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Vehicle Instrument Cluster Layout Differentiation for Elderly Drivers

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Objective: The objective of this study is to identify essential requirements of the instrument cluster's features and layout for elderly drivers through interview and paper prototyping.

Background: Recent updates implemented in passenger vehicles require more complex information to be processed by drivers. Concurrently, a large portion of the US population, the baby boomer generation has aged, causing their physical and cognitive abilities to deter. Thus it is crucial that new methods be implemented into vehicle design in order to accommodate for the deterioration of mental and physical abilities.

Method: Forty elderly drivers and twenty young drivers participated in this study. The test included three sessions including: 1) location value assessment to identify the priority of areas within the instrument cluster; 2) component value assessment to capture rankings of the degree of importance and frequency of use for possible instrument cluster components; and 3) paper prototyping to collect self-designed cluster with selection of designs for each component and location of features from each participant.

Results: Results revealed differences in the area priority of the instrument cluster as well as the shape and location of component features for age and gender groups.

Conclusion: The study provided insights on instrument cluster layout guidelines by proving elderly driver's mental model and preferred cluster design configurations to improve driving safety.

Application: LCD-based vehicle instrument cluster design, with an adaptable feature configuration for cluster components and layouts.

Keywords: Cluster layout, Elderly drivers, Interview, Paper prototyping, Vehicle design

1. Introduction

Elderly people experience a general degradation of their body functions, especially in visual and cognitive capabilities (West et al., 1997). According to the 2010 Census for US population, there were 40.3 million people who were 65 years and older, which is an increase of 5.3 million people since the 2000 Census (United States Census Bureau, 2011). This is a result of baby boomers - a period of American history with the largest birth rate - reaching maturity. For elderly drivers, the deterioration of their visual (Kline et al., 1992) and hearing capabilities (Hickson et al., 2010) significantly deters their driving abilities. There have been a number of studies to reveal the interrelation of age, visual acuity and cognitive function to investigate the role of sensory ability on age-cognation relations. Salthouse et al. (1996) found a strong negative relationship between age and corrected visual acuity, as well as a high proportion of the age-related variance in measures of speed, working memory, associated learning, and concept identification that share the measures of vision. For example, they confirmed a negative correlation between age and letter comparison, which indicated that older people's perceptual speed in comparing letters was slower than young adults. This may imply that vehicle designers should design a high acuity instrument cluster for the older drivers to assist them in information processing. It is also reported that driving performance was shown to deteriorate with increasing age, and this was exacerbated when drivers had visual impairment (Wood, 2002).

Due to recent breakthroughs in technology, new hardware has developed to eliminate such deficits. These technologies include: head-up displays, collision avoidance systems, navigation systems, and vision enhancement systems (Parel, 1998). However, the instrument cluster is especially essential because it delivers dynamic information regarding to velocity, rotation speed, warnings, fuel level, and mileage to the driver. Historical studies have demonstrated differences in how elderly drivers respond to instrument clusters in typical vehicles. In order to provide a better information processing environment for the elderly drivers, researchers have conducted studies in aspects of eye strategies, visual acuity, display preferences, and the appropriate position for displaying information. Pauzié et al. (1991) demonstrated that elderly drivers modify their visual strategies under guidance systems. On average, elderly drivers tend to glance at the guidance systems longer and with greater frequency than younger drivers. It was also found that elderly drivers spend less time looking at the road when utilizing a guidance system (Pauzié et al., 1991). It can be concluded that elderly drivers could spend equal amounts of time between the road and the guidance system, which may divert the driver's ability to properly respond to an emergency on the road. Kline et al. (1992) pointed out that older drivers have problems with stimuli that are dimly illuminated, near to them, rapidly changing or embedded in more complex arrays.

Since eye movement and eye attention shifts between out-to-window to the instrument cluster are critical in perceiving driving information as well as in driving safety, there were also research efforts to examine effects of different features of the instrument cluster on eye attention movements. Research on driving and dual task performance based on the instrument cluster, separation, and modality demonstrated that adjacent displays work the best in supporting driving performance in elderly drivers (Horrey and Wickens, 2004). A study to examine the sensitivity of eye movement for different in-vehicle task difficulties revealed that two measures (percent road center and standard deviation of gaze) were found to be more sensitive, robust, and reliable in testing the driving performance (Victor et al., 2005). Another study examining the effect of location and eccentricity of control panel displays on driving performance under different levels of mental workload was undertaken to find out the most appropriate position in the vehicle to display information without endangering the driver's safety (Wittmann et al., 2006). The study found that the ideal position for the control panel display was right above the instrument panel. Moreover, Owsley et al. (2011) found that it was necessary to make gauges more commonly used by drivers larger in size while either reducing the size of gauges that are infrequently used or removing them completely. It was also found that information should not be located in areas where the steering wheel or dashboard could obstruct the visibility of information. More research revealed that reducing clutter in the vehicle's display significantly enhances older drivers' driving performance. In addition to this, the addition of color elements and fill slightly improve performance (Kim et al., 2011). Other research efforts have tried to develop specific guidelines to design instrument clusters for elderly drivers, including, for example general location and size of the speedometer including text size (Yoon et al., 2012).

