle of the gauge)
- Labeling scheme is numerical (0 mi- 0 mi)
- Individual ranges are presented in numerical form inside each component
- Total range is presented in numerical form
- Gas and battery component pointers moving in opposite directions to each other. Depletion of gas level takes place from left to right and depletion for battery takes place from right to left.
- Gas and battery icons are located outside the gauge to the left and right extremes

**Gauge 10:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

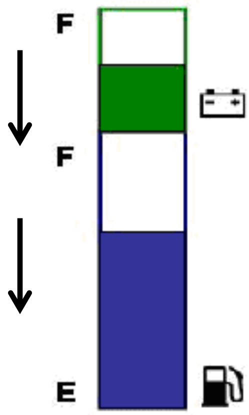
**Working:**

This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards middle of the gauge, which represents the empty level for the battery. Similarly, as the gas begins to deplete the blue area begins to shrink towards the bottom, which represents the empty level for the gas. It is important to note that the colored regions for gas and battery components shrink in the same direction (towards the bottom). The empty level for the battery component coincides with the full level for the gas component. In the PHEV under consideration, once the battery has depleted completely the vehicle begins to operate on gas. Given the top to bottom direction of fuel depletion in this gauge, the placement of the battery component on top of the gas component makes this gauge intuitive.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation
- Equal area for gas and battery components
- Gas and battery components are in close spatial proximity
- Empty level for the gas is at the bottom of the gauge (unlabeled). Empty level for the battery component is at the middle of the gauge (also unlabeled).
- The full level for the battery is labeled “F”
- Individual and total range information is not presented in numerical form
- Depletion for the gas and battery components is from top to bottom.
- Gas and battery icons are located outside the gauge near the empty level of each component.

**<u>Gauge 11:</u>**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

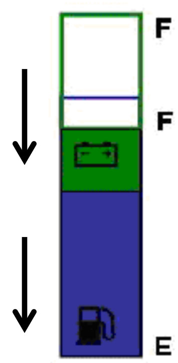
This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards middle of the gauge, which represents the empty level for the battery. Similarly, as the gas begins to deplete the blue area begins to shrink towards the bottom, which represents the empty level for the gas. It is important to note that the colored regions for gas and battery components shrink in the same direction (towards the bottom). The empty level for the battery component coincides with the full level for the gas component. In the PHEV under consideration, once the battery has depleted completely the vehicle begins to operate on gas. Given the top to bottom direction of fuel depletion in this gauge, the placement of the battery component on top of the gas component makes this gauge intuitive.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation

- Size of gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source
- Gas and battery components are in close spatial proximity
- Empty level for the gas is at the bottom of the gauge and labeled “E”. Empty level for the battery component is not labeled.
- Labeling scheme is F-F-E
- Individual and total range information is not presented in numerical form
- Depletion for the gas and battery components is from top to bottom.
- Gas and battery icons are located outside the gauge near the empty level of each component.

**Gauge 12:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

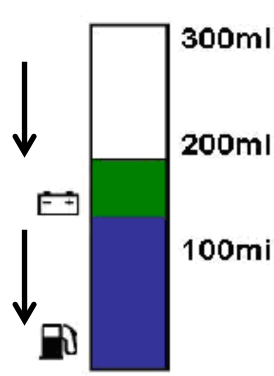
**Working:**

This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards middle of the gauge, which represents the empty level for the battery. Similarly, as the gas begins to deplete the blue area begins to shrink towards the bottom, which represents the empty level for the gas. It is important to note that the colored regions for gas and battery components shrink in the same direction (towards the bottom). The empty level for the battery component does not coincide with the full level for the gas component. There is an overlap between the gas and battery components. In the PHEV under consideration, once the battery has depleted completely the vehicle begins to operate on gas. Given the top to bottom direction of fuel depletion in this gauge, the placement of the battery component on top of the gas component makes this gauge intuitive.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation
- Size of gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source.
- Gas and battery components are in close spatial proximity and overlap each other
- Empty level for the gas is at the bottom of the gauge and labeled "E". Empty level for the battery component is in the middle of the gauge and is unlabeled.
- Labeling scheme is F-F-E
- Individual and total range information is not presented in numerical form
- Depletion for the gas and battery components is from top to bottom.
- Gas and battery icons are located inside the gauge near the bottom of each component

**<u>Gauge 13:</u>**



Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

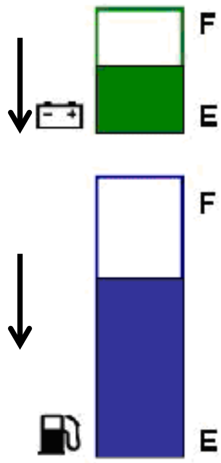
This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards middle of the gauge, which represents the empty level for the battery. Similarly, as the gas begins to deplete the blue area begins to shrink towards the bottom, which represents the empty level for the gas. It is important to note that the colored regions for gas and battery components shrink in the same direction (towards the bottom). The empty level for the battery component coincides with the full level for the gas component. In the PHEV under consideration, once the battery has depleted completely the vehicle begins to operate on gas. Given the top to bottom direction of fuel depletion in this gauge, the placement of the battery component on top of the gas component makes this gauge intuitive.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation
- Equal area for gas and battery components
- Gas and battery components are in close spatial proximity
- Empty level for the gas is at the bottom of the gauge and is unlabeled. Empty level for the battery component is in the middle of the gauge and is also unlabeled.
- Labeling scheme is numerical (300 mi – 200 mi- 100 mi) with no label for the empty level of the gas component
- Individual and total range information is not presented in numerical form
- Depletion for the gas and battery components is from top to bottom.

- Gas and battery icons are located outside the gauge near the bottom of each component

**<u>Gauge 14</u>**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

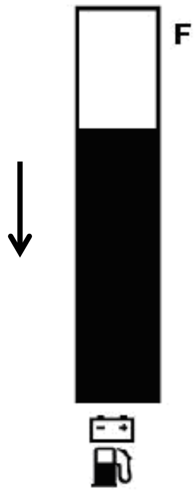
**Working:**

The gas and battery components of this gauge are separate. This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete, the green area begins to shrink towards the bottom of the gauge near the "E" level. Similarly, as the gas begins to deplete the blue area begins to shrink towards the bottom of the gauge near the "E" level. It is important to note that the colored regions for gas and battery components shrink in the same direction (top to bottom). Each component has its own independent full and empty levels. In the PHEV under consideration, once the battery has depleted completely the vehicle begins to operate on gas. Given the top to bottom direction of fuel depletion in this gauge, the placement of the battery component on top of the gas component makes this gauge intuitive.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation
- Size of gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source.
- Gas and battery components are separate
- Empty levels for the gas and battery components are at the bottom and labeled “E”
- Labeling scheme is F-E for each component
- Individual and total range information is not presented in numerical form
- Depletion for the gas and battery components is from top to bottom.
- Gas and battery icons are located outside the gauge near the bottom (empty level)

**Gauge 15:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

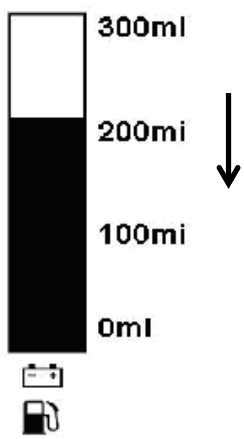
This is a unique gauge in that both gas and battery components are represented together. Only combined information is presented and only in relative form (no numerical information). This gauge is designed so that when there is any fuel (gas or battery) in the vehicle, it is represented by the black area. When the gas tank is full and the battery is fully charged the gauge is completely colored black. As either fuel depletes, the black area shrinks towards the bottom of the gauge. The driver can only get a sense for whether or not the vehicle has any fuel in it. This gauge provides no information on how much of each fuel is available and which fuel the vehicle is operating on at that time.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation
- Individual range information is not presented in relative or absolute (numeric) form
- Total range information is only presented in relative form (not in numeric form)

- Labeling scheme is “F”. The empty level is unlabeled.
- Fuel depletion is from top to bottom.
- Gas and battery icons are located outside the gauge at the bottom in a stacked fashion.

**Gauge 16:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

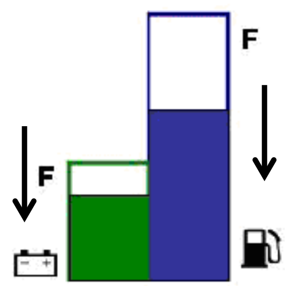
This is a unique gauge in that both gas and battery components are represented together. Only combined information is presented and only in relative form (no numerical information). This gauge is designed so that when there is any fuel (gas or battery) in the vehicle, it is represented by the black area. When the gas tank is full and the battery is fully charged the gauge is completely colored black. As either fuel depletes, the black area shrinks towards the bottom of the gauge. The driver can only get a sense for whether or not the vehicle has any fuel in it. This gauge provides no information on how much of each fuel is available and which fuel the vehicle is operating on at that time.

**Interesting attributes:**

- Linear moving pointer with fixed scale

- Vertical orientation
- Individual range information is not presented in relative or absolute (numeric) form
- Total range information is only presented in relative form (not in numeric form)
- Labeling scheme is “300 mi-200 mi-100 mi- 0 mi”
- Fuel depletion is from top to bottom.
- Gas and battery icons are located outside the gauge at the bottom in a stacked fashion.

**<u>Gauge 17:</u>**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

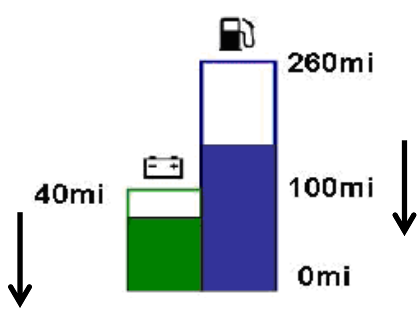
**Working:**

In this gauge the gas and battery components are placed side-by-side. This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards the bottom of the gauge. Similarly, as the gas begins to deplete the blue area begins to shrink towards the bottom. It is important to note that the colored regions for gas and battery components shrink in the same direction (top to bottom). The empty level for the gas and battery components is on the same horizontal line formed due to the side-by-side placement of the two components.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation
- Size of gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source.
- Gas and battery components are in close spatial proximity
- Empty level for the gas and battery components is at bottom of the gauge
- Labeling scheme is F for both gas and battery. Empty level is unlabeled.
- Individual and total range information is not presented in absolute (numeric) form
- Depletion for the gas and battery components is from top to bottom.
- Gas and battery icons are located outside the gauge near the bottom of each component (empty level)

**<u>Gauge 18:</u>**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

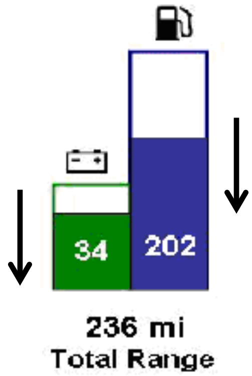
**Working:**

In this gauge the gas and battery components are placed side by side. This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards the bottom of the gauge, which is not labeled. Similarly, as the gas begins to deplete the blue area begins to shrink towards the bottom labeled “0 mi”. It is important to note that the colored regions for gas and battery components shrink in the same direction (top to bottom). The empty level for the gas and battery components is on the same horizontal line formed due to the side-by-side placement of the two components.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation
- Size of gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source.
- Gas and battery components are in close spatial proximity
- Empty level for the gas and battery components is at bottom of the gauge
- Labeling scheme for gas is “260 mi- 100 mi- 0 mi”, for battery “40 mi-”
- Individual and total range information is not presented in absolute (numeric) form
- Depletion for the gas and battery components is from top to bottom.
- Gas and battery icons are located outside the gauge at the top of each component

**Gauge 19:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

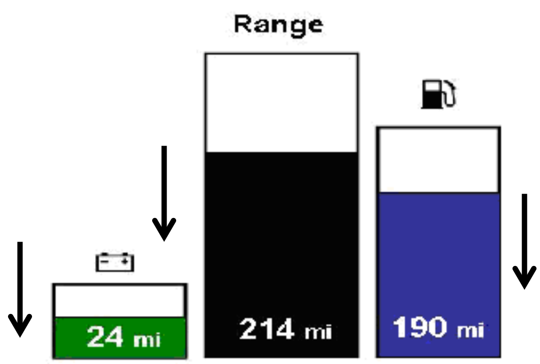
In this gauge the gas and battery components are placed side by side. This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete the green area begins to shrink towards the bottom of the gauge, which is not labeled. Similarly, as the gas begins to deplete the blue area begins to shrink towards the bottom. It is important to note that the colored regions for gas and battery components shrink in the same direction (top to bottom). The empty level for the gas and battery components is on the same horizontal line formed due to the side-by-side placement of the two components. The individual range is presented numerically inside each gauge component. The total range is also presented numerically.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation
- Size of gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source.

- Gas and battery components are in close spatial proximity
- Empty level for the gas and battery components is at bottom of the gauge
- No labeling scheme for fuel levels
- Individual range information is presented in absolute (numeric) form
- Total range information is not presented in absolute (numeric) form
- Depletion for the gas and battery components is from top to bottom.
- Gas and battery icons are located outside the gauge at the top of each component

**Gauge 20:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

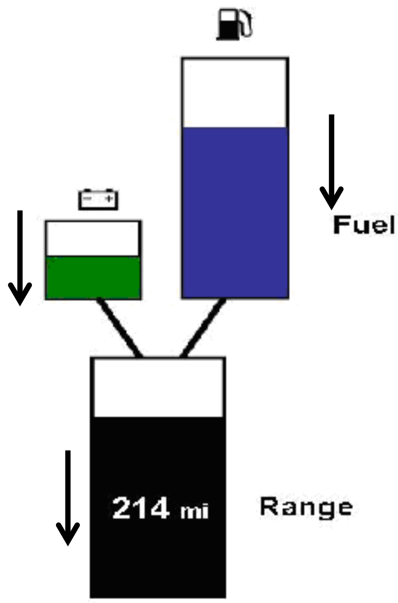
**Working:**

This gauge is unique in that there is a third design component representing combined gas and battery information (referred to as the "total" component). In this gauge the gas, battery and "total" components are separate and placed side by side. The "total" component is placed between the battery and gas components. This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue, the battery component is completely filled with green and the "total" component is completely filled with black. As the battery begins to deplete the green area begins to shrink towards the bottom of the component. Similarly as the gas begins to deplete the blue area begins to shrink towards the bottom. At the same time the black area in the "total" component shrinks towards the bottom. It is important to note that the colored regions for gas, battery and total components shrink in the same direction (top to bottom). The empty level for the gas, battery and total components is along the same horizontal level formed by the side-by-side placement of the three components. Additionally, the individual range is displayed numerically inside each gauge component. The total range is presented numerically inside the "total" component.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation
- Size of gas, battery and "total" components is proportional to the number of miles that the vehicle can travel on each fuel source and combined.
- Gas, battery and "total" components are in close spatial proximity but do not have common borders
- Empty level for the three components is at bottom of the gauge
- No labeling scheme for fuel levels
- Individual and total range information is presented in absolute (numeric) form
- Depletion for the gas, battery and total components is from top to bottom.
- Gas and battery icons are located outside the gauge at the top of each component. No icons have been used for the "total" component but the word "range" has been placed on top.

**Gauge 21:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

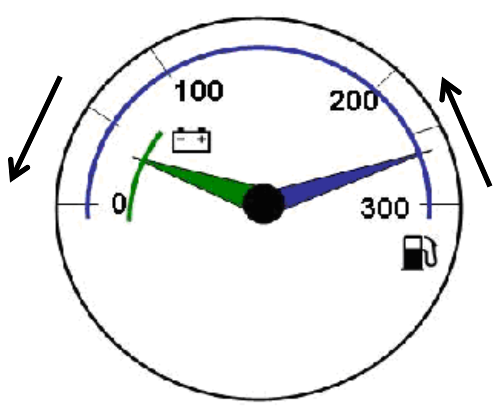
This gauge is unique in that there is a third design component representing combined gas and battery information (referred to as the “total” component). In this gauge the gas, battery and “total” components are separate and placed in a unique arrangement. The gas and battery components are connected to the “total” component by lines. The “total” component is placed below the battery and gas components. This gauge is designed so that when the gas tank is full and the battery is completely charged, the gas component is completely filled with blue, the battery component is completely filled with green and the “total” component is completely filled with black. As the battery begins to deplete the green area begins to shrink towards the bottom of the gauge. Similarly, as the gas begins to deplete the blue area begins to shrink towards the bottom. At the same time, the black area in the “total” component shrinks towards the bottom. It is important to note that the colored regions for gas, battery and total components shrink in the same direction (top to bottom). The individual range is not presented in absolute or numeric form. The total range is presented numerically inside the “total” component.

**Interesting attributes:**

- Linear moving pointer with fixed scale
- Vertical orientation
- Size of gas, battery and “total” components is proportional to the number of miles that the vehicle can travel on each fuel source and combined.
- Gas, battery and “total” components are separate but connected by lines
- Empty level for the three components is at bottom of the gauge
- No labeling scheme for fuel levels
- Individual ranges are not presented in absolute form
- Total range information is presented in absolute (numeric) form
- Depletion for the gas, battery and total components is from top to bottom.
- No icons have been used. The words “fuel” and “range” are located next to the gas and “total” components respectively.

**B. Dial shaped or circular gauges**

<u>**Gauge 22:**</u>




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

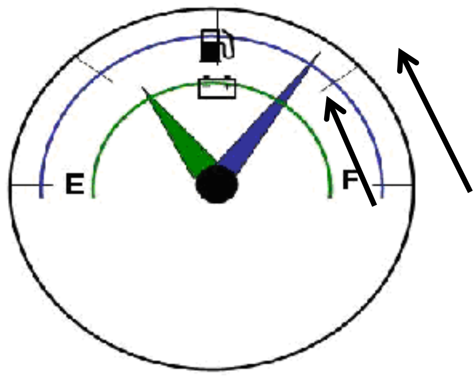
**Working:**

This is a circular gauge with two moving needle pointers. Both the gas and battery components are represented on the same dial. The gas component is represented by the blue scale line and blue needle pointer while the battery component is represented by the green scale line and green needle pointer. The length of the gas and battery scales is proportional to the number of miles that the vehicle can travel on each fuel source. When the gas tank is completely full and the battery is fully charged, then the blue needle points to “300” and the green needle points to the end of the green scale next to the battery icon. When the vehicle is completely out of fuel then both pointers are aligned at the “0” mark. The designers have used a full circle even though the gas and battery components only occupy the top half or semicircle.

**Interesting attributes:**

- Circular gauge with two moving needle pointers
- Length of scale for gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source
- Gas and battery components are in close spatial proximity
- Empty level for the gas and battery components is common at the 9 o’clock position.
- Common labeling scheme for gas and battery (0-100-200-300)
- Individual and total range information is not presented in absolute or numeric form
- Pointers for gas and battery components move in the same direction (counter clockwise when depleting)
- Gas and battery icons are located inside the gauge at the end of each individual scale

## Gauge 23:




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

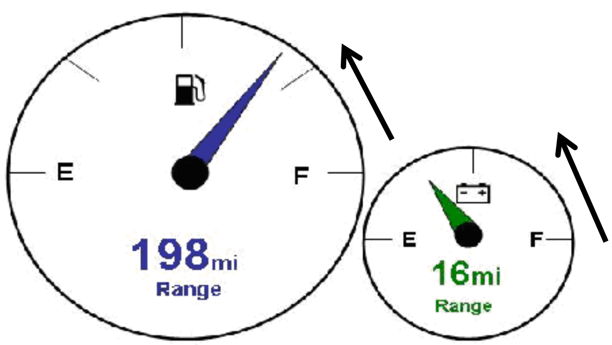
This is a circular gauge with two moving needle pointers. Both the gas and battery components are represented on the same dial. The gas component is represented by the blue scale line and blue needle pointer while the battery component is represented by the green scale line and the green needle pointer. When the gas tank is completely full and the battery is fully charged, then the blue and green needles both point to "F" mark (in the 3 o'clock position). When the vehicle is completely out of fuel then both needles are aligned at the "E" mark (in the 9 o'clock position). The designers have used a circular design even though the gas and battery components only occupy the top half or semicircle.

**Interesting attributes:**

- Circular gauge with two moving needle pointers
- Length of scale for gas and battery components is not proportional to the number of miles that the vehicle can travel on each fuel source
- Gas and battery components are in close spatial proximity
- Empty level for the gas and battery components is common at the 9 o'clock position.

- Common labeling scheme for gas and battery (E-F)
- Individual and total range information is not presented in absolute or numeric form
- Pointers for gas and battery components move in the same direction (counter clockwise when depleting)
- Gas and battery icons are located inside the gauge at the 12 o'clock position. The scale lines cross over the icons.

**<u>Gauge 24:</u>**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

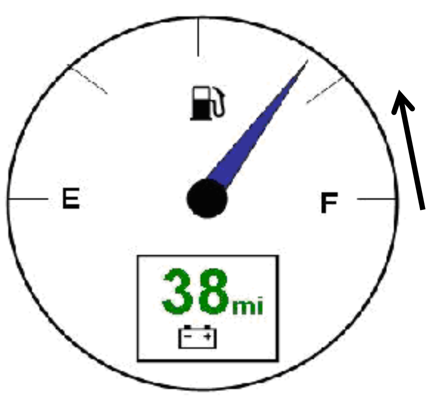
**Working:**

This gauge has two dials with moving needle pointers. The gas and battery components are separate. The gas component is represented by the larger circle, blue needle and blue text. The battery component is represented by the smaller circle, green needle and green text. The size of the gas and battery components (dials) is in proportion to the number of miles that the vehicle can travel on each fuel source. When the gas tank is completely full and the battery is fully charged, the needle in each circle points to the "F" mark at the 3 o'clock position. When the vehicle is completely out of fuel the needle in each circle points to the “E” mark at the 9 o’clock position. Individual ranges for the gas and battery components are presented in numeric form in the bottom half of each circle.

**Interesting attributes:**

- Circular gauge with two moving needle pointers
- Size of circle for gas and battery components is proportional to the number of miles that the vehicle can travel on each fuel source.
- Gas and battery components are in close spatial proximity but do not share a border
- Empty levels for both the gas and battery components are at the 9 o’clock positions on each circle.
- Common labeling scheme for gas and battery (E-F)
- Individual ranges are presented in absolute or numeric form
- Total range information is not presented in numeric form
- Pointers for gas and battery components move in the same direction (counter clockwise when depleting)
- Gas and battery icons are located inside the gauge at the 12 o’clock position on each circle.

**<u>Gauge 25:</u>**



Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

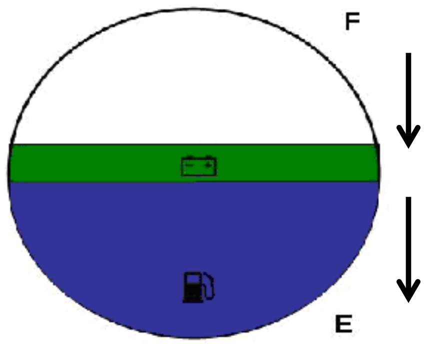
**Working:**

This gauge is a combination of moving pointer and numeric display. The gas component is represented by the circle with a blue needle pointer while the battery component is represented by the numerical gauge with green text. When the gas tank is completely full the blue needle is at the “F” mark or 3 o’clock position. When the battery is fully charged the number on the numerical gauge represents the maximum number of miles that can be traveled on the battery alone (40 miles in the case of this PHEV). When the vehicle is completely out of fuel the blue needle is at the “E” mark (9 o’clock position) and the numerical gauge shows “0 mi”.

**Interesting attributes:**

- Circular gauge with a moving pointer (needle) and numerical display
- Gas, battery components are in close spatial proximity
- Empty levels for gas and battery are represented by different elements.
- Labeling scheme for gas is E-F
- Only the individual range for battery is presented in numeric form
- Total range information is not presented in numeric form
- Pointer for the gas component moves in the counter clockwise direction when depleting
- Gas icon is located inside the gauge, at the 12 o’clock position. The battery icon is located inside the numerical display.

**Gauge 26:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

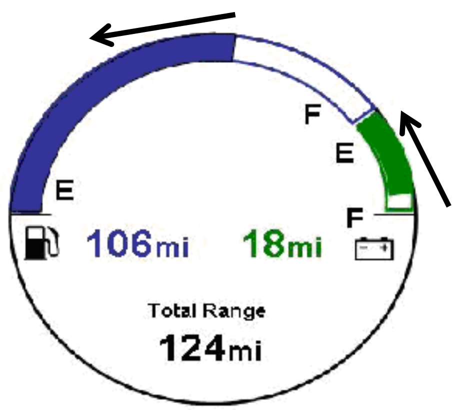
In this gauge each half of the circle represents one of the two components. The designers have represented fuel depletion in a linear fashion (from top to bottom) even though this is a circular design. When the gas tank is full and the battery is completely charged, the gas component is completely filled with blue and the battery component is completely filled with green. As the battery begins to deplete, the green area begins to shrink towards middle of the gauge (representing the empty level for battery). Similarly, as the gas begins to deplete the blue area begins to shrink towards the bottom of the gauge near the “E” mark. Fuel depletion for gas and battery components occurs in the same direction (from top to bottom). The empty level for the battery component coincides with the full level for the gas component.

**Interesting attributes:**

- Circular gauge with two moving pointers (linear)
- Equal area for gas and battery components
- Gas and battery components are in close spatial proximity and share a common border

- Empty level for the gas is at the bottom of the gauge (labeled “E”). Empty level for the battery is in the middle of the gauge.
- Labeling scheme overall is F-E
- Empty level for the battery component coincides with the full level for the gas component.
- Individual and total range information is not presented in numerical form
- Pointers for the gas and battery component move in the same direction when depleting (from top to bottom)
- Gas and battery icons are placed inside the gauge.

**Gauge 27:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

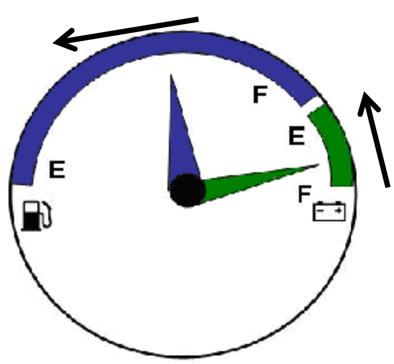
**Working:**

In this gauge both the gas and battery components are represented on the same dial. The gas component is represented by the blue arc and the battery component is represented by the green arc. The arc lengths for the gas and battery components are proportional to the number of miles that the vehicle can travel on each fuel source. When the gas tank is completely full and the battery is fully charged, then the arc representing the gas component is completely filled with blue and the arc representing the battery component is completely filled with green. When the vehicle is completely out of fuel then both arcs are empty (no color). The designers have used a circular design with the gas and battery components occupying the top semicircle. The bottom half of the circle is used to present the total range information in numeric form. The empty point for the battery component is located very close to the full point for the gas component.

**Interesting attributes:**

- Circular gauge with two moving pointers (linear)
- Arc lengths for the gas and battery components are proportional to the number of miles that the vehicle can travel on each fuel source.
- The gas and battery components are in close spatial proximity
- Empty level for the gas component is at the 9 o'clock position and the empty level for the battery component is at the 2 o'clock position (approximately) on the circle.
- Labeling scheme for gas and battery is E-F
- Individual and total range information is presented in numeric form
- Pointers for gas and battery components move in the same direction when depleting (counter clockwise)
- The gas and battery icons are placed inside the gauge at the 9 o'clock and the 3 o'clock positions respectively.

**<u>Gauge 28:</u>**



Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

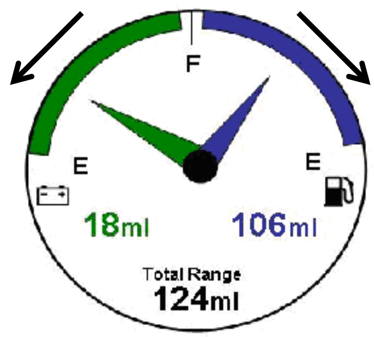
**Working:**

In this gauge both the gas and battery components are represented on the same dial. The gas component is represented by the blue arc and the blue needle pointer. The battery component is represented by the green arc and the green needle pointer. The arc lengths for the gas and battery components are proportional to the number of miles that the vehicle can travel on each fuel source. When the gas tank is completely full and the battery is fully charged, then the arc representing the gas component is completely filled with blue and the arc representing the battery component is completely filled with green. The blue and green needles point to the “F” marks for the gas and battery components. When the vehicle is completely out of fuel then both arcs are empty (no color) and both needles point to the “E” marks.

**Interesting attributes:**

- Circular gauge with four moving pointers (two linear and two needle)
- Arc lengths for the gas and battery components are proportional to the number of miles that the vehicle can travel on each fuel source..
- The gas and battery components are in close spatial proximity
- Empty levels for the gas and battery components are at the 9 o’clock and the 2 o’clock positions (approximately) respectively on the circle.
- Labeling scheme for gas and battery is E-F
- Individual and total range information is not presented in numeric form
- Pointers for gas and battery components move in the same direction when depleting (counter clockwise).
- The gas and battery icons are placed inside the gauge at the 9 o’clock and the 3 o’clock positions respectively.

**Gauge 29:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

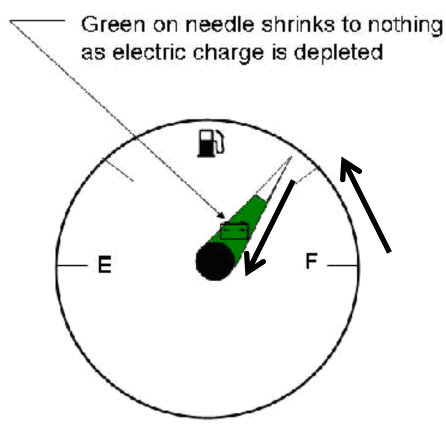
**Working:**

In this gauge both the gas and battery components are represented on the same dial. The gas component is represented by the blue arc, blue needle pointer and blue text. The battery component is represented by the green arc, green needle pointer and green text. The gauge uses two types of moving pointers for each component (needle pointer and linear pointer inside the arc). The gas component is represented in the right half of the top semicircle while the battery component is represented by the left half of the top semicircle. The arc lengths for gas and battery are equal. When the gas tank is completely full and the battery is fully charged, then the arc representing the gas component is completely filled with blue and the arc representing the battery component is completely filled with green. The blue and green needle pointers coincide at the 12 o'clock position ("F" mark). When the vehicle is completely out of fuel then both arcs are empty (no color) and both needles point to the "E" marks. The designers have used a circular design even though the gas and battery components only occupy the top semicircle. The bottom half of the circle is used to present individual and total range information in numeric form.

**Interesting attributes:**

- Circular gauge with four moving pointers (two linear and two needle)
- Arc lengths for the gas and battery components are equal
- The gas and battery components are in close spatial proximity
- Empty levels for the gas and battery components are at the 3 o’clock and the 9 o’clock positions (approximately) respectively on the circle.
- Labeling scheme for gas and battery is E-F
- Individual and total range information is presented in numeric form
- Pointers for gas and battery components move in opposite directions when depleting (battery- counter clockwise, gas- clockwise)
- The gas and battery icons are placed inside the gauge at the 3 o’clock and the 9 o’clock positions respectively.

**<u>Gauge 30:</u>**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

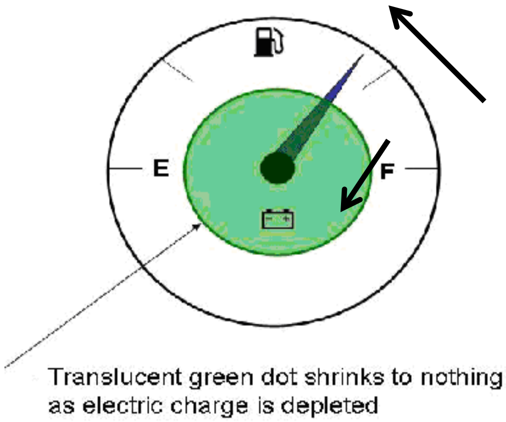
**Working:**

In this gauge the gas component comprises of the scale and needle pointer. When the gas tank is full, the needle points to the “F” mark at the 3 o’clock position on the circle. The needle pointer is a shared element between gas and battery components. The battery component is represented by the radial pointer inside the needle. The gauge makes use of only one color (green) to represent the battery component. When the battery is completely charged the needle pointer is completely filled with green. As the battery depletes the green area shrinks radially (towards the center of the circular dial). When the vehicle is completely out of fuel then the needle pointer is at the “E” mark in the 9 o’clock position and there is no green inside the pointer. The designers have used a full circle even though the gas and battery components only occupy the top semicircle.

**Interesting attributes:**

- Circular gauge with two moving pointers (needle and radial)
- The gas and battery components are in close spatial proximity
- Empty level for the gas is at the 9 o’clock position and for the battery is at the center of the circle (represented by a point with no green)
- Labeling scheme for gas is E-F, no fuel level labels used for battery
- Individual and total range information is not presented in numeric form
- Pointer for the gas component moves in the counter clockwise direction when depleting. Pointer for the battery component moves radially towards the center when depleting.
- The gas icon is placed inside the gauge at the 12 o’clock position. The battery icon is placed inside the needle pointer
- Only one color used in this gauge (to represent the battery)

**Gauge 31:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

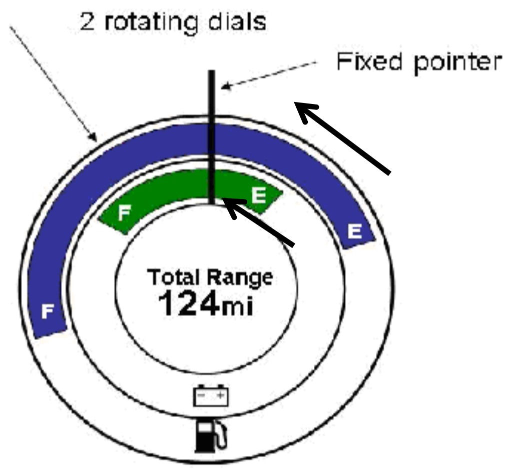
In this gauge the gas component is represented on the circular dial comprising of the scale and blue needle pointer. When the gas tank is full, the needle points to the "F" mark at the 3 o'clock position on the circle. The inner circle represents the battery component. When the battery is completely charged the inner circle is completely filled with green. As the battery depletes the green area shrinks radially (towards the center of the circular dial). When the vehicle is completely out of fuel then the blue needle pointer is at the "E" mark at the 9 o'clock position and there is no green inside the inner circle.

**Interesting attributes:**

- Circular gauge with two moving pointers (needle and radial)
- The gas and battery components are in close spatial proximity
- Empty level for the gas is at the 9 o'clock position and for the battery is at the center of the circle (represented by a point with no green)
- Labeling scheme for gas is E-F, no fuel level labels used for battery
- Individual and total range information is not presented in numeric form

- Pointer for the gas component moves in the counter clockwise direction when depleting. Pointer for the battery component moves radially towards the center when depleting.
- The gas icon is placed inside the gauge at the 12 o'clock position. The battery icon is placed inside the inner circle at the 6 o'clock position.

**Gauge 32:**




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

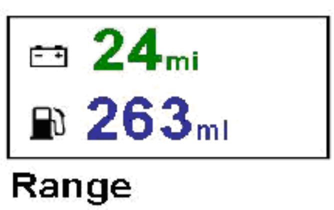
**Working:**

This is the only gauge in the set of thirty-three that is of the moving scale with fixed pointer format. The design comprises of concentric circles. The outer most circle (blue) with the largest circumference represents the gas component. The middle circle (green) represents the battery component. A fixed pointer is placed at the 12 o'clock position. Each circle has a colored arc that moves. The length of both arcs is proportional to the number of miles that the vehicle can travel on each fuel source. When the gas tank is full and the battery is fully charged, the ends of both arcs representing the full levels ("F") are aligned at the fixed pointer such that the colored portions of both arcs lie to the right of the fixed pointer. As the battery depletes the green arc moves in a counterclockwise manner so that the “E” point on the other end of the arc moves closer to the fixed pointer. Similarly, the gas level depletes the blue arc moves in a counterclockwise manner such that the “E” point on the arc moves closer to the fixed pointer. When there is no fuel in the vehicle the ends of both arcs at the “E” points are aligned at the fixed pointer such that the colored portions lie to the left of the fixed pointer. The center of the gauge is used to present total range information in numeric form.

**Interesting attributes:**

- Circular gauge with a fixed pointer and two moving scales.
- Length of each arc is proportional to the number of miles that the vehicle can travel on each fuel source.
- The gas and battery components are in close spatial proximity
- Fixed pointer is at the 12 o’clock position on the circle.
- Labeling scheme is E-F for gas and battery
- Total range information is presented in numeric form
- The gas and battery icons are placed inside the gauge at the 6 o’clock positions

**Gauge 33:**




**Working:**

This is the only numerical gauge (or digital gauge) in the set. It presents individual range information for the gas and battery components. When the gas tank is full and the battery is fully charged, the display shows “300 mi” in blue text and “40 mi” is green text. When the vehicle is completely out of fuel it shows “0 mi” for both components.

**Interesting attributes:**

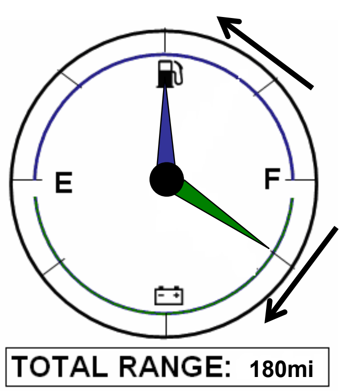
- Numeric display
- Individual range information displayed in numeric form
- Total range information is not presented in numeric form
- Blue text represents gas and green text represents battery
- Gas and battery icons are placed to the left of the text
- It has a label “range” located outside the rectangle

**6.2. Gauge designs created by the team at the** University of Minnesota

The team of human factors experts at the University of Minnesota (UMN) conducted a brainstorming session to create additional gauge options. These designs presented information differently than the gauges created by the designers at General Motors (GM). Although several new gauge designs were created only the following four designs have been documented since they were included for testing in the usability study soon after they were created. The author does not have a record of the other designs.

**UMN Gauge 1:**

None of the circular designs created by the GM team incorporated a scale in the bottom half of the circular gauges. It was of interest to understand how drivers would perform with such a design so the following gauge was created.



Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

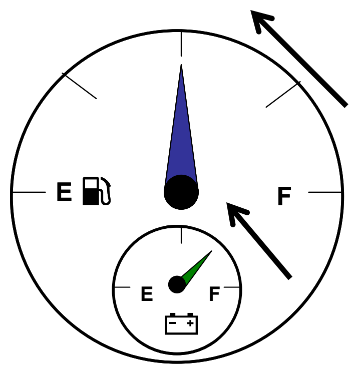
In this gauge the gas and battery components have common full and empty levels. When the gas tank is full and the battery is completely charged the blue and green needles coincide at the “F” mark. Similarly, when the vehicle is out of fuel both needles coincide at the “E” mark. As the gas in the tank depletes the blue needle moves in a counterclockwise direction and the green needle moves in a clockwise direction.

**Interesting attributes:**

- Circular gauge with two moving pointers (needle)
- Scale lengths for the gas and battery components are equal
- The gas and battery components are in close spatial proximity
- Empty level for the gas and battery is common at the 9 o’clock position. Full level for the gas and battery is also common at the 3 o’clock position. Labeling scheme is E-F for both gas and battery
- Individual and total range information is not presented in numeric form
- Pointers for gas and battery components moving in opposite directions when depleting (clockwise for battery, counterclockwise for gas)
- The gas and battery icons are placed inside the gauge at the 12 o’clock and 6 o’clock positions respectively

**UMN Gauge 2:**

The following design is unique in that it integrates two full circular dials one inside the other. It incorporates the conventional fuel gauge design that drivers are already familiar with.



**Total Range 180 mi**

Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

This gauge design comprises of two conventional fuel gauges, one for gas and battery each. The size of each circle is proportional to the number of miles that the vehicle can travel on each fuel source. When the gas tank is full and the battery is completely charged the blue and green needles point to the “F” marks on their respective scales (in the 3 o’clock positions). When the vehicle is out of fuel both needles point to “E” marks on their respective scales (in the 9 o’clock positions). The direction for fuel depletion is the same for both dials (counterclockwise).

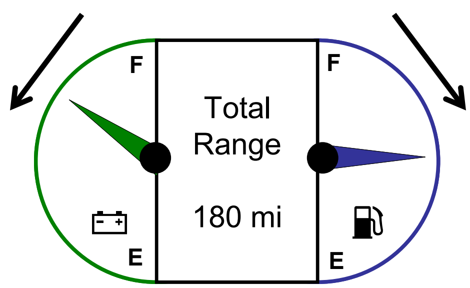
**Interesting attributes:**

- Circular gauge with two moving pointers (needle)
- Size of gas and battery components is proportional to their maximum individual ranges
- The gas and battery components are in close spatial proximity
- Empty and full levels are at the 9 o’clock and 3 o’clock positions on each component
- Labeling scheme is E-F for both gas and battery

- Total range information is presented in numeric form
- Individual range information is not presented in numeric form
- Pointers for gas and battery components move in the same direction (counterclockwise) when depleting
- The gas and battery icons are placed inside the gauge

**UMN Gauge 3:**

In this hybrid gauge design the gas and battery components are semicircles that are oriented vertically. These are joined by a rectangle that presents total range information in numeric form.




