DYNAMIC VISUAL PERFORMANCE CHARACTERISTICS OF ELDERLY DRIVERS

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ABSTRACT

The objective of the present study was to understand how the visual and mental processes work in tandem to affect the overall information processing capability of the individual, especially the older population, in a dynamic visual task such as driving. More specifically, our aim was to understand how the different parameters related to display of visual information in an in-vehicle display system and the age of the subject affect the information processing performance. The effects of stimulus distance, target size, display time, bits of information and the age group of the subject (young versus old) on the reading performance (information processing ability) under photopic and scotopic viewing conditions were thoroughly investigated in this study. Fifty-six individuals (28 young, 28 elderly) from the Montgomery County region were tested in the study in a mixed factorial repeated measures design with age as between subjects and the other independent variables as within subjects. The dependent variable was the reading score, i.e., the number of letters correctly identified. Results obtained from this study revealed that all of the independent variables had significant effects on the reading performance of the participants, except ambient illumination. Specifically, age has an important influence on the specific values of the design parameters. Also, these parameters interact among themselves so that one can be used to compensate for the other. These results can be used for developing the most relevant and optimal in-vehicle visual displays for the older population.

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1.0 Introduction

Driving is an important and indispensable part of everyday living for all segments of the population, and holds an even greater significance for the elderly due to their limited mobility otherwise. Indeed, studies have reported that automobiles serve a very important role in serving the transportation needs of the 65 and older age group (Jette & Branch, 1992). Despite these facts, every year a significant number of elderly individuals either give up their driver's license or terminate all driving activity. In the light of this background, not only the community on the whole has to bear a significant cost for fulfilling the needs of the elderly, but the elderly themselves also suffer from a loss of independence and self-esteem.

Furthermore, older drivers constitute the most rapidly growing segment of the driving population in the US. In 1988, 12% of the U.S. population was age 65 years or older. By 2020, the proportion of the population age 65 and older is expected to increase to 17%, with 50 million persons of this age eligible to drive. Almost half of these older persons will be age 75 or older (Transportation Research Board, 1988). Similar changes are occurring throughout the world.

Studies suggest that increasing age has an adverse effect on the driving ability due to age-related losses in visual perception (Bailey & Sheedy, 1988; Owsley & Sloane, 1990; Schieber, 1994a), cognition (Cerella, 1985; Denney & Palmer, 1981) and psychomotor functionality (Kausler, 1991; Marottoli & Drickamer, 1993; Yee, 1985). These changes may further influence driving safety of the elderly. For example, older drivers constituted 12% of all traffic fatalities and 12% of all vehicle occupant fatalities in 2002 (NHTSA, 2002). Furthermore, older drivers are reported to have a higher number of crashes per distance traveled than either young or middle-aged drivers (Stamatiadis and Deacon, 1995).

Impairment in visual perception is of particular interest and has been cited as a likely contributing factor to the increased crash rates of the elderly (Shinar and Schieber, 1991). Also, vision is the primary sensory channel responsible for up to 95% of driving-related inputs (Shinar and Schieber, 1991). However, visual performance are most often deteriorated with advanced age, and thus, effort should be directed to study those driving-related visual skills that are most susceptible to age-related visual degeneration most prevalent among the elderly.

Another very important aspect of designing for the elderly is related to understanding the mental processes which govern the processing of information, ultimately resulting in motor response. Both visual and cognitive functioning impairments are associated with driving cessation (Forrest et al., 1997; Stutts, 1998). While designing visual information display systems, which ultimately affect the driving behavior, it is necessary to take into account the entire information processing cycle starting from perception to processing to decision and response. Although we cannot hope to completely overcome the detrimental effects of aging by modifying the environmental (or design) variables, we can certainly mitigate their effects by designing for them, and is the goal that this study is intended to help accomplish.

1.1 Objective of Proposed Research

The future generation of vehicles will be equipped with many on-board systems which provide various types of information to the driver in order to enhance safety and comfort, for example, rear and front end collision warning systems, night assistive vision, etc. But for these systems to perform the desired functions, information provided by them must immediately be understood by the driver, so that the necessary response can be taken. Furthermore, the amount of information that the driver can accurately process and respond to in a given time interval is limited, and even more so in the case of elderly, due to various types of age-related declines. The objective of the present study was to investigate how the visual display systems in present and next generation vehicles should be designed so that it becomes possible to accommodate the elderly individuals' limited capability, in order to enable optimal driving performance.