However, despite previous work on demonstrating degradation of mental and physical abilities in elderly drivers, as well as generating guidelines for designing cluster components, there is still a lack of specific guidelines for feature layouts in the instrument cluster for elderly drivers. Therefore, the objective of this study was to identify essential requirements and preferences of the instrument cluster features and layout for elderly drivers. A series of interviews and self-prototyping methods were applied in the study to find; 1) subjective area priority in the instrument panel; 2) component priority of cluster components in terms of importance and frequency of use; and 3) links of area and component priorities based on self-designed cluster prototyping using paper mockups.

In order to compare the potential requirement of the instrument cluster for different driver groups, comparisons between age and gender groups also were investigated. It should be noted here that the study was focusing on the U.S. driving population.

2. Method

In this study, participants completed a semi-structured interview while completing three sessions. This means that all participants were asked to answer several basic questions after completing a task, and depending on a participant's response, more questions may have been asked. The three interview sessions that participants were asked to complete were: 1) Session 1 - Identification of important areas of focus in the instrument cluster; 2) Session 2 - Ranking of the features of the instrument cluster by importance and frequency of use; and 3) Session 3 - Designing their own instrument cluster. All ranking orders, feature selections, design selections, instrument cluster designs, and question responses were recorded for further analysis.

2.1 Participants

A total of sixty participants were recruited for the study. There were two age groups of participants, including old (participants 65 years of age and older) and young (participants 20 to 30 years of age) as well as two gender groups (male and female). The participants consisted of 40 old participants (20 males and 20 females) and 20 young participants (10 males and 10 females). Old participants were required to be 65 years of age or older, have a valid US driver's license, have driven for a minimum of 10 years, and drive at least three times per week. Young participants were required to be between the ages of 20 and 30, also have a valid driver's license, have driven for a minimum of 3 years, and drive at least three times per week. All participants were fluent in English.

The mean age for old drivers was 70.8 years (71.6 years for males, 70.0 years for females) with a standard deviation of 5.18 years (6.39 years for males, 5.18 years for females). The youngest participant in the old group was 65 years of age and the oldest participant in the old group was 86 years of age. The mean age for young drivers was 24.3 years (25.1 years for males, 23.4 years for females) with a standard deviation of 5.8 years (3.41 years for males, 2.8 for females). The youngest participant in the young group was 20 years of age and the oldest participant in the young group was 30 years of age.

After obtaining research approval from the Institutional Review Board (IRB) participants were recruited and the study was conducted. Participants were recruited through posting flyers in senior centers, campus email, and word of mouth. Participants were paid for their time and efforts with $40.00 USD per hour.

2.2 Session 1: Area of importance

Participants were given a sketch of an instrument cluster that was of average shape and size of instrument clusters in most current vehicles. The instrument cluster was divided up into 4 rows by 5 columns, for a total of 20 numbered sub-areas, as shown in Figure 1. Participants were asked to circle the areas of the instrument cluster that they felt were important or a primary area of focus. Participants were asked to select at least 3 total areas (noting that one selected area could consist of more than one numbered area). Figure 2 (a) shows how participants ranked the area using the sketch of sectioned instrument cluster. Once participants had completed this task, they were then asked which of the selected areas was the most important, followed by the second and third most important and why. Participants were then asked why they did not find other areas of the instrument cluster important. Some of the other common questions asked were whether the selected areas were due to the design of the instrument cluster in their current vehicle, if they had a tendency to look left versus right, and if all they ever experienced problems viewing any areas of the instrument cluster (possibly due to steering wheel blockage, turn stalks, etc.).