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

In this gauge when the gas tank is full and the battery is completely charged the blue and green needles point to the "F" marks on their respective scales in the 12 o'clock positions. When the vehicle is out of fuel both needles point to "E" marks on their respective scales in the 6 o'clock positions. The direction for fuel depletion is clockwise for the gas component and counterclockwise for the battery component.

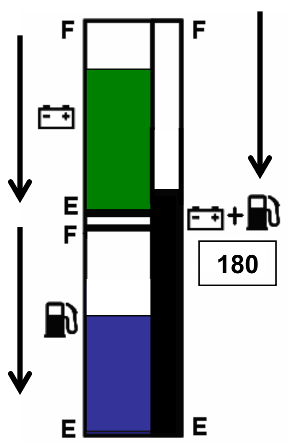
**Interesting attributes:**

- Oval shape

- Comprises of two semicircular gauges with two moving pointers (needle)
- Scale length for gas and battery components is equal
- The gas and battery components are in close spatial proximity
- Empty and full levels are at the 6 o'clock and 12 o'clock positions on the gas and battery components
- Labeling scheme is E-F for both gas and battery
- Total range information is presented in numeric form
- Individual range information is not presented in numeric form
- Pointers for the gas and battery components move in opposite directions during depletion (gas- clockwise, battery- counterclockwise)
- The gas and battery icons are placed inside the gauge

**UMN Gauge 4:**

This design includes a third "total" component arranged in an integrated manner with the gas and battery components.




Arrows have been added here to indicate direction of fuel depletion. These were not part of the actual gauge design.

**Working:**

This design comprises of three bars, one each for the gas, battery and "total" components. When the gas tank is full and the battery is fully charged, the gas component is filled with blue, battery component is filled with green and the “total” component is filled with black completely. When the vehicle is out of fuel the colored area in all three components disappears.

**Interesting attributes:**

- Bar gauge with three moving pointers (linear)
- Vertical orientation
- Gas and battery components are equal in size
- The gas, battery and “total” components are in close spatial proximity
- Empty level for each component is at the bottom and labeled “E”
- Labeling scheme is F-E for all three components
- Total range information is presented in numeric and relative form
- Individual range information is not presented in numeric form
- Pointers for the gas, battery and total components move in the same direction (from top to bottom)
- All icons are placed outside the gauge. A new icon was created for the “total” component that comprises of the gas and battery icons with a “+” sign in the middle.

# 7. Heuristic evaluation of gauge designs

Prior to the usability study a heuristic evaluation was conducted on the thirty-three hybrid gauge designs created by the team at General Motors (GM) and the four designs created by the team at the University of Minnesota (UMN). The goal of the heuristic evaluation was to quickly narrow down this vast set of designs to a subset of gauges that could be used for usability testing. Each design was evaluated according to human factors principles and best practices.

The method of heuristic evaluation was used as it offers some advantages. It is quick, inexpensive and does not require much advanced planning. Evaluators are presented with designs and are asked provide their comments and opinions on those (Nielsen and Molich (1990)). This method was effective in narrowing down the large set of gauge designs into a more manageable subset for efficient usability testing.

A team of four usability experts from the HumanFirst lab at the University of Minnesota (UMN) conducted the heuristic evaluation of the hybrid fuel gauges. The team included Dr. Nicolas Ward, Mick Rakauskas, Janet Creaser and the author.

### 7.1. Evaluation process

The heuristic evaluation was conducted in one session. After the UMN team evaluated the thirty-three designs provided by GM, they engaged in a small brainstorming session to generate additional gauge options. A heuristic evaluation was also conducted on these new designs in the same session.

The four usability experts reviewed all gauge designs together, with each expert taking a turn to present a critical assessment on the designs based on human factors principles. This was followed by a group discussion through which a consensus was reached on which gauges to include for usability testing. The gauge designs were printed on paper for review. The author and one other expert (Janet Creaser) informally documented the assessment of each design based on the comments provided by the all experts.

The evaluation was also influenced by subjective comprehension of the four experts based on intuition and common sense. Since the goal of the usability study was to determine the class of gauge that had the best performance, it was of interest to include a set of diverse gauge designs for usability testing. Some gauges that were very similar in design were reviewed in groups and only one design was selected from the group if it was found to be suitable. Gauges that were unique were reviewed individually. These groups are discussed later in this section.

### 7.2. Human factors principles used in heuristic evaluation

Wickens et al. (2003) defined principles of display design that can be used to create effective displays. These have been categorized into perceptual, mental model, attention and memory principles. Some of the benefits of these principles are reduced errors, reduced training time, increased efficiency and increased user satisfaction. The following human factors principles were found to be most applicable to the hybrid fuel gauges under consideration and were used to evaluate them.

#### Perceptual principles

Perceptual principles deal with the presentation of information in a clear manner so that it can be understood without ambiguity or confusion. The following perceptual principles were found to be most applicable to the hybrid fuel gauges under consideration.

- Principle of legibility

- Principle of redundancy gain
- Principle of discriminability

**Mental model principles**

These principles deal with presenting information in a manner that is consistent with a user's mental model of how a system works and what the user expects from it. The following mental model principles were found to be most applicable to the hybrid fuel gauges under consideration.

- Principle of the moving part
- Principle of pictorial realism

**Principles based on attention**

These principles deal with presenting information effectively without placing heavy demands on the user's attention so that the information can be accessed easily. The following principles were found to be most applicable to the hybrid fuel gauges under consideration

- Proximity compatibility principle
- Minimization of information access cost

**Memory principles**

These principles deal with presenting information taking into consideration the limitations of the human memory. The following memory principles were found to be most applicable to the hybrid fuel gauges under consideration.

- Replacement of memory with visual information
- Principle of consistency

Each of these principles is discussed below in the context of the hybrid fuel gauges.

## PERCEPTUAL PRINCIPLES

### Principle of legibility

In order for a display to be usable it is critical that is be legible. The right combination of colors and contrasts should be used so that the user gets the necessary information from the display.

**Principle of redundancy gain**

According to the principle of redundancy gain by Wickens et al. (2003), a message is more likely to be interpreted correctly when it is expressed more than once. The message may be presented in alternative physical forms such as print and pictures, color and shape etc. Redundancy of information can be very helpful in situations where viewing conditions may be degraded for example, during the task of driving during poor visibility conditions. Drivers cannot focus much attention on interpretation of the fuel gauge.

**Principle of discriminability**

Objects that appear to be similar are likely to be confused. Discriminable elements should be used. In the context of hybrid fuel gauges this principle suggests that dissimilar elements between the gas and battery components should be highlighted so that they are easily distinguishable.

**MENTAL MODEL PRINCIPLES**

**Principle of the moving part**

Roscoe (1968) stated that a moving element in a display of dynamic information should move in a manner compatible with the user's mental model of how the element moves in the physical system. This principle was discussed in the context of aircraft displays. Roscoe stated that when a pilot moves a control he naturally expects that the display indication will move in the same direction such that up means up, down means down and so on. This principle is relevant in the context of hybrid fuel gauges. For example, in the case of vertically oriented bar gauges the principle of the moving part suggests that the depletion of fuel level should be from the top to bottom, similar to the direction of depletion of water in a glass or tank.

### Principle of pictorial realism

Roscoe (1968) stated that a display should resemble the variable it represents and in a manner that the user would expect. For example, high values of variables should be placed on the top or right of the display and low values should be placed on the bottom or left. Continuous variables should have analog displays and discrete variables should have digital displays.

## PRINCIPLES BASED ON ATTENTION

### The proximity compatibility principle (PCP) and minimization of information access cost (IAC)

The PCP as described by Wickens and Carswell (1995) is a guideline for determining where a display should be located relative to its relationship with other displays. It depends on two dimensions of proximity or similarity- perceptual proximity and processing proximity. Perceptual proximity (also known as display proximity) refers to how similar two elements are in terms of conveying task-related information. Processing proximity (also known as mental proximity) refers to the extent to which two or more elements are used for the same task. Wickens and Carswell recommend that displays that are relevant to the same task or mental operation should be placed in close proximity to each other. Two elements that are perceptually similar should be located close together, should share the same color, should use the same physical dimensions (orientation or length) or use the same code (both digital or analog). This makes their comparison and integration easier. This is due to a decrease in visual search cost and the time taken to go from one element to the other. Wickens (2003) refers to this as information access cost (IAC). IAC involves the movement of the head, eyes and attention.

In the context of hybrid fuel gauges, drivers need to obtain combined information from the gas and battery components so that they can determine how much combined fuel is available and how far they can travel on both fuel sources. PCP suggests that for hybrid fuel gauges, the gas and battery components should be located close together in order to minimize the burden of computational integration for obtaining combined information. By increasing proximity of the individual components, the contributions of head and eye movements on IAC will be reduced, thus facilitating faster reading. In the context of hybrid fuel gauges this implies that designs in which the gas and battery components are in close spatial proximity and/or are connected by lines are likely to have reduced information access cost thus facilitating faster reading.

**MEMORY PRINCIPLES**

**Replace memory with visual information: knowledge in the world**

According to Norman (1988) users should not be required to retain important information in memory. Instead this information should be presented as knowledge in the world. The term “knowledge in the world” refers to the interface that the user interacts with. In the context of hybrid fuel gauges this principle suggests that users should be presented with the maximum range of the gas tank and the electric battery.

**Principle of consistency**

According to Wickens et al. (2003) old habits transfer positively from previous displays to support the processing of new displays. In the context of hybrid fuel gauge designs this means that subjects are likely to be familiar with gauges that include some elements from conventional fuel gauges (circular with needle pointer) because they are consistent with their expectations and understanding of fuel gauges.

Additionally, guidelines and recommendations on the minimization of clutter and the use of color in displays were used for evaluation.

**Minimization of clutter**

Wickens and Carswell (1995) stated that movement of attention is a contributing factor to information access cost. Visual clutter affects attention movement. The hybrid fuel gauge designs were examined to determine if they were cluttered. Some examples of cluttered elements include scale lines crossing over icons, placement of icons inside very small design elements such as needle pointers etc.

**Use of Color**

According to Simmonds et al. (1981) color should be used to group and/ or highlight information in displays. The advantage of using color is that it can aid visual search by making it easier for viewers to find items of interest on the display. Color is the most effective coding technique known for aiding visual search (Christ, 1975). In his study, Green (1984) found that subjects ranked color-coded displays to be more understandable than displays that were not color-coded. All of the hybrid fuel gauge designs used color-coding to distinguish between the gas and battery components.

Some of these principles may conflict each other. For example, trying to introduce redundancy of information in a gauge or designing to replace memory with information in the world may add clutter. Integrating the elements of a gauge for reduced information access cost may also cause the display to look cluttered. Appropriate trade-offs need to be made. In the heuristic evaluation, the four experts examined the hybrid gauges to determine the designs in which there was a functional balance among these principles.

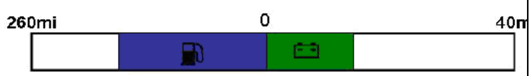
### 7.3. Results of the heuristic evaluation

The following table summarizes the evaluation of the thirty-three gauge designs provided by General Motors. Some gauges that were very similar were reviewed in groups while unique gauges were reviewed individually.

# GAUGES

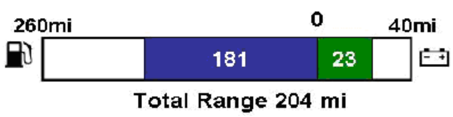
## GROUP OF GAUGES 1 THROUGH 7

### GAUGE 1




### GAUGE 2


### GAUGE 3

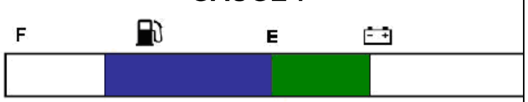



### GAUGE 4


### GAUGE 5


### GAUGE 6


### GAUGE 7




# EVALUATION SUMMARY

These seven gauges show variations of the same basic design.

**Central location of the empty mark ("0" or "E")**

The empty mark located in the center is common for both fuel sources. In order to check if the vehicle is running out of fuel (both sources) the driver needs to look at one common point in the middle of the gauge. So this design was considered to be more efficient than other designs in which the empty points were at the extremes (see next group).

**Spatial proximity**

According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of all these gauges are in close proximity resulting in low information access cost.

**Discriminability**

In all these gauges the gas and battery components are easily discriminable.

**Replacement of memory with visual information**

Gauges 1, 2, and 3 present maximum ranges for gas and battery thus reducing the burden on the user to remember

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| | these maximum ranges.<br><br>**Legibility**<br>The gas and battery icons in gauges 1 and 2 have poor legibility due to poor contrast between the colors used and the small size of the icons.<br><br>**Redundancy**<br>Only Gauge 3 presents individual range information in both relative (graphical) as well as absolute (numeric) forms. However, this causes the gauge to look cluttered.<br><br>**Clutter**<br>Gauges 1, 2, 3 and 4 were considered cluttered due to the placement of icons and text in the central areas of the gauge components. These gauges were eliminated.<br><br>**Size of gas and battery components**<br>In the remaining gauges 5, 6 and 7, the size of their gas and battery components was examined according to the principle of pictorial realism. In gauges 5 and 7 the gas and the battery components are equally sized. In Gauge 6, the gas and battery components are sized in proportion to the number of miles that can be traveled on each fuel source. This is representative of the actual operation of the hybrid vehicle. Gauges 5 and 7 were eliminated. |

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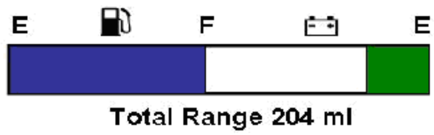
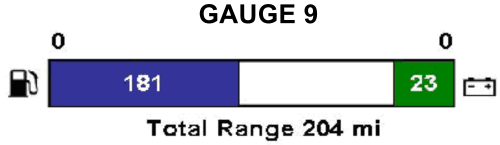
| | **Reduced cognitive burden**<br>Gauge 6 has an additional advantage in that the total range information is displayed numerically. This means that the user does not need to mentally integrate information from each individual source, which reduces the cognitive burden on the user.<br><br>**Based on this evaluation gauge 6 was selected to be part of the final set of designs for usability testing. It is labeled "GAUGE C" in the final set.** |

**GROUP OF GAUGES 8 AND 9**

**GAUGE 8**




**GAUGE 9**




**Spatial proximity**

According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of all these gauges are in close proximity resulting in low information access cost.

**Discriminability**

In all these gauges the gas and battery components are easily discriminable.

**Redundancy**

Only Gauge 9 presents individual range information in both relative (graphical) as well as absolute (numeric) forms. However, this causes the gauge to look cluttered.

**Reduced cognitive burden**

Gauges 8 and 9 present total range information numerically. So the user does not need to mentally integrate information from each individual source, which reduces the cognitive burden.

**Location of empty marks (“0” or “E”)**

In these designs the empty marks are located on each end of the gauge. In order to check if the vehicle is running out of fuel (both sources) the driver needs to look at two different points at

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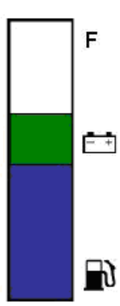
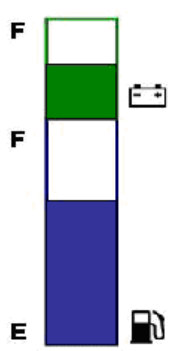
| | the opposite ends of the gauge. In this respect these designs were considered to be inefficient relative to the previous group discussed above.<br><br>**Replacement of memory with visual information**<br>Neither gauge presents the maximum ranges for gas and battery. So the burden of remembering these maximum ranges is on the user.<br><br>**Clutter**<br>Gauge 8 was considered cluttered due to the location of the icons towards the center of each gauge component. Gauge 9 was considered cluttered due to the placement of numbers inside each component.<br><br>Based on this evaluation gauges 8 and 9 were eliminated. |
| **<u>GROUP OF GAUGES 10, 11 AND 12</u>**<br><br>**GAUGE 10 GAUGE 11 GAUGE 12**<br><br>  | **Spatial proximity**<br>According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of all these gauges are in close proximity resulting in low information access cost.<br><br>**Discriminability**<br>In all these gauges the gas and battery components are easily discriminable.<br><br>**Legibility** |

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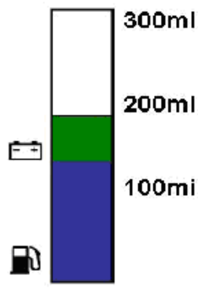
|  | Overall, these gauges are legible.<br><br>**Redundancy**<br>None of these gauges present individual range information in absolute or numeric form.<br><br>**Replacement of memory with visual information**<br>Only Gauge 12 presents the maximum range (300 miles in this case) for this PHEV thus reducing the need for the user to remember it. However, none of these gauges present individual maximum ranges for gas and battery.<br><br>**Size of gas and battery components**<br>In Gauge 11, the gas and battery components are sized in proportion to the number of miles that can be traveled on each fuel source. This is representative of the actual operation of the hybrid vehicle. In gauges 10 and 12 the gas and the battery components are equally sized.<br><br>**Single point represents both full and empty levels**<br>This design was considered to be confusing because the empty level for the battery component coincides with the full level for the gas component and the designs do not have an empty label for the battery.<br><br>**Clutter** |

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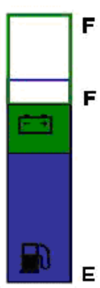
| | Gauge 12 was considered cluttered due to the placement of numerical labels (300 mi, 200 mi, 100 mi).<br><br>**Lack of total range information**<br>In designs that do not present total range information in numerical form, the user is burdened with the task of computational integration of information from the gas and battery components.<br><br>Based on this evaluation these designs were eliminated. |
| **GAUGE 13**<br> | **Spatial proximity and overlapping components**<br>According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of all these gauges are in close proximity. However, this design was considered to be confusing. The gas and battery components overlap such that the full level for the gas component is located inside the battery component near the middle. Similarly, the empty level for the battery component is located inside the gas component near the middle.<br><br>**Discriminability** |

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| | The gas and battery components are not easily discriminable.<br><br>**Size of gas and battery components**<br>In this gauge the gas and the battery components are sized equally, not in proportion to the number of miles that can be traveled on each fuel source.<br><br>**Replacement of memory with visual information**<br>Maximum ranges for gas and battery are not presented. The user is required to remember these ranges.<br><br>**Legibility**<br>The gas and battery icons in have poor legibility due to poor contrast between the colors used and the small size of the icons.<br><br>**Lack of total range information**<br>In designs that do not present total range information in numerical form, the user is burdened with the task of computational integration of information from the gas and battery components.<br><br>**Clutter**<br>For the reason stated above and due to the placement of icons inside the gauge components this design was considered cluttered.<br><br>Based on this evaluation this design was eliminated. |

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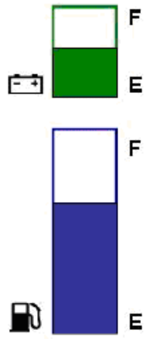
| **GAUGE 14**<br><br> | **Discriminability**<br>The gas and battery components are easily discriminable.<br><br>**Legibility**<br>Overall, the gauge is legible.<br><br>**Size of gas and battery components**<br>In this gauge the gas and battery components are sized in proportion to the number of miles that can be traveled on each fuel source. This is representative of the actual operation of the hybrid vehicle.<br><br>**Spatial proximity**<br>According to the proximity compatibility principle elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of this gauge are separate resulting in high information access cost<br><br>**Lack of total range information**<br>In designs that do not present total range information in numerical form, the user is burdened with the task of computational integration of information from the gas and battery components. In the case of this gauge design, the lack of total range information in numeric form along with the spatially separate gas and battery components is likely to cause an increased cognitive burden on the driver. |

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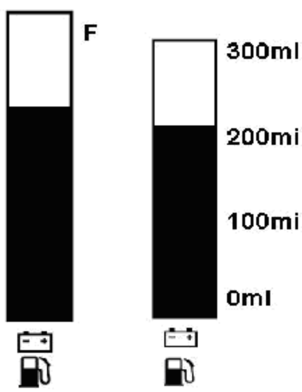
| | **Replacement of memory with visual information**<br>Maximum ranges for gas and battery are not presented. The user is required to remember these ranges.<br><br>Based on this evaluation this design was eliminated. |
| <u>**GROUP OF GAUGES 15 AND 16**</u><br><br>**GAUGE 15** **GAUGE 16**<br><br> | **Replacement of memory with visual information**<br>Only Gauge 16 presents the maximum range (300 miles in this case) for this PHEV thus reducing the need for the user to remember it. However, these gauges do not present individual maximum ranges for gas and battery.<br><br>**Lack of information on individual components**<br>In the context of HEVs it is important that drivers are presented with information on each fuel source individually so that they can plan when to recharge the electric battery. This is to enable drivers to reduce their dependency on gasoline. Gauges 15 and 16 do not present any information on the gas and battery individually.<br><br>**Discriminability**<br>In all these gauges the gas and battery components are not discriminable.<br><br>**Legibility**<br>The gas and battery icons in gauge 15 |

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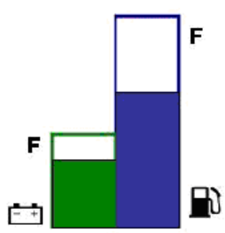
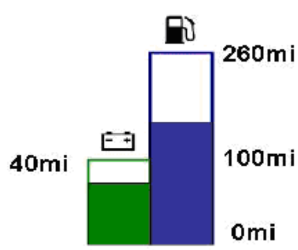
| | have poor legibility.<br><br>**Clutter**<br>Gauge 16 was considered cluttered due to use of numerical labels.<br><br>Based on this evaluation these two designs were eliminated. |
| <u>**GROUP OF GAUGES 17, 18 AND 19**</u><br><br>**GAUGE 17** **GAUGE 18**<br><br><br><br><br>**GAUGE 19** | **Spatial proximity**<br>According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of all these gauges are in close proximity resulting in low information access cost.<br><br>**Discriminability**<br>In all these gauges the gas and battery components are easily discriminable.<br><br>**Legibility**<br>Overall, these gauges are legible.<br><br>**Size of gas and battery components**<br>In these gauges the gas and battery components are sized in proportion to the number of miles that can be traveled on each fuel source. This is representative of the actual operation of the hybrid vehicle.<br><br>**Location of the components**<br>The side-by-side location of the bars forms a common empty level for the gas |

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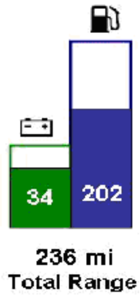
|  | and battery components. So in order to check if the vehicle is running out of fuel (both sources) the driver needs to look at one level or area at the bottom of the gauge. This was considered to be important for efficient reading.<br><br>**Replacement of memory with visual information**<br>Only Gauge 18 presents the maximum range (300 miles in this case) for this PHEV thus reducing the need for the user to remember it. However, these gauges do not present individual maximum ranges for gas and battery.<br><br>**Redundancy**<br>Only Gauge 19 presents individual range information in both relative (graphical) as well as absolute (numeric) forms. However, this causes the gauge to look cluttered.<br><br>**Clutter**<br>Gauge 18 was considered cluttered due to placement of the numerical labels. Gauge 19 was also considered cluttered due to the placement of the numerical individual ranges inside the bars.<br><br>**Total range presented**<br>Gauge 19 presents total range information numerically which was considered to be an important factor. Gauge 17 is clutter free but it does not present the total range in numerical |

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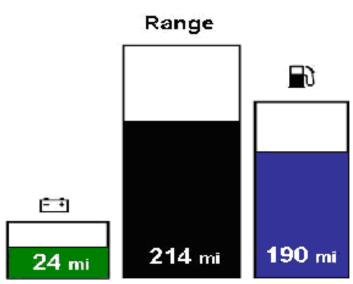
| | form.<br><br>Based on this evaluation, gauges 17 and 19 were considered potential candidates for the usability study (with some modifications). However, the goal was to select one representative design from this group. **Based on subjective preferences of the four experts, a modified version of gauge 19 was selected to be part of the final set of designs for usability testing. It was de-cluttered by removing the numeric individual ranges. The modified version is labeled "GAUGE D" in the final set.** |
| <u>**GAUGE 20**</u><br> | **Use of a third design element**<br>In this design a third "total" component has been used that represents combined gas and battery fuel levels and ranges.<br><br>**Redundancy**<br>This gauge presents individual and total range information in both relative (graphical) as well as absolute (numeric) forms. However, this causes the gauge to look slightly cluttered.<br><br>**Discriminability**<br>In all these gauges the gas and battery components are easily discriminable.<br><br>**Legibility**<br>Overall, these gauges are legible. |

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| | **Size of gas and battery components**<br>In this gauge the gas, battery and total components are sized in proportion to the number of miles that can be traveled on each fuel source individually and combined. This is representative of the actual operation of the hybrid vehicle.<br><br>**Side by side placement**<br>Each component is placed side-by-side causing the overall design to be spread out. This requires more eye movements and takes up more space on the dashboard.<br><br>**Spatial proximity**<br>According to the proximity compatibility principle elements should be in close perceptual proximity if close processing proximity is required. The three components of this gauge are separate resulting in high information access cost.<br><br>**Replacement of memory with visual information**<br>Maximum ranges for the gas, battery, and "total" components are not presented. The user is required to remember these ranges.<br><br>Based on this evaluation this design was eliminated but the experts liked the idea of a gauge design with a "total" component. So designs with this third component were explored further in the brainstorming session to see how the |

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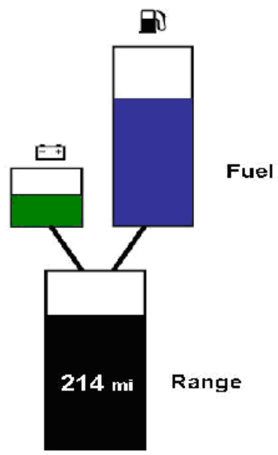
| | proximity between the three components could be reduced. |
| **GAUGE 21**<br> | This is a complex design that is very different from conventional fuel gauges.<br><br>**Use of a third design element**<br>In this design a third "total" component has been used that represents combined gas and battery fuel levels and ranges.<br><br>**Discriminability**<br>The components are easily discriminable.<br><br>**Legibility**<br>The gauge is legible.<br><br>**Overall size**<br>The components are spread out. This requires more eye movements and takes up more space on the dashboard.<br><br>**Size of gas and battery components**<br>In this gauge the gas, battery and total components are sized in proportion to the number of miles that can be traveled on each fuel source individually and combined. This is representative of the actual operation of the hybrid vehicle.<br><br>**Spatial proximity**<br>According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The three |

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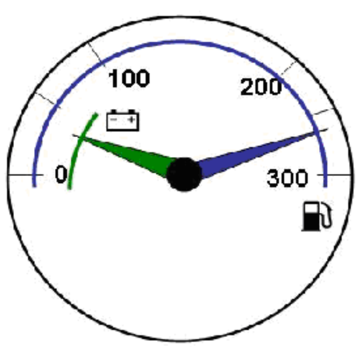
| | components of this gauge are separate.<br><br>**Redundancy**<br>Only the "total component presents information in both relative (graphical) as well as absolute (numeric) forms.<br><br>**Replacement of memory with visual information**<br>Maximum ranges for the gas, battery and "total" components are not presented. The user is required to remember these ranges.<br><br>Based on this evaluation this design was eliminated but the experts liked the idea of a gauge design with a "total" component. So designs with this third component were explored further in the brainstorming session to see how the proximity between each component could be reduced. |
| **GAUGE 22**<br><br> | **Spatial proximity**<br>In this design the gas and battery components are in close spatial proximity resulting in low information access cost.<br><br>**Common empty point**<br>The empty point for gas and battery components is common. In order to check if the vehicle is running out of fuel (both sources) the driver needs to look at one common point at the 9 o'clock |

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| | position on the circle.<br><br>**Scale lengths**<br>The scale length for each component is proportional to the number of miles that the vehicle can travel on each fuel source.<br>This is representative of the actual operation of the hybrid vehicle.<br><br>**Discriminability**<br>The components are easily discriminable.<br><br>**Legibility**<br>The gauge is fairly legible. The legibility is poor in some areas (near "0" and "200") due to lack of space between the number and scale.<br><br>**Clutter**<br>A shorter scale for the battery component helps reduce clutter, however the scale markings, numbered labels and placement of the battery icon are cluttering this design.<br><br>**Based on this evaluation a modified version of gauge 22 was selected to be part of the final set of designs for usability testing. The modified version is labeled "GAUGE A" in the final set.**<br><br>In Gauge A the scale markings and labels (numbers) have been removed in |

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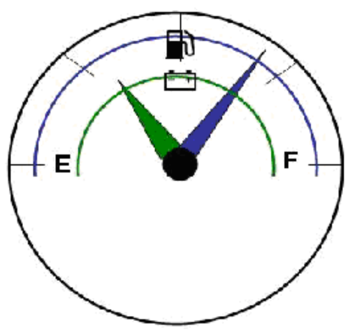
| | order to reduce clutter. The labeling scheme has been changed to “E-F”. The icons for gas and battery are consistently located near the empty points for the gas and battery. Additionally, the total range information has been presented in numerical form |
| <u>**GAUGE 23**</u>   | **Clutter**<br>This gauge design was considered cluttered due to the equal scale length for each component, placement of the icons and the scale markings.<br><br>**Legibility**<br>The gas and battery icons have poor legibility due to their placement and overlap with the scale and other markings.<br><br>**Discriminability**<br>The components are not very easily discriminable.<br><br>**Lack of total range information**<br>In this design the total range information is not presented in numerical form. So the user is burdened with the task of computational integration of information from the gas and battery components.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user |

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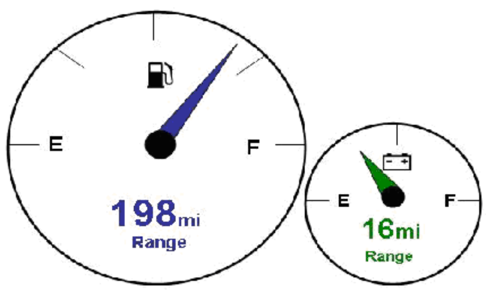
| | is required to remember these ranges.<br><br>Based on this evaluation this design was eliminated. |
| **GAUGE 24**<br> | **Conventional design**<br>This is the only design that incorporates the conventional fuel gauge so participants are likely to have a level of familiarity with this gauge.<br><br>**Legibility**<br>The gas and battery icons have poor legibility when the needle pointers are at the 12 o'clock positions.<br><br>**Discriminability**<br>The gas and battery components are easily discriminable.<br><br>**Overall size**<br>The design is spread out and places more demands on eye movements. It also takes up more space on the dashboard.<br><br>**Spatial proximity**<br>According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of this gauge are separate resulting in high information |

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| | access cost.<br><br>**Size of gas and battery components**<br>In this gauge the gas, battery and total components are sized in proportion to the number of miles that can be traveled on each fuel source individually and combined. This is representative of the actual operation of the hybrid vehicle.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Redundancy**<br>The individual ranges for gas and battery are presented in both relative as well as absolute forms.<br><br>**Lack of total range information**<br>In this design the total range information is not presented in numerical form. So the user is burdened with the task of computational integration of information from the gas and battery components.<br><br>Although there are some issues with this design, **the experts decided to include this for usability testing.** Since this design incorporates the conventional fuel gauge it was of interest to see how participants performed with this gauge in comparison with the other unconventional designs. **This gauge is** |

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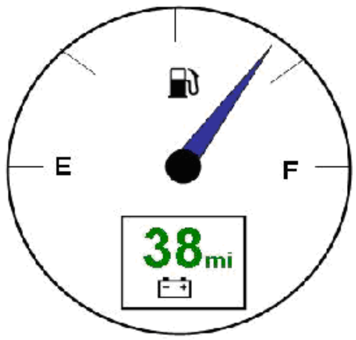
| | **labeled "GAUGE I" in the final set.** |
| **GAUGE 25**<br><br> | **Discriminability**<br>The gas and battery components are easily discriminable.<br><br>**Legibility**<br>The gas icon has poor legibility when the needle pointer is at the 12 o'clock position.<br><br>**Two different formats (analog and digital)**<br>In this design the gas component is represented by an analog mechanism (moving pointer on circular scale) while the battery component is represented by a digital mechanism (numerical display). According to the principle of pictorial realism by Roscoe (1968), continuous variables should have analog displays and discrete variables should have digital displays. Since the range of the battery is a continuous variable, an analog display should have been used.<br><br>**Spatial proximity**<br>According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of this gauge are in close proximity but use two different formats (one analog and the other digital). The PCP states that two elements that are perceptually similar should use the same code or format |

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| | (digital or analog). This difference complicates the task of integrating information from the gas and battery components.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Lack of total range information**<br>This design does not present total range information in numerical form so the user is burdened with the task of computational integration of information from the gas and battery components.<br><br>**Redundancy**<br>The gauge presents the range for battery in absolute form (numerically), but not in relative form (graphically). It can be difficult to process numbers for many people.<br><br>Based on this evaluation this design was eliminated. |
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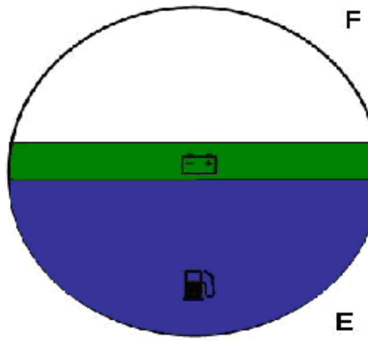
| **GAUGE 26**<br><br> | This design is similar to gauge 10 except that this is a circular design while gauge 10 is bar shaped.<br><br>**Discriminability**<br>The gas and battery components are easily discriminable.<br><br>**Legibility**<br>The gas and battery icons have poor legibility due to poor contrast between the colors used and the small size of the icons.<br><br>**Common line represents both full and empty levels**<br>This design is slightly confusing because the empty level for the battery component coincides with the full level for the gas component. There is no empty label "E" for the battery and no full label "F" for the gas.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Redundancy**<br>The gauge does not present individual ranges in absolute form (numerically).<br><br>**Size of gas and battery components**<br>In this gauge the gas, battery and total components are equally sized and are |

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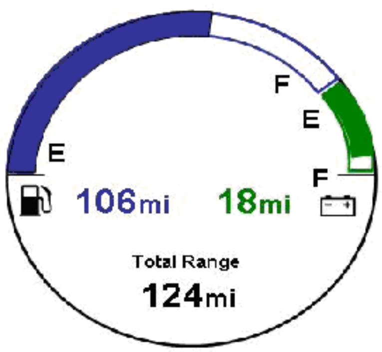
| | not representative of the number of miles that can be traveled on each fuel source individually.<br><br>**Lack of total range information**<br>This design does not present total range information in numerical form so the user is burdened with the task of computational integration of information from the gas and battery components.<br><br>Based on this evaluation this design was eliminated. |
| <u>**GAUGE 27**</u><br> | **Discriminability**<br>The gas and battery components are easily discriminable.<br><br>**Legibility**<br>The gauge is fairly legible.<br><br>**Redundancy**<br>The gauge presents the individual ranges for gas and battery in absolute (numerically) and relative (graphical) forms.<br><br>**Total range information**<br>This design presents total range information in numerical form so the user is not burdened with the task of computational integration of information from the gas and battery components.<br><br>**Arc lengths**<br>The arc lengths for gas and battery components are proportional to the |

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| | number of miles that the vehicle can travel on each fuel source. While this is representative of the actual operation of the hybrid vehicle, the asymmetrical design makes this slightly confusing.<br><br>**Lack of needle pointers**<br>Users are likely to expect needle pointers because of their understanding and expectations of a conventional fuel gauge.<br><br>**Single point represents both full and empty**<br>This design was also considered to be confusing because the empty point for the battery component coincides with the full point for the gas component. Additionally the two “E” and “F” labels close together make this design look cluttered.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>Based on this evaluation this design was eliminated. |
| **GAUGE 28** | **Discriminability**<br>The gas and battery components are easily discriminable. |

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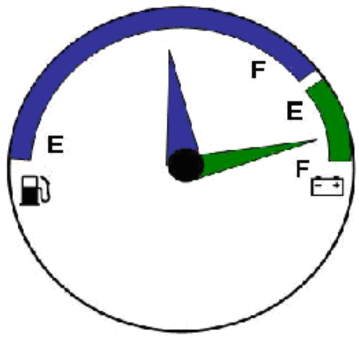
|  | **Legibility**<br>The gauge is legible.<br><br>**Arc lengths**<br>The arc lengths for gas and battery components are proportional to the number of miles that the vehicle can travel on each fuel source. While this is representative of the actual operation of the hybrid vehicle, the asymmetrical design makes this slightly confusing.<br><br>**Single point represents both full and empty**<br>This design was also considered to be confusing because the empty point for the battery component coincides with the full point for the gas component. Additionally the two “E” and “F” labels close together make this design look cluttered.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Redundancy**<br>The gauge does not present individual ranges in absolute form (numerically).<br><br>**Lack of total range information**<br>This design does not present total range information in numerical form so the user is burdened with the task of |

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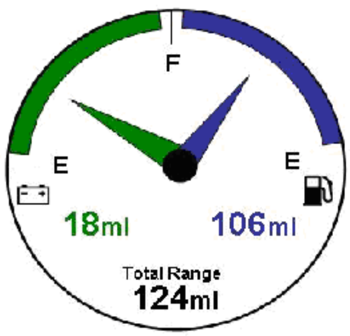
| | computational integration of information from the gas and battery components.<br><br>Based on this evaluation this design was eliminated. |
| **GAUGE 29**<br><br> | **Discriminability**<br>The gas and battery components are easily discriminable.<br><br>**Legibility**<br>The gauge is legible.<br><br>**Redundancy**<br>The gauge presents the individual ranges for gas and battery in absolute (numerically) and relative (graphical) forms.<br><br>**Total range information**<br>This design presents total range information in numerical form so the user is not burdened with the task of computational integration of information from the gas and battery components.<br><br>**Arc lengths**<br>The arc lengths for the gas and battery components are equal. They are not representative of the number of miles that can be traveled on each fuel source individually. However, the symmetrical arcs make this design potentially less confusing than the previous two.<br><br>**Replacement of memory with visual** |

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| | **information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Two different "E" points**<br>The empty points for the two fuel sources are located at opposite sides of the scale. So in order to check if the vehicle is running out of fuel (both sources) the driver needs to look at two points at opposite ends. So this design was considered to be inefficient.<br><br>**Direction of depletion is opposite for the two components**<br>The direction of depletion of the battery component is counterclockwise while the direction of depletion of the gas component is clockwise.<br><br>**Clutter**<br>The needle pointers combined with individual and total range information makes it relatively cluttered.<br><br>**Although this design has some drawbacks, it was of interest to the experts to include a design in the usability test that displayed individual as well as total range information. In this design, the bottom half of the circle is free of scale lines, markings and needle pointers making it a convenient location for presenting individual and total ranges. Thus it** |

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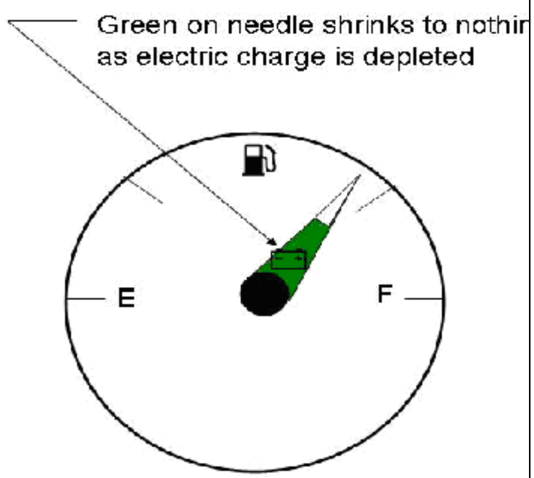
| | **was selected to be part of the final set of designs for usability testing. This design is labeled "GAUGE F" in the final set.** |
| **<u>GAUGE 30</u>**<br><br> | This is a complex design.<br><br>**Two very different mechanisms**<br>In this design a moving needle pointer on a circular scale represents the gas component while a radial moving pointer inside of the needle represents the battery component. The two components are using a common design element (the needle pointer) in different ways, which is likely to be confusing for the user.<br><br>**Discriminability**<br>The gas and battery components are not easily discriminable.<br><br>**Legibility**<br>Legibility of the battery icon is poor.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Redundancy**<br>The gauge does not present individual ranges in absolute form (numerically).<br><br>**Lack of total range information** |

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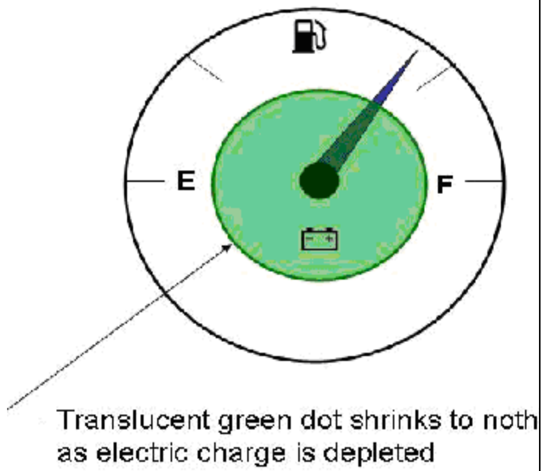
| | This design does not present total range information in numerical form so the user is burdened with the task of computational integration of information from the gas and battery components.<br><br>Based on this evaluation this design was eliminated. |
| **GAUGE 31**<br><br><br> | This is a complex design.<br><br>**Two very different mechanisms**<br>In this design a moving needle pointer on circular scale represents the gas component while a radial moving pointer inside the inner circle represents the battery component.<br><br>**Discriminability**<br>The gas and battery components are not easily discriminable as there is overlap.<br><br>**Legibility**<br>The details of the battery icon are not very legible. It is also difficult to see the color of the needle pointer.<br><br>**Lack of total range information**<br>This design does not present total range information in numerical form so the user is burdened with the task of computational integration of information from the gas and battery components.<br><br>**Replacement of memory with visual information** |

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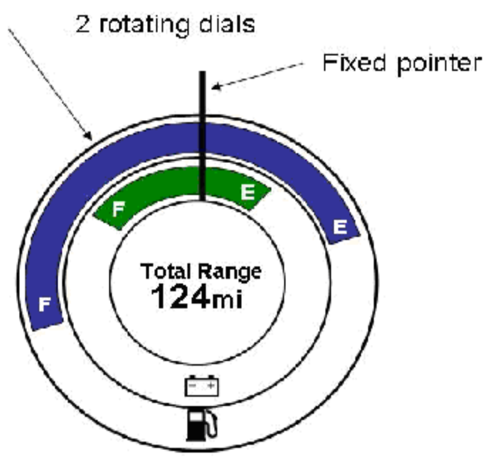
| | Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Redundancy**<br>The gauge does not present individual ranges in absolute form (numerically).<br><br>Based on this evaluation this design was eliminated. |
| **<u>GAUGE 32</u>**<br><br> | This is a complex design that uses two moving scales with a fixed pointer. This mechanism is very different from conventional fuel gauges. Users are required to read this gauge very differently than what they are used to. For example, users need to look at the fixed pointer, where it lies on the moving arc as well as the overall size of the moving arc in order to determine the reading. The full and empty points are constantly moving.<br>In moving pointer displays the empty and full levels are fixed and over time users can easily determine the fuel level by glancing at the position of the pointer.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Discriminability**<br>The gas and battery components are |

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| | discriminable but the design is potentially confusing for a new user.<br><br>**Legibility**<br>The gas icon has poor legibility.<br><br>**Redundancy**<br>The gauge does not present the individual ranges for gas and battery in absolute form (numerically).<br><br>**Total range information**<br>This design presents total range information in numerical form so the user is not burdened with the task of computational integration of information from the gas and battery components.<br><br>This design was eliminated. |
| <u>**GAUGE 33**</u><br> | **Discriminability**<br>The gas and battery components are easily discriminable.<br><br>**Legibility**<br>The gauge is legible.<br><br>**Lack of redundancy**<br>This design only presents information in numeric or absolute form. However, many people find it difficult to process numbers.<br><br>**Replacement of memory with visual information** |

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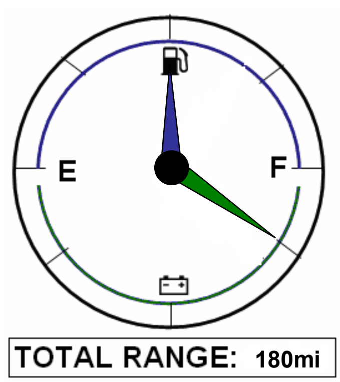
| | Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Analog displays for continuous variables**<br>According to the principle of pictorial realism by Roscoe (1968), continuous variables should have analog displays and discrete variables should have digital displays. Since the gas and battery ranges are continuous variables, analog displays should have been used for each component.<br><br>**Lack of total range information**<br>Total range information is not presented. Based on this evaluation this design was eliminated |

The following table summarizes the evaluation of the four gauge designs created by the UMN team.