In a study conducted by Campbell et al (1993), it was found that problems related to vision were the single most powerful predictors of driving cessation. This is not surprising considering the fact that to respond appropriately to all manner of stimuli in the roadway environment, a driver has to first detect and recognize a wide variety of objects and potential hazards (pedestrians, other vehicles, etc.), both of static and dynamic nature. Static stimuli are those which do not change their position with time, for example, a stop sign, whereas dynamic are those which do so, for example a moving vehicle or pedestrian. Hence, vision is *the* most important sensory system to be taken into account and the relevant design guidelines for which should be formulated. It was our endeavor in this study to determine these guidelines with regard to display of information which would help present information to the driver in an optimal manner. Additionally, vital information as regards to visual deficiencies and how to design for those limitations was obtained from the results of this study. More importantly, this research will have significant implications for understanding age-related changes in information perception and processing.

1.2 Approach to the proposed research

Since the visual system is the primary source for the information that ultimately becomes available for processing and guides the motor response, the independent variables were derived from factors which affect it. Specifically, they were display time, target distance, ambient illumination, age-group of the subject and letter size. How we derived these independent variables is further detailed in Section 4.0 below. Since the objective is to measure information processing performance, we chose letters to represent the information to be processed, and the dependent variable was the reading score, i.e., number of letters correctly identified from a random set.

Initially, the participant looked at a far target which simulated the infinity viewing distance during normal driving. They were then made to focus, as they would during a normal driving task when some information is presented on the vehicle visual display, on desired target screens at different distance levels, simulating an on-board display location and a heads-up location. Parameters related to display of information, such as letter size and display time alongwith ambient illumination, were then varied so that their affect on processing performance could be measured.

2.0 Literature Review

2.1 Accommodation

In terms of visual performance, accommodation represents one of the initial responses of visual system. The accommodative system adjusts the refractive power of the eye in order to provide a clear retinal image of objects at various distances. The accuracy of this process determines how much information is extractable from visual stimulation and is therefore essential to virtually every visual task and processing of visual information. Moreover, it is widely known that accommodation is significantly affected by age-related changes in eye structure (Atchison, Capper and McCabe, 1994). Aging has been seen to increase the refractive index of the lens cortex (Primrose, 1972). Age related decline in accommodation amplitude has been observed leading to presbyopia (e.g., Kline and Schieber, 1985). This decline leads to reduced flexibility of the lens. A decline in amplitude of accommodation from an average of about 14 D at 8 yrs to less than 2 D after the age of 50 has been observed (Moses, 1981). It is also pertinent to note that when the stimulus changes from an object at a great distance to one much closer, the eye starts to change accommodation in the correct direction after a reaction time of 360msec ±90msec. Furthermore, the reaction-time for far-to-near focus is about 20 msec longer than that from near-to-far on the average (Campbell and Westheimer, 1960). The elderly not only suffer from a decreased amplitude of accommodation, but also its reduced speed. This decrease (dynamic visual characteristics) can be attributed to stiffening of the eye lens and weakening of the ciliary muscles which control the curvature of the eye lens. In this regard, the distance and time for which information is presented has the potential to significantly influence processing performance. Previous research conducted by Lockhart, Atsumi, Nam and Ghosh (2004), pointed to this effect where static visual acuity increased with increasing distances. The following chart (Figure 1) depicts this effect found in the results of that study:

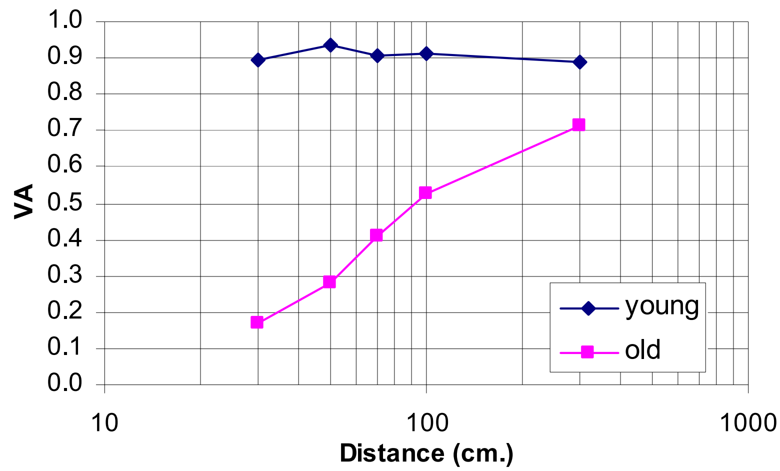

Figure 1: Effect of target distance on Static Visual Acuity

We can see from the above chart that increase of distance has a marked effect on the performance of elderly individuals. Static Visual Acuity (VA) in this study was measured by means of Landolt circle chart and ranges from a minimum of 0 to a maximum of 1. In this study, only the ability of the eye to discriminate details at a particular distance was studied (static VA), which is important in correctly perceiving the target, but information processing and accommodation was not taken into account. In general we may characterize the actions involved in *reading* a visual display into four items (Atsumi, Kanamori and Miyao, 2003):