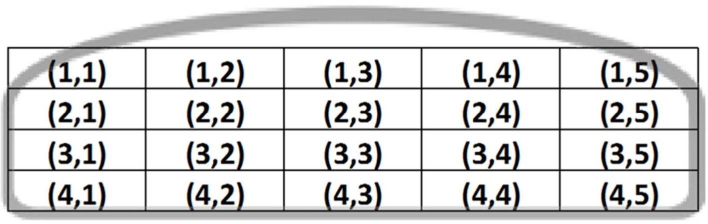


Figure 1. Sectioned instrument cluster and index of locations

2.3 Session 2: Feature importance and frequency of use

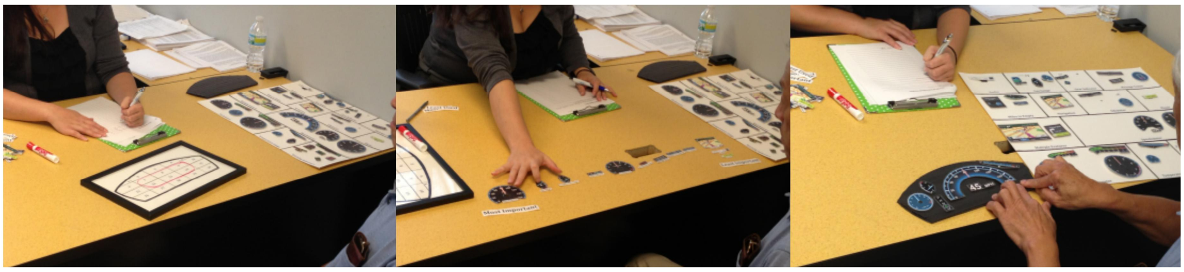
Labeled cardboard cutouts of most features found in instrument panels were placed in front of each participant, including speedometer, tachometer, odometer, fuel indicator, temperature gauge, media window, phone window, navigation, warning indicators, gear indicator, distance to empty indicator, and message center. Participants were then asked to line the features from the most important feature to the least important feature, thus ranking them. Participants were instructed to include all of the features shown, including those that they did not currently have in their vehicle (in this instance, participants were asked to estimate their importance as if they did have the features). Additionally, participants were instructed that if there were a feature not shown, a paper mockup would be made for their inclusion. Once participants ranked the features by importance, they were then asked why the top 5 features they selected were most important to them. Participants were also asked why the last 5 features they selected were least important. Some of the other questions asked were if the participant understood the functions of all features and if they had ever been involved in an incident that resulted from not paying attention to a feature.

The labeled cardboard cutouts were then shuffled up and placed in front of the participant again to ensure that the participant did not repeat same ranking as before. Participants were then asked to line the features from most frequently used to least frequently used, thus ranking them. Participants were then asked similar questions to those asked in the ranking of importance. Figure 2 (b) shows how each participant ranked the features in instrument cluster in order of importance and use frequency.

2.4 Session 3: Designing own instrument cluster

Upon completing all of the ranking information, participants were then asked to design their own instrument cluster. They were given a large assortment of features with various designs of each feature to choose from as well as a mockup of a blank instrument panel. All features and the instrument panel were scaled to be of average size. Appendix shows the feature set of instrument cluster components, which were given to participate to select and arrange in the blank instrument cluster. Participants were instructed that they must include a speedometer, odometer, fuel indicator, and all warning lights. All other features were considered optional. Participants were also given the option to make a paper mockup in order to include features not shown. If participants wanted a design not shown, a paper mockup of their preferred design was included for their use as well. Participants were then told to place the features in the instrument cluster where they felt it should be located. Participants were also given the option to include more than one feature in one location, thus creating a multifunctional menu for those features.

Once the participant had completed their design, they were asked a series of questions regarding their design. Participants were asked why they selected the features that they did, why they did not include specific features, why the participant chose the design that they did, what they didn't like about other designs of specific features, and why they placed features in the areas that they did. Depending on participant's feedback, other questions were often asked. Other common questions were if the design was similar to that of their current vehicle and would they include specific features if given the option of being able to turn off those specific features. Figure 2 (c) shows how the participants created the self-designed prototype.



(a) (b) (c)

Figure 2. Interview sessions: (a) area importance in cluster; (b) feature importance and use frequency; and (c) designing own instrument cluster

3. Results and Discussion

3.1 Session 1 - Location value assessment

Rank data for the 20 sub-areas (4 rows by 5 columns) of the instrument cluster was collected for each subject (see Figure 1). Since the rank data is a form of non-parametric data, a series of Kruskal-Wallis tests was employed to identify the statistical differences of location values for age groups and gender groups. Results revealed statistical differences on perceived importance of location in cluster by each area ($\chi^2_{19}=287.04$, $p<0.0001$) and age group ($\chi^2_{1}=6.24$, $p=0.013$). The effect of gender group was marginally significant ($\chi^2_{1}=3.21$, $p=0.073$). In general, both young and elderly drivers rated the center areas (2.3 and 3.3) are most important (median rank=1) followed by surrounding areas (2.2, 2.4, and 3.4 with median rank of 2 as well as 3.2 with median rank of 3.5). However, it was observed that elderly drivers rated higher location priorities for upper-center areas (median ranks of 3 and 2 for the area 2.2 and 2.4, respectively, while ranks of 4 for both areas 3.2 and 3.4) while young drivers did for lower-center areas (median ranks of 4 and 3.5 for areas 3.2 and 3.4 while ranks of 2 and 2.5 for areas 3.2 and 3.4, respectively). The interview comments were supportive to infer this result. That is, it might be a result of elderly drivers being less willing to shift their eyes over longer distances (i.e. from the road view through the windshield to the lower locations to read information in cluster). Young drivers rated lower areas to be more important than the upper area in cluster. This also can be confirmed that young drivers provided a least ranking on top corner area (median rank of 10.5 for both areas 1.1 and 1.5) while elderly drivers rated the areas to be similar to other lateral areas. This may imply that most critical or warning information for driving should be presented in upward area in the instrument cluster for elderly drivers in order to assist in detecting them effectively.