**Table 7.2: Evaluation summary for gauges created by the UMN team**

| GAUGE | EVALUATION SUMMARY |
|---|---|
| **UMN GAUGE 1**<br><br> | None of the other circular gauge designs from GM made use of the bottom half of the circle for displaying the scale. This design is visually cleaner than the ones that show both gas and battery scale lines in the top half of the circle.<br><br>Common "E" and "F" marks could make reading easier and faster. It is easy to see when both fuel sources are nearing empty due to pointer alignment.<br><br>**Spatial proximity**<br>According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of all these gauges are in close proximity resulting in low information access cost.<br><br>**Discriminability**<br>In all these gauges the gas and battery components are easily discriminable.<br><br>**Legibility** |

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| | Overall, these gauges are legible.<br>**Total range information**<br>Presenting total range information in numerical form reduces the burden of computational integration of information from the gas and battery components.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Redundancy**<br>The gauge does not present the individual ranges for gas and battery in absolute form (numerically).<br><br>Although this gauge has some drawbacks, it was of interest to understand how drivers would perform with this design that comprises of an “upside down” scale and needle pointer in the bottom half of the circle. **This gauge was included in the final set of designs for usability testing. It is labeled “GAUGE B” in the final set.** |

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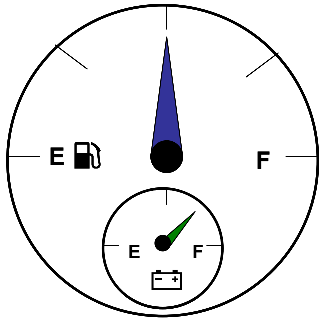
| **UMN GAUGE 2**<br><br>**Total Range 180 mi** | **Discriminability**<br>It uses the conventional fuel gauge mechanisms (circular scale and needle pointer). Each component is well integrated yet easily distinguishable.<br><br>**Spatial proximity**<br>According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of all these gauges are in close proximity resulting in low information access cost.<br><br>**Legibility**<br>This gauge is legible.<br><br>**Consistency**<br>Having the empty and full points at the same positions (9 o'clock and 3 o'clock respectively) on both dials could make reading easier and faster.<br><br>**Total range information**<br>Presenting total range information in numerical form reduces the burden of computational integration of information from the gas and battery components.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges. |

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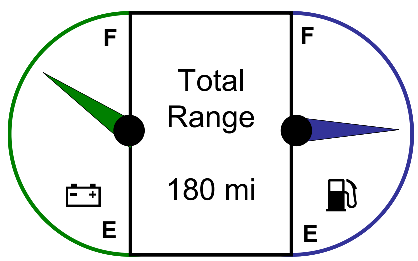
| | **Redundancy**<br>The gauge does not present the individual ranges for gas and battery in absolute form (numerically).<br><br>Although this gauge has a few drawbacks, is different from the other designs created by GM. It was of interest to understand how drivers would perform with this variation of the conventional fuel gauge. **This gauge was included in the final set of designs for usability testing. This is labeled "GAUGE E" in the final set.** |
| **UMN GAUGE 3**<br> | **Discriminability**<br>Each component is well integrated yet easily distinguishable.<br><br>**Spatial proximity**<br>According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of all these gauges are in close proximity resulting in low information access cost.<br><br>**Legibility**<br>This gauge is legible.<br><br>**Consistency**<br>Having the empty and full points at the same positions (6 o'clock and 12 o'clock respectively) on both dials could |

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| | make reading easier and faster.<br><br>**Total range information**<br>Presenting total range information in numerical form reduces the burden of computational integration of information from the gas and battery components.<br><br>**Replacement of memory with visual information**<br>Individual ranges for the gas and battery components are not presented. The user is required to remember these ranges.<br><br>**Redundancy**<br>The gauge does not present the individual ranges for gas and battery in absolute form (numerically).<br><br>It is different from the other designs created by GM. It was of interest to understand how drivers would perform with this variation of the conventional fuel gauge. **This gauge was included in the final set of designs for usability testing. This is labeled "GAUGE H" in the final set.** |

| UMN GAUGE 4 | |
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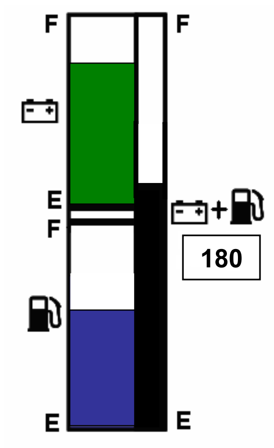
|  | **Discriminability**<br>Each component is easily distinguishable. The “E” mark for battery and “F” mark for gas are visually separated and represented by two parallel lines.  Similar designs created by the GM designers represent both empty and full levels on the same line.<br><br>**Spatial proximity**<br>According to the proximity compatibility principle, elements should be in close perceptual proximity if close processing proximity is required. The gas and battery components of all these gauges are in close proximity resulting in low information access cost.<br><br>**Legibility**<br>This gauge is legible.<br><br>**Total range information**<br>It includes the total range information in relative form as a separate bar (black). Presenting total range information in numerical form reduces the burden of computational integration of information from the gas and battery components.<br><br>**Replacement of memory with visual information**<br>Maximum ranges for the gas, battery and “total” components are not presented. The user is required to remember these ranges. |

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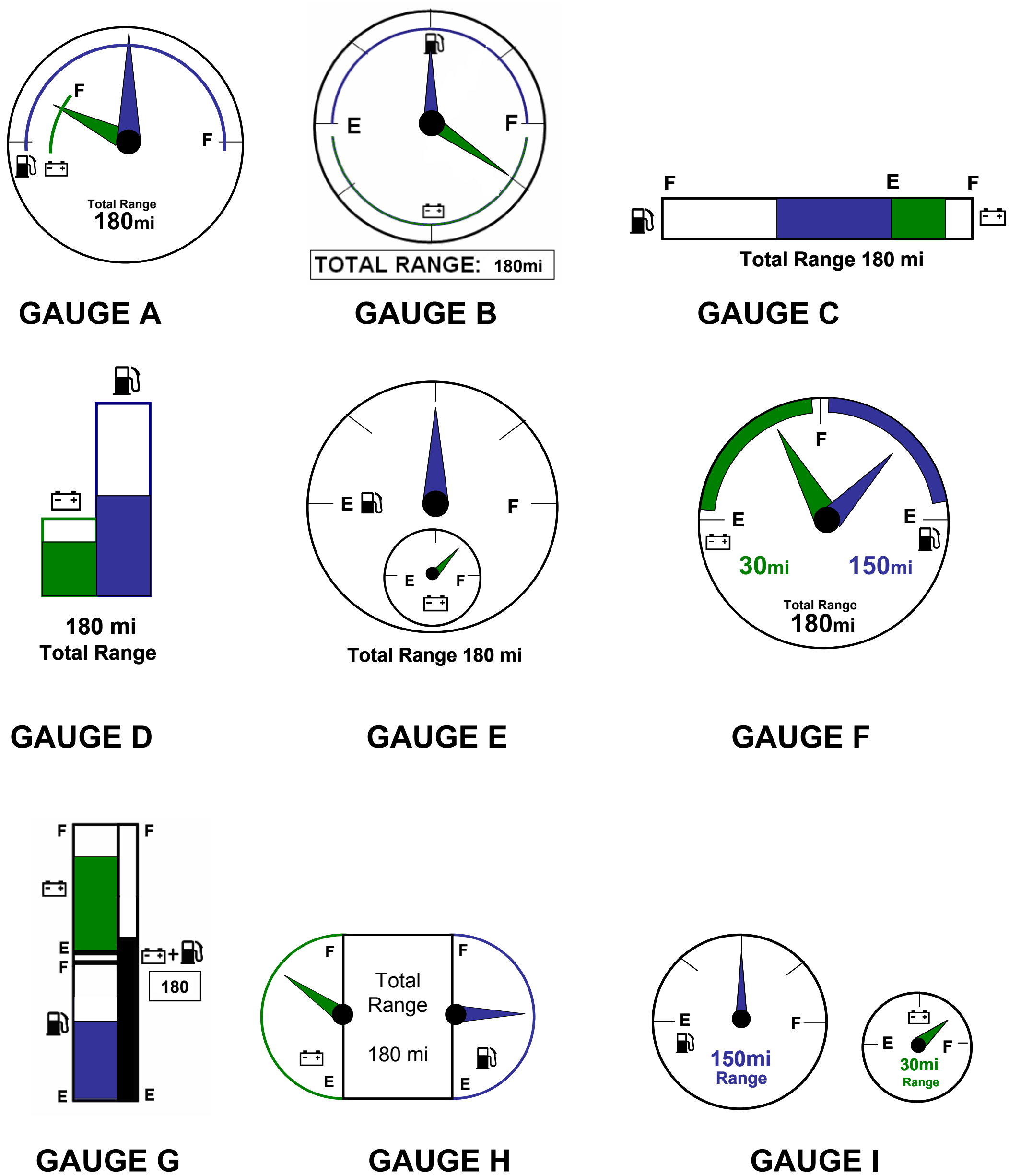
| | **Redundancy**<br>The gauge does not present the individual ranges for gas and battery in absolute form (numerically).<br><br>It is different from the other designs created by GM. It was of interest to understand how drivers would perform with this variation of the conventional fuel gauge. This **gauge was included in the final set of designs for usability testing. This is labeled “GAUGE G” in the final set.** |

### 7.4. Final set of gauge designs for usability testing

The heuristic evaluation resulted in a set of nine gauge designs for testing in the usability study. These designs (shown below) are representative of a number of variations of the attributes of interest to this study (shape, orientation, proximity of individual components and presentation of information in relative and absolute form). They explore dials as well as bars. They include horizontally as well as vertically oriented bar gauges. The designs include varying levels of spatial proximity between the gas and battery components. They also vary in terms of how much information is presented in absolute form (numerically). Most designs present total range information numerically. Two designs present individual range information numerically.

**Figure 7.1: Final set of gauge designs selected for usability testing with subjects**



# 8.Usability Study

A usability study was conducted to evaluate the nine hybrid gauge designs selected through the heuristic evaluation process. The study involved a timed comprehension task followed by a subjective questionnaire.

### 8.1. Timed comprehension task

The goal of this task was to see if there were any performance differences across the nine gauges that had varying design attributes. The independent variables of the task were the nine designs. The dependent variables were reading speed (measured by response time in milliseconds) and reading accuracy (measured by the number of correct responses to the questions presented).

The task aimed at evaluating how accurately and quickly subjects could comprehend information presented to them by the hybrid fuel gauges. Gauges that elicited the shortest response times and the highest accuracy rates were the easiest to comprehend.

#### 8.1.1. Structure of the task

While designing this task some key questions were considered around the two broad use cases of the vehicle, which are short and long-distance trips.

The first key question was, **what would a driver of this vehicle need to know when planning a short-distance trip of less than 40 miles?** Those drivers who want to eliminate their dependency on gasoline would want the vehicle to operate on electric battery alone. It was important for those drivers to be able to easily get information from the gauge on how far they could travel on the current level of charge in the battery. This would allow them to plan when to stop and recharge the battery.

The second key question was, **what would a driver of this vehicle need to know when planning a long-distance trip (over 40 miles)?** The driver would need to determine how much fuel is remaining in the vehicle and how far the vehicle can travel on it. It would also be important for the driver to know when he or she needs to stop and refill the gas tank or recharge the battery. This information would enable the driver to identify opportunities to recharge the battery during the trip. Since the battery in this PHEV needs to be plugged in for eight hours in order to be charged completely, recharging it overnight would be the most efficient use of time.

Based on these two main use cases, drivers of this PHEV need to be able to quickly and accurately get information on each fuel source individually as well as get combined information on both fuel sources. For these reasons, participants were presented with the following three questions in the timed comprehension task:

1. Is it possible for me to travel 20 miles on the battery alone? This question requires the driver seek information on the fuel level in the battery.
2. Is it possible for me to travel 150 miles on the gas tank alone after the battery is depleted? This question requires the driver requires the driver to seek information on the fuel level in the gas tank.
3. Is it possible for me to travel 200 miles on the battery and gas tank combined? This question requires the driver to seek combined information on both fuel sources.

Prior to the timed comprehension task participants were informed about the maximum range of the gas tank and the electric battery. They were provided with a study introduction (see Appendix D), which stated that the vehicle could be driven for a maximum of 300 miles on a full gas tank, for a maximum of 40 miles on a fully charged electric battery and for a maximum of 340 miles on a full gas tank and fully charged battery. The study introduction was available to them for reference throughout the comprehension task. Based on this knowledge, subjects could determine the level of fuel presented by each gauge. For example, if the pointer for the gas tank was over the half mark then it could be interpreted that the vehicle could travel more than 150 miles on the gas tank alone after the battery had depleted.

### 8.1.2. Study participants

Subjects were recruited from Minneapolis and St. Paul with the help of a local staffing agency. The criteria for selection of participants were that all participants possessed a valid driver's license and that they had normal (20/20 vision) or corrected to 20/20 vision via contact lenses or glasses.

A total of sixty subjects were recruited across the three age groups of 18-30 years, 31-54 years and 55 years and above. There were twenty subjects in each age group. Each group was balanced for gender comprising of ten males and ten females. This was done in order to get a varied sample by age and gender. None of the participants had any apparent physical or cognitive limitations that could have affected their performance in this experiment. Other than age and gender, no additional demographic information was gathered on the study participants.

### 8.1.3. Procedure

As much as possible, the subjects were run through the study protocol by one researcher (the author) in order to achieve consistency in instructions given to all subjects. However due to unavoidable reasons and scheduling conflicts, a few subjects (five) had to be run by a second researcher (Janet Creaser) who was equally involved in the study and familiar with the study protocols.

Each subject was given a consent form that provided information on the study background and procedures, risks and benefits of the study, confidentiality of data and the voluntary nature of the study. The subject was then asked to read a study introduction on the working of the hybrid vehicle (see Appendix D). The researcher answered any questions that the subject had. The subject then began with the timed comprehension task.

The comprehension task was computer-based and was developed using the E-Prime software. E-prime is a suite of applications that allow researchers to design computerized experiments and collect and manage the data. It allows response time to be measured in milliseconds. The timed comprehension task was programmed in E-prime such that a particular question could be asked nine times consecutively (once per gauge) in a subprogram called a "block". Subjects were seated in front of a 17" monitor and were asked to input their responses to each question using an attached response box. Before beginning with the main study task, the subjects were made to do a practice task that was similar to the main experimental task.

After subjects had completed the practice task they were given instructions for the experimental task. Subjects were also reminded that the vehicle could travel a maximum of 40 miles on a fully charged battery, 300 miles on a full gas tank and 340 miles on both combined. They used this information while answering questions presented in the task. They were also provided with a copy of the study introduction and were allowed to refer to it at any time during the task if they needed to.

**Experiment task**

In the experimental task, subjects were presented with the following three questions:

1. Is it possible for me to travel 20 miles on the battery alone?
2. Is it possible for me to travel 150 miles on the gas tank alone after the battery is depleted?

3. Is it possible for me to travel 200 miles on the battery and gas tank combined?

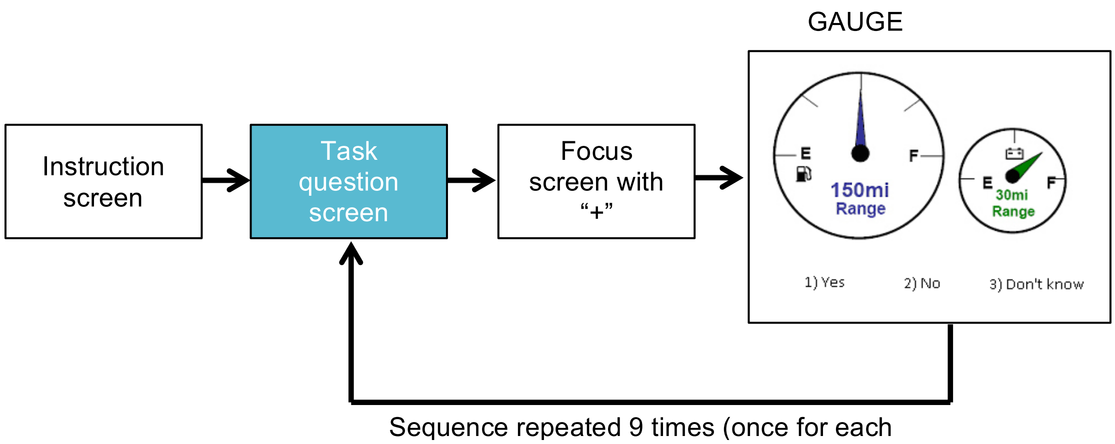
The task was structured such that each subject saw the nine gauges for each of the three questions. The three questions were presented in three blocks, one block per question. Subjects were shown all nine designs for the same question before moving on to the next question block. So each subject saw each gauge three times, once for each question.

The presentation of the three questions was fully counterbalanced to account for learning effects. Participants were presented with the three questions in different orders. The order of presentation of gauges within each question block was randomized.

The experimental task started with an instruction screen that provided task-related instructions to the subjects. They were informed that the question would not be visible while they viewed the gauge and were encouraged to read each question carefully before moving on. When subjects felt comfortable with the instructions, they pressed the “start” button on the response box. Subjects were then presented with one of the three questions and were asked to press the “start” button when they felt they were ready to move on. Subjects were instructed to answer each question to the best of their ability based on the information presented by the gauge and also to answer as quickly as possible. The next screen was a white screen with a cross in the middle. This was designed to appear for 3 seconds. Subjects were instructed to focus their attention on the cross, which served as a fixation point. It was designed to help subjects prepare for presentation of the gauges so that they were looking at the screen and not elsewhere when the task began. This allowed for a more accurate measure of the time taken by the subject to comprehend the information presented by each gauge. The next screen presented one of the nine gauges along with the three possible responses to the question: 1) yes, 2) no, and 3) don't know. The response box buttons were labeled to match the three possible answers to each question. Subjects were instructed to use the "don't know" option only if they truly felt they could not answer the question based on the information they saw on the gauge.

The following figure shows the flow of the screens presented in the experimental task.

**Figure 8.1: Flow diagram of the order of screens presented in the task**




There was only one correct answer for each question-gauge combination.

Once participants entered their responses for each of the nine gauges, the program moved on to the next block and the next question was presented to them. Each question screen within the same block was given the same background color to indicate to the subjects that the same question was being asked. When the question block changed, the color of the question screen changed. This served as a reminder to the subjects to read the question very carefully because it had changed. While designing and testing the task in the E-prime software, it was anticipated that when the same question is presented nine times consecutively, there could be a tendency to spend less time on reading the question as it would be assumed that it was the same question read previously. This meant that while switching from one question block to the next, subjects could end up skipping the first presentation of the next question (completely different than the one they would have seen previously). At the time when this study was conducted (2007), E-prime did not offer any means of going back to a previous screen. The color-coding of the question screens was done to remind subjects that the question had changed and that they needed to read it carefully. This was explained to them before beginning the experimental task.

**Practice task** (done before the experimental task)
The practice task was also developed in E-prime and was designed to be very similar to the experimental task. It was also a self-paced task. The practice task took about 5 to 10 minutes to complete depending on the subject's speed. The goal was to help subjects get familiar with the procedures of the task and with the working of the software and response box. In the practice task subjects were shown two images of conventional gas gauges and were asked questions on the amount of fuel remaining in the gas tank.

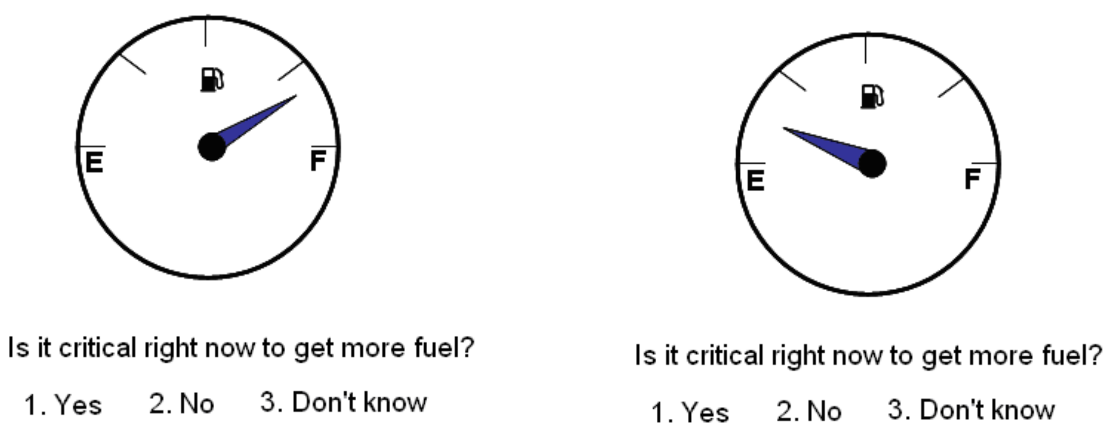
A conventional gas gauge design was used for the practice task because subjects were likely to be familiar with the design since they saw it on a regular basis in their own vehicles. The use of a design with which subjects were already familiar meant that they could spend more effort on familiarizing themselves with the task protocol rather than on understanding the gauge design. Each gauge showed a different fuel level. The following practice questions were asked:
1. Is it critical right now to get more fuel?
2. Is it possible to travel 200 miles with the amount of fuel in your gas tank?
3. Can you make a 150-mile trip with the amount of fuel in your gas tank?

These are typical questions that subjects ask themselves on a daily basis while driving. So they were used in the practice task in order to introduce a level of familiarity. Questions 2 and 3 are very similar to the questions asked in the experimental task. Question 1 is different and was included in this task because it was considered to be one of the most common concerns of drivers in the context of planning trips.

Just as in the experimental task, each question had three answer options: 1) yes, 2) no and 3) don't know. The subjects were asked to input their responses using the response box.  Gauge images were presented randomly within each question block. In the practice task, the question was presented on the screen along with the gauge design and the answer options. In the experimental task, the question was presented before a gauge design. Each slide contained only an image of a hybrid fuel gauge and the three answer options.

The following figure shows the two gas gauge designs that were developed for the practice task.

**Figure 8.2: Examples of the 2 designs used for the practice task**




## 8.2. Subjective questionnaire

After completing the timed comprehension task involving twenty-seven trials (three questions and nine gauges), participants were asked to complete a subjective questionnaire.

This four-part questionnaire was used to assess subjective preferences for each fuel gauge and specific design attributes. The results provided subjective opinions on the usability of each gauge design and also helped identify specific attributes made a design more usable according to the subjects.

### 8.2.1. Questionnaire design

Janet Creaser from the HumanFirst lab was responsible for designing the four-part questionnaire (see Appendix E). The first part focused on understanding the perceived ease of reading the gauges, the second part gauged subjects' preferences for certain design attributes, the third part focused on understanding subjects' preferences for the amount of information presented and the fourth part required subjects to state the best and worst features of the nine gauges used in the comprehension task.

**Questionnaire part 1:**

In part 1 subjects were asked to rank order the nine gauges from the comprehension task according to how easily comprehensible they found each gauge to be while trying to answer the following 5 questions:

1. How easy or difficult is it to know how much energy is in the battery?
2. How easy or difficult is it to understand when it is time to recharge the battery?
3. How easy or difficult is it to know if I can make a 20-mile trip using only the battery?
4. How easy or difficult is it to understand if I can travel 100 more miles on gasoline alone once the battery is depleted?
5. How easy or difficult is it to know if I can make a 250-mile trip using both the battery and gasoline?
6. Overall which gauge do you find most useful (i.e. easiest) to answer all the questions above?

In the first five questions, subjects were asked to rank order the nine gauges on a scale of 1 to 9 with 1 representing the "easiest" gauge (that made it easiest to answer the question) and 9 representing the "most difficult" gauge (that made it most difficult to answer the question). Questions 1, 2 and 3 are based on the battery component. This is because the battery component was new to most of these subjects where as conventional gas gauges are generally well understood. Question 4 was based on the ease of understanding the gas component of the gauge designs. Question 5 was based on the ease of understanding the overall gauge requiring subjects to focus on the battery and gas components. In question 6, subjects were asked to choose one gauge that they found to be most useful (easiest to use).

Subjects were presented with the nine gauge designs with alphabetical labels on a separate sheet.

**Questionnaire part 2:**

The purpose of part 2 was to see if subjects preferred gauge designs with certain attributes. In this part subjects were presented with seven pairs of gauges that showed the same information, but differed in terms of certain design attributes. The selection of the gauges in each pair was subjective.

Each pair of designs differed in terms of at least one of the following attributes:

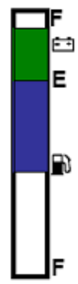
1. Shape (dial vs. bar)
2. Orientation of bar gauges (horizontal vs. vertical)
3. Proximity of the gas and battery components (single gauge vs. two separate gauges)
4. Presentation of information (absolute vs. relative form)

The pairs do not systematically explore each possible variation of each attribute. The designs in each pair also were not controlled in terms of all other design attributes except for the attribute of interest. Subjects were not informed about the attribute of interest in each pair.

Subjects were presented with the following pairs of gauge designs

1.

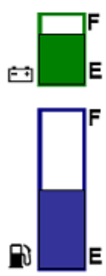

1 A



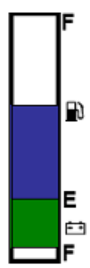

1 B

The attribute of interest to the researchers was orientation.

2.



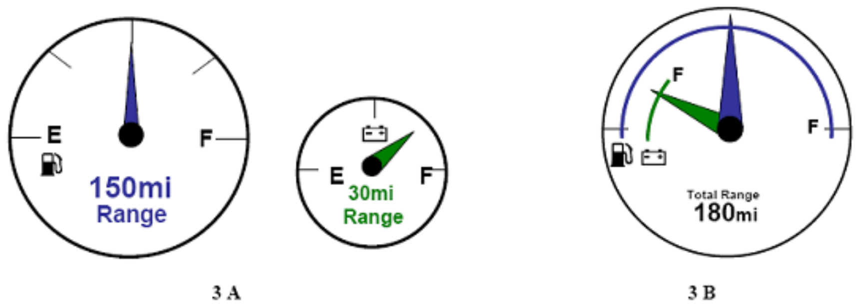

2 A




2 B

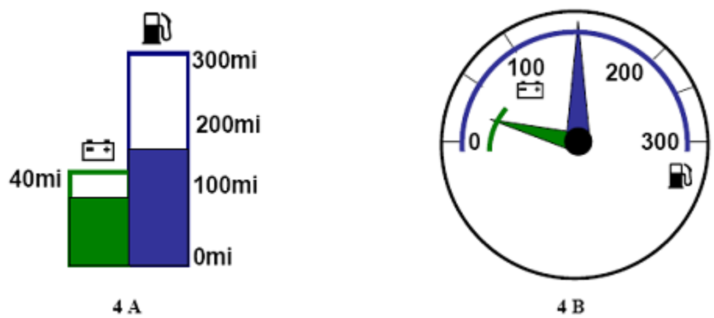
The attribute of interest to the researchers was the proximity of the gas and battery components.

3.



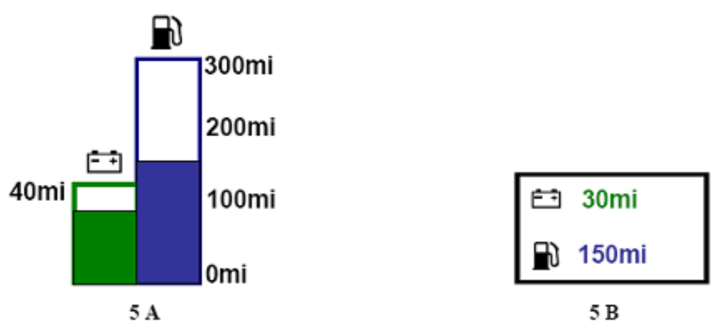

The attribute of interest to the researchers was the proximity of the gas and battery components.

4.



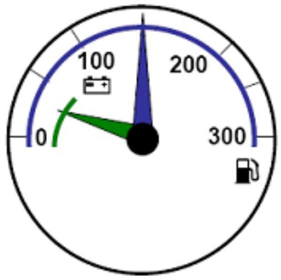

The attribute of interest to the researchers was shape.

5.




The attribute of interest to the researchers was the presentation of information (absolute vs. relative form).

6.



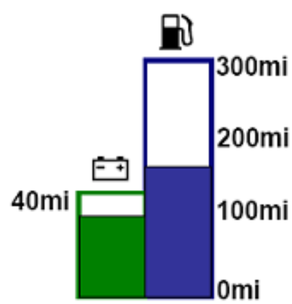

6 A


6 B

The attribute of interest to the researchers was the presentation of information (absolute vs. relative form).

7.


7 A




7 B

The attribute of interest to the researchers was the presentation of information (absolute vs. relative form).

For each of the seven pairs of gauge designs presented, subjects were required to pick one gauge that they considered to be easiest and the most effective for answering each of the following six questions:

1. How much energy do I have in the battery?
2. Does the battery need to be recharged?
3. Can I make a 20-mile trip only using the battery?
4. Can I travel 100 more miles on gasoline alone once the battery is depleted?

5. Can I make a 250-mile journey using both the battery and the gas tank?
6. Overall which gauge do you prefer for answering the above questions?

**Questionnaire part 3:**

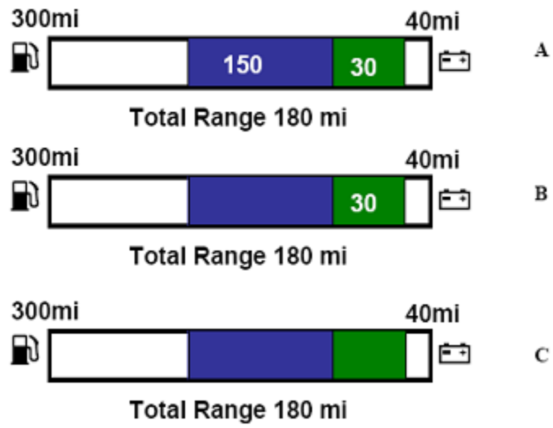
The purpose of part 3 was to determine the subjects' preferences for the amount of information presented in absolute or numeric form. In this part subjects were presented with three variations of a single gauge design and asked to rank them based on ease of use in answering the following six questions:

1. How much energy do I have in the battery?
2. Does the battery need to be recharged?
3. Can I make a 20-mile trip only using the battery?
4. Can I travel 100 more miles on gasoline alone once the battery is depleted?
5. Can I make a 250-mile journey using both the battery and the gas tank?
6. Overall which gauge do you prefer for answering the above questions?

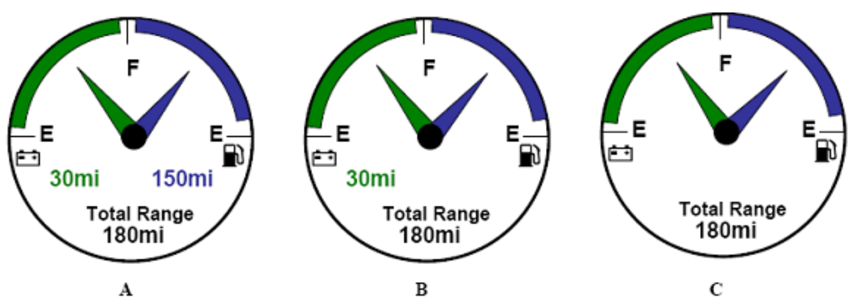
These are the same questions asked in questionnaire parts 1 and 2. The four sets of gauges presented varied in terms of how much range information was presented numerically. Option A displayed individual ranges for the gas tank and electric battery as well as the combined range in numeric form. Option B displayed the individual range for the electric battery and the combined range in numeric form. Option C displayed only the combined range in numeric form. The subjects were asked to rank the three versions on a best-worst scale.

The following four sets of gauges were presented to the subjects.

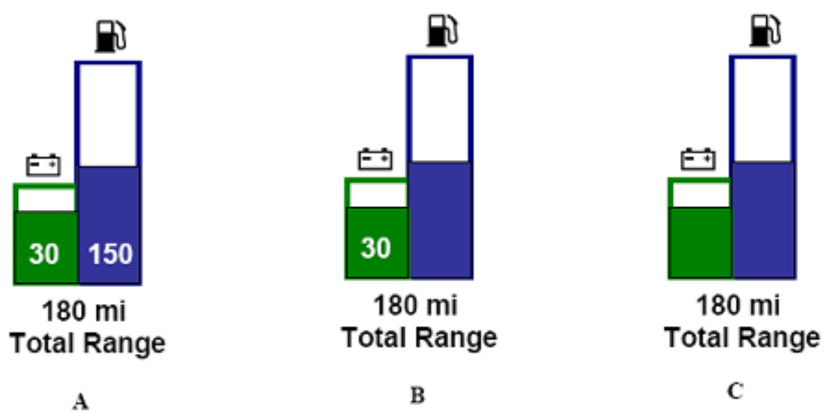
1.


300mi
40mi
150
30
Total Range 180 mi
A
300mi
40mi
30
Total Range 180 mi
B
300mi
40mi
Total Range 180 mi
C

2.


F
E
E
30mi
150mi
Total Range
180mi
A
F
E
E
30mi
Total Range
180mi
B
F
E
E
Total Range
180mi
C

3.


30
150
180 mi
Total Range
A
30
180 mi
Total Range
B
180 mi
Total Range
C

4.


A B C

**Questionnaire part 4:**

The purpose of part 4 was to get qualitative feedback on the nine hybrid gauge designs. In this part subjects were asked to describe what they perceived to be the best and worst features of each of the nine gauges involved in the timed comprehension task.

# 9. Data analysis and Results

## 9.1 Overview of the data analysis

Analysis was conducted on the data from the timed comprehension task and the subjective questionnaire.

### Data analysis for the timed comprehension task

The experimental procedure and setup resulted in one data file for each subject. The data for all subjects were combined into one excel spreadsheet for the analysis. There were five points of interest with respect to the analysis conducted on the data from the comprehension task:

- Overall analysis (as a whole group)
- Analysis by gender
- Analysis by age group
- Analysis by gauge
- Analysis by question

### Excluded data

Data for one participant has been excluded from the analysis because the subject (id 12304) was not able to understand or complete the tasks correctly as per the given instructions. This was a middle-aged, male subject.

After the first twenty-one subjects (ids 12301, 12302, 12303, 12304, 12305, 12306, 12307, 12309, 13206, 13207, 21306, 23101, 23103, 23105, 23106, 23107, 31203, 31205, 31206, 31207, 32106) had completed the study, the author discovered that the design of Gauge H shown to participants in the timed comprehension task was incorrect. Specifically, the total range presented in miles was not reflected by the positions of the needles for the gas tank and battery components of this gauge. The author corrected this flaw immediately upon discovery and the remaining subjects who participated in the study viewed the corrected design. Since there was a strong possibility that this flawed design had confused the participants who viewed it, it was considered best for the purpose of the analysis to eliminate the data for those twenty-one subjects. However, removing the data for gauge H for those twenty-one subjects led to an unbalanced data set in which there was data for fifty-nine subjects for gauges A, B, C, D, E, F and G but only data for thirty-nine subjects for gauge H. Thus for the purpose of a cleaner analysis it was decided to eliminate the data for gauge H entirely. Statistical analyses were conducted on data for eight gauges (A, B, C, D, E, F and G).

**1.Overall analysis (all subjects as one group):** In order to determine how successful the gauges were in communicating information for accurate and fast reading, it was important to determine the proportion of correct responses. The experiment was designed to allow participants to make correct responses, incorrect responses and to respond by selecting a third, “don’t know” option. There were only a few “don’t know” responses and early on in the creation of the dataset these responses were grouped into the incorrect response category. An analysis was conducted on the entire dataset to determine the percentages of correct and incorrect responses and their corresponding average response times. The author no longer has a record of the “don't know” responses. In retrospect, it would have been helpful to keep that third category separate so as to determine the percentage and average response time for that category.

**2. Data analysis for male and female subjects:** The data was analyzed to determine the accuracy rates and average response times for males and females to examine performance differences based on gender. Additional tests were conducted to check for significant differences in accuracy rates and response times for the two groups.

**3. Data analysis for the three age groups:** Human beings experience a decline in cognitive capabilities with age (Welford, 1977). The data was analyzed to determine the accuracy rates and response times for each of the three age groups (18-30 years, 31-54 years and 55 years and above). Additional tests were conducted to check for significant differences in accuracy rates and response times for the three age groups.

**4. Data analysis for each of the eight gauges:** As the purpose of the study was to determine which gauges elicited the fastest and most accurate responses, the data was analyzed to determine the accuracy rates and response times for each gauge. Additional tests were conducted to check for significant differences in accuracy rates and response times for the eight gauges.

**5. Data analysis by questions in the timed comprehension task:** The data was also analyzed to determine the accuracy rates and response times for each of the three questions presented in the timed comprehension task. Question 1 required the driver to focus on the battery component of the gauge, question 2 required the driver to focus on the gas tank component of the gauge and question 3 required the driver to elicit combined information on both fuel sources. Since each question focused on a specific component of the gauge design, the response times and accuracy rates corresponded to those components.