a. Directing gaze to screen: Eye movement time

b. Preparing to read: Accommodation time

c. Reading visual information: Information processing time

d. Gaze returning to origin: Eye movement time

Hence, a through d is the time required for reading the visual display, and the older the people are, the more time they require. This will be an important consideration in designing the time for which the information is presented to the user. The time factor “b” may also be related to the tonic position of the accommodative system, i.e., its resting state when no stimuli are presented. When an observer sits in a totally dark room the far point of his eye is not localized in the same point in space as that obtained when his visual field is highly structured as in daytime condition. Whenever visual stimulation is degraded, as it is at night or in bad weather, the eyes tend to adjust involuntarily for a distance determined by the individual’s resting or tonus state. This resting focus, also referred to as the dark-focus and tonic accommodation, usually corresponds to an intermediate distance. Additionally, Leibowitz and Owens (1978) found that accommodation rests at an intermediate distance that shows wide interindividual variation. Certain studies have pointed to the fact that the accommodative efforts required to bring an object into focus, as well as the associated time and errors in focus, increase with increase in distance of an object from the position of tonic focus (Wolfgang Jachinski, 2000). Hence distance and time are important parameters affecting the readability of visual displays.

2.2 Target luminance levels

In addition to distance, the visual performance is influenced by a variety of complex stimuli provided by the target in terms of size, contrast, and spatial orientation. Parameters such as these may also serve as stimuli for accommodation (Toates, 1972). In a study conducted by Anderton et al (1974) which investigated luminance effects on legibility information signs, it was found that legend recognition was not adequately better for luminances greater than 20-100 cd/ m^2. Hence the luminance levels of target stimuli (letters) presented to the participants should be kept within this range for different ambient illumination conditions. Furthermore, while deciding on target luminance levels and chromaticity, we have to take into account the luminance characteristics of display screens being used present generation vehicles.

2.3 Stimulus size

Studies also suggest that among the various depth cues, changes in target size alone can result in substantial changes in accommodation (Kruger, and Pola, 1985). This may be due to indirect relationship between the target size and influences of accommodation – i.e., changing size is not a particularly effective stimulus, but that it influences accommodations indirectly through changes in apparent distance. This apparent distance can interfere with the actual distance at which a target is present, and must be controlled for. An effective way to control for distance is to use instead angle subtended by the letter at the eye. Studies have been conducted to examine the effect of angular letter size on reading performance (Howell and Kraft, 1960; Bouma et al.,1982; Legge, Pelli, Rubin and Schleske, 1985). A consistent finding among these studies is improvement of legibility and reading speed with increase in angle subtended by the letter at the eye. Legge et al. (1985) reported best performance within the range 0.3˚ - 2˚. Also, the size of a letter is proportional to the stimulus energy that it projects. Larger sizes lead to more informational energy being transmitted to the subject. Indeed, there may exist an optimal level for this energy, beyond which performance will not be affected significantly by an increase in the level of this energy, i.e., the size of the letter.

2.4 Ambient Illumination

Another design parameter considered in this study is related to ambient illumination conditions, i.e., (daytime vs. nighttime), since driving has to occur during both times. The daytime and nighttime levels will be represented by 1000 lux and 5 lux respectively based on studies conducted by Lockhart et al. (2004). The ambient illumination also has physiological effects on the human eye such as dilation of the pupil. The maximum dilation attained by the pupil begins to decline with advancing age (i.e., senile miosis). Under conditions of dim illumination, the resting diameter of the pupil falls from approximately 7 mm at age 20 to around 4mm at age 80 (Lowenfeld, 1979). This reduces the amount of light which reaches the retina and can have detrimental effects upon performance. On the other hand, several recent studies suggest that smaller pupil size may actually benefit older observers by acting to minimize the emerging optical imperfections of the aging lens (Sloane, Owsley and Alvarez, 1988). The results of this study can shed light on which of these effects is dominant, and also how other display parameters need to be modified for different ambient conditions. Ambient illumination may also play a role in reducing the overall contrast, and hence the visual acuity, afforded by a visual display, and thus affect reading performance.