When comparing the rankings between gender groups for young drivers, it was found that male drivers ranked right-center areas (2.4 and 3.4) to be similar to center areas (2.3 and 3.3). It may support that speedometer needs to be placed at the center area (areas 2.3 and/or 3.3) or right-center area (areas 2.4 and/or 3.4) since the speedometer was identified as the most important and frequently used instrument cluster component (see next session results).

3.2 Section 2 - Component value assessment

Based on the collected ranking data of the twelve cluster components, median rank of the components was calculated for age groups. Table 1 shows the median ranks of importance and use frequency on the twelve cluster components aggregated for all driver groups. Obviously, most drivers rated the speedometer as the most important and frequently used feature, followed by fuel indicator and gear position indicator. Also, it was observed that advanced features including audio, phone, and navigation features were ranked the lowest, which are typically presented in vehicles' center stack. This may be due to the fact that features are not included in traditional clusters and that drivers may believe including the features in cluster would cause clutter effects or redundancy.

Table 1. Ranks of cluster component in terms of importance and frequency of use

Median ranks ($\tilde{M}$) for cluster components	
Importance of component	Use frequency of component
Speedometer (1) Fuel gauge (2) Gear position indicator, warning icons (4) Engine temperature (5) Miles to empty (6.5) Tachometer, odometer (7) Message window (8) Navigation (9) Phone, audio (11)	Speedometer (1) Fuel gauge (2) Gear position indicator (5) Engine temperature, warning icons, miles to empty (6) Tachometer, odometer (7) Message window, navigation (8) Audio (10) Phone (11)

However, a series of Kruskal-Wallis tests revealed differences in rankings between driver groups for the two criteria. Table 2 shows the list of components that were ranked differently in terms of importance and Table 3 lists the components that were ranked differently in terms of frequency of use. Both had a significance level of $\alpha < 0.05$. As shown in the Tables 2 and 3, the subjective importance and frequency of use for tachometer are ranked differently between driver groups. In general, elderly drivers and female drivers feel that the tachometer is less important and use it less frequently than young drivers and male drivers do. More so, elderly female drivers ranked the tachometer similarly to the advanced features, such as the phone interface (median ranks are 11 for importance and 12 frequency of use). This may mean they believe the tachometer is not important and they do not look at it purposefully. It was revealed during the interview that most senior female drivers participated in the study expressed that they do not understand what the tachometer shows or how it works. This could support that the rank of tachometer rated lower in elderly and female drivers group. They also believe that the absence of the tachometer would not cause any safety problems while driving. This may imply that the tachometer could be removed in specific clusters designed for elderly female drivers in order to save space and attract attention to other critical features.

Table 2. Components with different rank of importance for different driver groups

Drivers	Comparison	Component	Median rank	χ^2	*p*-value
All	Age	Tachometer	6.5 (Y) < 9.5 (O)	15.37	<0.0001
		Warning icons	4 (O) < 5 (Y)	5.54	0.0185
		Message window	5.5 (O) < 10 (Y)	15.37	<0.0001
	Gender	Not significant for all components			
Young	Gender	Not significant for all components			
Old	Gender	Tachometer	8.5 (M) < 11(F)	5.59	0.0181
		Miles to empty	5.5 (F) < 7.5 (M)	5.52	0.0188

Table 3. Components with different rank of frequency of use for different driver groups

Drivers	Comparison	Component	Median rank	χ^2	*p*-value
All	Age	Tachometer	6 (Y) < 10 (O)	7.42	0.0064
		Fuel indicator	2 (O) < 3 (Y)	8.09	0.0044
		Message window	6.5 (O) < 9.5 (Y)	8.19	0.0042
	Gender	Tachometer	6 (M) < 9 (F)	4.09	0.0432
Young	Gender	Fuel indicator	2.5 (F) < 5 (M)	4.50	0.0339
Old	Gender	Tachometer	7.5 (M) < 12 (F)	4.55	0.0328
		Engine temperature	4 (M) < 6 (F)	5.20	0.0226
		Miles to empty	4 (F) < 8 (M)	6.71	0.0096