**Data analysis for the subjective questionnaire**

The data from the subjective questionnaire was analyzed separately for each of the four parts.

**Excluded data**

Data for one participant has been excluded from this study completely because the subject (id 12304) was not able to understand or complete the tasks correctly as per the given instructions. The subjective questionnaire data for this subject has been excluded from this analysis. Even though data for gauge H has been excluded from the timed comprehension task, participant feedback on gauge H collected in the subjective questionnaire has been included in this section. Participants were asked to provide feedback on Gauge H in parts 1 and 4 of the questionnaire. Due to incorrect experimental design of parts 2 and 3, they have been excluded from this analysis. Please see Appendix F for more information on those parts.

Data from Part 1 was analyzed to determine the gauges that were ranked at the top three positions by the majority of the subjects. In part 4, subjects were asked to comment on what they considered to be the best and worst features of each gauge. Features that were brought up by the majority of the subjects were determined from this data.

## 9.2. Results of data analysis for the timed comprehension task

### Participants

The following table summarizes demographic information of the fifty-nine subjects whose data has been used in the analysis. The following table shows the average ages of the subjects by gender and by age group.

**Table 9.1: Average ages, standard deviation and ranges for participants by gender and by age groups**

| | Total number | Average ages (years) | Std. Dev. (years) | Range (years) |
|---|---|---|---|---|
| All participants | 59 | 43.3 | 16.4 | 20-72 |
| **BY GENDER** | | | | |
| Females | 30 | 43.4 | 15.6 | 20-66 |
| Male | 29 | 43.1 | 17.5 | 20-72 |
| | | | | |
| **BY AGE-GROUP** | | | | |

| | | | | |
|---|---|---|---|---|
| Young (18- 30 years) | 20 | 24.9 | 2.9 | 20-30 |
| Middle aged (31-54 years) | 19 | 42.4 | 6.3 | 31-53 |
| Older (55+ years) | 20 | 62.5 | 5.3 | 55-72 |
| | | | | |

### 9.2.1. Overall analysis

The responses from fifty-nine subjects were analyzed to determine the proportion of correct and incorrect responses. The corresponding average response times for each of those categories have also been calculated. These are summarized in the table below.

**Table 9.2: Overall response times and accuracy rate**

| | COUNT | PERCENTAGE | AVERAGE RESPONSE TIME (milliseconds) |
|---|---|---|---|
| CORRECT RESPONSES | 1274 | 89.97% | 5708.34 |
| INCORRECT RESPONSES | 142 | 10.03% | 8859.08 |
| **OVERALL RESPONSES** | **1416** | **100%** | **6024.31** |

From the table it can be seen that approximately 90% of all responses made were correct and it took subjects 5.7 seconds on average to make correct responses. Overall, it took subjects 6 seconds on average to respond to questions (irrespective of whether the response was correct or not). It can also be seen that it took subjects much longer, 8.8 seconds on average to make incorrect responses.

### 9.2.2. Analysis for gender

The responses from fifty-nine subjects were analyzed based on gender to determine the proportion of correct and incorrect responses and average response times (overall and for correct responses).

#### 9.2.2.1 Overall analysis for gender

The following table shows the overall and correct response times and accuracy rates for male and female subjects. The average overall response time (ORT) for each group indicates how long subjects in that group took to respond to questions, irrespective of whether the response was correct or not. The average correct response time (CRT) indicates how long subjects in that group took to respond correctly. The table also shows the response accuracy (RA), which is the percentage of responses that were correct.

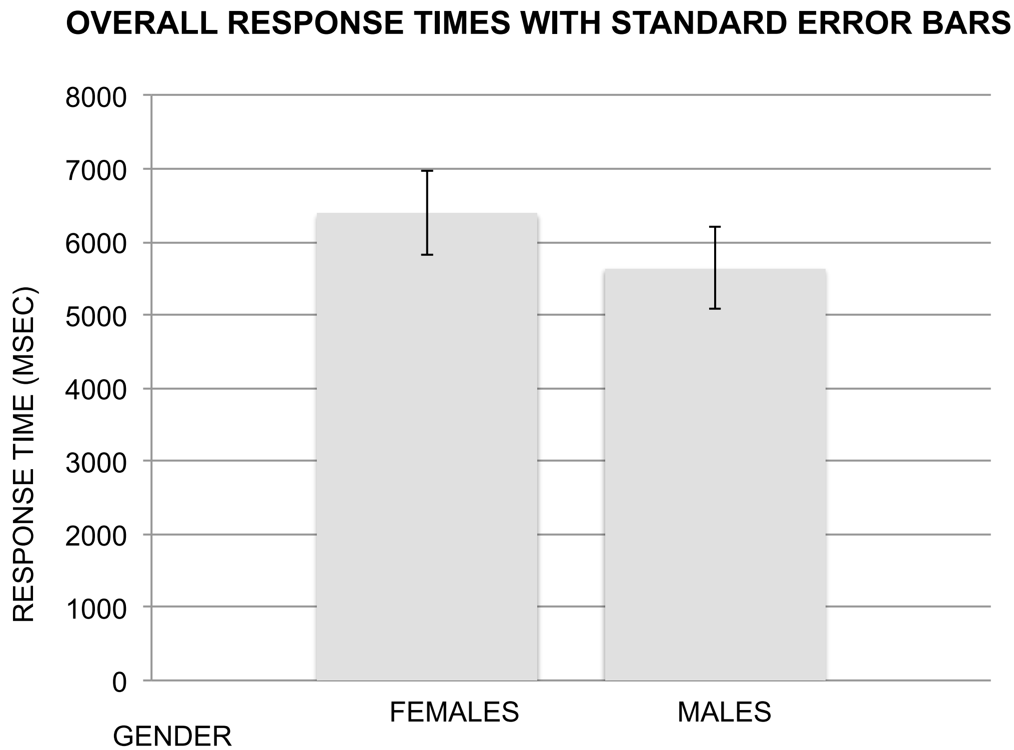
**Table 9.3: Overall and correct response times and accuracy rates by gender**

| GEN | ORT | S.E. (ORT) | CRT | S.E. (CRT) | RA | TOT. | NO. CORR |
|---|---|---|---|---|---|---|---|
| Female | 6393.79 | 174.12 | 6078.65 | 168.42 | 89.31% | 720 | 643 |
| Male | 5642.08 | 169.7 | 5330.99 | 150.71 | 90.66% | 696 | 631 |

GEN = Gender, ORT = average overall response time in milliseconds, CRT= average correct response time in milliseconds, S.E = standard error, RA= response accuracy in percentage, TOT= total number of responses, NO. CORR= number of correct responses

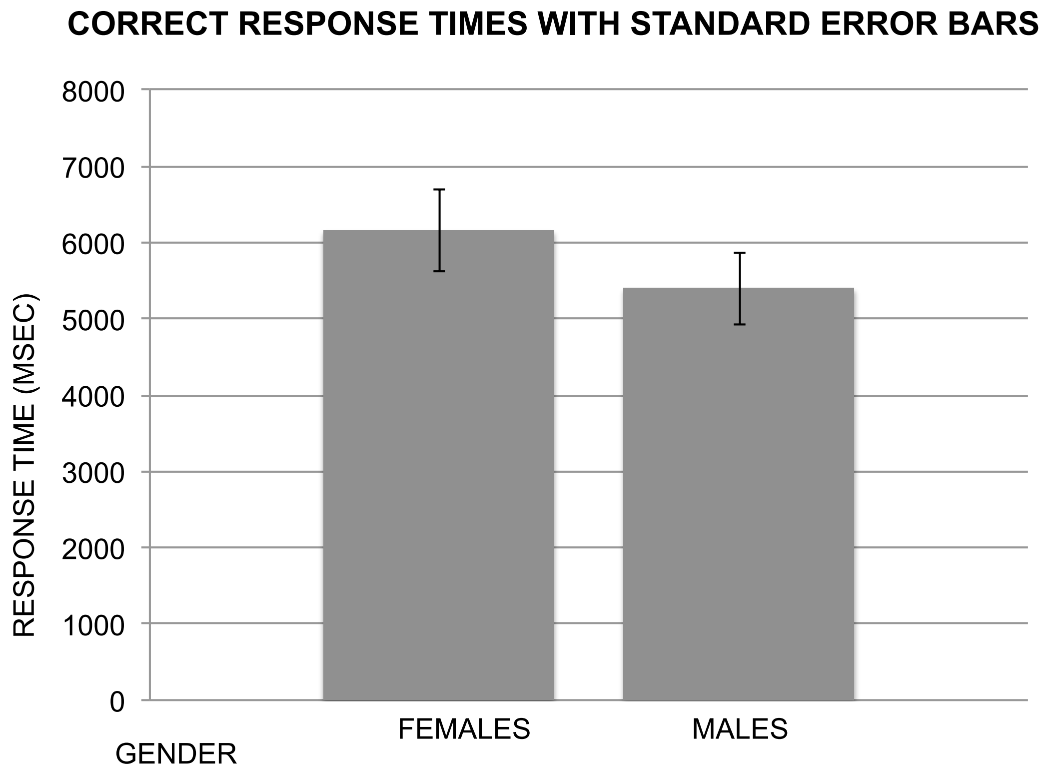
The following figure shows the average overall responses times for male and female participants.

**Figure 9.1: Average overall response times by gender**




The following figure shows the average correct responses times for male and female participants.

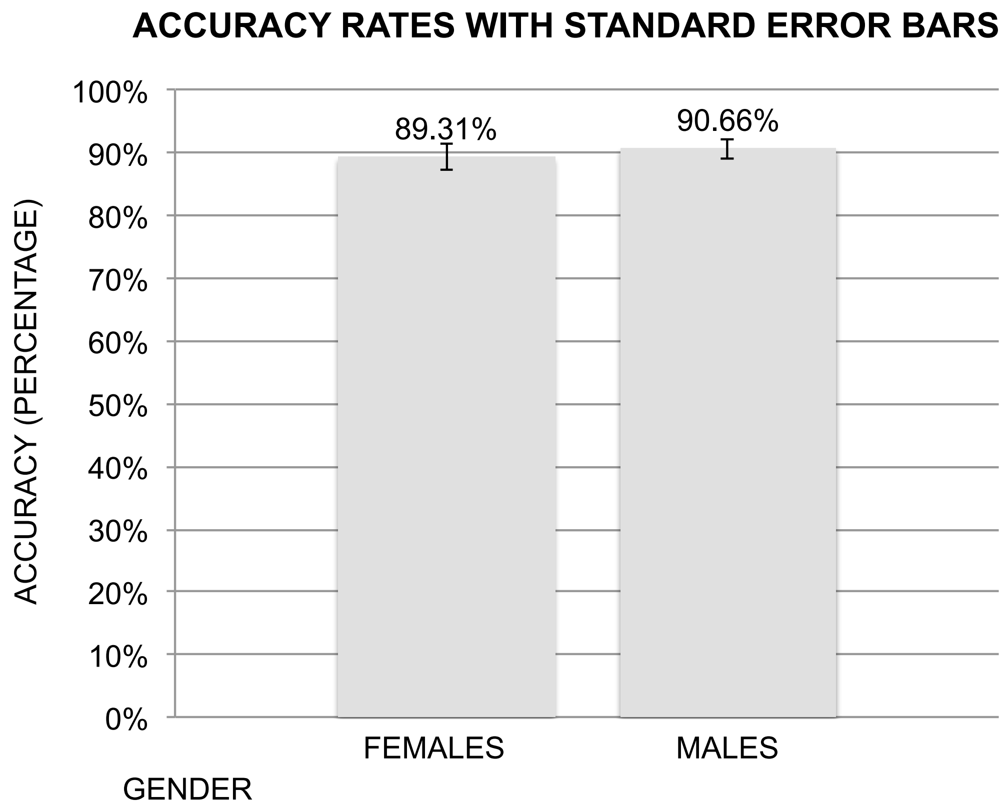
**Figure 9.2: Average correct response times by gender**




The above charts show that male subjects were faster to respond overall (5.6 seconds on average) and with correct responses (5.3 seconds on average). The average response time taken by female subjects to respond (overall) was 6.3 seconds and to make correct responses was 6 seconds.

The following figure shows the accuracy rates for male and female participants.

**Figure 9.3: Accuracy rates by gender**




The above chart shows that males had a slightly higher accuracy rate of 90.6% compared to females who had an accuracy rate of 89.3%.

### 9.2.2.2 Tests for significant differences in gender data

Further analyses were conducted in order to test for any significant differences between the response times and accuracy rates for male and female subjects. The tests have been described below.

**Mann-Whitney tests:**

Two Mann-Whitney tests were conducted, one each for the average overall and correct response times to test for significance at the 95% confidence level. The Mann-Whitney test is a non-parametric test of the null hypothesis that two independent samples are the same against an alternative hypothesis. This test was conducted using the XLSTAT package for Mac.

**Z-value tests:**

A z-value test was conducted to test for significant differences in accuracy rates between male and female subjects. This is a hypothesis test of a proportion and can be used on the response accuracy data because the following conditions have been met:

- The sampling method is simple random sampling
- Each sample point can result in only two possible outcomes- success and failure. In this case a participant's response is either correct or incorrect.
- The sample includes at least ten successes and ten failures
- The population size is at least ten times as big as the sample size

**A) Mann-Whitney test for average overall response times**

A Mann-Whitney test at significance level 0.05 was conducted to test for any significant differences between the average overall response times for male and female subjects.

**Table: 9.4 Results of the Mann-Whitney test for average overall response times for male and female subjects**

Mann-Whitney test / Two-tailed test:

| | |
|---|---|
| U | 496 |
| Expected value | 435 |
| Variance (U) | 4350 |
| **P-value (Two-tailed)** | **0.359** |
| Alpha | 0.05 |

An approximation has been used to compute the p-value.

Test interpretation:

H0: The difference of location between the samples is equal to 0

Ha: The difference of location between the samples is different from 0

As the computed p-value is greater than the significance level alpha= 0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 35.90%

From the results it can be seen by the p-value of 0.36 that there were **no significance differences between the average overall response times for male and female subjects at alpha = 0.05.**

**B) Mann-Whitney test for average correct response times**

A Mann-Whitney test at significance level 0.05 was conducted to test for any significant differences between the average correct response times for male and female subjects.

**Table 9.5: Results of Mann-Whitney test for average correct response times between male and female subjects**

Mann-Whitney test / Two-tailed test:

| | |
|---|---|
| U | 503 |
| Expected value | 435 |
| Variance (U) | 4350 |
| **P-value (Two-tailed)** | **0.306** |
| Alpha | 0.05 |

An approximation has been used to compute the p-value

Test interpretation:

H0: The difference of location between the samples is equal to 0

Ha: The difference of location between the samples is different from 0

As the computed p-value is greater than the significance level alpha= 0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 30.61%

From the results it can be seen by p-value of 0.306 that there were **no significance differences found between the average correct response times for male and female subjects at alpha = 0.05.**

**C) Z-value Test to compare two proportions (accuracy rates)**

A z-value test was conducted to test for any significant differences between the accuracy rates for male and female subjects.

**Table 9.6: Results of the z-value test to check for significant differences between accuracy rates of male and female subjects.**

| | Males |
|---|---|
| Total no. of responses (n1) | 696 |
| No. of correct responses (c1) | 631 |
| Proportion (p1) | 0.91 |

| | Females |
|---|---|
| Total no. of responses (n2) | 720 |
| No. of correct responses (c2) | 643 |
| Proportion (p2) | 0.89 |

Null Hypothesis H0: p1 = p2

Alternative hypothesis Ha: p1 ≠ p2

For this analysis the significance level is 0.05

Using the sample data we calculate the standard deviation (σ) and compute the z-score test statistic (z)

$$z = \frac{(\hat{p}_1 - \hat{p}_2) - 0}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Where p1 is the proportion of correct responses for males
And p2 is the proportion of correct responses for females

Calculating the overall sample proportion (p)
p= (c1+c2) /(n1 + n2)
p = 0.90

Calculating the standard error (S.E)

$$\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}$$

S.E. = square root of (0.90 * 0.1* (1/696 + 1/720))
S.E = 0.016

Finally, calculating the Z statistic,
Z = (0.91-0.89)/ 0.016
**Z =0.848**

Since we have a two-tailed test, the p-value is the probability that the z-score is less than -0.85 or greater than 0.85

Using the normal distribution table to find P (z < -0.85) = 1- 0.8023 = 0.1977 and P (z > 0.85) = 0.1977 (since this is a two-tailed test)

Thus, the **P-value** = 0.197 + 0.197 = **0.394**
Since p is > 0.05, we accept the null hypothesis.

From the above results it can be seen by p value of 0.394 that **no significant differences were found between the accuracy rates for male and female subjects at alpha = 0.05.**

### 9.2.3. Analysis for age groups

The responses from fifty-nine subjects were analyzed based on age groups to determine the accuracy rates and average response times for overall and correct responses.

#### 9.2.3.1 Overall analysis for age groups

The following table shows the overall and correct response times and accuracy rates for young drivers (18-30 years), middle-aged drivers (31- 54 years) and older drivers (55 years and over).

The average overall response time (ORT) for each age group indicates how long subjects in that group took to respond to questions, irrespective of whether the response was correct or not. The average correct response time (CRT) indicates how long subjects in that age group took to respond correctly. The table also shows the response accuracy (RA), which is the percentage of all responses that were correct.

**Table 9.7: Overall and correct response times and accuracy rates by age group**

| AGE GRP | ORT | S.E. (ORT) | CRT | S.E. (CRT) | RA | TOT. | NO. CORR |
|---|---|---|---|---|---|---|---|
| YOUNG (18-30 YEARS) | 4265.6 | 194.7 | 4205.54 | 199.36 | 92.71% | 445 | 480 |
| MIDDLE-AGED (31-54 YEARS) | 6113.57 | 286.29 | 5748.2 | 287.41 | 87.72% | 400 | 456 |
| OLDER (55+ YEARS) | 7698.22 | 351.37 | 7230.03 | 349.07 | 89.38% | 429 | 480 |

AGE GRP = age group, ORT = average overall response time in milliseconds, CRT= average correct response time in milliseconds, S.E = standard error, RA= response accuracy in percentage, TOT= total number of responses, NO CORR= number of correct responses

The following chart shows the overall and correct responses times (in milliseconds) for each of the three age groups.

**Figure 9.4: Average overall response times by age groups**

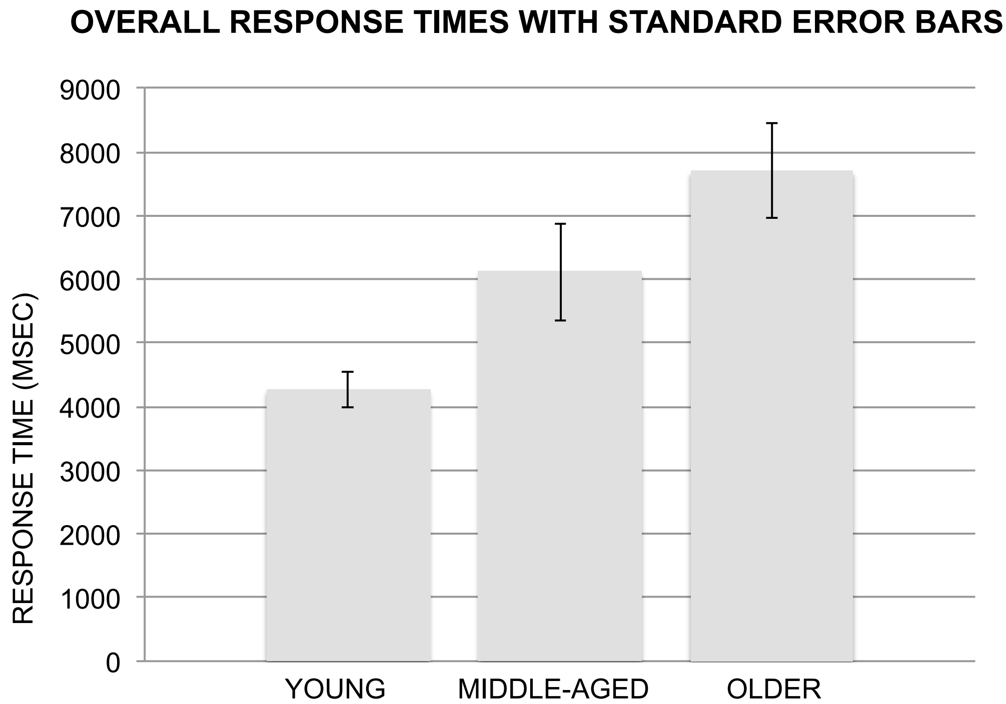
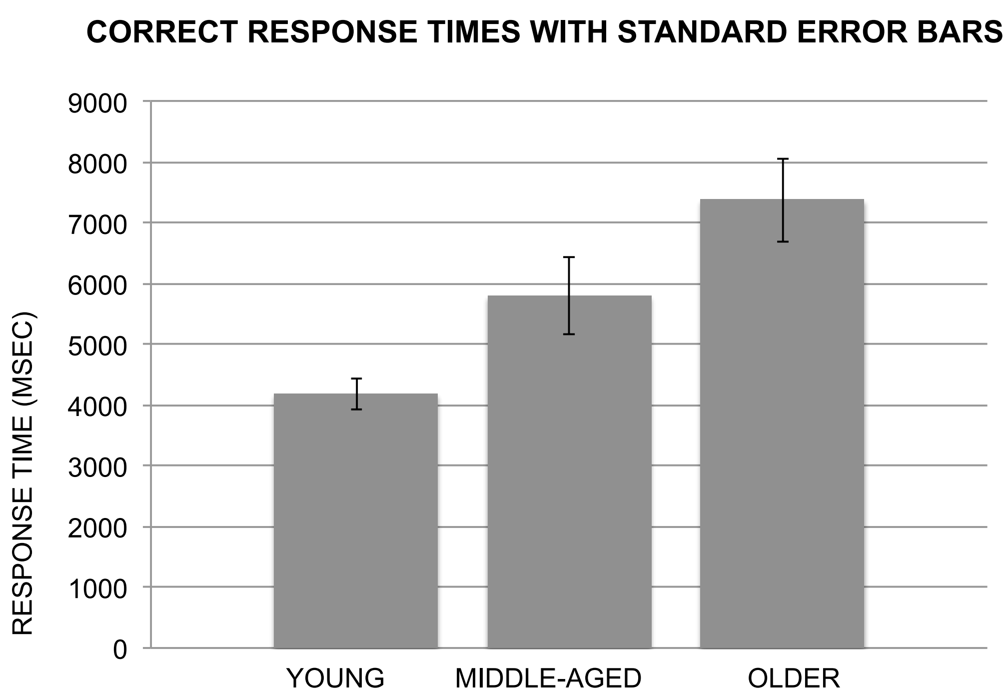
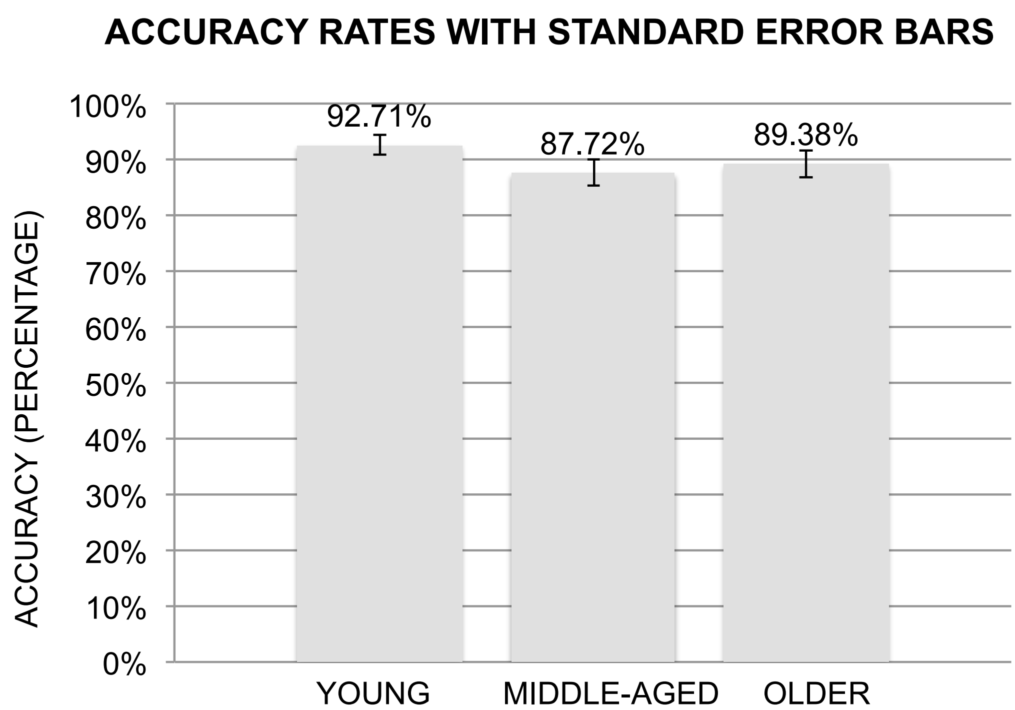



**Figure 9.5: Average correct response times by age groups**



The results show that the young drivers (18-30 years) were the fastest to respond overall (4.3 seconds on average) and also to respond correctly (4.2 seconds on average). Older drivers were the slowest to respond overall (7.6 seconds on average) and also to respond correctly (7.2 seconds on average). Middle-aged were faster to respond overall (6.1 seconds on average) and to respond correctly than older drivers (5.7 seconds on average). The following chart shows the accuracy rates for each of the three age groups.

**Figure 9.6: Accuracy rates by age groups**




The results show that the younger drivers had the highest accuracy rate of 92.7% among the three age groups. Older drivers had the second highest accuracy rate of 89.3% and middle-aged drivers had the lowest accuracy rate of 87.7%

#### 9.2.3.2 Tests for significant differences in age group data

Further analyses were conducted to test for any significant differences between the response times and accuracy rates for the three age groups. The tests have been described below.

**Kruskal-Wallis tests**

Two Kruskal-Wallis tests were conducted on the overall and correct response times to test for significance at the 95% confidence level. The Kruskal-Wallis test is a non-parametric test that allows comparison of k independent samples, (where k >2) in order to determine if the samples come from a single population or if at least one sample comes from a different population than the others. This test was conducted using the XLSTAT package for Mac.

**Multiple pairwise comparisons using Dunn's procedure with Bonferroni correction**

Dunn's procedure was conducted on the overall and correct response times to determine between which of the age groups there were significant differences. Dunn's procedure is a multiple comparisons post-hoc test. Since multiple comparisons were made on the same sample, the alpha level was adjusted using Bonferroni's correction. This test was conducted using the XLSTAT package for Mac.

**Z-value tests**

Z-value tests were conducted to test for significant differences in accuracy rates between the age groups. This is a hypothesis test of a proportion and can be used on the response accuracy data because the following conditions have been met:

- The sampling method is simple random sampling

- Each sample point can result in only two possible outcomes- success and failure. In this case a participant's response is either correct or incorrect.
- The sample includes at least ten success and ten failures
- The population size is at least ten times as big as the sample size

**A) Kruskal-Wallis test for average overall response times**

A **Kruskal-Wallis test** was conducted to test for any significant differences between the overall average response times between the three age groups.

**Table 9.8: Results of Kruskal-Wallis test on overall response times for young, middle-aged and older drivers**

Summary Statistics:

| Variable | Obs. | Obs. with missing data | Obs. without missing data | Minimum | Maximum | Mean | Std. Dev. |
|---|---|---|---|---|---|---|---|
| OVERALL AVG RT-YOUNG | 20 | 0 | 20 | 2375.917 | 7154.125 | 4265.598 | 1237.582 |
| OVERALL AVG RT-MIDDLE AGED | 20 | 1 | 19 | 3028.333 | 17770.542 | 6113.566 | 3376.02 |
| OVERALL AVG RT-OLDER | 20 | 0 | 20 | 4136.292 | 15168.875 | 7698.219 | 3318.515 |

Kruskal-Wallis test:

| | |
|---|---|
| K (Observed value) | 16.676 |
| K (Critical value) | 5.991 |
| DF | 2 |
| p-value (Two-tailed) | 0.0002 |
| alpha | 0.05 |

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population

Ha: The samples do not come from the same population

As the computed p-value is lower than the significance level alpha= 0.05, one should reject the null hypothesis H0 and accept the alternative hypothesis Ha

The risk to reject the null hypothesis H0 while it is true is lower than 0.02%

From the above results it can be seen by the **p-value of 0.0002 that there was a significant difference in the overall response times for young, middle-aged and older drivers at alpha = 0.05.**

**B) Multiple pairwise comparisons using Dunn's procedure (two-tailed test) for overall response times**

To further investigate between which of the three groups there was a significant difference in overall response times, multiple pairwise comparison was conducted using Dunn's procedure. The Bonferroni correction has also been applied.

**Table 9.9: Results of Dunn's procedure for multiple pairwise comparisons of overall response times**

| Sample | Frequency | Sum of ranks | Mean of ranks | Groups | |
|---|---|---|---|---|---|
| OVERALL AVG RT-YOUNG | 20 | 372 | 18.6 | A | |
| OVERALL AVG RT-MIDDLE AGED | 19 | 583 | 30.684 | A | B |
| OVERALL AVG RT-OLDER | 20 | 815 | 40.75 | | B |

Table of pairwise differences:

| | OVERALL AVG RT-YOUNG | OVERALL AVG RT-MIDDLE AGED | OVERALL AVG RT-OLDER |
|---|---|---|---|
| OVERALL AVG RT-YOUNG | 0 | -12.084 | -22.15 |
| OVERALL AVG RT-MIDDLE AGED | 12.084 | 0 | -10.066 |
| OVERALL AVG RT-OLDER | 22.15 | 10.066 | 0 |

P-values:

| | OVERALL AVG RT-YOUNG | OVERALL AVG RT-MIDDLE AGED | OVERALL AVG RT-OLDER |
|---|---|---|---|
| OVERALL AVG RT-YOUNG | 1 | 0.028 | < 0.0001 |
| OVERALL AVG RT-MIDDLE AGED | 0.028 | 1 | 0.067 |
| OVERALL AVG RT-OLDER | < 0.0001 | 0.067 | 1 |

**Bonferroni corrected significance level: 0.0167**

Significant differences:

| | OVERALL AVG RT-YOUNG | OVERALL AVG RT-MIDDLE AGED | OVERALL AVG RT-OLDER |
|---|---|---|---|
| OVERALL AVG RT-YOUNG | No | No | **Yes** |
| OVERALL AVG RT-MIDDLE AGED | No | No | No |
| OVERALL AVG RT-OLDER | **Yes** | No | No |

Note- significant differences have only been identified by this procedure for p-values that are less than the Bonferroni corrected significance level of 0.0167. This is why the above chart showing significant differences doesn't identify a significant difference between the overall response times for middle-aged and young drivers even though the p-value for that comparison is 0.028 which is less than alpha (0.05).

From the above results it can be seen by the **p-value of less than 0.0001 that there was a significant difference in the overall response times for young and older drivers (at the Bonferroni corrected significance level of 0.0167)**

**There was also a significant difference in the overall response times for young and middle-aged drivers at alpha = 0.05 but not at the Bonferroni corrected significance level of 0.0167.**

**C) Kruskal-Wallis tests for average correct response times**

A **Kruskal-Wallis test** was conducted to test for any significant differences between the average correct response times between of three age groups.

**Table 9.10: Results of Kruskal-Wallis test on correct response times for young, middle-aged and older drivers**

Summary Statistics:

| Variable | Obs. | Obs. with missing data | Obs. without missing data | Minimum | Maximum | Mean | Std. deviation |
|---|---|---|---|---|---|---|---|
| OVERALL AVG RT-YOUNG | 20 | 0 | 20 | 2387.13 | 7154.125 | 4182.891 | 1196.37 |
| OVERALL AVG RT-MIDDLE AGED | 20 | 1 | 19 | 3059.045 | 14430 | 5797.311 | 2775.046 |
| OVERALL AVG RT-OLDER | 20 | 0 | 20 | 4136.292 | 14330.591 | 7380.181 | 3081.9 |

Kruskal-Wallis test:

| | |
|---|---|
| K (Observed value) | 16.416 |
| K (Critical value) | 5.991 |
| DF | 2 |
| p-value (Two-tailed) | 0.0002 |
| alpha | 0.05 |

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population

Ha: The samples do not come from the same population

As the computed p-value is lower than the significance level alpha= 0.05, one should reject the null hypothesis H0 and accept the alternative hypothesis Ha

The risk to reject the null hypothesis H0 while it is true is lower than 0.03%

From the above results it can be seen by **p-value of 0.0002 that there was a significant difference between the correct response times for young, middle-aged and older drivers at alpha = 0.05.**

**D) Multiple pairwise comparisons using Dunn's procedure (Two-tailed test) for correct response times**

To further investigate between which of the three groups there was a significant difference in correct response times, multiple pairwise comparisons were conducted using Dunn's procedure. The Bonferroni correction has also been applied.

**Table 9.11: Results of Dunn's procedure for multiple pairwise comparisons of correct response times**

| Sample | Frequency | Sum of ranks | Mean of ranks | Groups | |
|---|---|---|---|---|---|
| AVG CORRECT RT-YOUNG | 20 | 377 | 18.85 | A | |
| AVG CORRECT RT-MIDDLE AGED | 19 | 576 | 30.316 | A | B |
| AVG CORRECT RT-OLDER | 20 | 817 | 40.85 | | B |

Table of pairwise differences:

| | AVG CORRECT RT-YOUNG | AVG CORRECT RT-MIDDLE AGED | AVG CORRECT RT-OLDER |
|---|---|---|---|
| AVG CORRECT RT-YOUNG | 0 | -11.466 | -22 |
| AVG CORRECT RT-MIDDLE AGED | 11.466 | 0 | -10.534 |

| | | | |
|---|---|---|---|
| AVG CORRECT RT-OLDER | 22 | 10.534 | 0 |

P-values:

| | AVG CORRECT RT-YOUNG | AVG CORRECT RT-MIDDLE AGED | AVG CORRECT RT-OLDER |
|---|---|---|---|
| AVG CORRECT RT-YOUNG | 1 | 0.037 | < 0.0001 |
| AVG CORRECT RT-MIDDLE AGED | 0.037 | 1 | 0.056 |
| AVG CORRECT RT-OLDER | < 0.0001 | 0.056 | 1 |

**Bonferroni corrected significance level: 0.0167**

Significant differences:

| | AVG CORRECT RT-YOUNG | AVG CORRECT RT-MIDDLE AGED | AVG CORRECT RT-OLDER |
|---|---|---|---|
| AVG CORRECT RT-YOUNG | No | No | **Yes** |
| AVG CORRECT RT-MIDDLE AGED | No | No | No |
| AVG CORRECT RT-OLDER | **Yes** | No | No |

Note- significant differences have only been identified by this procedure for p-values that are less than the Bonferroni corrected significance level of 0.0167. This is why the above chart showing significant differences doesn't identify a significant difference between the correct response times for young and middle-aged drivers even though the p-value for that comparison is 0.037 which is less than alpha (0.05).

From the above results it can be seen by **p-value of less than 0.0001 that there was a significant difference in the correct response times for young and older drivers (at alpha = 0.05 and at the Bonferroni corrected significance level of 0.0167).**

**There was also a significant difference in the correct response times for middle-aged and young drivers at alpha = 0.05 but not at the Bonferroni corrected significance level of 0.0167.**

### E) Z-value tests to compare two proportions (accuracy rates)

Three z-value tests were conducted to test for any significant differences between the accuracy rates of the three groups. Tests were conducted for:

- Young and middle-aged drivers
- Middle-aged and older drivers
- Young and older drivers

### Z-value test for accuracy rates of young and middle-aged drivers

The following table summarizes the z-value test for significant differences between accuracy rates of young and middle-aged drivers.

**Table 9.12: Results of the z-value test to check for significant differences between accuracy rates of young and middle-aged drivers**

| YOUNG DRIVERS | |
|---|---|
| Total no. of responses (n1) | 480 |
| No. of correct responses (c1) | 445 |
| Proportion (p1) | 0.93 |

| MIDDLE-AGED DRIVERS | |
|---|---|
| Total no. of responses (n2) | 456 |
| No. of correct responses (c2) | 400 |
| Proportion (p2) | 0.88 |

Null Hypothesis H0: $p1 = p2$

Alternative hypothesis Ha: $p1 \neq p2$

For this analysis the significance level is 0.05

Using the sample data we calculate the standard deviation (σ) and compute the z-score test statistic (z)

$$z = \frac{(\hat{p}_1 - \hat{p}_2) - 0}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Where p1 is the proportion of correct responses for young drivers

p2 is the proportion of correct responses for middle-aged drivers

Calculating the overall sample proportion (p)

p= (c1+c2) /(n1 + n2)

p = 0.90

Calculating the standard error (S.E)

$$\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

S.E. = square root of (0.90 * 0.1* (1/480 + 1/456))

S.E = 0.019

Finally, calculating the Z statistic,

Z = (0.93-0.88)/ 0.019

**Z =2.63**

Since we have a two-tailed test, the p-value is the probability that the z-score is less than –2.63 or greater than 2.63.

Using the normal distribution table to find P (z < -2.63) = 1- 0.9957= 0.0043 and P (z > 0.85) = 0.0043 (since this is a two-tailed test)

Thus, the **P-value** = 0.0043 + 0.0043 = **0.0086**

Since p is < 0.05, we reject the null hypothesis.

From the above results it can be seen by the **p-value of 0.0086** that there were **there was a significance difference between the accuracy rates of young and middle-aged drivers at alpha = 0.05.**

**Z-value test for accuracy rates of middle-aged and older drivers**

The following table summarizes the z-value test for significant differences between accuracy rates of middle-aged and older drivers.

**Table 9.13: Results of the z-value test to check for significant differences between accuracy rates of middle-aged and older drivers**

| MIDDLE-AGED DRIVERS | |
|---|---|
| Total no. of responses (n1) | 456 |
| No. of correct responses (c1) | 400 |
| Proportion (p1) | 0.88 |

| OLDER DRIVERS | |
|---|---|
| Total no. of responses (n2) | 480 |
| No. of correct responses (c2) | 429 |
| Proportion (p2) | 0.89 |

Null Hypothesis H0: p1 = p2

Alternative hypothesis Ha: p1 ≠ p2

For this analysis the significance level is 0.05

Using the sample data we calculate the z-score test statistic (z)

$$z = \frac{(\hat{p}_1 - \hat{p}_2) - 0}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Where p1 is the proportion of correct responses for middle-aged drivers

p2 is the proportion of correct responses for older drivers

Calculating the overall sample proportion (p)

p= (c1+c2) /(n1 + n2)

p = 0.88

Calculating the standard error (S.E)

$$\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}$$

S.E. = square root of (0.88 * 0.12 * (1/456 + 1/480))

S.E = 0.021

Finally, calculating the Z statistic,

Z = (0.88-0.89)/ 0.021

**Z =-0.476**

Since we have a two-tailed test, the p-value is the probability that the z-score is less than –**0.476**or greater than **0.476**

Using the normal distribution table to find P (z < -0.47) = 1- 0.6808= 0.3192 and P (z > 0.47) = 0.3192 (since this is a two-tailed test)

Thus, the **P-value** = 0.3192 + 0.3192= **0.6384**

Since p is > 0.05, we accept the null hypothesis.

From the above results it can be seen by p value of 0.6384 that **there was no significance difference between the accuracy rates of middle-aged and older drivers at alpha = 0.05.**

**Z-value test on accuracy rates of young and older drivers**

The following table summarizes the z-value test for significant differences between accuracy rates of young and older drivers

**Table 9.14: Results of the z-value test to check for significant differences between accuracy rates of young and older drivers**

| YOUNG DRIVERS | |
|---|---|
| Total no. of responses (n1) | 480 |
| No. of correct responses (c1) | 445 |
| Proportion (p1) | 0.93 |

| OLDER DRIVERS | |
|---|---|
| Total no. of responses (n2) | 480 |
| No. of correct responses (c2) | 429 |
| Proportion (p2) | 0.89 |

Null Hypothesis H0: p1 = p2

Alternative hypothesis Ha: p1 ≠ p2

For this analysis the significance level is 0.05

Using the sample data we calculate the z-score test statistic (z)

$$z = \frac{(\hat{p}_1 - \hat{p}_2) - 0}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Where p1 is the proportion of correct responses for young drivers

p2 is the proportion of correct responses for older drivers

Calculating the overall sample proportion (p)

p= (c1+c2) /(n1 + n2)

p = 0.91

Calculating the standard error (S.E)

$$\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}$$

S.E. = square root of (0.91 * 0.09* (1/480 + 1/480))
S.E = 0.018

Finally, calculating the Z statistic,
Z = (0.93-0.89)/ 0.018
**Z =2.22**

Since we have a two-tailed test, the p-value is the probability that the z-score is less than –2.22 or greater than 2.22

Using the normal distribution table to find P (z < -2.22) = 1- 0.9868= 0.0132 and P (z > 2.22)= 0.0132 (since this is a two-tailed test)

Thus, the **P-value** = 0.0132 + 0.0132 = **0.0264**
Since p is < 0.05, we reject the null hypothesis.