2.5 The Information processing paradigm - dependent variable

The perceptual system tolerates a fair amount of retinal blur, making accurate accommodation often unnecessary for good acuity (Moses, 1981). Additionally, cognitive factors have been shown to affect accommodation distance (Malstrom and Randle, 1976).

In general, the human-machine interface is judged efficient to the extent that the transmission of information can occur at rates that are sufficiently high to accomplish the task for which the system was designed quickly and accurately. Information transfer in human communication systems is dependent on a number of variables, including basic sensory resolution, stimulus-response compatibility, encoding strategies, learning, memory, and perceptual organization (Miller, 1956; Deininger and Fitts, 1955; Pollack and Ficks, 1954). In this study, basic sensory resolutions associated with accommodative processes will be investigated further by controlling all other variables utilizing "information theory." That is, by randomly assigning alphabet characters, and not going over the bit capacity associated with human visual attention processes, we can control extraneous variables effectively.

Information processing is associated with encoding, transferring, and decoding. In terms of encoding, Shannon's "Information Theory" (1951) provided us with bit assignment of each letters and Miller's "Information Transfer Rate" (1954) provided us with capacity of transmission of a signal. Miller (1952) in his study provided valuable insights into the paradigm of information measurement. He elucidated the concept of amount of information by giving an example of a child who was told of a piece of candy lying in one of the 16 boxes. The child would be able to consume the candy if he lifted the proper box. Anything which facilitates in reducing the number of boxes (possible outcomes) would provide him information. The question of whether the information was true, valuable, understood or believed does not arise – only the amount of information mattered. The amount of information is dependent on the fraction of the alternatives that are removed, not the absolute number. The amount of information present in a message that reduces k to k/x is $\log_2 x$ bits. An example could be used to illustrate this point – When the child's 16 boxes are reduced to two, then x is 8 and $\log_2 8$ is three bits of information. Thus, with 4 bits of information, the child will know exactly where the candy is hidden.

The source determines a message from a set of k alternative messages that it might send. Consequently, every time the source selects a message, the channel has to supply $\log_2 k$ bits of information in order to convey to the receiver what selection was made. The receiver can anticipate the messages having high probability and in this scenario less information would have to be transmitted. Simply put, frequent messages should be the short ones. The amount of information that ought to be transmitted for a message having probability p selected from a set of 1/p alternative messages is: $-\log_2 p$.

The average amount of information per message expected to be transmitted from the source is denoted by:

$H(x) = \text{the mean value of } (-\log_2 p_i)$

$$= \sum_{I=1}^{k} p_i \left(-\log_2 p_i\right)$$

H(x) which is the bits per message is defined as the mean logarithmic probability for all messages from source x:

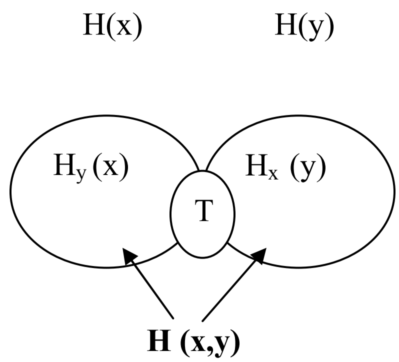

Figure 2. Schematic representation of the several quantities of information that are involved when message are received from two related sources.

H(x) – average amount of information in bits per event expected from source x.

H(y) – average amount of information in bits per event expected from source y.

T – average amount of information in bits per event which is the common information due to correlation of x and y.

$H_y(x)$ - average amount of information per event expected from x when y is known

$H_x(y)$ - average amount of information per event expected from y when x is known

H (x,y) – total amount of information in bits per event present in x and y

$T = H(x) + H(y) - H(x,y)$

T has been seen to exhibit the properties of a measure of the correlation (contingency, dependence) between x and y. As a matter of fact, 1.3863 nT (where n is the number of occurrences of the event used for estimation of the probabilities).

2.5.1 Information Processing and Reading

Human verbal behavior is a unique and interesting example whose behavioral sequence can be analyzed to calculate its conditional probabilities. Normal English has built in constraints which serve the purpose of reducing the number of alternatives from which successive words can be selected. Information is transmitted when the number of probable alternatives is reduced. Simply put, it means that by decreasing the range of choice, the context provides information about what the next word would be. Consequently, when the next word is presented, part of the information it conveys is similar to the information we perceived from the context. The repeated information is termed as "redundancy".

The ensuing discussion gives us some insight in the relation of the variables in the sequential situation with the various quantities of information highlighted in the Figure 2.

Let x be the source that creates the context

Let y be the source that creates the successive word

The common information or overlap in x and y is the redundancy.