It was also observed that rankings of the message window are higher for elderly drivers than young drivers. The median rankings of the message window for elderly drivers were 5.5 and 6.5 while it was 10 and 9.5 for young drivers for importance and frequency of use, respectively. The reason of this difference was inferred from participants' comments during interview. Elderly drivers expressed a desire to read information in the format of text to better understand messages from the vehicle while young drivers believe they can sufficiently understand the vehicle's status through warning icons and further stated that text messages are redundant. Since elderly drivers may have difficulties with detecting and decoding symbolic icons due to degraded physical and cognitive abilities, they seem to prefer detailed text information despite of sacrificing space in cluster area and potential problems due to clutter effects. This might yield a design guideline that cluster designs for elderly drivers needs to provide critical vehicle messages in the form of detailed text.

In addition, another trend on different levels of concern for fuel management was also observed from the analysis. Rankings on cluster components regarding fuel level such as 'fuel indicator' and 'miles to empty' were higher in elderly and female drivers than young and male drivers.

3.3 Session 3 - Paper prototyping

Using paper mockups of the cluster components and an empty cluster panel, participants selected desired features and designs

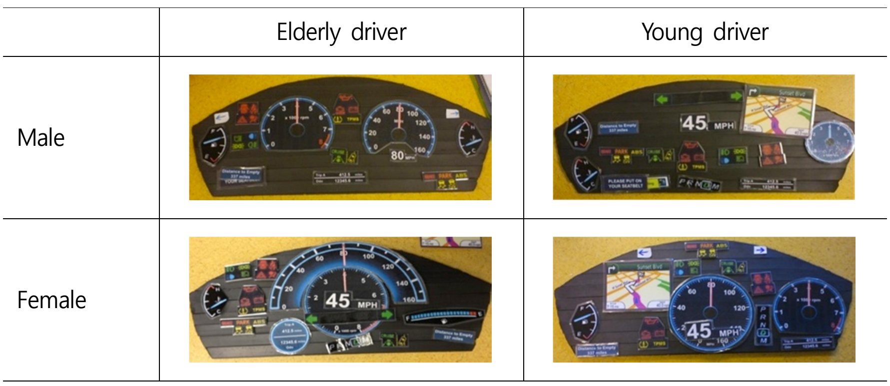


Figure 3. Sample of self-designed cluster prototypes

and arranged them in the panel. Figure 3 shows some sample images of the self-designed cluster prototypes. Based on the collection of the paper prototypes designed by participants, data on the selection of feature for each function was encoded for different driver groups (see Appendix for feature set, including images and descriptions). The locations of selected features in the panel also were encoded.

3.3.1 Speedometer - Gauge shape

In general, elderly drivers preferred the half-circle ("rainbow shape") gauge (50% for SPD-G3) to the circle shape gauges (30% for SPD-G1 and 15% for SPD-G2) while young drivers showed similar preferences between the half-circle and full circle feature (20%, 35%, and 35% for SPD-G1, G2, and G3, respectively), even though the text sizes for speed labeling of the three alternative speedometer gauges were same. Ten percent (10%) for both young and elderly drivers did not select any of gauge types of speedometer. The elderly participants subjectively rated the semi-circle shape gauge (SPD-G3) as "attractive to the eyes", "visually appealing", "easy to see at night", "easy to read", and "good size" even though it is not what has been used in conventional vehicles. Participants arranged the speedometer at the center of cluster (78% and 72% for young and elderly driver, respectively), which is in line with findings in location and component value assessment sessions. Drivers felt the speedometer is most important feature in cluster and the most important area in cluster is the center. However, 17% of the young drivers placed it on right-center area and 22% of the elderly drivers did on top-center area, which were also similar to patterns found in the location value assessment session.

3.3.2 Speedometer - Digital readout

Results revealed that the general preference on the digital readout was the smaller text size (SPD-D2), which may serve supplementary information of gauge shape speedometer in order to obtain accurate speed. However, the percent of not including digital speedometer is higher in the elderly driver group (28%) than the young driver group (5%). During the interview, elderly drivers expressed concerns in using the digital speedometer, such as redundancy and confusion with the gauge speedometer, which might cause distraction while driving. Results of feature arrangement are similar to results of gauge-type speedometer arrangement.