From the above results it can be seen by **p-value of 0.0264** that there were **there was a significance difference found between the accuracy rates for young and older drivers at alpha = 0.05.**

### 9.2.4. Analysis for gauges

This subsection covers the analysis conducted on the data for the eight gauges.

#### 9.2.4.1 Overall analysis for gauges

The following tables show the average response times and accuracy rates for each of the eight gauge designs.

The average overall response time (ORT) for each gauge indicates how long subjects took to respond to questions on that gauge, irrespective of whether the response was correct or not. The average correct response time (CRT) indicates how long subjects in to respond correctly to questions on that gauge. The table also shows the response accuracy (RA), which is the percentage of all responses that were correct.

The following table shows data for all gauges are arranged in alphabetical order with corresponding average overall response times, average correct response times and accuracy rates.

**Table 9.15: Gauges listed in alphabetical order with corresponding response times and accuracy rates.**

| GAUGES | ORT | S.E. (ORT) | CRT | S.E. (CRT) | RA | TOT. | NO. CORR |
|---|---|---|---|---|---|---|---|
| A | 6309.77 | 345.89 | 5917.4 | 308.13 | 89.83% | 177 | 159 |
| B | 6761.57 | 347.8 | 6470.29 | 363.69 | 86.44% | 177 | 153 |
| C | 6128.5 | 331.76 | 5990.08 | 333.86 | 93.79% | 177 | 166 |
| D | 4792.3 | 269.55 | 4592.15 | 242.93 | 96.61% | 177 | 171 |
| E | 6054.97 | 439.99 | 5263.22 | 275.8 | 88.14% | 177 | 156 |
| F | 6781.51 | 367.22 | 6517.14 | 384.78 | 83.05% | 177 | 147 |
| G | 5326.53 | 264.75 | 5259.89 | 271.26 | 94.35% | 177 | 167 |
| I | 6039.31 | 342.45 | 5835.56 | 362.97 | 87.57% | 177 | 155 |

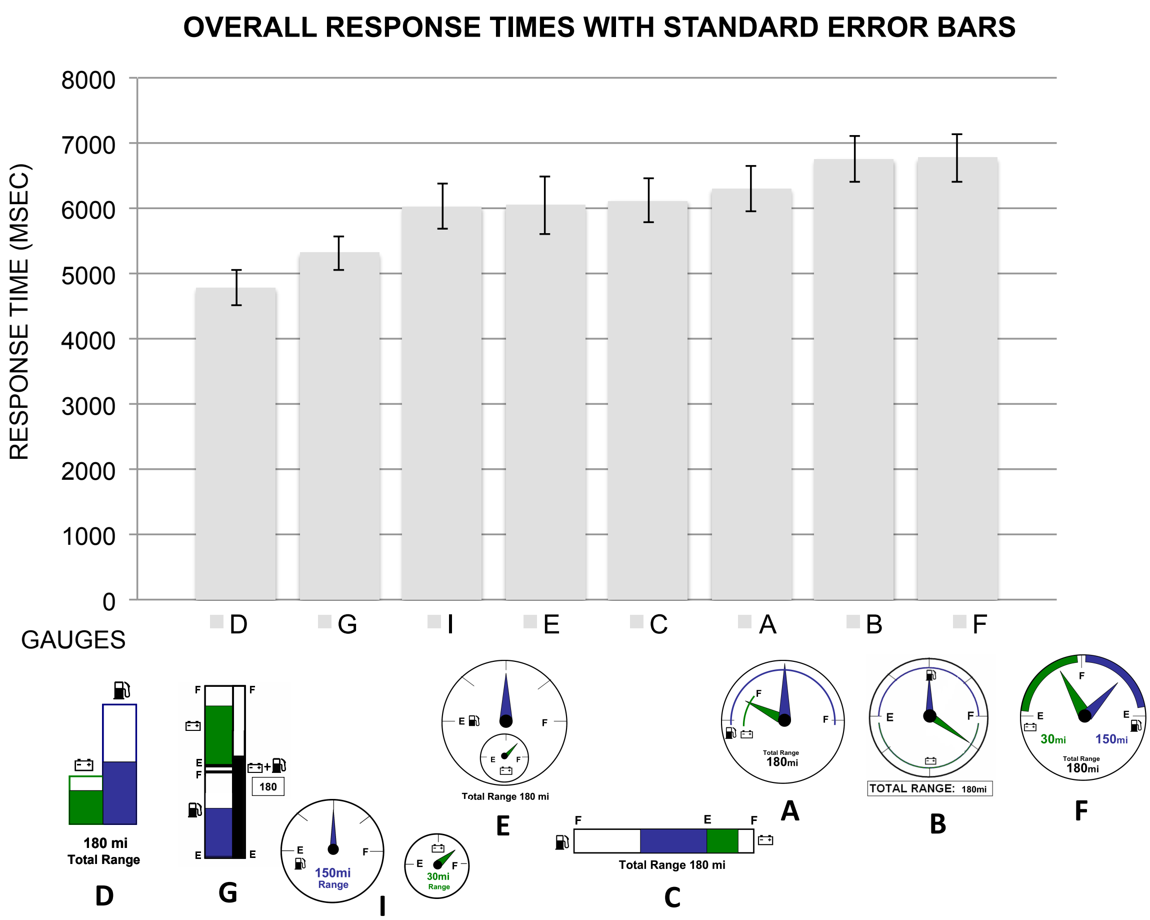
ORT = average overall response time in milliseconds, CRT= average correct response time in milliseconds, S.E = standard error, RA= response accuracy in percentage, TOT= total number of responses, NO CORR= number of correct responses

**Gauge D** had lowest average overall response time of 4.8 seconds and the lowest average correct response time of 4.6 seconds. **Gauge F** had the highest average overall response time of 6.78 seconds and the highest average correct response time of 6.5 seconds.

**Average overall response time by gauge**

The following chart shows the overall responses times (in milliseconds) for each of the eight gauges. The gauges are **arranged in order of increasing overall response times** (lowest to highest) on the x-axis.

**Figure 9.7: Overall response times for gauges (arranged from left to right in order of lowest to highest response times)**

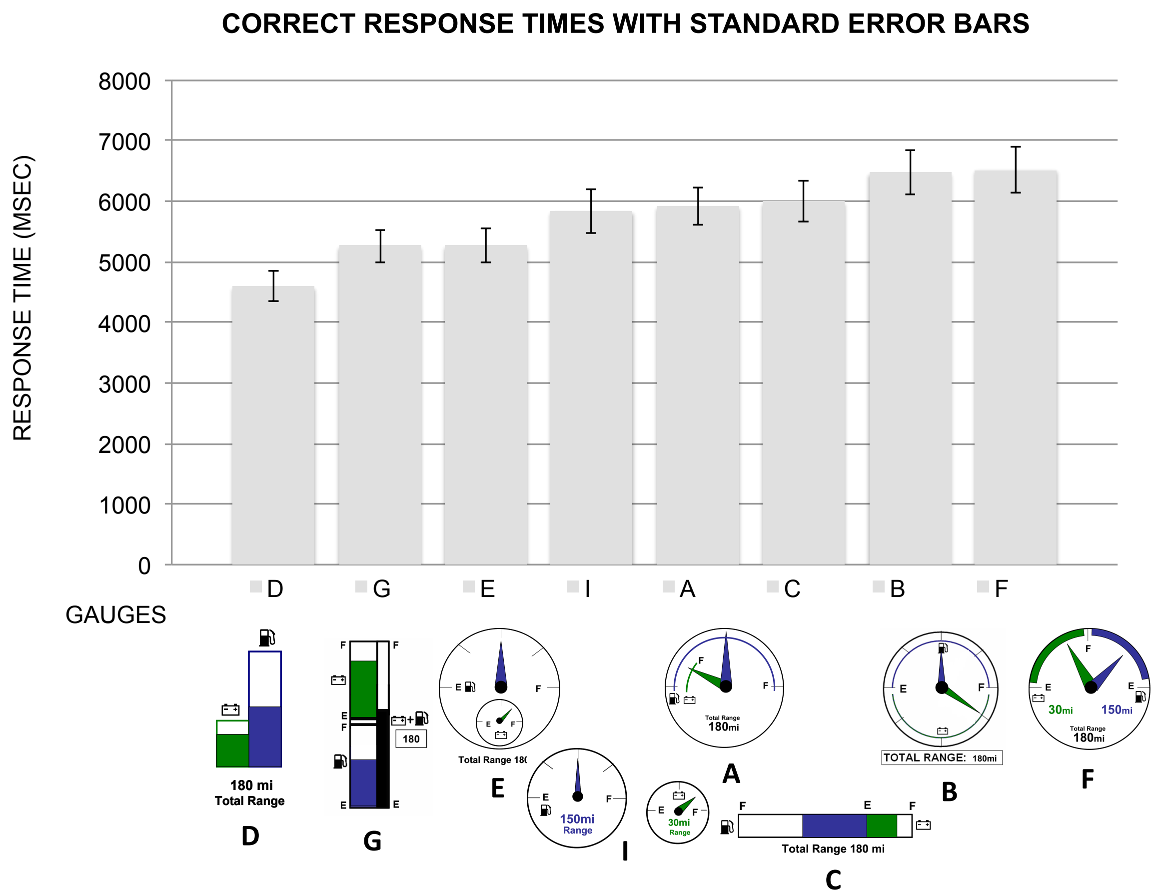



The results show that the vertically oriented bar gauges (D and G) had the lowest average overall response times while a majority of the circular gauges (A, B and F) had the highest average overall response times.

**Correct response times by gauge**

The following chart shows the correct responses times (in milliseconds) for each of the eight gauges. The gauges are **arranged in order of increasing correct response times** (lowest to highest) on the x-axis.

**Figure 9.8: Correct response times for gauges (arranged from left to right in order of lowest to highest response times)**

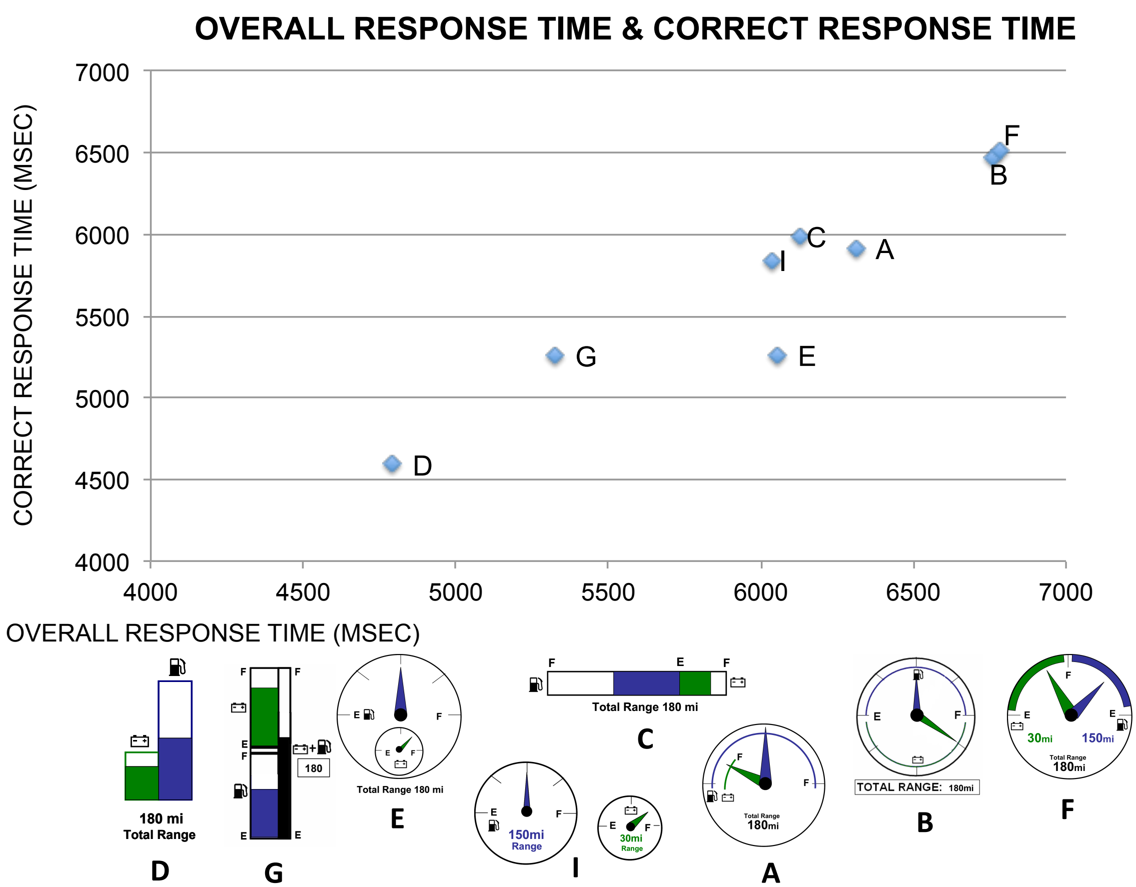



The results show that the vertically oriented bar gauges (D and G) had the lowest average correct response times while circular gauges B and F had the highest average correct response times.

**Relationships between overall and correct response times**

The following scatterplot shows the overall and correct responses times (in milliseconds) for each gauge. The gauges are **arranged in order of increasing overall response times** (lowest to highest) on the x-axis and **in order of increasing correct responses times** (lowest to highest) on the y-axis.

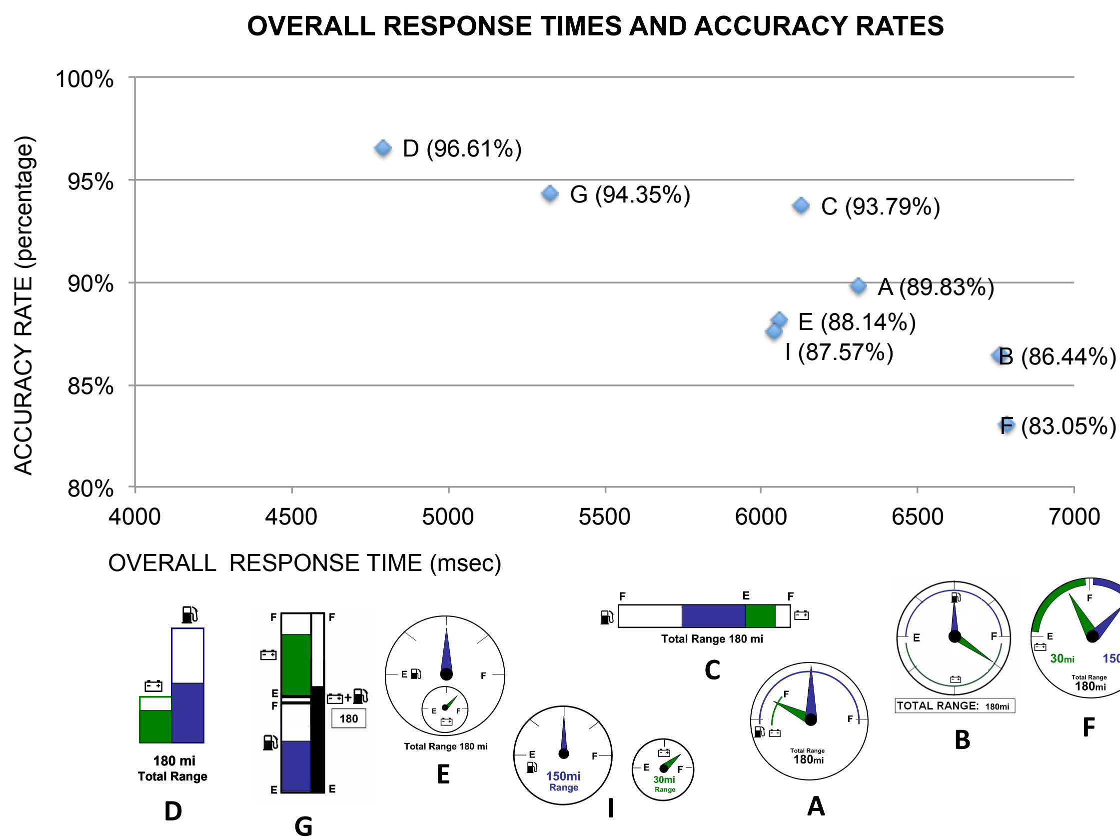
**Figure 9.9: Scatterplot showing relationship between overall response times and correct response times for the eight gauges**




Vertically oriented bar gauges D and G had the best performance in terms of reading speed with lowest overall and correct response times. Circular gauges I, A, B and F had the worst performance in terms of reading speed with some of the highest overall and correct response times. Horizontally oriented bar gauge C also performed poorly in terms of reading speed with high overall and correct response times. It can also be seen that the overall response time was always higher than the correct response time for each gauge although there was no clear pattern in the difference between the two. For example, in case of gauge E the overall response time was higher than the correct response time by 0.8 seconds while in the case of gauge G it was higher by only 0.06 seconds.

The following scatterplot shows indicates the overall responses times (in milliseconds) and accuracy rates for each gauge. The gauges are **arranged in order of increasing overall response times** (lowest to highest) on the x-axis and **in order of increasing response accuracy** (lowest to highest) on the y-axis.

**Figure 9.10: Scatterplot showing relationship between overall response times and accuracy rates for the eight gauges**

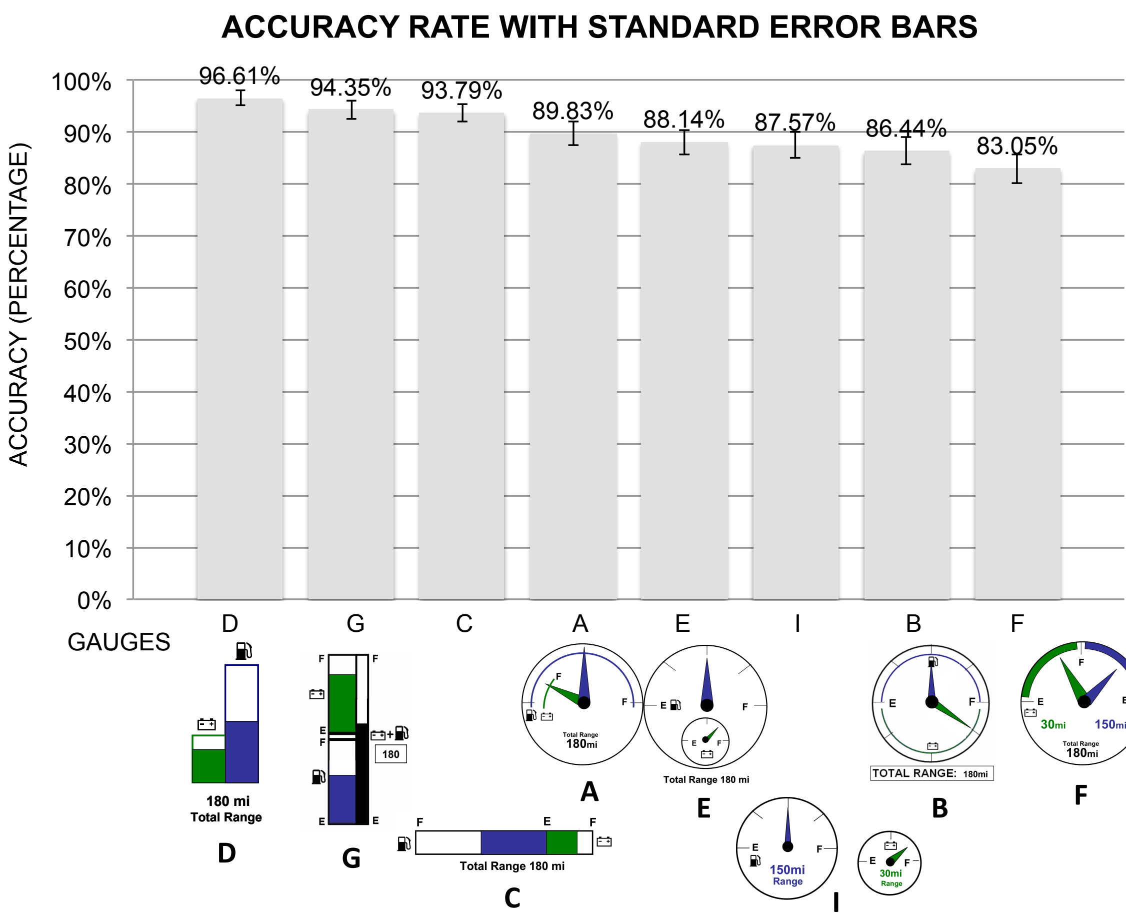


The results show that vertically oriented bar gauges D and G had the best performance with the highest accuracy rates and lowest overall response times. Circular gauges A, B and F had the worst performance with the lowest accuracy rates and the highest overall response times.

### Accuracy rates by gauge

The following chart shows the accuracy rate for each of the eight gauges. The gauges are **arranged in order of decreasing accuracy** (highest to lowest) on the x-axis.

**Figure 9.11: Accuracy rates for gauges (arranged from left to right in order of highest to lowest)**



Bar gauges had higher accuracy rates than circular gauges. Vertically oriented bar gauges D (highest at 96.6%) and G had the highest accuracy rates while circular gauges A, E, I, B and F (lowest at 83.05%) had the lowest accuracy rates.

#### 9.2.4.2 Tests for significant differences in gauge data

Further analyses were conducted to test for any significant differences between the response times and accuracy rates for the eight gauges. The tests have been described below.

**Kruskal-Wallis tests**

Two Kruskal-Wallis tests were conducted on the overall and correct response times to test for significances at the 95% confidence level. The Kruskal-Wallis test is a non-parametric test that allows comparison of k independent samples, (where k>2) in order to determine if the samples come from a single population or if at least one sample comes from a different population than the others. The test was conducted using the XLSTAT package for Mac.

**Multiple pairwise comparisons using Dunn's procedure with Bonferroni correction**

Dunn's procedure was conducted on the overall and correct response times of the gauges to determine between which of the gauges there were significant differences. Dunn's procedure is a multiple comparisons post-hoc test. Since multiple comparisons were made on the same sample, the alpha level was adjusted using Bonferroni's correction. This test was conducted using the XLSTAT package for Mac.

**Chi-square test**

A chi-square test was conducted for accuracy rates to test for significance at the 95% confidence level. The chi-square test is conducted to test the hypothesis of no association between two or more groups. This test can be conducted if each observation is independent of all others, no more than 20% of the expected counts are less than five and all individual expected counts are one or more. This test was conducted using the XLSTAT package for Mac.

**Marascuilo procedure**

The Marascuilo procedure was conducted on accuracy rates for the eight gauges in order to determine between which gauges there were significant differences. The Marascuilo procedure enables simultaneous pairwise comparisons between all pairs of groups. It is used to test for any significant differences between pairs of proportions. This test was conducted using the XLSTAT package for Mac.

**A) Kruskal-Wallis test for overall response times**

A **Kruskal-Wallis test** was conducted to test for any significant differences between the overall average response times between the eight gauges.

**Table 9.16: Results of Kruskal-Wallis test for overall response times for the eight gauges**

Summary statistics:

| Variable | Obs. | Obs. with missing data | Obs. without missing data | Minimum | Maximum | Mean | Std. deviation |
|---|---|---|---|---|---|---|---|
| A-OVERALL RT | 177 | 0 | 177 | 1165 | 32444 | 6309.768 | 4601.745 |
| B-OVERALL RT | 177 | 0 | 177 | 1347 | 30077 | 6761.571 | 4627.217 |
| C-OVERALL RT | 177 | 0 | 177 | 1471 | 25060 | 6128.503 | 4413.724 |
| D-OVERALL RT | 177 | 0 | 177 | 958 | 22573 | 4792.299 | 3586.192 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| E-OVERALL RT | 177 | 0 | 177 | 1276 | 53074 | 6054.966 | 5853.62 |
| F-OVERALL RT | 177 | 0 | 177 | 1322 | 28241 | 6781.514 | 4885.57 |
| G-OVERALL RT | 177 | 0 | 177 | 1189 | 22163 | 5326.525 | 3522.272 |
| I-OVERALL RT | 177 | 0 | 177 | 1260 | 30507 | 6039.305 | 4555.952 |

Kruskal-Wallis test:

| | |
|---|---|
| K (Observed value) | 43.869 |
| K (Critical value) | 14.067 |
| DF | 7 |
| p-value (Two-tailed) | < 0.0001 |
| alpha | 0.05 |

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population

Ha: The samples do not come from the same population

As the computed p-value is lower than the significance level alpha= 0.05, one should reject the null hypothesis H0 and accept the alternative hypothesis Ha

The risk to reject the null hypothesis H0 while it is true is lower than 0.01%

From the above results it can be seen by **p-value of less than 0.0001 that there was a significant difference in the overall response times between the gauges at alpha = 0.05.**

**B) Multiple pairwise comparisons using Dunn's procedure (two-tailed test) for overall response times**

To further investigate between which of the eight gauges there was a significant difference in overall response times, a multiple pairwise comparisons test was conducted using Dunn's procedure. The Bonferroni correction has also been applied.

**Table 9.17: Results of Dunn's procedure for multiple pairwise comparisons of overall response times**

| Sample | Frequency | Sum of ranks | Mean of ranks | Groups | | |
|---|---|---|---|---|---|---|
| D-ORT | 177 | 99855.5 | 564.155 | A | | |
| G-ORT | 177 | 116203 | 656.514 | A | B | |
| E-ORT | 177 | 120266.5 | 679.472 | A | B | C |
| I-ORT | 177 | 126166.5 | 712.805 | | B | C |
| C-ORT | 177 | 126865.5 | 716.754 | | B | C |
| A-ORT | 177 | 131775 | 744.492 | | B | C |
| F-ORT | 177 | 140181.5 | 791.986 | | B | C |
| B-ORT | 177 | 141922.5 | 801.822 | | | C |

Table of pairwise differences:

| | A-ORT | B-ORT | C-ORT | D-ORT | E-ORT | F-ORT | G-ORT | I-ORT |
|---|---|---|---|---|---|---|---|---|
| A-ORT | 0 | -57.331 | 27.737 | 180.336 | 65.02 | -47.494 | 87.977 | 31.686 |
| B-ORT | 57.331 | 0 | 85.068 | 237.667 | 122.35 | 9.836 | 145.308 | 89.017 |
| C-ORT | -27.737 | -85.068 | 0 | 152.599 | 37.282 | -75.232 | 60.24 | 3.949 |
| D-ORT | -180.336 | -237.667 | -152.599 | 0 | -115.316 | -227.831 | -92.359 | -148.65 |
| E-ORT | -65.02 | -122.35 | -37.282 | 115.316 | 0 | -112.514 | 22.958 | -33.333 |
| F-ORT | 47.494 | -9.836 | 75.232 | 227.831 | 112.514 | 0 | 135.472 | 79.181 |
| G-ORT | -87.977 | -145.308 | -60.24 | 92.359 | -22.958 | -135.472 | 0 | -56.291 |
| I-ORT | -31.686 | -89.017 | -3.949 | 148.65 | 33.333 | -79.181 | 56.291 | 0 |

Critical difference: 135.7777

P-values:

| | A-ORT | B-ORT | C-ORT | D-ORT | E-ORT | F-ORT | G-ORT | I-ORT |
|---|---|---|---|---|---|---|---|---|
| A-ORT | 1 | 0.187 | 0.523 | **< 0.0001** | 0.135 | 0.275 | 0.043 | 0.466 |
| B-ORT | 0.187 | 1 | 0.05 | **< 0.0001** | 0.005 | 0.821 | **0.001** | 0.041 |
| C-ORT | 0.523 | 0.05 | 1 | **0** | 0.391 | 0.083 | 0.166 | 0.928 |
| D-ORT | **< 0.0001** | **< 0.0001** | **0** | 1 | 0.008 | **< 0.0001** | 0.034 | **0.001** |
| E-ORT | 0.135 | 0.005 | 0.391 | 0.008 | 1 | 0.01 | 0.597 | 0.443 |
| F-ORT | 0.275 | 0.821 | 0.083 | **< 0.0001** | 0.01 | 1 | 0.002 | 0.069 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| G-ORT | 0.043 | **0.001** | 0.166 | 0.034 | 0.597 | 0.002 | 1 | 0.195 |
| I-ORT | 0.466 | 0.041 | 0.928 | **0.001** | 0.443 | 0.069 | 0.195 | 1 |

Bonferroni corrected significance level: 0.0018

Significant differences:

| | A-ORT | B-ORT | C-ORT | D-ORT | E-ORT | F-ORT | G-ORT | I-ORT |
|---|---|---|---|---|---|---|---|---|
| A-ORT | No | No | No | **Yes** | No | No | No | No |
| B-ORT | No | No | No | **Yes** | No | No | **Yes** | No |
| C-ORT | No | No | No | **Yes** | No | No | No | No |
| D-ORT | **Yes** | **Yes** | **Yes** | No | No | **Yes** | No | **Yes** |
| E-ORT | No | No | No | No | No | No | No | No |
| F-ORT | No | No | No | **Yes** | No | No | No | No |
| G-ORT | No | **Yes** | No | No | No | No | No | No |
| I-ORT | No | No | No | **Yes** | No | No | No | No |

Note- significant differences have only been identified by this procedure for p-values that are less than the Bonferroni corrected significance level of 0.0018. This is why the above chart showing significant differences doesn't identify a significant difference between the overall response times for some gauges. For example, even though the p-value for the comparison between gauges A and G is 0.043, which is less than alpha (0.05) this test does not consider it to be a significant difference.

From the results it can be seen that there were significant differences in the overall responses times for the following gauges at the corresponding p values **at the Bonferroni corrected significance level of 0.0018**:

1. Gauges D and A (p value < 0.001)
2. Gauges D and B (p value < 0.0001)
3. Gauges D and C (p value 0.0004)
4. Gauges D and F (p value < 0.0001)
5. Gauges D and I (p value 0.001)
6. Gauges G and B (p value 0.001)

**There was also a significant difference in the overall response times for the following gauges at alpha = 0.05**

1. Gauges D and A (p value < 0.001)
2. Gauges D and B (p value < 0.0001)
3. Gauges D and C (p value 0.0004)
4. Gauges D and E (p value 0.008)
5. Gauges D and F (p value < 0.0001)
6. Gauges D and G (p value 0.034)
7. Gauges D and I (p value 0.001)
8. Gauges G and A (p value 0.043)
9. Gauges G and B (p value 0.001)
10. Gauges G and F (p value 0.002)
11. Gauges B and C (p value 0.05)
12. Gauges B and E (p value 0.005)
13. Gauges B and I (p value 0.041)
14. Gauges E and F (p value 0.01)

**Figure 9.12: Results of the multiple pairwise comparisons using Dunn's procedure conducted on the overall response times for the eight gauges (at the Bonferroni corrected significance level of 0.0018)**

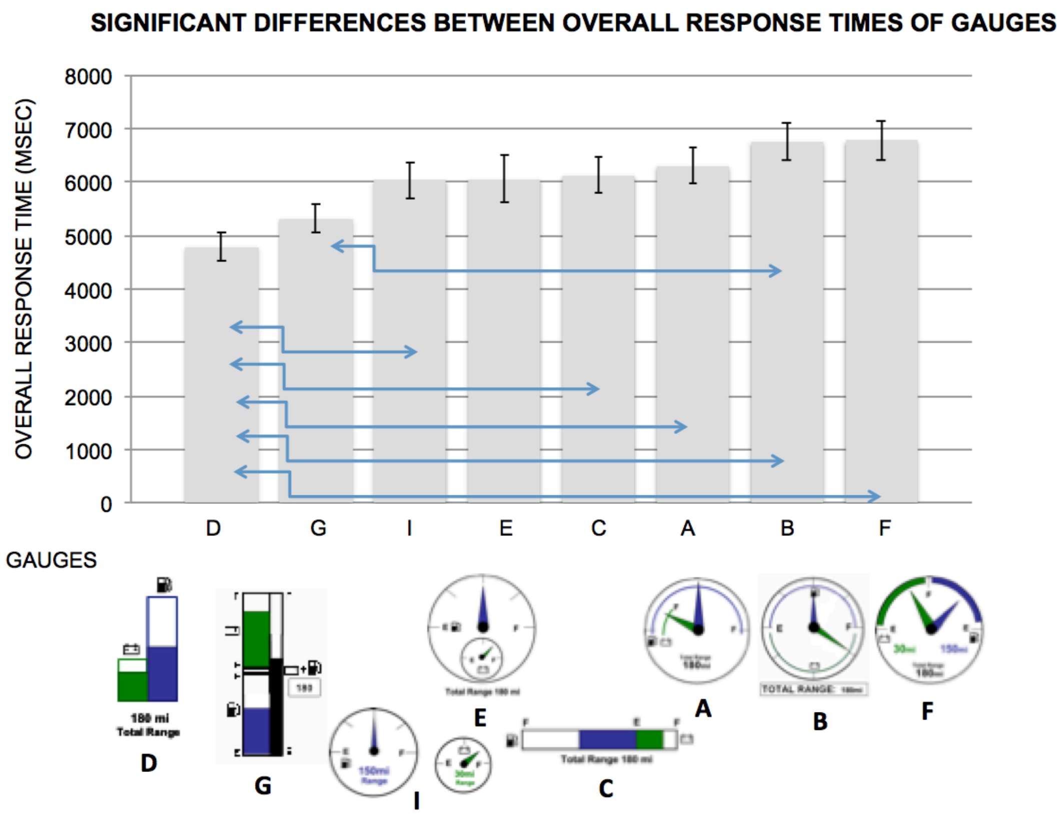
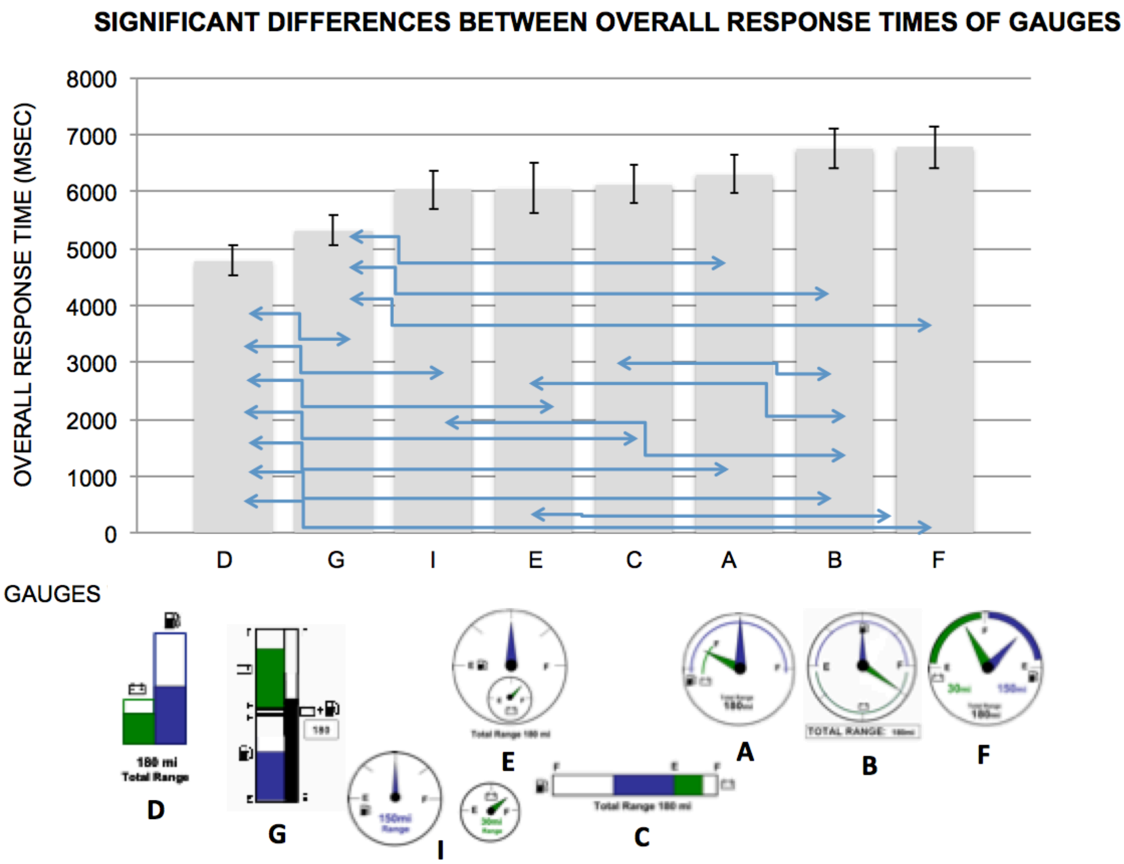


**Figure 9.13: Results of the multiple pairwise comparisons using Dunn's procedure conducted on the overall response times for the eight gauges (at significance level of 0.05)**




## C) Kruskal-Wallis test for correct response times

A **Kruskal-Wallis test** was conducted to test for any significant differences between the average correct response times of the eight gauges.

**Table 9.18: Results of Kruskal-Wallis test for correct response times for the eight gauges**

Summary Statistics:

| Variable | Obs. | Obs. with missing data | Obs. without missing data | Minimum | Maximum | Mean | Std. deviation |
|---|---|---|---|---|---|---|---|
| A-OVERALL RT | 171 | 12 | 159 | 1165 | 19154 | 5917.396 | 3885.323 |
| B-OVERALL RT | 171 | 18 | 153 | 1347 | 30077 | 6470.288 | 4498.592 |
| C-OVERALL RT | 171 | 5 | 166 | 1471 | 25060 | 5990.084 | 4301.458 |
| D-OVERALL RT | 171 | 0 | 171 | 958 | 21123 | 4592.152 | 3176.75 |
| E-OVERALL RT | 171 | 15 | 156 | 1276 | 22270 | 5263.224 | 3444.702 |
| F-OVERALL RT | 171 | 24 | 147 | 1322 | 28241 | 6517.143 | 4665.249 |
| G-OVERALL RT | 171 | 4 | 167 | 1249 | 22163 | 5259.886 | 3505.493 |
| I-OVERALL RT | 171 | 16 | 155 | 1260 | 30507 | 5835.561 | 4518.951 |

Kruskal-Wallis test:

| | |
|---|---|
| K (Observed value) | 39.495 |
| K (Critical value) | 14.067 |
| DF | 7 |
| p-value (Two-tailed) | < 0.0001 |
| alpha | 0.05 |

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population

Ha: The samples do not come from the same population

As the computed **p-value of less than 0.0001** is lower than the significance level alpha= 0.05, one should reject the null hypothesis H0 and accept the alternative hypothesis Ha. The risk to reject the null hypothesis H0 while it is true is lower than 0.01%.

From the above results it can be seen by **p-value of less than 0.0001 that there was a significant difference in the correct response times between the gauges at alpha = 0.05.**

**B) Multiple pairwise comparisons using Dunn's procedure (Two-tailed test) for correct response times**

To further investigate between which of the eight gauges there was a significant difference in correct response times, a multiple pairwise comparisons test was conducted using Dunn's procedure. The Bonferroni correction has also been applied.