H(x) is the average amount of information present in the initial (n-1) words (the context)

H(y) is the average amount of information in the nth word

T is the average amount of redundant information

H_y (x) is the average amount of information in the context that is not related to the next word

H_x (y) is the average amount of information in the next word that cannot be got from the context

H (x,y) is the total amount of information in the case where n words, the context and the next word are known.

The parameter of interest is basically H_x (y) which is the average quantity of information per word when the context is known. H_x (y) can also be explained as a measure of the average number of bits per unit (or per word). This model has been used as a basis to study the sequence of letters in written English. On average, it has been estimated that a context of 100 letters will decrease the number of alternatives for the next letter to less than three possibilities. In other words, H_x (y) is approximately 1.4 bits per letter in Standard English. In the case of independent selection of successive letters, each letter would have to be selected from 26 choices and would carry $\log_2 26$ or about 4.7 bits of information.

Mathematically:

$$F_n = - \sum_{i,j} p(b_i, j) \log_2 p_b(j)$$

$$= - \sum_{i,j} p\,(b_i, j)\,log_2\, p\,(b_i, j) + \sum_{i} p\,(b_i)\,log\, p\,(b_i)$$

in which : b_i is a block of N-1 letters [(N-1) – gram entropy]

j is an arbitrary letter following b_i

p (b_i, j) is the probability of the *N*- gram b_i , j

p_{bi} (j) is the conditional probability of letter j after block b_i , and is given by

p (b_i, j) / p (b_i).

In the case, where spaces and punctuation are neglected, a twenty-six letter alphabet remains and F_o may be considered (by definition) to be $\log_2 26$, or 4.7 bits per letter. F_1 consists of letter frequencies and is indicated by (reduced by one):

$$F_1 = - \sum_{i=1}^{26} p\,(i\,)\,log_2\, p\,(i\,) = 4.14 \text{ bits per letter.}$$

The diagram approximation F_2 shows the result :

$$F_2 = - \sum_{i,j} p\,(i, j)\,log_2\, p_i\,(j)$$

$$= - \sum_{i,j} p\,(i, j)\,log_2\, p\,(i, j) + \sum_{i} p\,(i)\,log_2\, p\,(i)$$

$$= 7.70 - 4.14 = 3.56 \text{ bits per letter,}$$ ***Thus,***

	F_o	F_1	F_2
26 letter …………….	**4.70**	**4.14**	**3.56**

2.5.2 Information capacity and transfer

Transfer of information can be elucidated in simple terms as the increase in information after the signal is transmitted i.e. a measure of knowledge of the receiving system about the state of transmitting system after signal is received than before it is received. A number of studies have been conducted to apply concepts derived from information theory to human performance (Quastler, 1955; Garner, 1962, 1974; Sheridan and Ferrell, 1974; Stelmach, 1978; Rasmussen, 1986). In a study conducted by Verghese and Pelli (1991), the information capacity of visual attention was investigated by measuring the amount of information an observer's attention could handle when display information was reduced without deterioration of the observer's performance. The detection of a stationary dot amidst a field of moving dots and detection of a static square within a field flashing squares were the two attentive visual tasks investigated in the study. The subject performed perfectly up to a critical number of elements beyond which deterioration in performance was seen. The results showed that visual attention processed only 30 to 60 bits of display information. More importantly, in terms of reading rates and information rate of a human channel, Pierce and Karlin (1956) found measured human channel capacity to be 40-50 bits/ sec. It was seen that the highest information rate for humans was 43 bits/ second. Hence it was decided that we should present about 9 letters in random per one second, which, if all the letters were to be read correctly, would represent the maximum performance level for the individual, and would serve as a top-level baseline.

3.0 Methods

3.1 Research Questions

In order to determine design guidelines for optimal display of information, the research questions that we posed were:

1. Would age have any effect on reading (information processing) performance?
2. What is the distance at which performance is better - far or near?
3. What the best letter size for displaying that information?
4. How would daytime/nighttime conditions affect performance?
5. How would display time affect performance?
6. How do these parameters interact with each other?

3.2 Hypotheses

In order to answer these research questions, we derived the following hypotheses:

Hypothesis 1. The readability of the visual display (as measured by number of correct alphabet character identification – i.e., bits of information gained) will be reduced with advancing age.

Hypothesis 2. The readability of the visual display (as measured by number of correct alphabet character identification – i.e., bits of information gained) will be increased with an increase of display time, more so for the elderly subjects.

Hypothesis 3. The readability of the visual display (as measured by number of correct alphabet character identification – i.e., bits of information gained) will be augmented with an increase of the letter size.