3.3.3 Tachometer

As found in the component value assessment session, many elderly drivers (40%) did not want to include the tachometer in the instrument cluster. In particular, 55% of the elderly female drivers did not select the tachometer because they do not understand what information it displays or how the tachometer works. In the cases for selecting the tachometer in the self-cluster design, both young and elderly drivers preferred the gauge type (TACH3, 4, or 5) to the bar type design (TACH1 and TACH2). None of participants selected a large horizontal bar type tachometer (TACH1). While young drivers placed the tachometer in either the right or left center area, elderly drivers placed it in the center or the left side of center area in cluster panel.

3.3.4 Fuel gauge

Both majority of young (75%) and elderly driver (63%) groups preferred the 90˚ gauge feature (GAS3), followed by bar readout (GAS1) with approximately 20% of selection for both group. Participants positioned the fuel gauges in either the left or the right side of the instrument cluster. Ten percent (10%) of young drivers and 19% of elderly drivers arranged the fuel gauge at the center of cluster in horizontal plane. However, in general, both driver groups preferred the right side of cluster for the indicator (approximately 56% for right side area vs. 35% for left side area).

3.3.5 Coolant temperature gauge

Similar to fuel gauge, a general preference of 90° Gauge feature (TEMP3) for both age groups was observed (60%), followed by bar readout (TEMP1) with 10~15% of selection. Interestingly, 30% of young drivers and 20% of elderly drivers did not select any feature of coolant temperature gauge. However, participants expected the temperature gauge to be located on the left side (approximately 70%) rather than the right side (30%) in the instrument panel.

3.3.6 Gear position indicator

More than half of the participants (50% of the young drivers and 58% of the elderly drivers) selected the horizontal bar shaped gear indication (GEAR1). The vertical bar feature (GEAR3) was selected approximately 30% of drivers and the single letter gear indicator (GEAR2) was the least selected. More than 50% of participants suggested placing the gear indication at the center bottom area of the instrument panel. Otherwise, participants arranged the indicator at right side area of cluster while few drivers preferred it on left side. This might be due to a spatial compatibility between the physical object of gear lever in drivers' perspective and position of the indicator in cluster area. However, while the physical gear lever for most current automatic transmission vehicles are designed to move along vertical line, majority of elderly drivers selected horizontal bar shared gear indicator in cluster (GEAR1), which is not visually compatible with physical gear lever movement. This might be due to that the participated elderly drivers from US population are adapted to use the stalk shaped gear lever attached to steering column, which usually was equipped in old vehicles and moving along horizontal plane in viewpoint of drivers.

3.3.7 Miles to empty indicator (drivable range indicator)

The simple text type indicator (M2E3) was primarily selected (approximately 70%) rather than the gauge (M2E1) or graphical shape (M2E2) for both age groups. Twenty percent (20%) of drivers did not include the feature in their own design. Participants arranged the indicator on either the right or the left side or the lower area of the cluster panel. Most drivers that chose to include the miles to empty indicator preferred to have it located near the fuel indicator or odometer.

3.3.8 Odometer

All participants were required to include the odometer in their cluster mock-ups. Among different features, stand-alone features (ODO2 and ODO3) were preferred to the feature associated with other graphics (ODO1: 5~10%). In specific, 70% and 50% of young and elderly drivers, respectively, choose the vertically arranged feature (ODO3). More than 50% of the participants expected the location of odometer to be at the lower central area of the instrument panel.

3.3.9 Message center

Most participants preferred a simple text window with comparably narrow width (MSG1 with approximately 50% of selection for both age group). The feature using graphics (MSG3) was least preferred (5~10%) because it would require additional thought for decoding information after perceiving it. In general, the feature was arranged around the lateral area of the panel but higher percentages of lower and left side area were observed.

3.3.10 Advanced functions (navigation, phone, and audio windows)

The majority of the participants did not want to include these advanced features in instrument cluster: The percentages that chose not to incorporate the features are: Navigation - 70% of young drivers, 58% of elderly drivers; Phone - 60% of young drivers, 70%

of elderly drivers; and Audio - 50% of young drivers, 75% of elderly. Participants expressed concerns that it would cause clutter effects. It also was expressed that this information was preferred to be located in the center stack instead of instrument cluster.

3.4 General preferences on component layout

Based on findings of preferred locations of cluster components from the self-designed cluster using the paper mockup as well as associating with findings in location and components value assessment session, a general layout of the cluster components for elderly drivers was drawn. Figure 4 illustrates the general preferences on cluster components layout, which shows the areas of each components where the majority of participants positioned the component. As shown in the Figure 4, the top area may need to include warning icons, which are critical information in terms of driving safety. Since elderly drivers expressed reluctance to move their eye attention for comparably long distance (e.g., from out to windshield view to bottom area of cluster), the critical information such as tire pressure monitoring alarm need to be positioned in top area of cluster so that the drivers could detect it more effectively.