**Table 9.19: Results of Dunn's procedure for multiple pairwise comparisons of correct response times**

| Sample | Frequency | Sum of ranks | Mean of ranks | Groups | |
|---|---|---|---|---|---|
| D-CRT | 171 | 87242 | 510.187 | A | |
| G-CRT | 167 | 100317 | 600.701 | A | B |
| E-CRT | 156 | 94669 | 606.853 | A | B |
| I-CRT | 155 | 99183.5 | 639.894 | | B |
| C-CRT | 166 | 108892.5 | 655.979 | | B |
| A-CRT | 159 | 106113 | 667.377 | | B |
| B-CRT | 153 | 109916.5 | 718.408 | | B |
| F-CRT | 147 | 105841.5 | 720.01 | | B |

Table of pairwise differences:

| | A-CRT | B-CRT | C-CRT | D-CRT | E-CRT | F-CRT | G-CRT | I-CRT |
|---|---|---|---|---|---|---|---|---|
| A-CRT | 0 | -51.031 | 11.398 | 157.19 | 60.525 | -52.633 | 66.677 | 27.484 |
| B-CRT | 51.031 | 0 | 62.43 | 208.221 | 111.556 | -1.602 | 117.708 | 78.515 |
| C-CRT | -11.398 | -62.43 | 0 | 145.792 | 49.126 | -64.031 | 55.278 | 16.085 |
| D-CRT | -157.19 | -208.221 | -145.792 | 0 | -96.665 | -209.823 | -90.513 | -129.706 |
| E-CRT | -60.525 | -111.556 | -49.126 | 96.665 | 0 | -113.158 | 6.152 | -33.041 |
| F-CRT | 52.633 | 1.602 | 64.031 | 209.823 | 113.158 | 0 | 119.31 | 80.117 |
| G-CRT | -66.677 | -117.708 | -55.278 | 90.513 | -6.152 | -119.31 | 0 | -39.193 |
| I-CRT | -27.484 | -78.515 | -16.085 | 129.706 | 33.041 | -80.117 | 39.193 | 0 |

P-values:

| | A-CRT | B-CRT | C-CRT | D-CRT | E-CRT | F-CRT | G-CRT | I-CRT |
|---|---|---|---|---|---|---|---|---|
| A-CRT | 1 | 0.221 | 0.78 | 0 | 0.144 | 0.211 | 0.102 | 0.508 |
| B-CRT | 0.221 | 1 | 0.13 | < 0.0001 | 0.008 | 0.97 | 0.004 | 0.061 |
| C-CRT | 0.78 | 0.13 | 1 | 0 | 0.231 | 0.124 | 0.17 | 0.695 |
| D-CRT | 0 | < 0.0001 | 0 | 1 | 0.018 | < 0.0001 | 0.024 | 0.001 |
| E-CRT | 0.144 | 0.008 | 0.231 | 0.018 | 1 | 0.007 | 0.881 | 0.428 |
| F-CRT | 0.211 | 0.97 | 0.124 | < 0.0001 | 0.007 | 1 | 0.004 | 0.059 |
| G-CRT | 0.102 | 0.004 | 0.17 | 0.024 | 0.881 | 0.004 | 1 | 0.34 |
| I-CRT | 0.508 | 0.061 | 0.695 | 0.001 | 0.428 | 0.059 | 0.34 | 1 |

Bonferroni corrected significance level: 0.0018

Significant differences:

| | A-CRT | B-CRT | C-CRT | D-CRT | E-CRT | F-CRT | G-CRT | I-CRT |
|---|---|---|---|---|---|---|---|---|
| A-CRT | No | No | No | **Yes** | No | No | No | No |
| B-CRT | No | No | No | **Yes** | No | No | No | No |
| C-CRT | No | No | No | **Yes** | No | No | No | No |
| D-CRT | **Yes** | **Yes** | **Yes** | No | No | **Yes** | No | **Yes** |
| E-CRT | No | No | No | No | No | No | No | No |
| F-CRT | No | No | No | **Yes** | No | No | No | No |
| G-CRT | No | No | No | No | No | No | No | No |
| I-CRT | No | No | No | **Yes** | No | No | No | No |

Note- significant differences have only been identified by this procedure for p-values that are less than the Bonferroni corrected significance level of 0.0018. This is why the above chart showing significant differences doesn't identify a significant difference between the overall response times for some gauges. For example, even though the p-value for the comparison between gauges B and G is 0.004, which is less than alpha (0.05) this test does not consider it to be a significant difference.

From the results it can be seen that there were significant differences in the correct responses times for the following gauges at the corresponding p values **at the Bonferroni corrected significance level of 0.0018**:

1. Gauges D and A (p value 0.0001)
2. Gauges D and B (p value < 0.0001)
3. Gauges D and C (p value 0.0002)
4. Gauges D and F (p value < 0.0001)
5. Gauges D and I (p value 0.001)

**There was also a significant difference in the correct response times for the following gauges at alpha = 0.05:**

1. Gauges D and A (p value 0.0001)
2. Gauges D and B (p value < 0.0001)
3. Gauges D and C (p value 0.0002)
4. Gauges D and E (p value 0.018)
5. Gauges D and F (p value < 0.0001)
6. Gauges D and G (p value 0.024)
7. Gauges D and I (p value 0.001)
8. Gauges B and E (p value 0.008)
9. Gauges B and G (p value 0.004)
10. Gauges F and E (p value 0.007)

11. Gauges F and G (p value 0.004)

**Figure 9.14: Results of the multiple pairwise comparisons using Dunn's procedure conducted on the correct response times for the eight gauges (at the Bonferroni corrected significance level of 0.0018)**

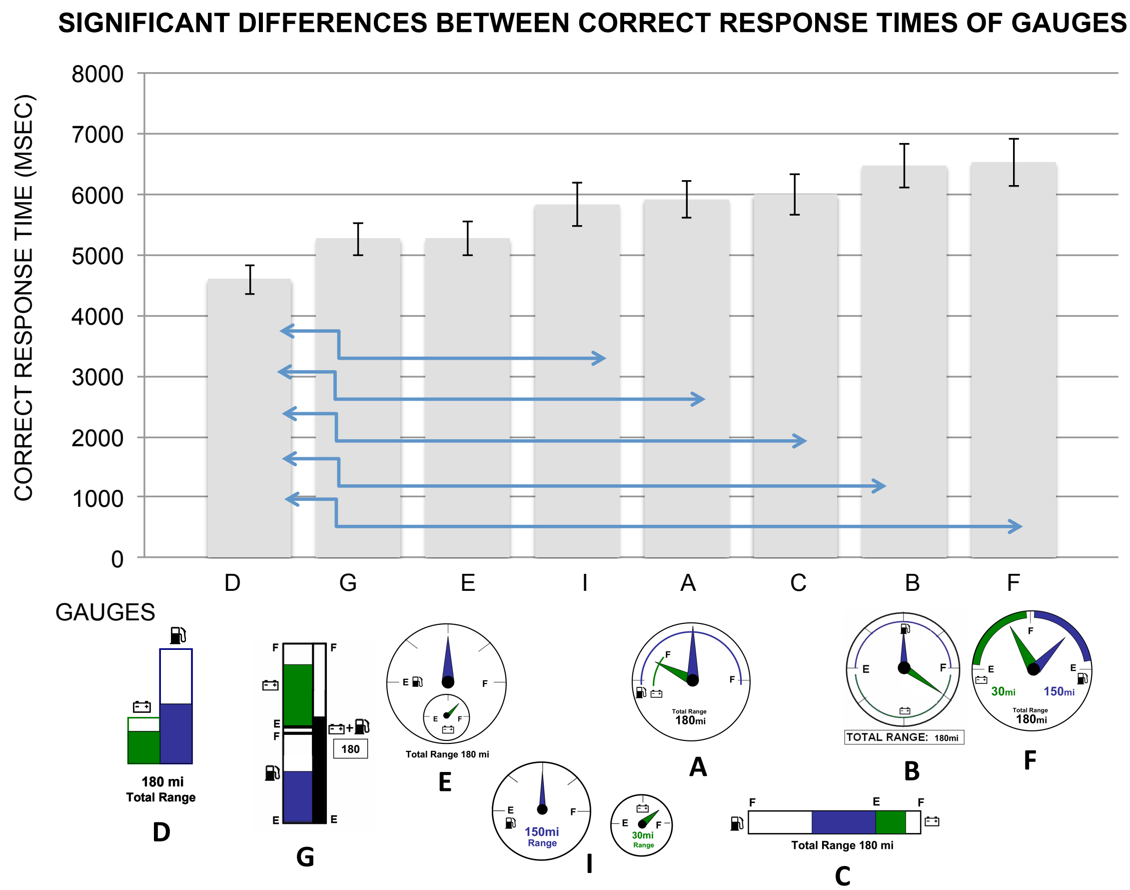
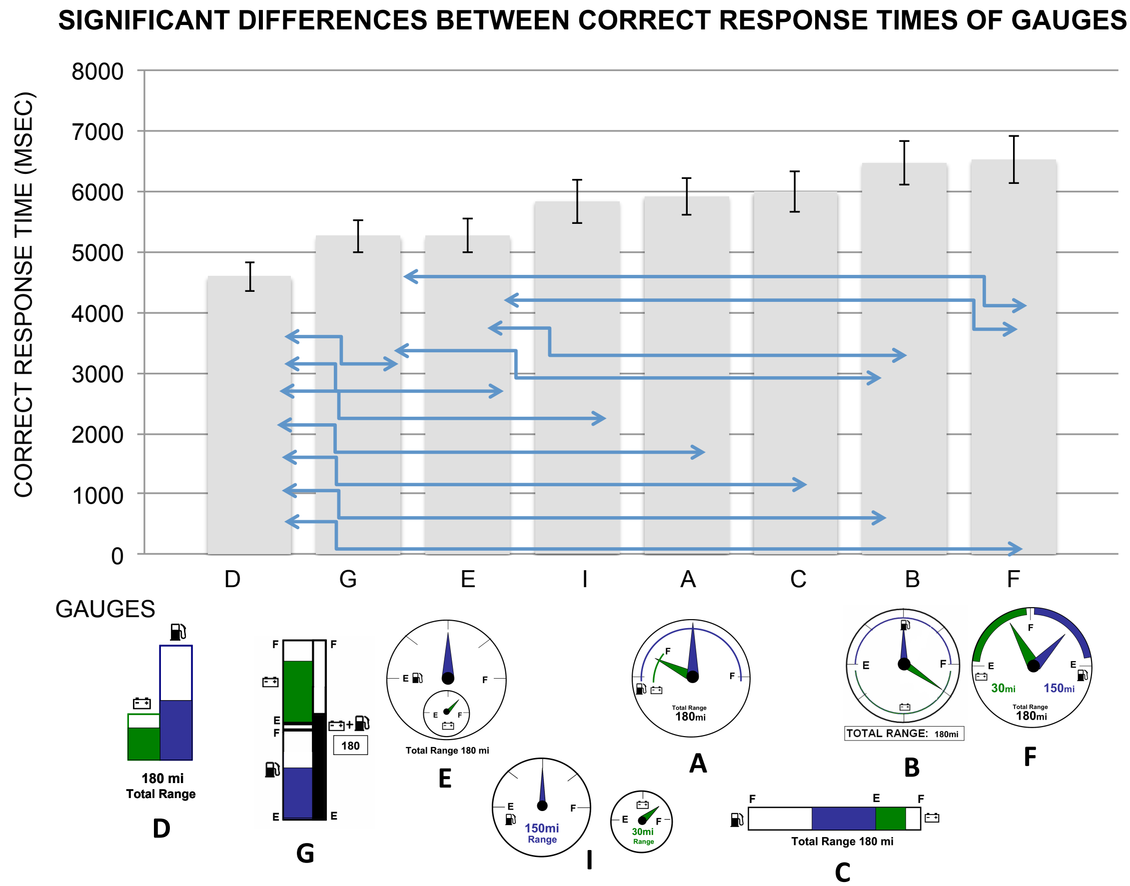


**Figure 9.15: Results of the multiple pairwise comparisons using Dunn's procedure conducted on the correct response times for the eight gauges (at significance level of 0.05)**




## E) Chi-square test for accuracy rates

A Chi-square test was conducted to test for any significant differences in the accuracy rates of the eight gauges. The following table summarizes the results of the test.

**Table 9.20: Results of the Chi-square test for significant differences between accuracy rates of the eight gauges**

Chi-square test:

| | |
|---|---|
| Chi-square (Observed value) | 28.898 |
| Chi-square (Critical value) | 14.067 |
| DF | 7 |
| p-value | 0.0001 |
| alpha | 0.05 |

Test interpretation:

H0: The proportions are equal

Ha: At least one proportion is different from another

As the computed p-value is lower than the significance level alpha= 0.05, one should reject the null hypothesis H0 and accept the alternative hypothesis Ha

The risk to reject the null hypothesis H0 while it is true is lower than 0.02%

From the above results it can be seen by p-value of 0.0001 that there **was a significant difference in the accuracy rates for the 8 gauges** at alpha = 0.05.

**F) Marascuilo procedure for accuracy rates**

To further investigate between which of the eight gauges there was a significant difference in accuracy rates, a multiple pairwise comparisons were conducted using the **Marascuilo procedure.**

**Table 9.21: Results of the Marascuilo procedure for significant differences between accuracy rates of the eight gauges**

Marascuilo procedure:

| Contrast | Value | Critical value | Significant |
|---|---|---|---|
| \|p(A) - p(B)\| | 0.034 | 0.129 | No |
| \|p(A) - p(C)\| | 0.040 | 0.109 | No |
| \|p(A) - p(D)\| | 0.068 | 0.099 | No |
| \|p(A) - p(E)\| | 0.017 | 0.125 | No |
| \|p(A) - p(F)\| | 0.068 | 0.136 | No |
| \|p(A) - p(G)\| | 0.045 | 0.107 | No |
| \|p(A) - p(I)\| | 0.023 | 0.126 | No |
| \|p(B) - p(C)\| | 0.073 | 0.118 | No |
| \|p(B) - p(D)\| | 0.102 | 0.109 | No |
| \|p(B) - p(E)\| | 0.017 | 0.133 | No |
| \|p(B) - p(F)\| | 0.034 | 0.143 | No |
| \|p(B) - p(G)\| | 0.079 | 0.116 | No |
| \|p(B) - p(I)\| | 0.011 | 0.134 | No |
| \|p(C) - p(D)\| | 0.028 | 0.085 | No |
| \|p(C) - p(E)\| | 0.056 | 0.114 | No |
| \|p(C) - p(F)\| | 0.107 | 0.126 | No |
| \|p(C) - p(G)\| | 0.006 | 0.094 | No |
| \|p(C) - p(I)\| | 0.062 | 0.115 | No |
| \|p(D) - p(E)\| | 0.085 | 0.104 | No |
| **\|p(D) - p(F)\|** | **0.136** | **0.117** | **Yes** |
| \|p(D) - p(G)\| | 0.023 | 0.083 | No |
| \|p(D) - p(I)\| | 0.090 | 0.106 | No |
| \|p(E) - p(F)\| | 0.051 | 0.140 | No |
| \|p(E) - p(G)\| | 0.062 | 0.112 | No |
| \|p(E) - p(I)\| | 0.006 | 0.130 | No |
| \|p(F) - p(G)\| | 0.113 | 0.124 | No |
| \|p(F) - p(I)\| | 0.045 | 0.141 | No |
| \|p(G) - p(I)\| | 0.068 | 0.114 | No |

| Sample | Proportion | Groups | |
|---|---|---|---|
| F | 0.831 | A | |
| B | 0.864 | A | B |
| I | 0.876 | A | B |
| E | 0.881 | A | B |
| A | 0.898 | A | B |
| C | 0.938 | A | B |
| G | 0.944 | A | B |
| D | 0.966 | | B |

From the above results it can be seen that since the value (absolute value) for gauge pair D and F is greater than the corresponding critical value, there **was a significant difference in the accuracy rates between gauges D and F**.

### 9.2.5. Analysis by question

The responses from fifty-nine subjects were analyzed for each of the three questions presented in the timed comprehension task to determine accuracy rates and average response times for overall and correct responses.

**Subjects were asked to respond to three following three questions:**

Q1: Is it possible for me to travel 20 miles on the battery alone?

Q2: Is it possible for me to travel 150 miles on the gas tank alone after the battery is depleted?

Q3: Is it possible for me to travel 200 miles on the battery and gas tank combined?

Question 1 examined subjects' understanding of the battery component of the gauge designs. The following table shows the average overall response times and average correct response times for question 1. The response accuracy for each gauge has also been calculated.

**Table 9.22: Response times and accuracy rates for question 1 (battery component) for each gauge**

Q1: Is it possible for me to travel 20 miles on the battery alone?

| GAUGE | ORT | S.E. (ORT) | CRT | S.E. (CRT) | RA | TOT. | NO CORR |
|---|---|---|---|---|---|---|---|
| A | 6857.85 | 608.9 | 6437.94 | 591.49 | 81.36% | 59 | 48 |
| B | 6912.1 | 500.23 | 6404.91 | 516.22 | 79.66% | 59 | 47 |
| C | 5756.12 | 530.1 | 5638.45 | 526.85 | 94.92% | 59 | 56 |
| D | 4935.05 | 499.71 | 4953.35 | 515.59 | 96.61% | 59 | 57 |
| E | 6210.83 | 614.95 | 5345.8 | 423.37 | 83.05% | 59 | 49 |
| F | 5599.88 | 526.54 | 5086.1 | 528.14 | 86.44% | 59 | 51 |
| G | 5704.42 | 439.31 | 5723.91 | 476.41 | 89.83% | 59 | 53 |
| I | 5543.9 | 701.05 | 5452.74 | 707.19 | 98.31% | 59 | 58 |

ORT = average overall response time in milliseconds, CRT= average correct response time in milliseconds, S.E = standard error, RA= response accuracy in percentage, TOT= total number of responses, NO CORR= number of correct responses

Question 2 examined subjects' understanding of the gas tank component of the gauge designs. The following table shows the average overall response times, average correct response times and the response accuracy for each gauge.

**Table 9.23: Response times and accuracy rates for question 2 (gas tank component) for each gauge**

Q2: Is it possible for me to travel 150 miles on the gas tank alone after the battery is depleted?

| GAUGE | ORT | S.E. (ORT) | CRT | S.E. (CRT) | RA | TOT. | NO CORR |
|---|---|---|---|---|---|---|---|
| A | 5728.78 | 425.96 | 5726.09 | 440.53 | 94.92% | 59 | 56 |
| B | 6154.54 | 546.3 | 5745.74 | 478.31 | 89.83% | 59 | 53 |
| C | 6446.2 | 583.78 | 6104.27 | 584.9 | 88.14% | 59 | 52 |
| D | 4471.05 | 338.98 | 4466.07 | 344.84 | 98.31% | 59 | 58 |
| E | 5210.71 | 500.31 | 4920.73 | 484.62 | 93.22% | 59 | 55 |
| F | 7372.59 | 717.15 | 7110.02 | 768.58 | 83.05% | 59 | 49 |
| G | 4595.95 | 379.02 | 4504.12 | 374.12 | 98.31% | 59 | 58 |
| I | 5598.61 | 440.21 | 5286.05 | 421.9 | 94.92% | 59 | 56 |

ORT = average overall response time in milliseconds, CRT= average correct response time in milliseconds, S.E = standard error, RA= response accuracy in percentage, TOT= total number of responses, NO CORR= number of correct responses

Question 3 examined how accurately and quickly subjects were able to get combined information on the battery and gas components of the gauge designs. The following table shows the average overall response times, average correct response times and the response accuracy for each gauge.

**Table 9.24 Response times and accuracy rates for question 3 (combined information) for each gauge**

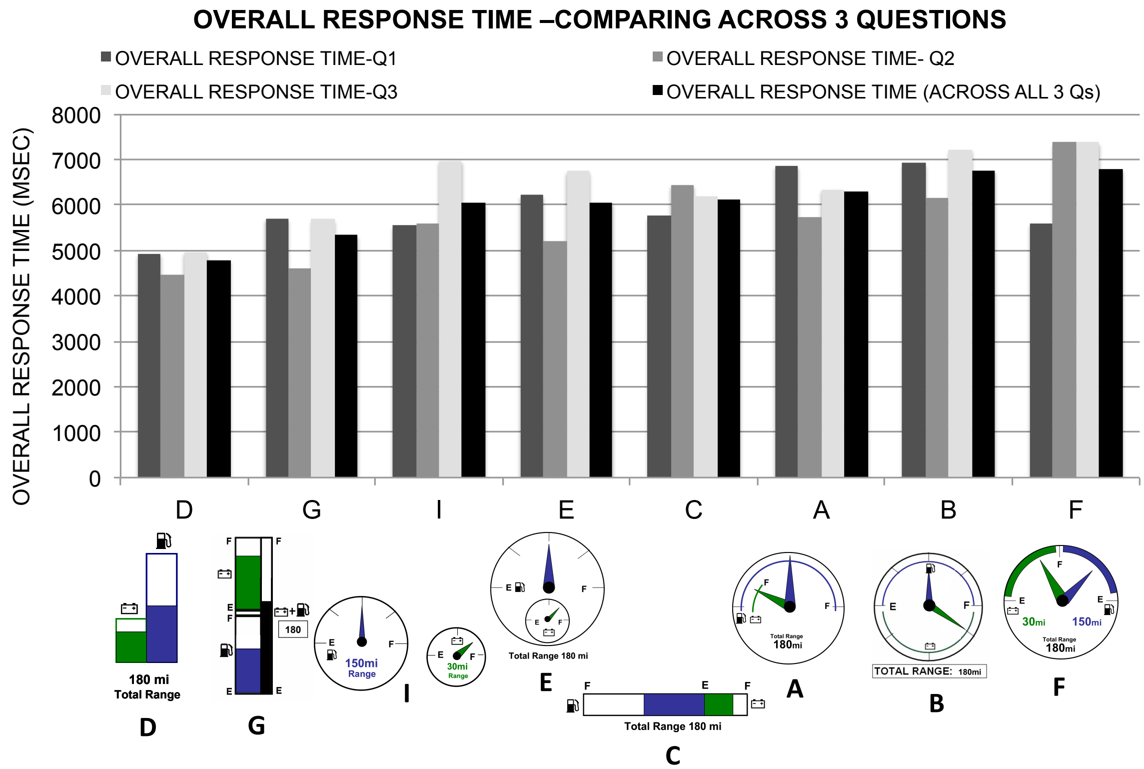
Q3: Is it possible for me to travel 200 miles on the battery and gas tank combined?

| GAUGE | ORT | S.E. (ORT) | CRT | S.E. (CRT) | RA | TOT. | NO CORR |
|---|---|---|---|---|---|---|---|
| A | 6342.68 | 725.19 | 5657.89 | 574.24 | 93.22% | 59 | 55 |
| B | 7218.07 | 736.34 | 7252.81 | 810.16 | 89.83% | 59 | 53 |
| C | 6183.19 | 613.15 | 6227.22 | 622.2 | 98.31% | 59 | 58 |
| D | 4970.8 | 542.36 | 4355.09 | 387.48 | 94.92% | 59 | 56 |
| E | 6743.36 | 1054.97 | 5547.67 | 517.1 | 88.14% | 59 | 52 |
| F | 7372.07 | 632.42 | 7451.87 | 650.29 | 79.66% | 59 | 47 |
| G | 5679.2 | 536.31 | 5585.35 | 531.45 | 96.61% | 59 | 57 |
| I | 6975.41 | 599.68 | 7127.66 | 719.65 | 69.49% | 59 | 41 |

ORT = average overall response time in milliseconds, CRT= average correct response time in milliseconds, S.E = standard error, RA= response accuracy in percentage, TOT= total number of responses, NO CORR= number of correct responses

The following chart shows the overall response times for each gauge for each of the three questions overall (across all questions).

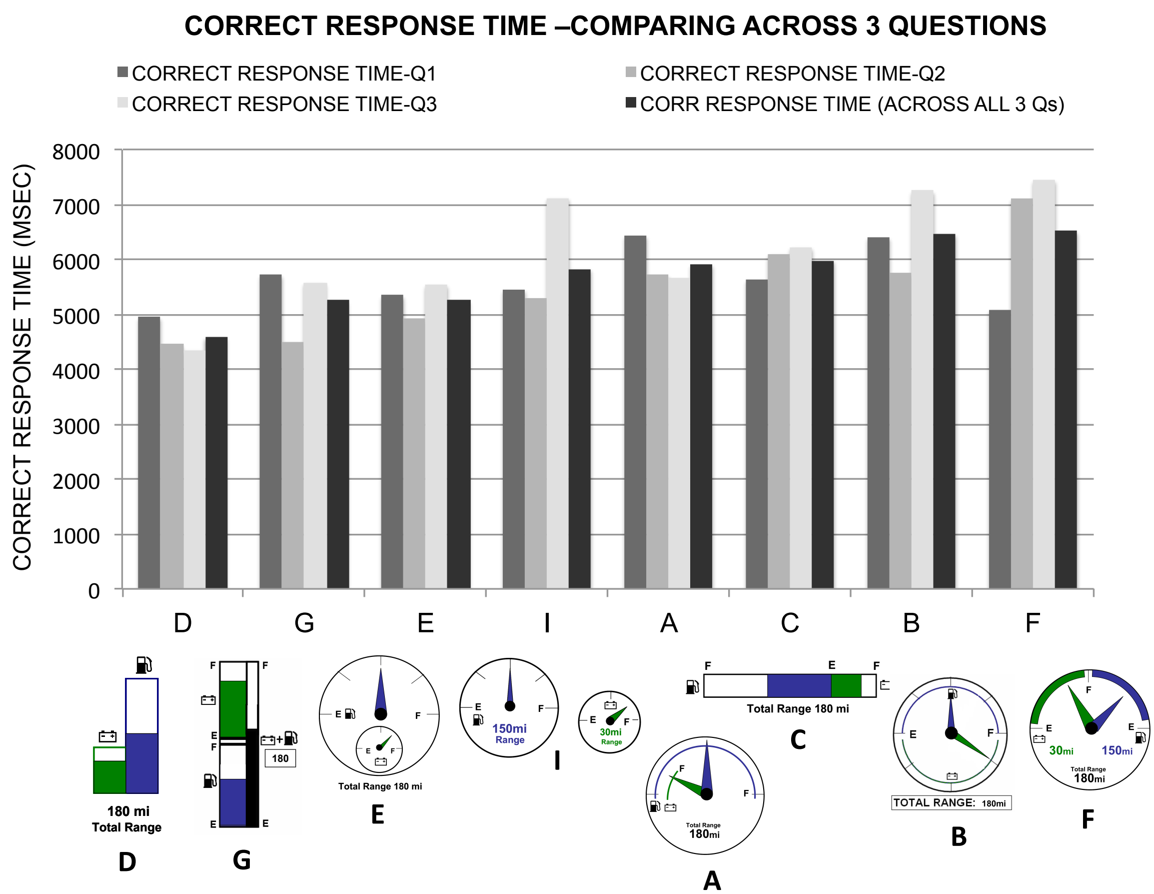
**Figure 9.16: Overall response times for each gauge for each of the three questions and overall (across all questions). Note- Q1-on battery only, Q2-on gas tank only, Q3- combined info on gas and battery.**




It can be seen that vertically oriented bar gauges D and G consistently had the lowest overall response times for each of the three questions and overall (across all questions). Circular gauges A, B and F had some of the highest response times. Although gauge I elicited relatively low overall response times for questions 1 and 2, subjects took considerably long to seek combined information from this gauge as seen by the high overall response time for question 3.

The following chart shows the correct response times for each gauge for each of the three questions and overall (across all questions).

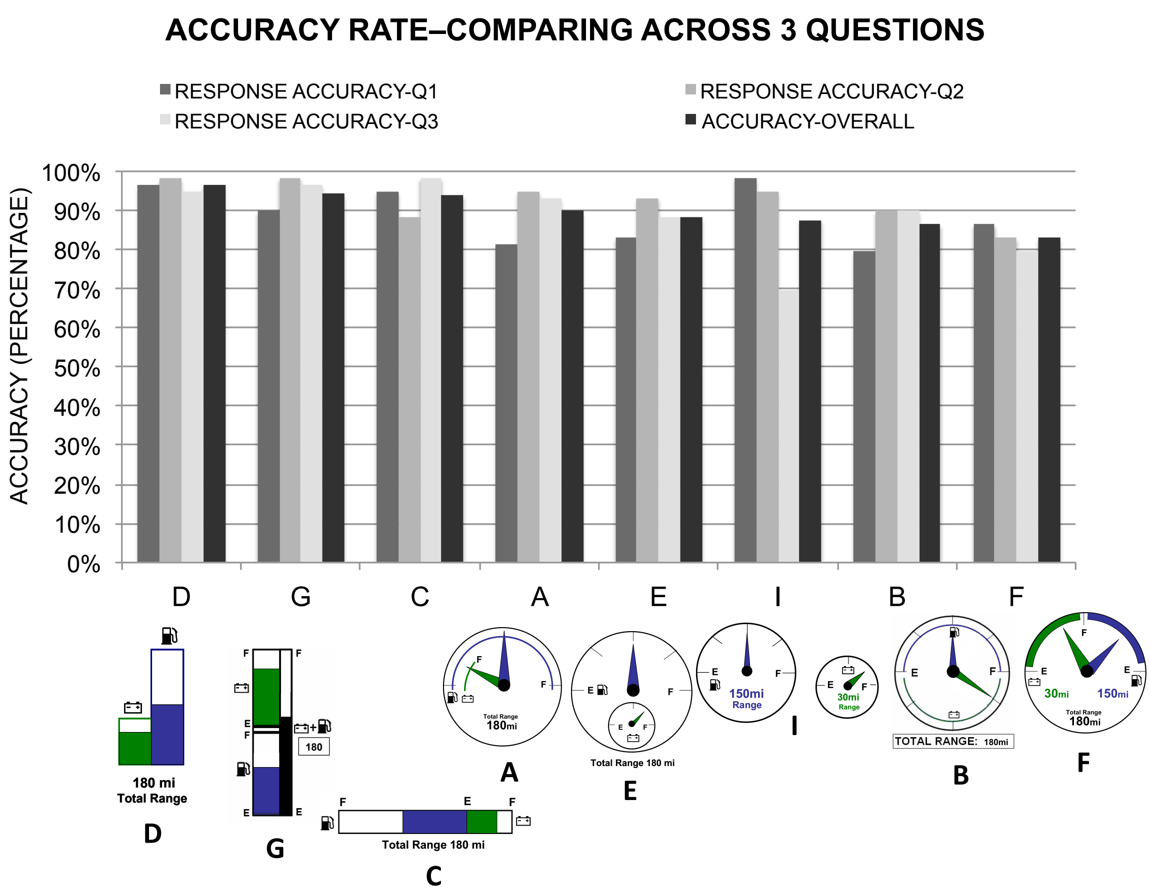
**Figure 9.17: Correct response times for each gauge for each of the three questions and overall (across all questions). Note- Q1-on battery only, Q2-on gas tank only, Q3- combined info on gas and battery.**




It can be seen that vertically oriented bar gauges D and G consistently had the lowest correct response times for each of the three questions and overall (across all questions). Interestingly, the horizontally oriented bar gauge C had high correct response times. Circular gauges B and F had some of the highest correct response times. Although gauge I elicited relatively low correct response times for questions 1 and 2, subjects took considerably long to seek combined information from this gauge as seen by the high correct response time for question 3.

The following chart shows the accuracy rates for each gauge for each of the three questions and overall (across all questions).

**Figure 9.18: Accuracy rates for each gauge for each of the three questions as and overall. Note- Q1-on battery only, Q2- on gas tank only, Q3-combined info on gas and battery.**




It can be seen that bar gauges D, G and C consistently had the highest accuracy rates for each of the three questions and overall (across all questions). Vertically oriented bars performed slightly better than the horizontally oriented bar gauge. Circular gauges I, B and F had some of the lowest accuracy rates.

In summary, the vertically oriented bar gauges D and G consistently elicited the highest response accuracy and lowest response times across all gauges. Gauge

D consistently elicited the lowest overall response times, lowest correct response times and the highest response accuracy for each of the three questions. Circular gauges B and F (designs with two needle pointers with opposing directions of fuel depletion) consistently had the lowest response accuracy and highest response times across.

### 9.3. Results of data analysis for the subjective questionnaire

Although data for gauge H has been excluded from the timed comprehension task, participant feedback on gauge H collected in the subjective questionnaire has been included in this section. Participants were asked to provide feedback on Gauge H in parts 1 and 4 of the questionnaire.

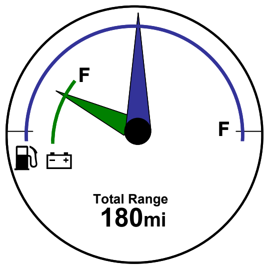
**Excluded data**

Data for one participant has been excluded from this study completely because the subject (id 12304) was not able to understand or complete the tasks correctly as per the given instructions. The subjective questionnaire data for this subject has been excluded from this analysis.

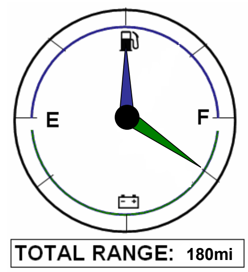
Due to incorrect experimental design of questionnaire parts 2 and 3, the data from those parts has been excluded from this analysis. Please see Appendix F for more information on those parts.

#### 9.3.1. Results of questionnaire part 1

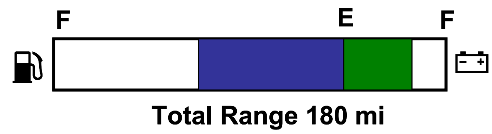
In this section participants were asked to rank order the nine gauges according to how easy they found each gauge to be for answering the six questions. Each participant was given a sheet with the nine gauges for reference during this part of the subjective questionnaire.



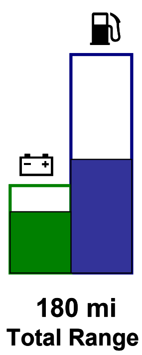

GAUGE A



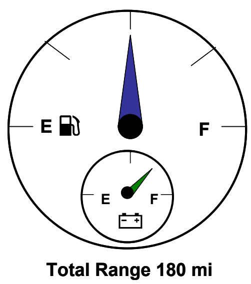

GAUGE B



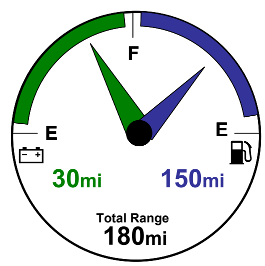

GAUGE C



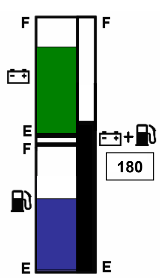

GAUGE D



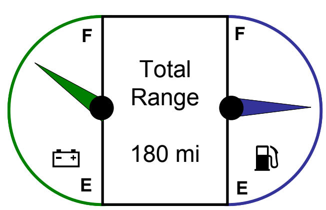

GAUGE E



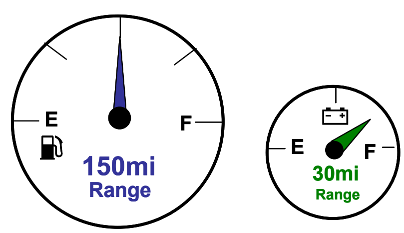

GAUGE F




GAUGE G




GAUGE H




GAUGE I

**Table 9.25: Gauges and corresponding percentages of subjects that ranked the nine gauges based on ease of use for answering each question.**

| RANK 1 | RANK 2 | RANK 3 | RANK 4 | RANK 5 | RANK 6 | RANK 7 | RANK 8 | RANK 9 |
|---|---|---|---|---|---|---|---|---|
| **QUESTION 1: How easy or difficult is it to know how much energy is in the battery?** | | | | | | | | |
| I 42.11% | F 17.54% | D 28.07% | G 17.86% | E 16.07% | C 19.64% | B & C 16.36% | B 19.64% | C 27.27% |
| **QUESTION 2:How easy or difficult is it to understand when it is time to recharge the battery?** | | | | | | | | |
| I 40.35% | I 19.64% | D 25% | A, E & F 14.55% | A 18.18% | E 20% | C & E 18.18% | G 21.82% | C 32.73% |
| **QUESTION 3: How easy or difficult is it to know if I can make a 20-mile trip using only the battery?** | | | | | | | | |
| I 56.14% | E 31.58% | D 26.32% | F 21.43% | H 21.43% | A 21.43% | C 19.64% | C 25% | G 23.64% |
| **QUESTION 4: How easy or difficult is it to understand if I can travel 100 more miles on gasoline alone once the battery is depleted?** | | | | | | | | |
| I 50.88% | E 24.56% | A & F 17.54% | D 19.64% | G 19.64% | D 17.86% | C 23.31% | G 25% | C 23.64% |
| **QUESTION 5:How easy or difficult is it to know if I can make a 250-mile trip using both the battery and gasoline?** | | | | | | | | |
| I 26.32% | D 21.05% | A 21.05% | F 21.43% | B & E 16.07% | B 21.43% | F 17.86% | G 32.14% | I 27.27% |
| **QUESTION 6: Overall, which gauge do you find the most useful (i.e., easiest) to answer all the questions above?** | | | | | | | | |
| I 49.12% | E 14.04% | D & F 8.77% | H 7.02% | A 5.26% | B & G 3.51% | - | - | - |

Gauge I was ranked by majority of the participants as being the easiest to use for answering the above questions. Gauge D, which elicited the highest accuracy rate in the comprehension task was ranked third in terms of ease of use for answering majority of the six questions, indicating it wasn't liked as much as gauge I.

For part 1 of the questionnaire, another analysis was conducted to determine the percentage of subjects who ranked each of the nine gauges as number 1 for answering the six questions.

**Table 9.26: Percentage of subjects who ranked each of the nine gauges as number 1. These are arranged in order of popularity from highest to lowest (left to right)**

| | | GAUGES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | I | H | E | A | F | D | B | G | C |
| 1 | How easy or difficult is it to know how much energy is in the battery? | | | | | | | | | |
| | | 42.11% | 17.54% | 7.02% | 8.77% | 8.77% | 12.28% | 1.75% | 1.75% | 1.75% |
| 2 | How easy or difficult is it to understand when it is time to recharge the battery? | | | | | | | | | |
| | | 40.35% | 28.07% | 3.51% | 8.77% | 3.51% | 7.02% | 5.26% | 1.75% | 1.75% |
| 3 | How easy or difficult is it to know if I can make a 20-mile trip using only the battery? | | | | | | | | | |
| | | 56.14% | 5.26% | 15.79% | 7.02% | 5.26% | 3.51% | 1.75% | 5.26% | 0.00% |
| 4 | How easy or difficult is it to understand if I can travel 100 more miles on gasoline alone once the battery is depleted? | | | | | | | | | |
| | | 50.88% | 3.51% | 15.79% | 14.04% | 3.51% | 3.51% | 5.26% | 0.00% | 3.51% |
| 5 | How easy or difficult is it to know if I can make a 250-mile trip using both the battery and gasoline? | | | | | | | | | |
| | | 26.32% | 14.04% | 15.79% | 14.04% | 10.53% | 5.26% | 3.51% | 5.26% | 5.26% |
| 6 | Overall, which gauge do you find the most useful (i.e., easiest) to answer all the questions above? | | | | | | | | | |
| | | 50.91% | 5.45% | 14.55% | 5.45% | 9.09% | 7.27% | 3.64% | 3.64% | 0.00% |
| | **Average popularity (average of percentages for each gauge)** | | | | | | | | | |
| | | **44.45%** | **12.31%** | **12.07%** | **9.68%** | **6.78%** | **6.48%** | **3.53%** | **2.95%** | **2.05%** |

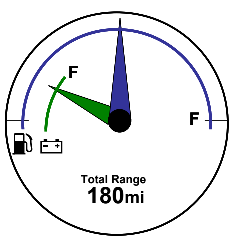
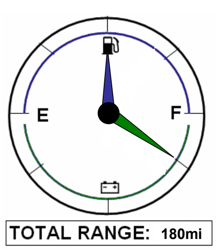
It can be seen that for each of the six questions, circular gauge I was preferred by an overwhelming majority of participants. Although vertically oriented bar gauges D and G elicited the highest response accuracy in the comprehension task, they were among the least popular gauges.

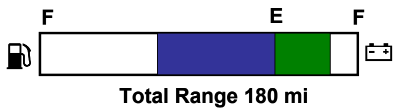
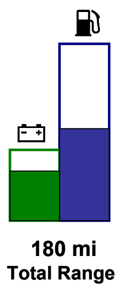
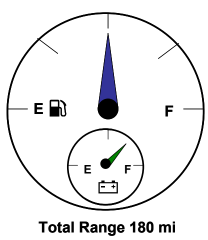
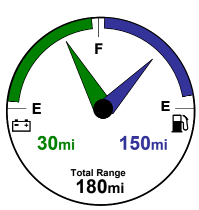
### 9.3.2. Results of questionnaire part 4

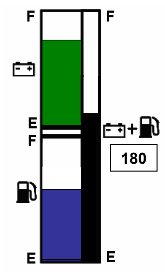
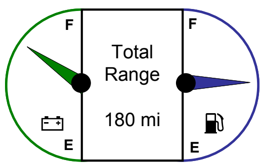
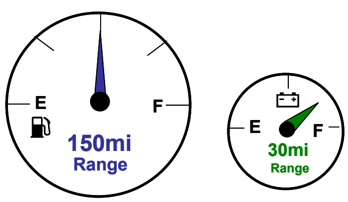
**Best and worst features**

Subjects were asked to provide their opinion on the best and worst features of each gauge. A number of similarities were found in their comments and they have been summarized in the table below.