Hypothesis 4. The readability of the visual display (as measured by number of correct alphabet character identification – i.e., bits of information gained) will be better during the daytime than the nighttime condition.

Hypothesis 5. The readability of the visual display (as measured by number of correct alphabet character identification – i.e., bits of information gained) will increase with an increase in target distance, and this effect will be more pronounced for the elderly.

3.3 Participants

A total number of 56 individuals (28 young, 28 elderly) were recruited as participants for the study. The younger participants' age group ranged from 18-25 years old and the elderly were 65+ years old. The sample size was determined using power calculation. The subjects had no history of binocular vision anomalies or ocular pathology, and had a normal or corrected to normal vision of 20/20, for younger individuals. For elderly subjects this was relaxed to 20/20 - 20/30 since most of the elderly subjects tested initially had vision inaccuracies within that range. This was checked using a Bausch and Lomb Vision Tester. Both the young and elderly participants were recruited from the Montgomery County region. An equal number of male/ female individuals for both age-groups were recruited. The participants were required to have a valid driver's license and be an active driver. They were given the informed consent form detailing the objectives, procedures and risks involved in the experiment.

The means and standard deviations of the different characteristics of the participants such as age, weight and height are listed in Table 1 below, according to their age group:

Table 1: Participant Characteristics according to Age Group

	Young	**Old**
	Mean (SD)	**Mean (SD)**
Age (years)	22.74 (3.54)	72.31 (8.49)
Weight (kg)	70.28 (12.75)	71.55 (15.47)
Height (cm)	171.63 (6.68)	168.91 (9.52)

3.4 Sample Size Calculation

Power calculations were performed to determine sample sizes large enough to determine the main effects of age on reading scores. The general test statistic used for determining sample sizes based on power was the standard F test, for which the power of the test (Neter et al., 1996) is given by:

$$Power = P\{F^* > F(1-\alpha; r-1, n-r) \mid \varphi\}$$

where φ is the noncentrality parameter, or a measure of the distance between the mean scores for Elderly and Young individuals for a single factor. Also:

$$\varphi = \Delta/\sigma$$

Where Δ is a specification of the minimum range of the factor level means (reading scores for the two age groups) for which it is important to detect differences between the μ_i (means) with high probability and σ is the standard deviation of the distribution of reading scores. We also specify the values of risks of Type I error ($\alpha = 0.05$) and Type II error ($\beta = .05$, i.e., Power = 0.95). A value of 1 was specified for the ratio φ. Also, for age, $r = 2$ (2 levels). Using this information, sample size for each age group was determined to be 28.

3.5 Apparatus

The experiment was conducted in a laboratory room with non-reflective black cloth covering the walls. The letters were presented to the participants using PowerPoint software on a laptop screen. A sequence containing nine random alphabets was provided as stimulus in each trial. The participants were asked to look at a far target intermittently, by means of a movable mirror, while reading the presented letters at given distances and particular time intervals, and number of letters read correctly were then recorded. The testing setup is illustrated in Figure 3 and Figure 4. It consists of the following parts:

1. A movable mirror controlled by an electronic switch which was used to focus the eyes of the participant on a far target and the laptop screen.
2. Adjustable chin rest and forehead rest to restrict the head movement and fix the position of eyes on the desired target (far target and laptop screen).
3. Sliding table for moving the laptop screen to specific distances from the eye.

A photometer was used to check the luminance and color characteristics of the letters presented to the participant, which could be adjusted using the in-built features of the PowerPoint software. An illuminometer was used to set the ambient illumination at the screen at daytime (1000 lux) or nighttime (5 lux) level.