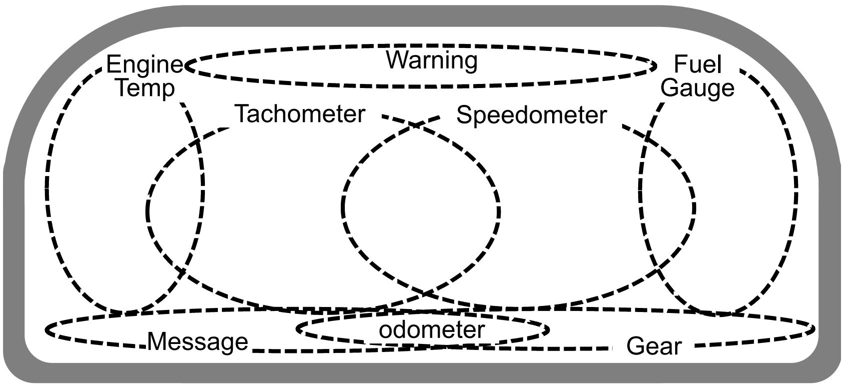


Figure 4. General preferences on cluster component layout

The general preferred layout might demonstrate the elderly drivers' mental stereotypes for cluster layout. For example, the general left side area includes engine temperature gauges and tachometer, which represent activities and status of engine in perspective of driver. The right side area including speedometer and fuel gauge may represent driving status. Similarly, it can be inferred that the drivers expect the bottom area may represent vehicle status such as system message, odometer, and current gear position. A spatial compatibility issue (Wickens and Hollands, 2000) also seems to be involved in this general preference. That is, the driving information such as speed and fuel level indicator is allocated in right side area where the accelerator peal is positioned. As mentioned previously, the gear position indicator also was allocated in right bottom area where the physical position of gear lever is located in perspective of drivers. This spatial conformity may increase driving performance and safety by promoting information proximity between physical objects and visual components in cluster, especially for elderly drivers whose cognitive activities are getting degraded. However, the general layout depicted in Figure 4 is based on primarily selected area for each component among participants. That is, there were substantial numbers of variations in the cluster layout design for different drivers as well as their expectations.

4. Conclusion

The study provided a general expectation of instrument cluster features and layout for elderly drivers through a series of interviews and paper prototyping methods. The results of the study support findings in previous studies that elderly drivers have different preferences in instrument cluster features compared to young drivers due to degradation of physical and mental abilities. In general, the differences include: 1) elderly drivers prefer the upper area from the horizontal centerline in the instrument cluster panel while young drivers prefer the lower central area. This could result from elderly drivers attempt to reduce their eye attention movements from the windshield to critical features in the instrument cluster; 2) elderly drivers prefer text information of the vehicle's status to symbolic/iconic information because the use of graphical information requires additional cognitive activities in decoding the information as well as more visual attention to detail; 3) especially, female elderly drivers prefer not to have the tachometer in the instrument cluster because most of elderly female drivers do not understand what information the tachometer displays or how it works; 4) elderly drivers and female drivers have more concerns in fuel management than young drivers and male drivers; and 5) both young and old drivers prefer not to including advanced functions in the instrument cluster, such as navigation, audio, and phone information windows. They believe it would increase complexity in the instrument cluster yielding visual clutter effects. However, young drivers were more open to include the advanced features in the instrument cluster than elderly drivers.

The study has limitations to be overcome in future studies. First, the study was conducted throughout a series of semi-structured interviews and paper prototyping, which means there would be subjective biases in collecting and interpreting the data as well as it may not be guaranteed that subjective preference data is inline with actual objective driving performance data. In addition, even though rank data was used in statistical analyses for obtaining quantitative results, the statistical power of using the nonparametric data would be lower than the use of parametric data. Therefore, more elaborated experiments to validate the results of current study are required using a high-fidelity driving simulator or an actual vehicle. Eye tracking devices might be used for collecting more detailed information on driver's eye attention profiles and other driving performance data. This data should be collected and analyzed in the experiment to develop a more detailed and objective guideline to design an instrument cluster for elderly people.

Second, the number of features examined in the study was limited. The features in the study were collected from a preliminary benchmarking study on similar vehicles of a specific type in the current market and they may not involve more advanced features to be introduced in near future. Thus, it would be beneficial to include more futuristic cluster component features in future studies.

Third, two types of driver groups were investigated to compare their expectations of the instrument cluster, including age and gender groups. However, even though it was not presented in the study, it was observed from the interview that there might be other criteria to classify drivers. For example, different driver's background such as engineer versus non-engineer seems to affect their preferences in cluster features and layouts due to differences in their mental models (stereotypes). In this regard, it also would be interesting to find other drivers classification criteria and associated cluster features, beyond age and gender groups.