**Table 9.27: Summary of best and worst features**

| GAUGE | BEST FEATURE | WORST FEATURE |
|---|---|---|
|   GAUGE A | • Displays total range<br>• Separate colors have been used to differentiate the battery and gas tank | • Does not display individual ranges for the gas tank and battery<br>• Confusing |
|   GAUGE B | • Displays total range<br>• Separation of the battery and gas tank by upper/lower locations<br>• Compact gauge | • Can be confused with a car clock<br>• Does not display individual ranges for the gas tank and battery<br>• F to E direction not the same for battery and gas (clockwise vs. counterclockwise) |

| | | |
|---|---|---|
| <br><br>GAUGE C | • Displays total range<br>• Easy to read at a glance | • Different directions for full/empty makes it confusing<br>• No separation of gauges<br>• Does not display individual ranges for the gas tank and battery |
| <br><br>GAUGE D | • Separate gauges for gas and battery<br>• Displays total range<br>• Separate colors/easy to read | • Hard to determine levels (no max, ½, ¼ full labels/markings)<br>• Does not display individual ranges for the gas tank and battery |
| <br><br>GAUGE E | • Separate gauges are easy to read<br>• Clear, direct, simple, familiar | • Does not display individual ranges for the gas tank and battery<br>• Battery gauge is small |
| <br><br>GAUGE F | • Easy to read since it has both the individual and total ranges displayed | • Dials move in opposite directions<br>• No ½ or ¼ full labels |

| | | |
|---|---|---|
| <br>GAUGE G | • Displays total range<br>• Separation of gauges | • Confusing; too cluttered<br>• No ranges for each fuel source<br>• No labels ( ½,  ¼, etc) |
| <br>GAUGE H | • Displays total range<br>• Separate gauges<br>• Simple, concise, space saver, easy to read | • No ranges for each fuel source<br>• No labels ( ½,  ¼, etc) |
| <br>GAUGE I | • Totally separate gauges<br>• Easy to read, simple | • No total range |

Subjects preferred simple gauges that were easy to read and familiar to them. They expressed a liking for individual and total ranges presented in absolute or numerical form. Gauges with opposing directions of fuel depletion for the gas and battery components were disliked and found to be confusing. A number of subjects wanted gauges to have ¼, ½ and ¾ scale markings. Subjects expressed a liking for designs in which the gas and battery components were “separate” or easily distinguishable (such as in gauges D and I).

# 10. Discussion

## 10.1. Discussion on results from the timed comprehension task

It was found that **participants made correct responses faster than they made incorrect responses**. While they took 5.7 seconds on average to make correct responses, they took almost 3 seconds longer on average to make incorrect responses (8.6 seconds). About **90% of all responses made were correct** indicating that the gauges evaluated in the timed comprehension task were reasonably well understood.

### 10.1.1. Performance differences based on demographics

The timed comprehension task was set up as a counterbalanced study in which each participant was exposed to the same conditions. Any differences due to order effects were averaged out. The task was also set up such that the same number of young, middle-aged and older drivers was presented with all gauges so any differences between them were averaged out. Overall, the **performance levels of young drivers were found to be significantly different than those of middle-aged and older drivers**.

Young drivers had the highest accuracy rate of 92.7% among the three groups. There was a **statistically significant difference (at alpha = 0.05) between accuracy rates of young and middle-aged drivers and also between young and older drivers.** Interestingly, older drivers had a slightly higher accuracy rate of 89.4% compared to middle aged drivers (88%). However, this difference was not statistically significant at alpha = 0.05.

Of the three age groups, **young drivers were the fastest to make any response and also the fastest to respond correctly** taking 4.3 seconds and 4.2 seconds respectively. The data also showed that on average, middle-aged drivers took 1.5 seconds more (~35% increase) than young drivers and older drivers took 1.5 seconds more (~26% increase) than middle-aged drivers to make correct responses. The **differences in overall response times and correct response times between young and older drivers were found to be statistically significant** at the Bonferroni corrected significance level of 0.0167. The differences in the overall and correct response times between young and middle-aged drivers were not statistically significant (at the Bonferroni corrected significance level of 0.0167).

It is not surprising that younger drivers were able to comprehend and respond faster than the other age groups. Perhaps this can be attributed to the fact that young individuals have sharper motor skills and are able to react faster than middle-aged and older individuals. It has been observed that reaction time slows with age once a person reaches the late twenties. According to Welford (1977), simple reaction time shortens from infancy into the late twenties, then increases slowly until the fifties and sixties, and then lengthens faster as the person gets into his seventies and beyond.

Significant differences were found among the age groups. **Young drivers were clearly faster and more accurate than middle-aged and older drivers**. Although older drivers were slower to respond compared to middle-aged drivers, they had a slightly higher accuracy rate than these drivers. These results suggest that while response speed decreases considerably with age, the ability to comprehend information accurately does not decline, but on the contrary seems to improve after a driver reaches “middle age” (somewhere within 31- 54 years). Perhaps after a certain age, drivers tend to become more deliberate while reading gauges. Further investigation is needed to be able to draw more conclusive insights.

**Differences in response times and accuracy rates between male and female participants were not statistically significant** at alpha 0.05. Male participants were slightly faster to respond overall and faster to make correct responses compared to females by 0.8 seconds. Their accuracy rate (90.6%) was marginally higher than that of females (89.3%). Overall, **male and female drivers showed similar comprehension skills.**

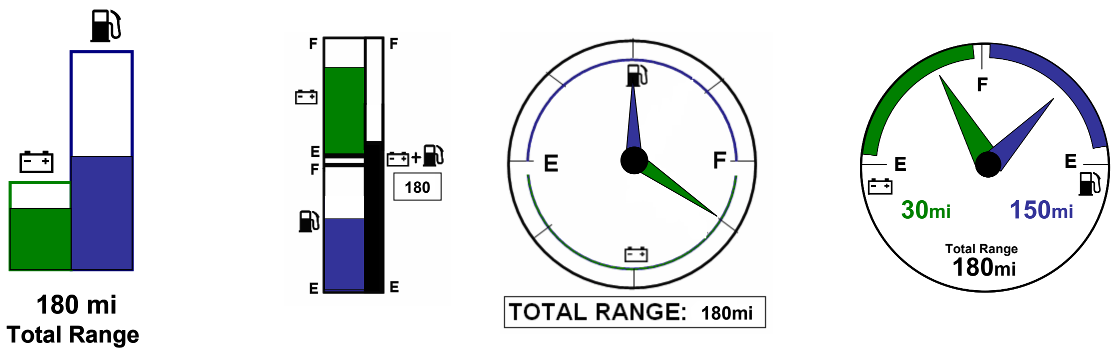
Although the study was set up to understand if there were high-level differences in performance based on age groups and gender, detailed investigation on the performance of each age group with each gauge was not conducted. Further analysis may help provide some insights on which type of gauge is best suited for each age group. This type of information may be of interest to certain car manufacturers who are targeting specific cars to specific generations.

### 10.1.2. Performance differences based on gauge

Vertically bar gauge D emerged a clear winner among the eight designs with the highest response accuracy of 96.6% and the lowest average correct response time 4.6 seconds. Overall, **vertical bar gauges (D and G) elicited the best performance** (lowest response times and highest accuracy rates among all the other gauges).

The differences in the **overall response times and correct response times between vertical bar gauge D and a majority of the gauges (A, B, C, F and I) were statistically significant** (at the Bonferroni correct significance level of 0.0018). There was also a statistically significant difference in the overall response times between the vertical bar gauge G, and gauge B (at the Bonferroni correct significance level of 0.0018).

**A statistically significant difference was also found in the accuracy rates between gauge D** (highest accuracy rate of 96.6%) **and gauge F** (lowest accuracy rate of 83%).




GAUGE D GAUGE G GAUGE B GAUGE F

One possible explanation for the highest accuracy rates of the vertical bar gauges is the downward direction of fuel depletion, which is analogous to the commonly experienced situation of water depletion in a glass. Moreover, in both vertical gauges the direction of fuel depletion is consistent for each of the individual components. These attributes made the vertical gauges intuitive and easy and quick to comprehend.

Another factor that possibly contributed to the success of these gauges is the use of color to indicate fuel level, which made it easy to process the information at a glance. The iconic representation of information helped participants quickly determine the information by looking at the proportion of the colored area. Both vertical bar gauge designs include individual components that have close spatial proximity. According to Wickens and Carswell (1995), if a task requires mental integration then the close spatial proximity of the two information sources is helpful and it results in low information access cost (Wickens, 2003).

However, the attributes of color to indicate fuel level and the close spatial proximity of individual components are also prevalent in the horizontal bar gauge. This gauge had relatively poor response times and the third highest accuracy rate. Moreover, it is known that humans have a horizontal visual field, which makes it easier to read horizontally rather than vertically. Then why did the horizontal bar gauge not perform as well as the vertical bar gauges even though it had many of the same attributes? This possibly suggests that the use of inconsistent directions of fuel depletion in the individual components of the horizontal gauge contributed to its relatively poor performance.

In conclusion, some of the design attributes that possibly contributed to the success of the vertical bar gauges are:

- Bar shape
- Vertical orientation
- Downward direction of fuel depletion
- Consistent directions of fuel depletion for all individual components
- Close spatial proximity of individual components
- Graphical or pictorial representation of information by the use of color to indicate fuel level.

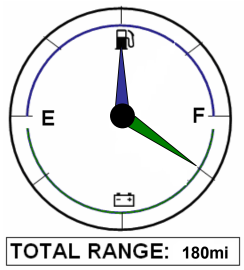
**Dial-shaped gauges in which the pointers for the gas and battery components are designed to move in opposite directions (Gauges B and F) elicited the worst performance** (highest response times and lowest accuracy rates among all other gauges). One possible explanation for this is the inconsistent direction of fuel depletion for the individual gauge components. This type of inconsistency makes it difficult to read and process the information presented and complicates the task of reading.

### 10.1.3. Performance differences based on question

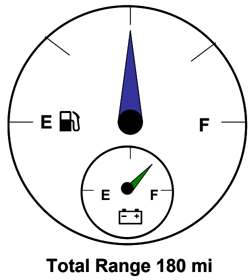
Each of the three questions presented to participants in the timed comprehension task was designed to examine their understanding of a specific aspect of the gauge. Question 1 focused on the battery component while Question 2 focused on the gas component of the gauge. Question 3 required participants to seek combined information on gas and battery levels.

**Vertical bar Gauges (D and G) elicited the best performance** (lowest response times and highest accuracy rates) **while dial-shaped gauges with pointers for the gas and battery components designed to move in opposite directions (B and F) elicited the worst performance** (highest response times and lowest accuracy rates). **Gauge D had the best performance,** consistently eliciting the lowest overall response times, lowest correct response times and the highest response accuracy for each of the three questions.

**It is worth noting that although participants were not familiar with Gauges D and G, they performed best with these gauges**. The gas components of Gauges B, E and I are fairly similar in design to a conventional gas gauge. So it can be assumed that participants were likely to be relatively more familiar with the gas components of these gauges than they were with the gas components of Gauges D and G. However a comparison between the correct response times to Question 2 (focused on gas tank) for Gauges B, E, I, D and G revealed that participants made correct responses to Question 2 faster with Gauges D and G than they did with Gauges B, E and I.




**GAUGE B**

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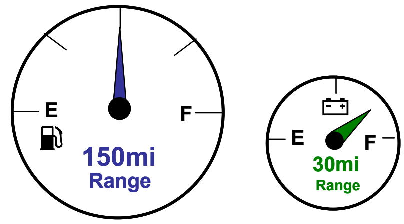
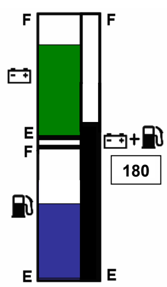
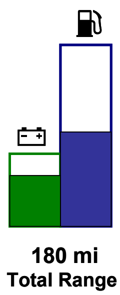



**GAUGE I**




**GAUGE G**



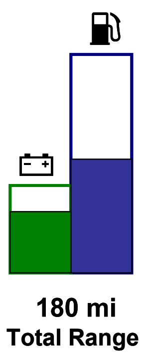

**GAUGE D**

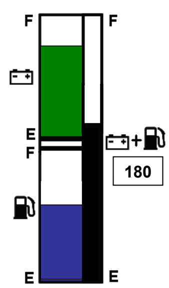
These findings indicate that **familiarity is not necessarily as important to performance as effective design**. It was not the goal of this study to challenge the design of conventional gas gauges. However, the findings from this study suggest that vertical bar gauges may facilitate even better reading performance than conventional dial-shaped fuel gauges. These differences in driver performance with conventional dial-shaped gauges and vertical bar gauges can perhaps be investigated further through additional studies.

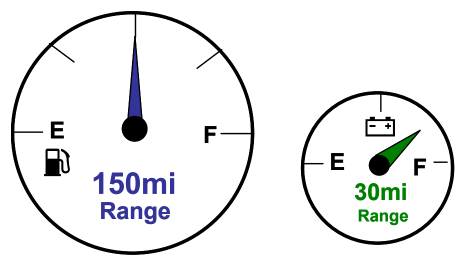
## 10.2. Discussion on results from the subjective questionnaire

The data from the subjective questionnaire revealed an interesting discrepancy**. Although participants performed best with Gauge D in the timed**

**comprehension task, the majority of participants ranked Gauge I as being easiest to use** for answering questions regarding fuel levels and trip planning. Gauge I was overwhelmingly popular with the majority of participants (about 44%) ranking it first in terms of ease of use. One possible explanation for this is that the design of Gauge I is closest to that of a conventional gas gauge and subjects were most familiar and comfortable with that gauge. So, the subjects perceived it to be simple to understand and easy to use. However, in the comprehension task, the accuracy rate for Gauge I was relatively low (third lowest at 87.57%).



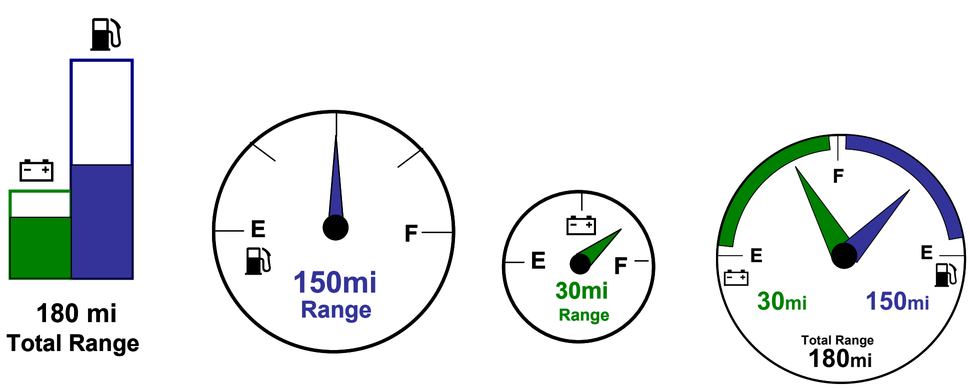

**GAUGE D** **GAUGE G** **GAUGE I**

Overall, Gauge D was ranked as third easiest to use for answering questions regarding fuel levels and trip planning. A closer look at the data showed that it was ranked first in terms of ease of use by only about 6.5% of the participants. So Gauge D was quite unpopular while Gauge I was a clear favorite of the participants. Gauge G, which was the other vertical bar gauge was also poorly ranked in the questionnaire. One possible explanation to the unpopularity of the vertical bar gauges is that the lack of familiarity with these gauges. Participants had never experienced using these vertical gauges in real-life scenarios. So perhaps participants were more inclined to favor gauge designs with which they had experience.

These results indicate that while **vertical bar-shaped gauges (D and G) are the best gauges for driver performance, some upfront marketing is required to inform users of their advantages over other types of gauges.** This is important so that users accept and adopt these new designs.

In the subjective questionnaire, participants were asked to state what they considered to be the best and worst features of each gauge design. Interestingly, for both gauges D and I **participants liked that the gas and battery components were "separate".** The author did not have the opportunity to ask participants specifically what they were referring to in terms of design features. The author believes that participants were referring to the attribute that each component has it's own space with no overlap.

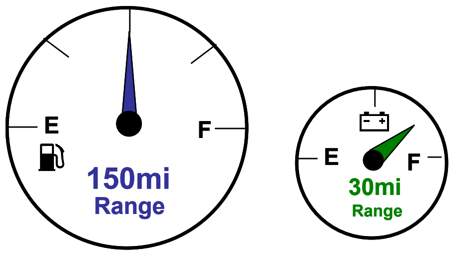
**Participants expressed a liking towards having individual range information presented in absolute or numerical form.** However, the differences in performance of gauges D, I and F in the timed comprehension task indicate that **presenting individual range information in numerical form does not necessarily contribute to a faster and more accurate response**.




GAUGE D GAUGE I GAUGE F

For example, Gauge D does not present any numerical information for the gas and battery components. However, for questions 1 and 2 in the timed comprehension task (focused on the gas and battery components) it was found that gauge D had the lowest overall response time, lowest correct response time and a very high accuracy rate. Gauge F presents individual range information numerically. However, for Question 2 in the timed comprehension task (focused on the gas component) it was found that Gauge F had the highest overall response time for, highest correct response time and the lowest accuracy rate. This indicates that **participants did not need numerical information in order to be able to answer questions on individual ranges accurately and quickly (as seen with gauge D) and they did not necessarily perform well when that information was presented to them** (as seen with gauge F). One possible explanation for this is that participants were able to absorb and process relative (pictorial or graphical information) more easily and accurately than numerical information. Even when the numerical information for individual components was presented to them, it appears that participants relied on the relative form rather than on numbers. However, whether or not they were able to comprehend information quickly and accurately with the relative form depended on the design elements of that gauge (example: shape, orientation, direction of fuel depletion etc.). **This emphasizes the importance of designing the overall relative form of a hybrid fuel gauge effectively.**

**Participants also expressed a preference towards having total range information presented in numerical form.** Since Gauge I was the only gauge presented in the comprehension task in which the total range information was not presented in numerical form, it is worth reviewing the performance of this gauge. Gauge I had the lowest accuracy rate among all gauges for answering Question 3 that required participants to seek combined or total range information. It is important to note that gauge I was also the only gauge in which the individual gauge components for gas and battery are not in close spatial proximity. It appears that **the lack of spatial proximity of individual gauge components combined with a lack of numerical total range information contributes to poor reading accuracy.**

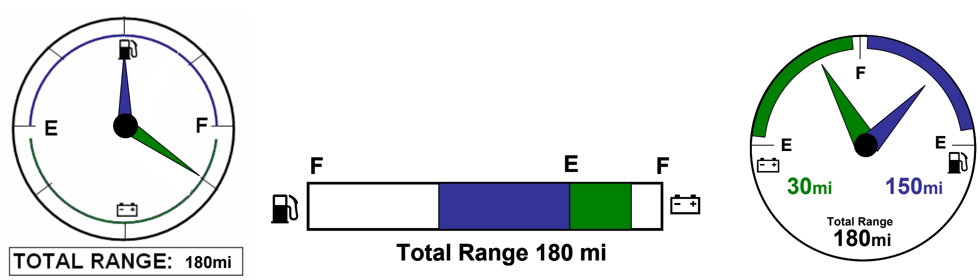



**GAUGE I**

**However, including these design features does not always guarantee high reading accuracy**. This can be seen from the differences in performance of the other gauges (A, B, C, D, E, F and G) for question 3 that required participants to seek combined or total range information. These gauges presented total range information in numerical form and also have components that are located in close spatial proximity. This suggests that **other design attributes like shape, orientation, direction of fuel depletion, use of color etc. have an important role to play in comprehension and reading accuracy**. Another possible explanation is that the style and format in which numerical total range information was presented may have had an effect on reading accuracy.

**So while participants expressed a preference towards having numerical information on the gauge, their performance suggests that they were better at accurately and quickly grasping relative information at a glance.** Although the comprehension study did not include any digital gauges, the results suggest that **gauges that present only absolute or numerical range information may not support high reading accuracy**. It can be difficult to process numbers for many people. Perhaps this is why analog watches are at least as common as digital watches.

In the subjective questionnaire participants also indicated a **dislike for gauges with opposing directions of fuel depletion for the gas and battery components**. Gauges B, F and C that incorporate this design attribute were **found to be among the worst performing gauges** in timed comprehension task. One possible explanation for this is the inconsistent nature of these gauges. The individual components required participants to read and process information in two opposing directions which complicated the tasks of integrating information and comprehension.




**GAUGE B** **GAUGE C** **GAUGE F**

A number of subjects indicated a preference for having ¼, ½ and ¾ scale markings on the gauges. Gauges B, E and I have some of these markings. The effect of scale markings on gauge performance was not the focus of this usability study. Further work is needed in order to draw conclusions.

The study did not investigate empty and full markings and the gas and battery icons. The size of individual components relative to the maximum range for gas and battery was also not investigated. Further work is necessary in order to determine the impact of these design elements.

# 11. Weaknesses of the study

Overall, this study was successful in identifying a class of hybrid fuel gauge designs that can be read with high accuracy and speed. However, there are a few areas in which the study could have been designed better.

**Overall study design**

One shortcoming of this study is that subjects were not individually interviewed after the timed comprehension task. Instead they were presented with a subjective questionnaire in which they were asked to select designs based on preferences and express their likes and dislikes for each gauge. The author did not get the opportunity to probe further into their choices and ask questions on why they made those selections. Those types of discussions would have been valuable in getting a deeper understanding of subjects' preferences for certain types of designs and attributes over others.

**Subjective questionnaire**

In Part 1 of the questionnaire, subjects were tasked with rank ordering each of the nine designs for six different questions. This required them to assess each of the nine designs repeatedly, potentially overwhelming the participants. Perhaps this led to some indifference towards answering the questions due to the monotonous nature of this task. In retrospect, this questionnaire should have used a smaller set of designs and questions.

In the Part 2 of the questionnaire, pairs of gauge designs were presented and subjects were asked for to answer the same six questions for each design in the pair. While the intent of this section was to understand subjects' preferences for a particular gauge attribute, the selection of the gauge designs in each pair was flawed. In some cases the pairs of designs presented were considerably different from each other not only in terms of the attribute of interest but also in other attributes. Moreover, subjects were not made aware of what the attribute of interest was for each pair of gauges. Due to this, it became difficult in the data analysis to determine why subjects selected one gauge over the other. In retrospect, each pair of gauges should have been controlled for all other attributes of the two gauges except the main attribute of interest.

In Part 3 of the questionnaire, participants were presented with three variations of a single gauge and were asked to rank them based on how easily they could use the gauges to answer the six questions. The three versions of each gauge differed in terms of how the range information was presented (absolute or relative form). Option A always presented the most amount of numerical information (absolute form), Option B presented some information in numerical form and Option C always presented information in relative form only (no numeric ranges). The options presented to participants in this section were not randomized to eliminate order effects. The results showed that the majority of the participants consistently ranked Option A as most preferred, irrespective of the gauge design. This is possibly because of an ordering effect due to the design of the questionnaire.

# 12. Future work

The goal of the usability study was to identify a class of gauges that support performance for specific tasks. Vertical bar gauges were found to have the best performance in terms of reading accuracy and speed. However these gauge designs were not popular with the participants. It is recommended that designers explore ways to market these gauges well so that users understand their benefits over other types of gauges. Designers should also explore through visual design how to make these gauges more appealing. These enhanced designs should be evaluated through further usability testing.

Although the hybrid gauge designs evaluated in the usability study provide a forward-looking estimate of fuel economy information in terms of miles to empty, they do not **provide feedback on driving behavior**. Future explorations could include ways to provide feedback to drivers on whether or not their driving behavior is contributing to fuel efficiency. This would **evolve hybrid fuel gauges into Fuel Economy Driver Interfaces (FEDIs)** (Jenness etal. (2009), Manser etal. (2010 a,b,c). It is also recommended that dynamic prototypes of these gauges are created and evaluated inside a driving simulator. Incorporating the designs inside a dashboard would allow for their evaluation in a dynamic environment.

Another area for further investigation is the differences in performance by age group. Some car manufacturers who are targeting specific cars to specific age groups or generations may be interested in understanding if **certain types of gauges are better suited to specific age groups**.

# 13. Recommendations

This study was successful in identifying a class of gauges that leads to high performance (high accuracy rate and low response time). Additionally, specific design attributes that contribute to good comprehension have also been identified.

The following are recommendations on the design of hybrid fuel gauges that present information on two fuel sources:

**1. Use of relative versus absolute information:**

- It is recommended that the **overall gauge design should present information in relative form including graphical or pictorial design elements.** This is because participants were able to process relative information more easily and accurately than absolute information (numbers).
- Presenting **individual and total range information in absolute form (numbers) is optional** and should be balanced with the need to keep the design clutter-free.

**2. Shape:**

- **Bar gauges are recommended** over circular gauges.

**3. Orientation:**

- **Vertically oriented bar gauges are recommended** over horizontally oriented bar gauges.

**4. Spatial proximity of individual components:**

- The gas and battery components should be designed to be in close spatial proximity. The lack of close proximity of the gas and battery components leads to poor performance when seeking combined information.

**5. Direction of fuel depletion**:

- The gas and battery components be designed to have **consistent directions of fuel depletion** (rather than opposing directions of depletion).

**6. Marketing of new gauge designs**

- More upfront marketing is needed to inform drivers of the benefits of vertical bar gauges (such as higher reading accuracy and speed). Familiar types of gauges, which appeal to participants, do not always contribute to better performance.

# 14. Conclusion

As more and more HEVs are being developed and brought to market there is a need to understand more about designing effective fuel gauges that present information on two fuel sources. The goal of this work was to identify a class of gauges that support quick and accurate reading so that the driver can understand when to recharge the electric battery or refill the gas tank for efficient trip planning. The primary questions investigated were:

- What types of hybrid fuel gauges are optimal for quick and accurate reading?
- What types of hybrid fuel gauges do drivers prefer and why?

These questions were investigated through a two-part usability study conducted with sixty drivers. In the first part, drivers participated in a timed comprehension task in which they were made to view certain gauges and answer questions on them. This was followed by a subjective questionnaire in which participants were asked about their preferences for various gauges.

The key findings of the usability study were:

- Bar gauges were more effective than circular gauges (higher accuracy rates and lower response times)
- Vertically oriented bar gauges were more effective than horizontally oriented bar gauges (higher accuracy rates and lower response times)
- Information in relative form (expressed in graphical or pictorial form) was processed more easily and accurately than information in absolute form (expressed in numeric form).
- Participants did not always need numerical information in order to be able to answer questions accurately and quickly. They did not necessarily perform well when that information was presented to them.

- The individual components of the vertical bar gauges that elicited the highest reading accuracy and speed were in close spatial proximity
- Participants expressed a dislike for gauges in which the gas and battery components had opposing directions of fuel depletion. Gauges that incorporated this attribute were found to be among the worst performing gauges.
- Familiar types of gauges, which appeal to participants, do not always contribute to better performance. Although participants ranked Gauge I to be the easiest to use in the subjective questionnaire, it performed poorly in the comprehension task. Vertically oriented bar gauges (D and G) that performed best in the comprehension task were among the least popular gauges.

Based on the study findings, the following recommendations have been made for automotive designers on designing hybrid fuel gauges:

- Bar gauges are recommended over circular gauges
- Vertically oriented bar gauges are recommended over horizontally oriented bar gauges
- Hybrid fuel gauges should be designed to include information in relative form
- The presentation of individual and total range information in numerical form is optional
- The gas and battery components should be designed to be in close spatial proximity
- The gas and battery components should be designed to have consistent directions of fuel depletion (not opposing).
- More upfront marketing is needed to inform drivers of the benefits of vertical bar gauges (such as higher reading accuracy and speed).

This study has helped identify a class of hybrid fuel gauges that can be read accurately and quickly. A set of recommendations has been created for automotive designers on how to create effective hybrid fuel gauges. These gauges encourage fuel-efficient behavior by helping drivers reduce their dependency on gasoline and rely more on electricity for the operation of their HEVs.  While gasoline has one, non-renewable source, electricity comes from renewable as well as non-renewable sources. As newer power plants are built using renewable energy, the generation of electricity will become more efficient. Hybrid fuel gauges have an important role to play in the adoption and sustained use of HEVs.

# References

Baker, C.A., and Grether, W.F. (1954) Visual Presentation of Information. Wright-Patterson Air Force Base WADC technical report, 54-160.

Brand J.E. (1990). Attitudes toward advanced automotive display systems: feedback from driver focus group discussions. UMTRI Report, 90-22. University of Michigan Transportation Research Institute.

Carveth,J.W., and Adams,J.A. (1964). Effects of practice on dial reading. Human Factors: The journal of the Human Factors and Ergonomics Society, 6, 81-85.

Churchill, A.V. (1956). The Effect of Scale Interval Length and Pointer Clearance on Speed and Accuracy of Interpolation. Journal of Applied Psychology, 40 (6), 358-361.

Churchill, A.V. (1959). Optimal Interval Length for Visual Interpolation: The Effect of Viewing Distance. Journal of Applied Psychology, 43 (2), 125-128.

Churchill, A.V. (1960). The Effect of Pointer Width and Mark Width on the Accuracy of Visual Interpolation. Journal of Applied Psychology, 44 (5), 315-318.

Christ, R.E. (1975). Review and analysis of color coding research for visual displays. Human Factors, 17 (6), 542-570.

Dashevsky,S.D. (1964) Check-Reading Accuracy As a Function of Pointer Alignment, Patterning, and Viewing Angle. Journal of Applied Psychology, 48(6), 344-347.

Endsley, M. (1988). Situation awareness global assessment technique. SAGAT Papers presented at the National Aerospace and Electronic Conference (NAECON) Dayton, OH.

Gonder,J., Earleywine,M., and Sparks,W.(2011). Final report on the fuel saving effectiveness of various driver feedback approaches. National Renewable energy laboratory. Report NRE/MP, 5400-50836.

Green,P.(1984). Driver understanding of fuel and engine gauges. Society of Automotive engineers, paper 840314.

Green,P. (1988). Human factors and gauge design: A literature review. University of Michigan Transportation Research Institute, Report no UMTRI-88-37

Graham, N.E. (1956). The speed and accuracy of reading horizontal, vertical and circular scales. The Journal of Applied Psychology, 40 (4).

Graving,J.S., Manser,M.P., and Becic,E. (2010). Reduction in fuel consumption depends on the fuel economy display and driver sex: An observed interaction. Adjunct proceedings of the second international conference on automotive user interface and interactive vehicular applications, November, 11-12.

Grether, W.F., and Connell,S.C (1948). Psychological factors in check reading of single instruments.  Wright-Patterson Air Force Base, OH: U.S. Air Force AeroMedical Laboratory technical report MCREXD-694- 4 L17A.

Grether, W.F. (1949). Instrument reading I. The design of long scale indicators for speed and accuracy of quantitative readings. Wright-Patterson Air Force Base, OH: U.S. Air Force AeroMedical Laboratory.

Grether, W.F., and Williams, A.C., Jr. (1949). Psychological Factors in Instrument Reading II. The Accuracy of Pointer Position Interpolation As a Function of the Distance Between Scale Marks and Illumination, Journal of Applied Psychology, 33 (4), 594-604.

Heglin, H.J. (1973). Navships display illumination Factors design guide. Section II: Human Factors. Naval Electronics Laboratory technical report NELC TD 223.

Jenness,J.W., Singer,J., Walrath,J., and Lubar, E.(2009). Fuel economy driver interfaces: design range and driver opinions (report on task 1 and task 2). National Highway Traffic Safety Administration Report no. DOT HS 811 092.

Johnsgard K.W.(1953). Check Reading As a Function of Pointer Symmetry and Uniform Alignment. Journal of Applied Psychology, 37( 5), 407-411.

Kappauf W.E., and Smith W.M. (1950a). Design of instrument dials for maximum legibility Part 3. Some data on the difficulty of reading in different parts of a dial. Wright-Patterson Air Force Base, Dayton, OH. AF technical report no. 5914, part 3.

Kappauf W.E., and Smith W.M. (1950b) Design of instrument dials for maximum legibility Part 4. Dial graduation, scale range and dial size as factors affects the speed and accuracy of scale reading. Wright-Patterson Air Force Base, Dayton, OH. AF technical report no. 5914, part 4.

Kurke, M.I., (1956). Evaluation of a Display Incorporating Quantitative and Check-Reading Characteristics, Journal of Applied Psychology I -40(4), 233-236.

Manser,M.P., Rakauskas,M., Graving,J., and Jenness.J.W. (2010a) Fuel Economy Driver Interfaces: Develop interface recommendations (Report on task 3). National Highway Traffic Safety Administration. Report DOT HS 811 319.
Manser etal (2010b). Fuel economy driver interfaces: usability study of component concepts. NHTSA Vehicle safety research notes DOT HS 811 320.

Manser et al (2010c). Fuel economy driver interfaces: driving simulator study of component concepts. NHTSA Vehicle safety research notes DOT HS 811 321

Meschtscherjakov,A., Wilfinger,D., Scherndl,T., and Tschelii,M.(2009) Acceptance of future persuasive in-car interfaces towards a more economic driving behavior. Proceedings of the first international conference on automotive user interactive vehicular applications, September, 21-22.

Mital, A., and Ramanan. S. (1986). Results of the Simulation of a Qualitative Information Display. Human Factors, June, 28 (3), 341-346.

Nielsen,J., and Molich,R. (1990) .Heuristic evaluation of user interface. CHI '90 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 249-256.

Norman,D. (1988). The Design of Everyday Things. New York: Basic books.

Roscoe,S.N. (1968). Airborne displays for flight and navigation. Human Factors: The Journal of the Human Factors and Ergonomics Society, 10: 321.

Ross,S., Katchmar,L.T., and Bell,H. (1955) Multiple-Dial Check Reading: Pointer Symmetry Compared with Uniform Alignment. Journal of Applied Psychology, 39 (4), 215-218.

Sanders, E.J., and McCormick, M.S. (1977). Visual displays of dynamic information. Chapter 5.

Simmonds,G.R.W., Galer,M., and Baines,A. (1981). Ergonomics of electronic displays. Society of Automotive Engineers, Tech. paper series 810826

Simon, C.W. (1977). Design, analysis and interpretation of screening studies for human factors engineering research. Air force office of scientific research. Technical report CWS-03-77A

Sleight, R.B. (1948). The Effect of Instrument Dial Shape on Legiblity. Journal of Applied Psychology, 32( 2), 170-188.

Thomas, D.R. (1957). Exposure time as a variable in dial reading experiments. The Journal of Applied Psychology,41(3).

United States Energy Administration (April 14, 2014). Retrieved from http://www.eia.gov/

United States Energy Administration (April 14, 2014). Retrieved from http://www.eia.gov/energy_in_brief/article/renewable_electricity.cfm

United States Department of Energy (2014) Retrieved from http://www.fueleconomy.gov/feg/topten.jsp

United States Department of Energy (n.d.) Retrieved from http://www.fueleconomy.gov/feg/driveHabits.jsp

United States Environmental Protection Agency (n.d.) Retrieved from http://www.epa.gov/climatechange/science/causes.html

Van Der Voort,M.V, Dougherty,M.S., and Maarseveen,M.V. (2001). A prototype fuel-efficiency support tool. Transportation Research, Part C (9) 279- 296.

Welford, A. T. (1977). Motor performance. In J. E. Birren and K. W. Schaie (Eds.), Handbook of the Psychology of Aging. Van Nostrand Reinhold, New York, pp. 450-496.

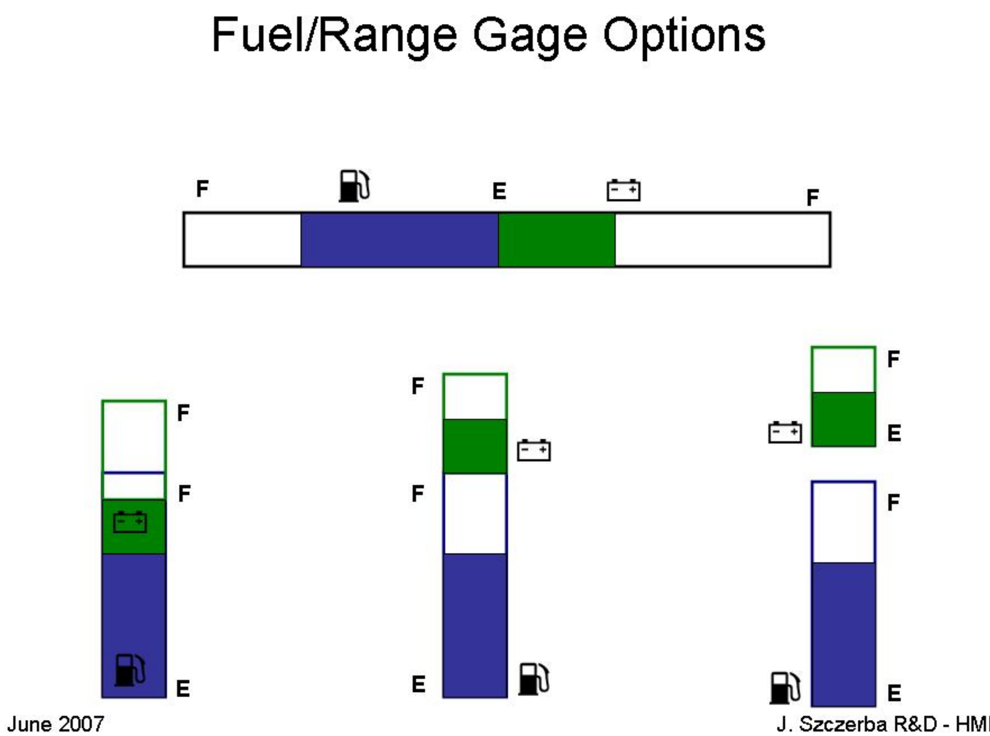
Whitehurst, H.O. (1982). Screening Designs Used to Estimate the Relative effects of Display Factors on dial reading. Human Factors, 24 (3), 301-310.

Wickens, C.D., Lee, J., Liu, Y., and Gordon, S. (2003). Introduction to Human Factors Engineering (2nd edition).

Wickens,C.D., and Carswell,C.M. (1995) The proximity compatibility principle: Its psychological foundation and relevance to display design. Journal of the Human Factors and Ergonomics Society, 37: 473.

# Appendix A

Fuel Gauge designs created by the General Motors design team.