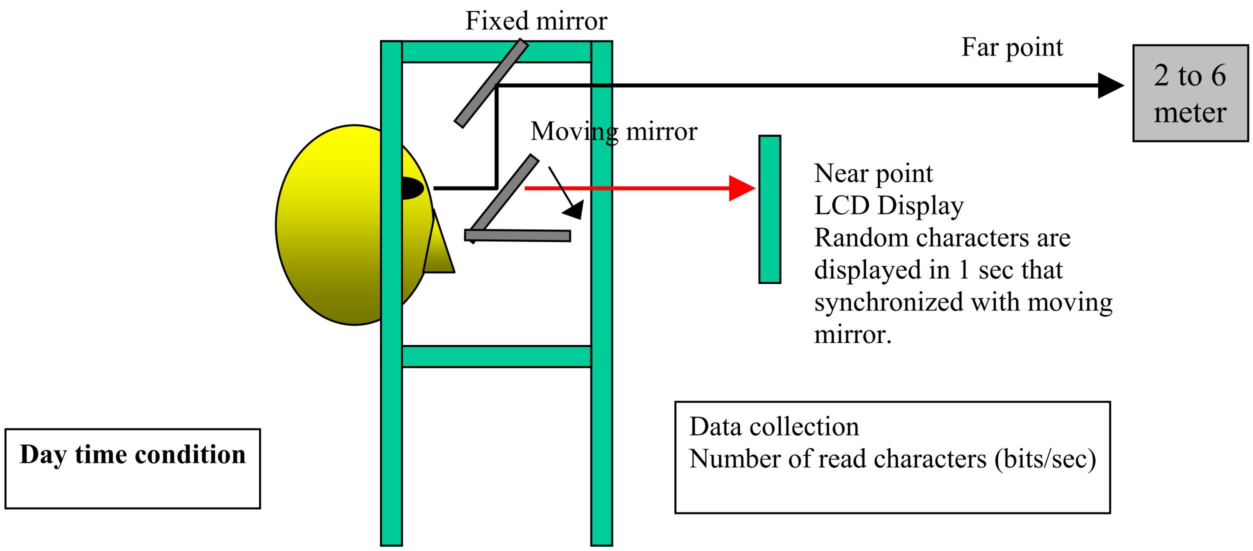

Figure 3: Schematic Experimental Set-up

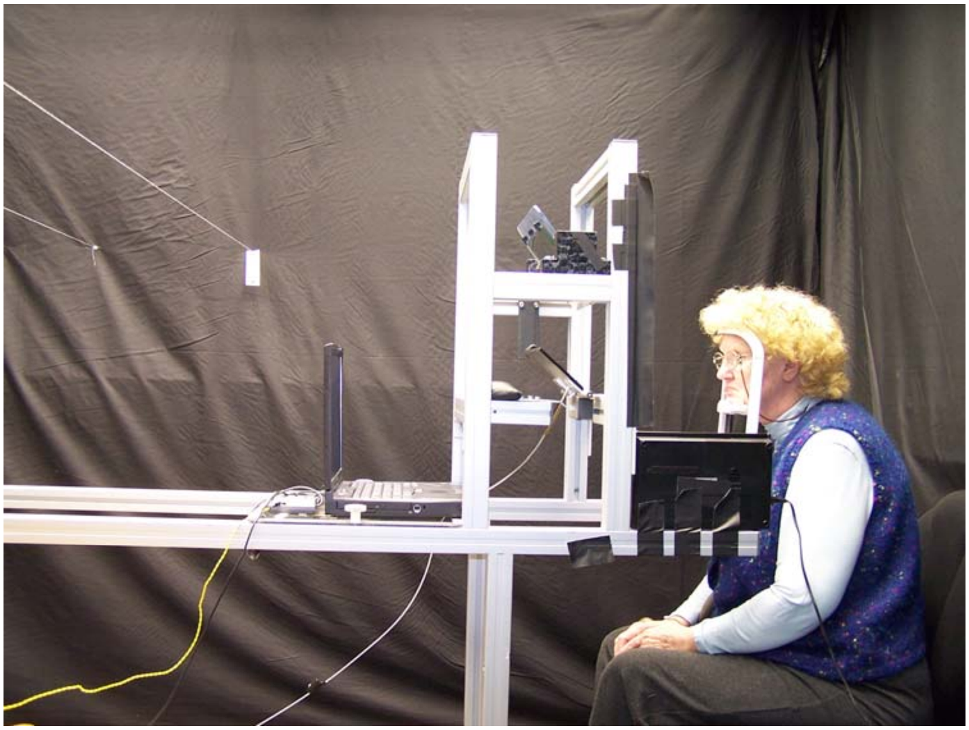

Figure 4: Actual Experimental Set-up

3.6 Experimental Variables

3.6.1 Independent Variables

1. Ambient lighting conditions (2) – day (photopic – 1,000 lx) and night (scotopic - 5 lx) (simulating the lighting conditions within an automobile during the two conditions, and were determined in previous studies by Lockhart, Atsumi, Nam and Ghosh, 2004).
2. Distances (2) – 750 mm and 2000mm - near and far, respectively. The letters will be presented at these two distances at specific intervals of time and the participant will look at a far target in between those intervals. The far target will be placed at a distance of 3 meters and will approximate infinite distance (distance at which a

person sees outside stimuli during driving). The 750 mm distance was based on the location of on-board display systems in passenger cars. The 2000 mm distance was based on the perceived distance of a heads-up display in an automobile.