The use of LCD instrument cluster is increasing and is expected to apply in many future vehicles, which would be completely different to current instrument cluster with fixed gauges and needles. This means it will be possible to design flexible cluster features and layouts for different drivers and driving contexts. Providing different levels of information complexity in the instrument cluster or adaptive cluster (change of cluster feature layout triggered by vehicle system based on context of driving and driver) would also be feasible. That is, it might be possible for vehicles to equip a function to adjust level of information complexity in the instrument cluster so that a wide range of drivers with different expectations in the instrument cluster, including age and gender groups as well as background and driving skills. The feature already has been applied to couple of luxury vehicles in current market but it could be more affective if the levels are designed based on the results of the present study. For example, the lowest complexity level of instrument cluster may include only speedometer, fuel indicator, and essential warning signs. The next level of complexity in the instrument cluster may include more component and features such as gear indicator, coolant temperature, and so on. Finally, the highest complexity level could include advanced functions such as navigation, audio, and/or phone call display in the cluster.

With this flexibility in cluster design in mind, more elaborated studies are required to develop guidelines for designing effective LCD featured instrument cluster, including unit component (e.g., size, color, brightness, shape, etc.), layout, and new interaction methods. However, these paradigm changes in the vehicle instrument cluster would be beneficial for elderly drivers, as the number of elderly drivers will increase and they could use distinctive cluster features and layouts. The future studies need to consider human factor issues for elderly drivers. Throughout the studies and efforts, it is expected that elderly drivers can drive their vehicles more safely and effectively.

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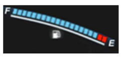
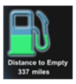
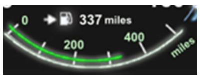
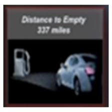
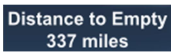
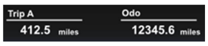
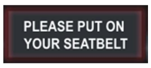
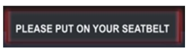
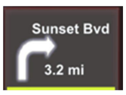
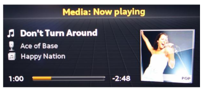
- Appendix -

Function	Name	Design	Feature description
Speedometer - gauge	SPD-G1		270° gauge with numbering every 20MPH and notches every 10 MPH for speed
	SPD-G2		Full circle gauge with numbering every 20MPH and notches every 2MPH for speed
	SPD-G3		Half circle gauge with numbering every 20MPH and notches every 10MPH for speed
Speedometer - digital	SPD-D1		Large digital readout of speed
	SPD-D2		Small digital readout of speed
Tachometer	TACH1		Large horizontal bar with color coding for RPM
	TACH2		Small horizontal bar with color coding for RPM
	TACH3		Large full circle gauge for RPM
	TACH4		Small full circle gauge for RPM
	TACH5		Medium sized 270° gauge for RPM
Fuel gauge	GAS1		Bar readout with 20 boxes for fuel
	GAS2		Small circular gauge ranging from 0 to 5 for fuel
	GAS3		90° gauge with notches every quarter tank for fuel
	GAS4		Pictorial representation of fuel with "Distance to Empty"
Coolant temperature gauge	TEMP1		Bar readout with 20 boxes and color coding for engine temperature
	TEMP2		Small circular gauge ranging from 0 to 5 for engine temperature

Function	Name	Design	Feature description
Coolant temperature gauge	TEMP3		90˚ gauge with notches with color coding for engine temperature
Gear position indicator	GEAR1		Horizontal bar for gear indication
	GEAR2		Single letter for gear indication
	GEAR3		Vertical bar for gear indication
Miles to empty indicator	M2E1		90˚ gauge with numbering every 200 miles and notches every 100 miles for estimated distance before needing refueling
	M2E2		Pictorial representation with digital readout of estimated distance before needing refueling
	M2E3		Digital readout of estimated distance before needing to refueling
Odometer	ODO1		Circular display with trip meter and odometer readouts stacked
	ODO2		Side by side digital readout of trip meter and odometer
	ODO3		Stacked digital readout of trip meter and odometer
Message window	MSG1		Digital readout for safety and maintenance messages
	MSG2		Shorter and longer digital readout for safety and maintenance messages
	MSG3		Circular icon with pictorial representation for safety and maintenance messages
Navigation	NAV1		Detailed map including street names, arrival time, and current speed
	NAV2		Turn by turn displaying street name and distance to street

Function	Name	Design	Feature description
Phone	PHONE		Digital readout with phone icon and status of phone call
Audio	AUDIO		Digital readout with track name, band name, album cover, and track length