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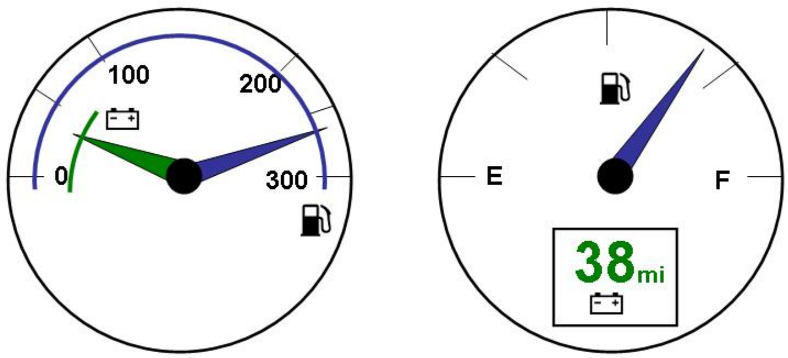


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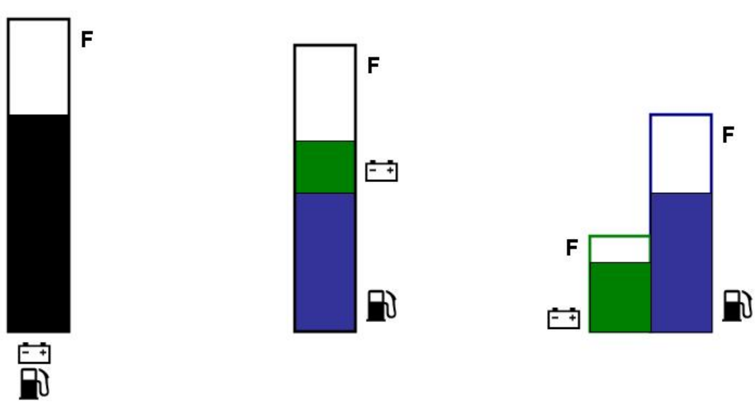


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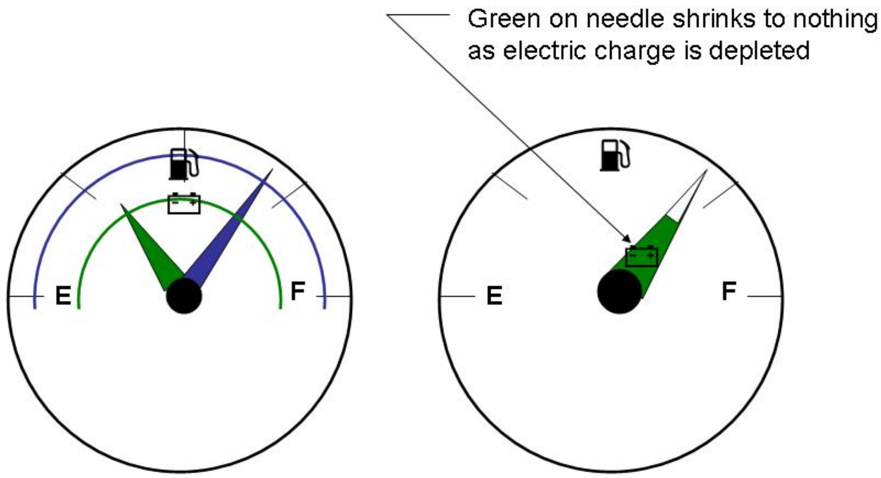


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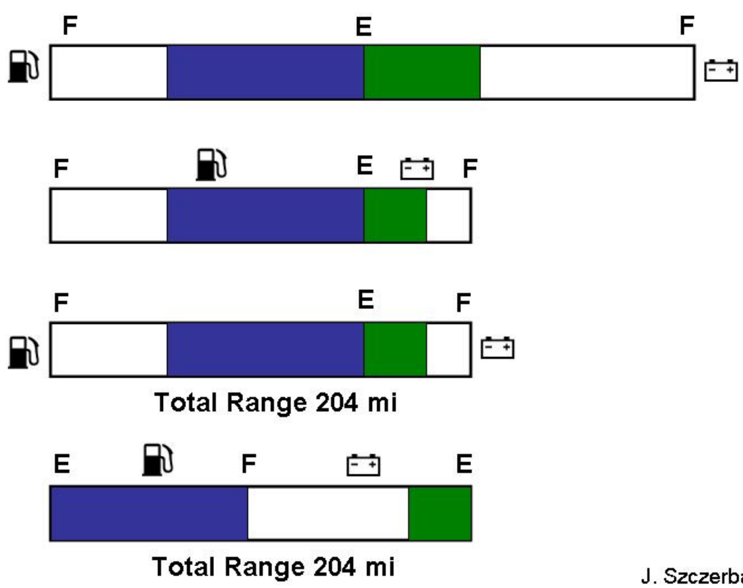


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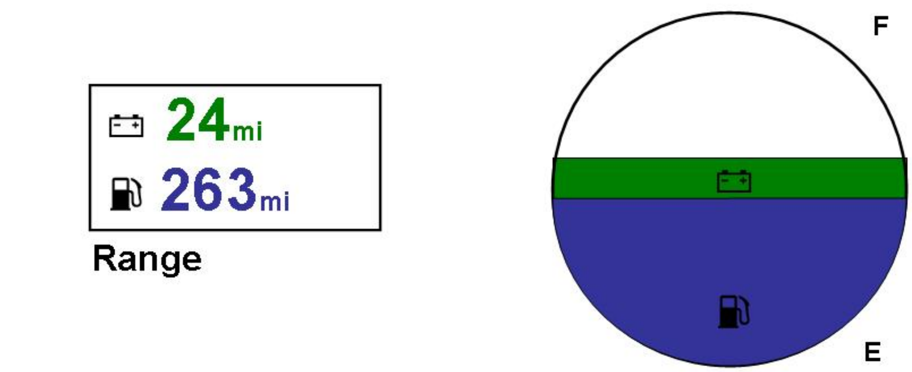


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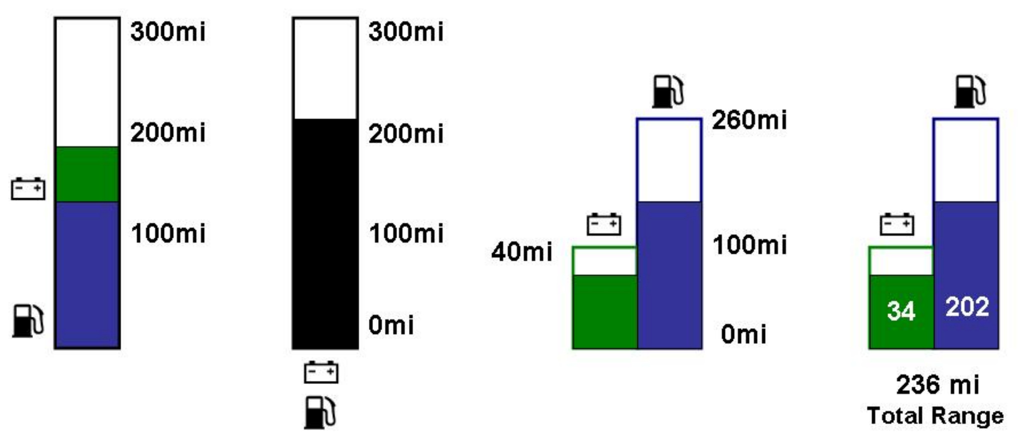


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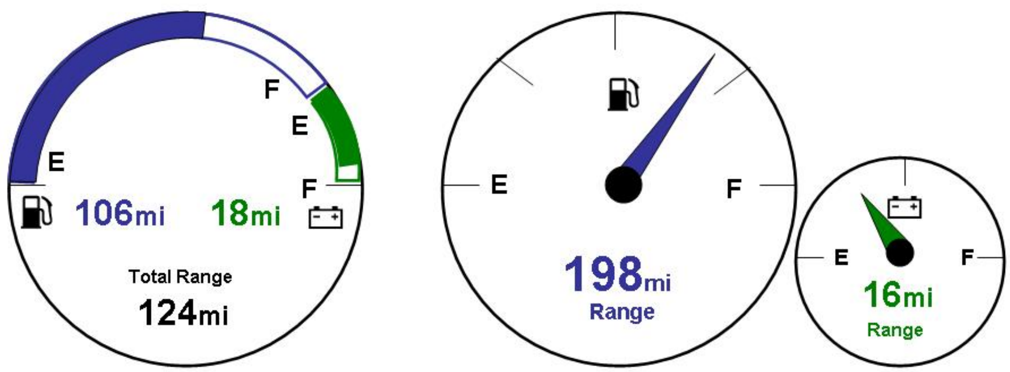


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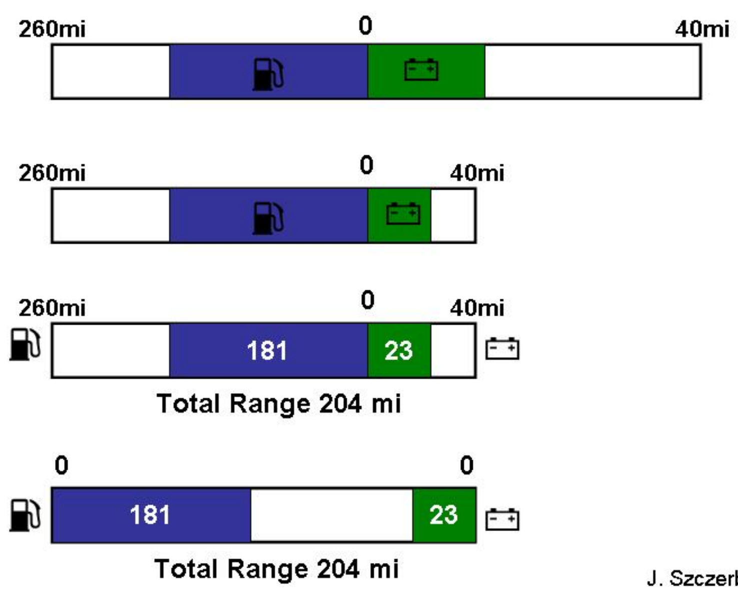


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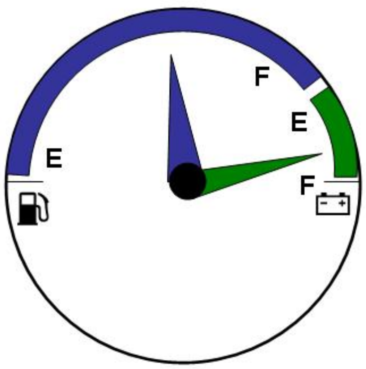


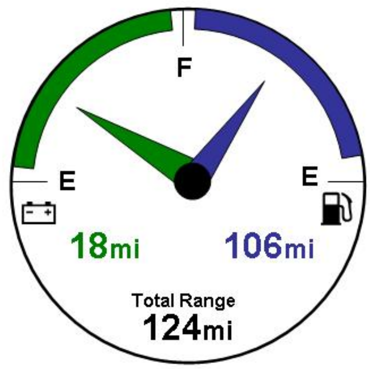


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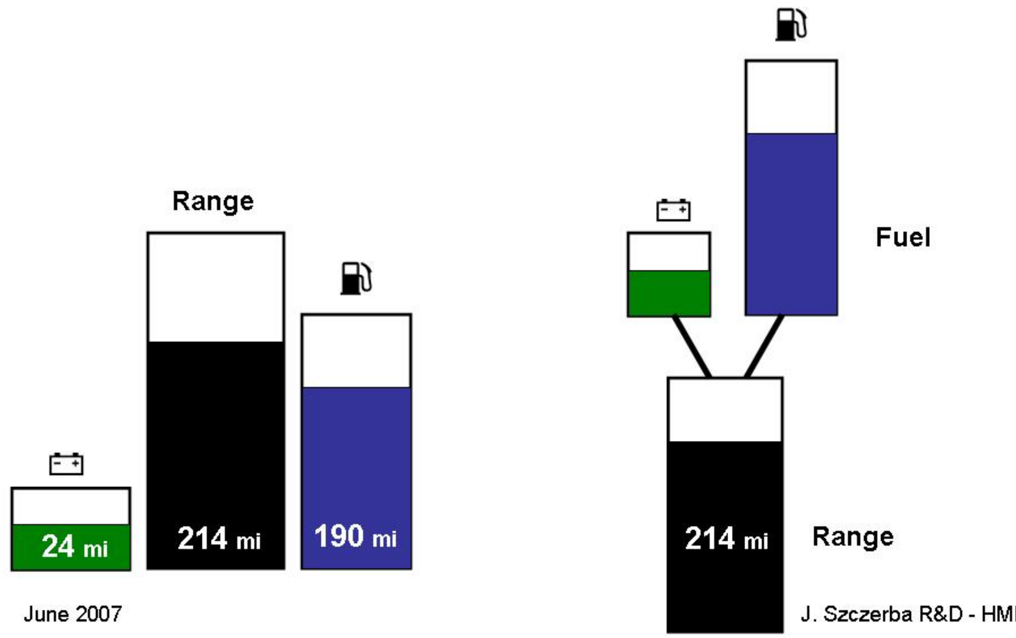

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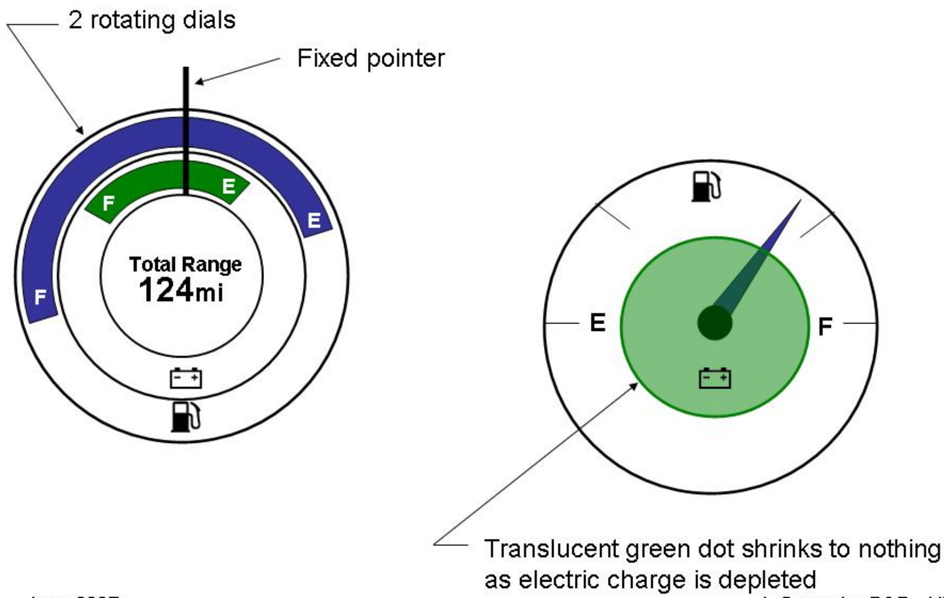


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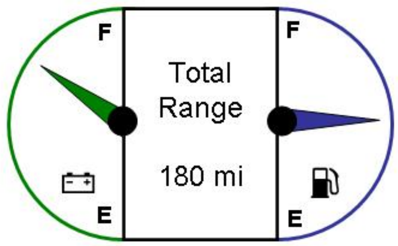
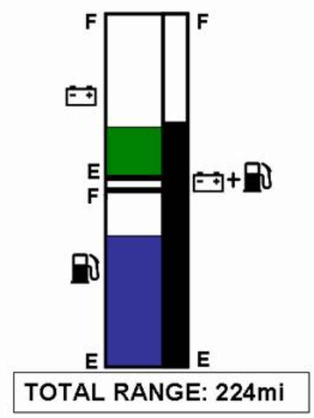
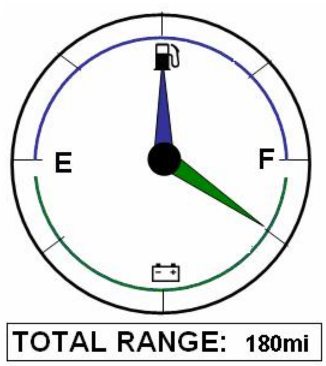
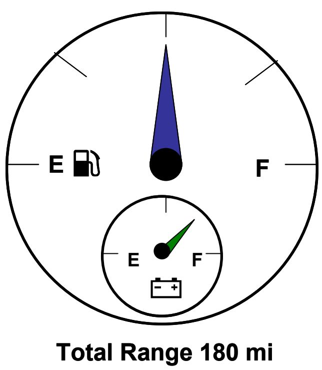
# Appendix B

New designs created by the UMN team



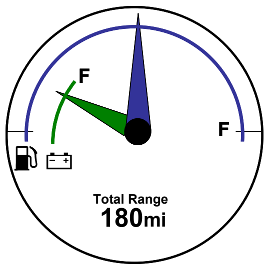



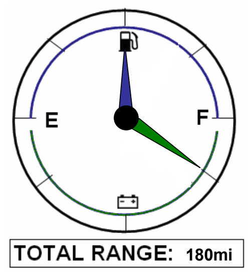



# Appendix C

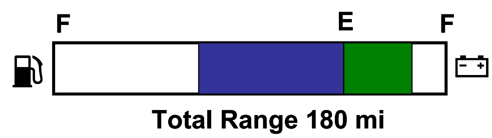
Final set of gauge designs evaluated in the usability study



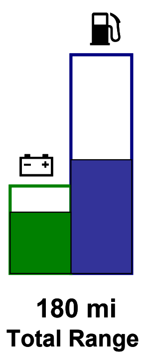

GAUGE A



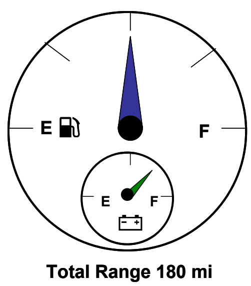

GAUGE B



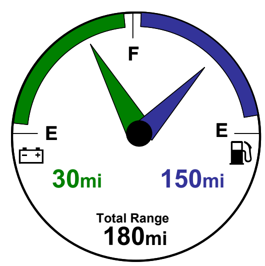

GAUGE C



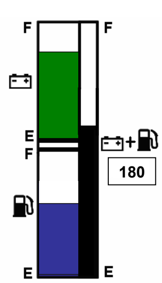

GAUGE D



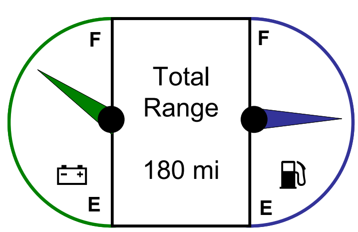

GAUGE E



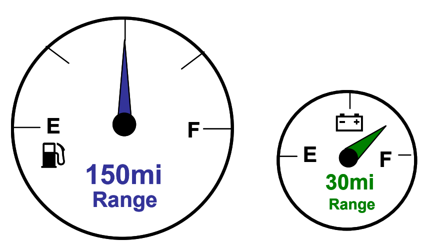

GAUGE F




GAUGE G




GAUGE H




GAUGE I

# Appendix D

**Study Introduction**

In this study, you will be asked to evaluate potential fuel gauges that can be used to provide information about a vehicle that contains two fuel types.

This vehicle either runs on a battery (electric power) or on fuel (gasoline). It can only run on **one** of these fuel types at a time. If the battery has a charge (e.g., partial or full), the vehicle will run on the battery power until it is fully depleted. If the battery charge is fully depleted during driving, the vehicle will automatically switch over to using gas as the fuel source.

A **fully charged battery** will allow the vehicle to drive for **40 miles** before it needs recharging. The battery is recharged by plugging the vehicle in for 8 hours, such as overnight or during the day at work. The goal of this battery is to help drivers reduce the use of gas, if they wish to.

The vehicle also runs on gasoline. A **full gas tank** will allow the vehicle to drive **300 miles** before the gas tank needs to be filled. The vehicle can be driven on gas only if the driver chooses not to charge the battery or the battery is depleted during driving.

In total, a driver can drive this vehicle **340 miles** when it has both a **full battery** and a **full gas tank.** Like any vehicle, the distance a driver can travel depends on how full each fuel source is at a given time.

Please take the time now to familiarize yourself with this introduction. If you have any questions, please ask. All the tasks you perform today are based on the vehicle described here and its fuel types.

This Study Introduction will be available to you throughout the study today.

# Appendix E

This section consists of the subjective questionnaire that was administered in the usability study.

## INSTRUCTIONS

This booklet contains four parts. The questions in this booklet ask you to evaluate fuel gauges that can be used to provide information about the electric battery and the fuel (gas) tank of the vehicle described in the study introduction.

Please work through this booklet in order, starting with Part 1, and answer each question to the best of your ability.

A section for "Comments" has been included in several places. Please use these areas to explain your answers or add any information you think was necessary to helped you answer a question.

If you have any questions while working through the booklet, please ask.

You may refer to the **Study Introduction** any time you wish.

Thank you.

## PART 1

Imagine that you are driving the vehicle described in the **Study Introduction**.

Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

For each of the following questions, **please rank order the 9 gauges from "easiest" to "most difficult" based on your opinion of how easy or difficult it is to answer each question using each gauge.**

| | Easiest | | | | | | | Most Difficult |
|---|---|---|---|---|---|---|---|---|---|
| Questions | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| How easy or difficult is it to know how much energy is in the battery? | | | | | | | | | |
| How easy or difficult is it to understand when it is time to recharge the battery? | | | | | | | | | |
| How easy or difficult is it to know if I can make a 20-mile trip using only the battery? | | | | | | | | | |
| How easy or difficult is it to understand if I can travel 100 more miles on gasoline alone once the battery is depleted? | | | | | | | | | |
| How easy or difficult is it to know if I can make a 250-mile trip using both the battery and gasoline? | | | | | | | | | |
| Overall, which gauge do you find the most useful (i.e., easiest) to answer all the questions above? | | | | | | | | | |

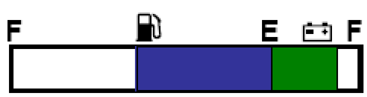
## PART 2

Imagine that you are driving the vehicle described in the **Study Introduction**.

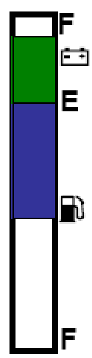
Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

Typically, drivers may use these icons to answer a variety of questions during a trip. For each of the following questions, **please choose the best icon from the pair that you believe is easiest and most effective for answering each question.** Please make comments if you feel it helps qualify your answers.

| Questions | Best |
|---|---|
| 1. How much energy do I have in the battery? | |
| 2. Does the battery need to be recharged? | |
| 3. Can I make a 20 mile trip only using the battery? | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | |
| 6. Overall, which gauge do you prefer for answering the above questions? | |




1 A




1 B

| Comments: | |
|---|---|

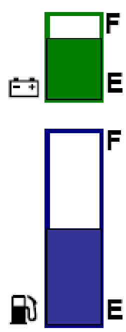
**PART 2**

Imagine that you are driving the vehicle described in the **Study Introduction**.

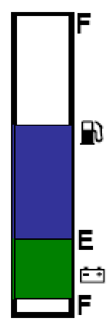
Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

Typically, drivers may use these icons to answer a variety of questions during a trip. For each of the following questions, **please choose the best icon from the pair that you believe is easiest and most effective for answering each question.** Please make comments if you feel it helps qualify your answers.

| Questions | Best |
|---|---|
| **1.** How much energy do I have in the battery? | |
| 2. Does the battery need to be recharged? | |
| 3. Can I make a 20 mile trip only using the battery? | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | |
| 6. Overall, which gauge do you prefer for answering the above questions? | |




**2 A**




**2 B**

| Comments: | |
|---|---|

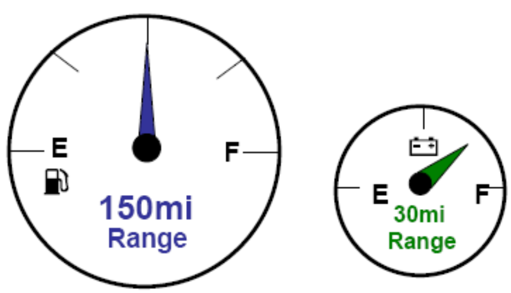
## PART 2

Imagine that you are driving the vehicle described in the **Study Introduction**.

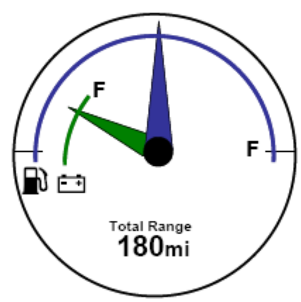
Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

Typically, drivers may use these icons to answer a variety of questions during a trip. For each of the following questions, **please choose the best icon from the pair that you believe is easiest and most effective for answering each question.** Please make comments if you feel it helps qualify your answers.

| Questions | Best |
| --- | --- |
| **1.** How much energy do I have in the battery? | |
| 2. Does the battery need to be recharged? | |
| 3. Can I make a 20 mile trip only using the battery? | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | |
| 6. Overall, which gauge do you prefer for answering the above questions? | |




**3 A**




**3 B**

| Comments: | |
| --- | --- |

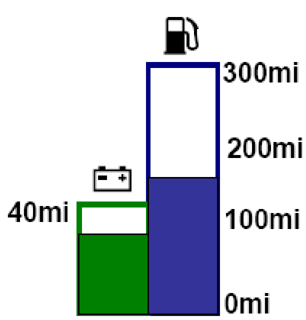
**PART 2**

Imagine that you are driving the vehicle described in the **Study Introduction**.

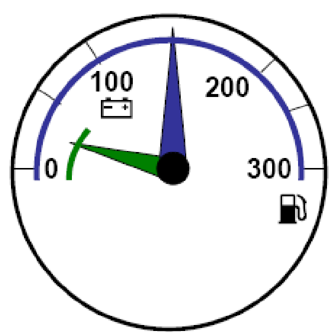
Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

Typically, drivers may use these icons to answer a variety of questions during a trip. For each of the following questions, **please choose the best icon from the pair that you believe is easiest and most effective for answering each question.** Please make comments if you feel it helps qualify your answers.

| Questions | Best |
|---|---|
| **1.** How much energy do I have in the battery? | |
| 2. Does the battery need to be recharged? | |
| 3. Can I make a 20 mile trip only using the battery? | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | |
| 6. Overall, which gauge do you prefer for answering the above questions? | |




**4 A**




**4 B**

| Comments: | |
|---|---|

6

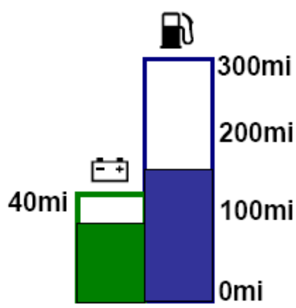
## PART 2

Imagine that you are driving the vehicle described in the **Study Introduction**.

Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

Typically, drivers may use these icons to answer a variety of questions during a trip. For each of the following questions, **please choose the best icon from the pair that you believe is easiest and most effective for answering each question.** Please make comments if you feel it helps qualify your answers.

| Questions | Best |
|---|---|
| **1.** How much energy do I have in the battery? | |
| 2. Does the battery need to be recharged? | |
| 3. Can I make a 20 mile trip only using the battery? | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | |
| 6. Overall, which gauge do you prefer for answering the above questions? | |




5 A


5 B

| Comments: | |
|---|---|
| | |

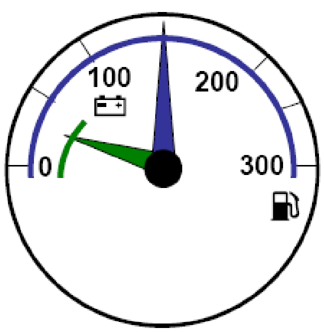
## PART 2

Imagine that you are driving the vehicle described in the **Study Introduction**.

Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

Typically, drivers may use these icons to answer a variety of questions during a trip. For each of the following questions, **please choose the best icon from the pair that you believe is easiest and most effective for answering each question.** Please make comments if you feel it helps qualify your answers.

| Questions | Best |
|---|---|
| **1.** How much energy do I have in the battery? | |
| 2. Does the battery need to be recharged? | |
| 3. Can I make a 20 mile trip only using the battery? | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | |
| 6. Overall, which gauge do you prefer for answering the above questions? | |




6 A


6 B

| Comments: | |
|---|---|

8

## PART 2

Imagine that you are driving the vehicle described in the **Study Introduction**.

Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

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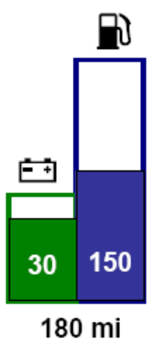
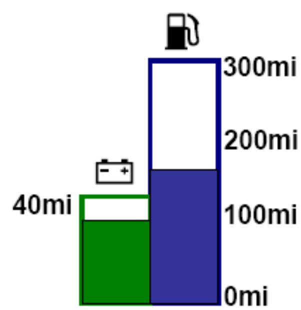
| Questions | Best |
|---|---|
| **1.** How much energy do I have in the battery? | |
| 2. Does the battery need to be recharged? | |
| 3. Can I make a 20 mile trip only using the battery? | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | |
| 6. Overall, which gauge do you prefer for answering the above questions? | |




7 A




7 B

| Comments: | |
|---|---|
| | |

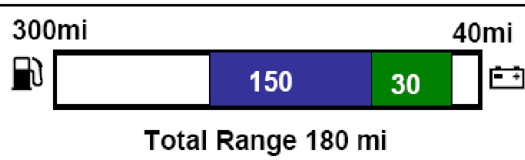
## PART 3

Imagine that you are driving the vehicle described in the **Study Introduction**.

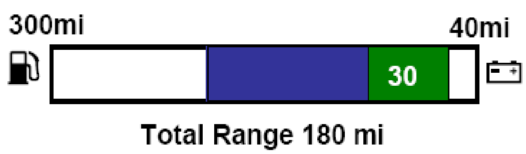
Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

Typically, drivers may use these icons to answer a variety of questions during a trip. For each of the following questions, **please rank order the gauges from best to worst based on which gauges you believe are easiest and most effective for answering each question.** Please make comments if you feel it helps qualify your answers.

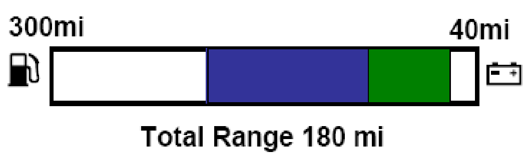
| Questions | Best | | Worst |
|---|---|---|---|
| **1.** How much energy do I have in the battery? | | | |
| 2. Does the battery need to be recharged? | | | |
| 3. Can I make a 20 mile trip only using the battery? | | | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | | | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | | | |
| 6. Overall, which gauge do you prefer for answering the above questions? | | | |




A




B




C

| Comments: | |
|---|---|
| | |

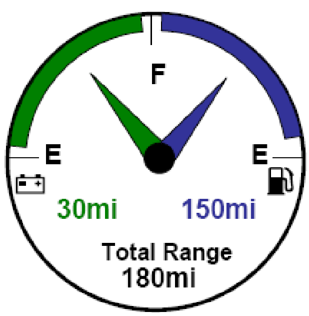
**PART 3**

Imagine that you are driving the vehicle described in the **Study Introduction**.

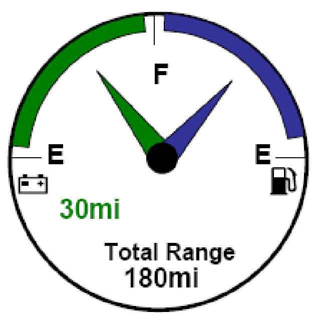
Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

Typically, drivers may use these icons to answer a variety of questions during a trip. For each of the following questions, **please rank order the gauges from best to worst based on which gauges you believe are easiest and most effective for answering each question.** Please make comments if you feel it helps qualify your answers.

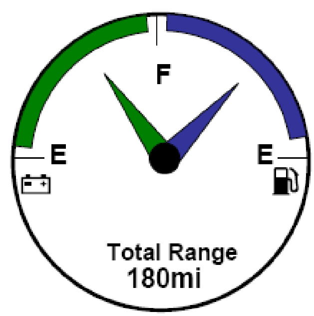
| Questions | Best | | Worst |
|---|---|---|---|
| **1.** How much energy do I have in the battery? | | | |
| 2. Does the battery need to be recharged? | | | |
| 3. Can I make a 20 mile trip only using the battery? | | | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | | | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | | | |
| 6. Overall, which gauge do you prefer for answering the above questions? | | | |



A



B



C

| Comments: | |
|---|---|
| | |

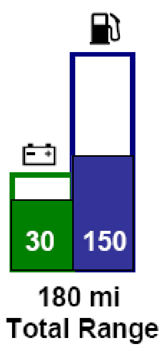
## PART 3

Imagine that you are driving the vehicle described in the **Study Introduction**.

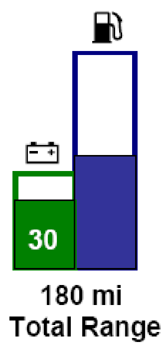
Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

Typically, drivers may use these icons to answer a variety of questions during a trip. For each of the following questions, **please rank order the gauges from best to worst based on which gauges you believe are easiest and most effective for answering each question.** Please make comments if you feel it helps qualify your answers.

| Questions | Best | | Worst |
|---|---|---|---|
| **1.** How much energy do I have in the battery? | | | |
| 2. Does the battery need to be recharged? | | | |
| 3. Can I make a 20 mile trip only using the battery? | | | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | | | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | | | |
| 6. Overall, which gauge do you prefer for answering the above questions? | | | |




A

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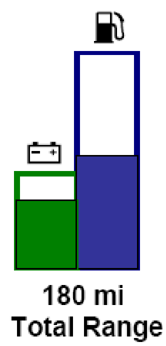



C

| | |
|---|---|
| Comments: | |

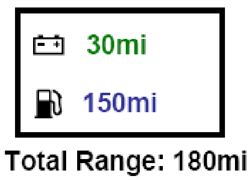
## PART 3

Imagine that you are driving the vehicle described in the **Study Introduction**.

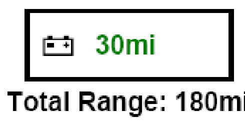
Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

Typically, drivers may use these icons to answer a variety of questions during a trip. For each of the following questions, **please rank order the gauges from best to worst based on which gauges you believe are easiest and most effective for answering each question.** Please make comments if you feel it helps qualify your answers.

| Questions | Best | | Worst |
|---|---|---|---|
| **1.** How much energy do I have in the battery? | | | |
| 2. Does the battery need to be recharged? | | | |
| 3. Can I make a 20 mile trip only using the battery? | | | |
| 4. Can I travel 100 more miles on gasoline alone once the battery is depleted? | | | |
| 5. Can I make a 250 mile journey using both the battery and the gas tank? | | | |
| 6. Overall, which gauge do you prefer for answering the above questions? | | | |




A




B


C

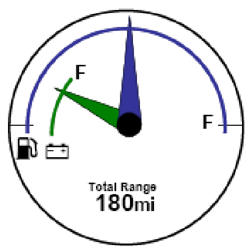
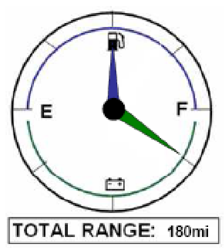
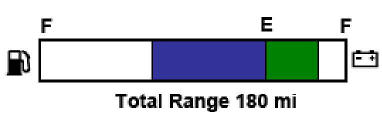
| Comments: | |
|---|---|

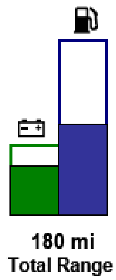
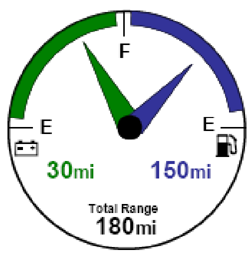
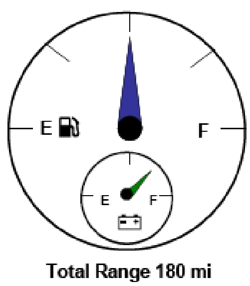
PART 4

Imagine that you are driving the vehicle described in the **Study Introduction**.

Shown below are pictures of fuel gauges that may be used in this vehicle to tell the driver about the level of remaining electric power and gasoline. Some of these gauges indicate the relative level of fuel available (e.g., how full a bar is) and others indicate absolute levels of fuel (e.g., the number of miles available for each source). Drivers may use these gauges when determining how far they can travel or when it may necessary to recharge the battery or fuel up the gas tank.

For each of the following gauges, **please write down what you think are its best and worst features. Please explain your answers.**

| | BEST FEATURE | WORST FEATURE |
|---|---|---|
|   | | |
|   | | |
|   | | |

| | BEST FEATURE | WORST FEATURE |
|---|---|---|
|  | | |
|  | | |
|  | | |

# APPENDIX F

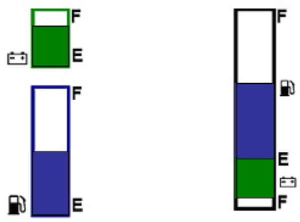
**RESULTS OF SUBJECTIVE QUESTIONNAIRE PART 2**

Due to incorrect experimental design of questionnaire part 2, it has been excluded from the data analysis.

In the part 2 of the questionnaire, pairs of gauge designs were presented and subjects were asked for to answer the same 6 questions for each design in the pair. Subjects were asked to select one gauge out of the options provided that they felt was most useful in trying to answer the 6 questions.

This section was designed with the intent of understanding attribute preferences. The pairs of gauges presented to participants in this section were not selected appropriately. For example, one attribute of interest was the proximity of gauge components. Did subjects prefer designs with separate gauge components over designs with integrated gauge components? The selection of the designs used in this pair were not controlled in all other attributes except in the attribute of interest (which was the proximity of the gauge components). Moreover, subjects were not made aware of what the attribute of interest was for each pair of gauges.

For example, in the pair below, the attribute of interest was level of integration between the two gauge components (gas and battery). However, these two gauges are not just different in terms of integration or separation level, they also differ in terms of which component is stacked on top. One design presents the battery on top while the other presents the battery at the bottom. This makes it difficult to determine in the analysis what the exact reason was for subjects' preferences of one over the other. When subjects expressed a preference for one design over the other, it was not clear if they selected it because they preferred to have designs with a certain degree of integration or separation of each gauge component, or because they preferred to have the battery gauge in a certain position.




In retrospect, each pair of gauges should have been controlled in all other attributes of the two gauges except the main attribute of interest. For a majority of the pairs presented in this part of the questionnaire, the selection of the gauges designs was not appropriate.

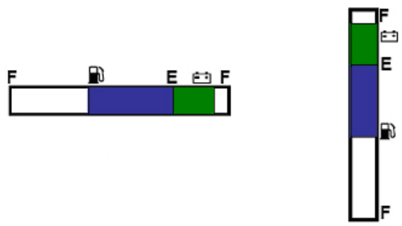
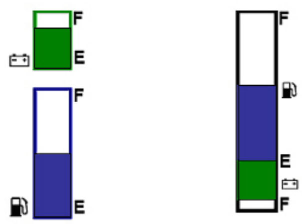
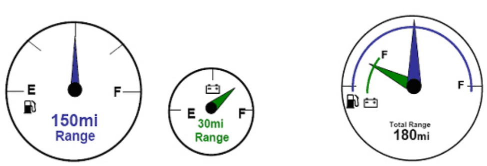
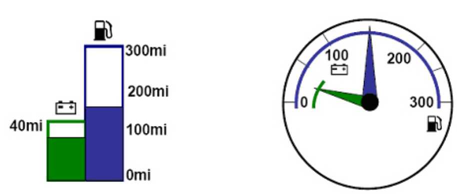
**Due to incorrect experimental design of questionnaire part 2, it has been excluded from the questionnaire analysis. The results of the analysis have been included here for reference.**

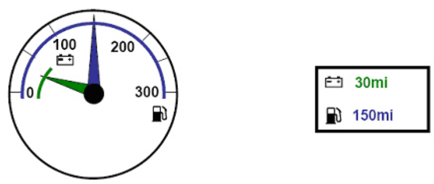
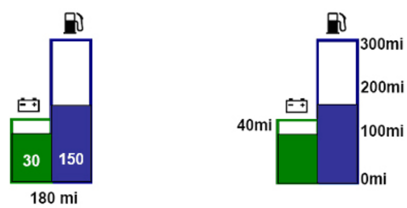
The following 6 questions were presented to subjects:

1. How much energy do I have in the battery?
2. Does the battery need to be recharged?
3. Can I make a 20 mile trip only using the battery?
4. Can I travel 100 more miles on gasoline alone once the battery is depleted?
5. Can I make a 250 mile journey using both the battery and the gas tank?
6. Overall, which gauge do you prefer for answering the above questions?

The following results show subjects' overall preferences to specific attributes while trying to answer question 6 using the information provided by the gauge and the percentage of subjects who preferred those attributes.

TABLE : Subject preferences by gauge attributes

| | GAUGES | ATTRIBUTE | PREFERRED ATTRIBUTE |
|---|---|---|---|
| 1 | Horizontal vs. Vertical bars   | Orientation | **Horizontal bar preferred** by 76.3% of the subjects |
| 2 | Separate vs. Integrated (bars)   | Integration | **Gauge with Separate bars preferred** by 96.6% of the subjects |
| 3 | Separate vs. Integrated (circular dials)   | Integration | **Separate circular dial preferred** by 89.8% of the subjects |
| 4 | Bars vs. dials   | Format or shape | **Bar shaped gauge was preferred** by 93.2% of the subjects |

| | | | |
|---|---|---|---|
| 5 | Bars vs. numerical (text only)<br><br> | Format | **Numerical (text) gauge was preferred** by 61% of the subjects |
| 6 | Circular dial vs. numerical (text only)<br><br> | Format | **Numerical (text) gauge was preferred** by 78% of the subjects |
| 7 | Absolute vs. relative information<br><br> | INFORMATION TYPE | **Information in absolute form (individual and total ranges displayed) was preferred** by 72.4% of the subjects |

## RESULTS OF SUBJECTIVE QUESTIONNAIRE PART 3:

**Due to incorrect experimental design of questionnaire part 3, it has been excluded from the questionnaire analysis.**

Participants were presented with three variations of a single gauge and were asked to rank them based on how easily they could use the gauges to answer 6 questions. The three versions of each gauge differed in terms of how the range information was presented (absolute or relative form). In the absolute form ranges were presented numerically (individual and combined). For each gauge subjects were presented with three variations or options:

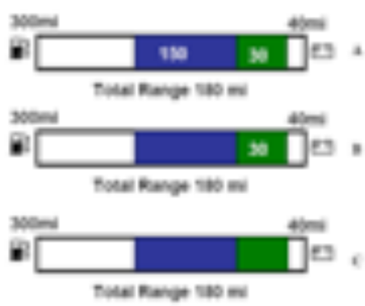
Option A: displayed ranges for fuel, battery and both combined

Option B: displayed battery range and combined total range (no individual range for gas tank)
Option C: displayed combined total range only (no individual ranges)

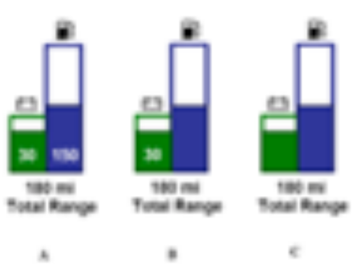
The gauges/ options presented to participants in this section were not randomized to eliminate order effects. Option A always presented the most amount of information. An analysis showed that majority of the participants consistently ranked option A as most preferred, irrespective of the gauge design. The possibility of this being due to an order effect cannot be ruled out.

The following table shows the preferred gauges of majority of participants in answering each of the 6 questions listed.

**TABLE :** Percentages of subjects for most preferred option (A,B or C) with each option representing different levels of information presented




SET A SET B



SET C SET D

| | SET 1 | SET 2 | SET 3 | SET 4 |
|---|---|---|---|---|
| **1** | **How much energy do I have in the battery?** | | | |
| | 83% preferred A | 93% preferred A (best) | 89.6% preferred A | 76.3% preferred A |
| **2** | **Does the battery need to be recharged?** | | | |
| | 76.3% preferred A | 84.4% preferred A | 84.5% preferred A | 67.8% preferred A |
| **3** | **Can I make a 20 mile trip only using the battery?** | | | |
| | 79.6% preferred A | 86.2% preferred A | 79.3% preferred A | 71.2 % preferred A |
| **4** | **Can I travel 100 more miles on gasoline alone once the battery is depleted?** | | | |
| | 95% preferred A | 94.8% preferred A | 100% preferred A | 100 % preferred A |
| **5** | **Can I make a 250 mile journey using both the battery and the gas tank?** | | | |
| | 91.5% preferred A | 93% preferred A | 94.8% preferred A | 89.8 % preferred A |
| **6** | **Overall, which gauge do you prefer for answering the above questions?** | | | |
| | 93.2% preferred A | 96.5% preferred A | 98.3% preferred A | 98.3 % preferred A |