3. Size of Text (3) – Small, medium and large. The size of the text on the presentation slide for the two distances is determined so that at both far and near distances, the letter height subtends the same angle at the eye and therefore consistency of perceived size is maintained (see Table.2 and Fig. 6), i.e., letter size does not influence target distance. The angle subtended at the eye is approximately 0.15, 0.30 and 0.45 degrees by the three letter sizes and corresponds with that subtended by different sizes of display letters commonly found in present generation vehicles.
4. Color Specifications- These specifications were designed based on the specifications outlined in section 2.2 of the proposal. The CIE system characterizes colors by a luminance parameter Y and two color coordinates x and y which specify the point on the chromaticity diagram (Figure 5).

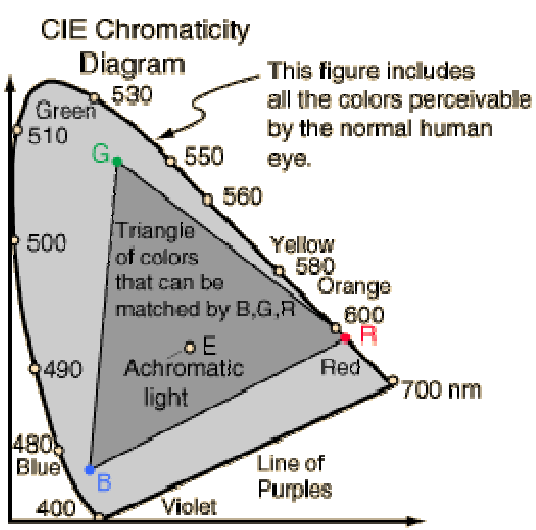

Figure 5: CIE color chart

These Y, x and y values were mapped to the PowerPoint software, used to present the letters, using a Minolta™ Chroma Meter CS-100. The Chroma Meter is an instrument used for taking non-contact color measurements of light sources, and displays the luminance (Y) and chromaticity (x, y) values for a particular color. The PowerPoint software has 6 values (RGB and HSL), ranging from 0 to 255, that need to be specified in order to obtain a particular color. These mapped values were obtained by means of trial and error. The particular values of Y, x and y for the white color letters and the black background, during daytime and nighttime conditions, were based upon the values that are being used in present generation vehicles possessing such electronic displays.

Background Black Luminance = 2.36 cd/ sqm

Nighttime condition

White – 20.1 cd/ sqm, x = 0.286, y = 0.282

Hue (H) – 170	Red (R) - 80
Sat (S) - 0	Green (G) - 80
Lum (L) – 80	Blue (B) - 80

Daytime Condition

White – 100 cd / sqm, x = 0.314, y = 0.315

Hue – 170	Red - 230
Sat - 0	Green - 230

Lum – 230 Blue - 230

5. Display Time (3) – 1s, 2s, and 3s. The display time of 1 sec corresponds with the maximum bit rate of information that can be processed by the human information channel (section 3.5.2), i.e., 9 random letters per second, and would serve as a maximum performance baseline. The three second interval is based on the *reading time* (section 3.1) of the elderly individuals such that they can read at least 90% of all letters presented to them of all sizes under all conditions. In other words this would be a comfortable *reading time* (a + b + c + d) for all subjects. This determination was based on the pilot test that was conducted. The 2 second interval was chosen to be the intermediate level.

6. Age (2) – young and old: The elderly age group was determined based on the age at which decline in various perceptive, cognitive and motor functions begins to accelerate, resulting in higher fatality rates. Although this age is not specifically demarcated, in part because of inter-individual differences, it is commonly believed that 65 is the age after which the decline starts to accelerate for most of the population. This is further supported by increased accident fatality rates for persons aged 65 and older (1996 Motor vehicle fatality rates, CDC). We also need to compare the characteristics of this set of population with one which does not show any signs of decline in physical and mental health, so we can establish what would be a an optimal set of characteristics. It is commonly accepted that such decline, however minute, does not begin until 25 years of age. Hence we selected the younger age group to be 18-25 years. Another reason for comparing young

with elderly is that we should not compromise the younger drivers while designing for the elderly. The upper limit for the elderly population was governed by the maximum age of subject population available to us while lower limit for younger individuals was decided to be 18 so that subjects consenting to participate in our study would not be minors.

3.6.2. Dependent Variable

Bits/sec information processing (i.e., correct number of alphabet characters identified or reading score). Nine random letters were presented in each slide and the number of letters correctly identified were recorded

Example of the letter "L"

Table 2: Size of Text

Visual Distance	750mm	2000mm
Real Letter Height (mm)	2.00	5.33
	4.00	10.67
	6.00	16.00

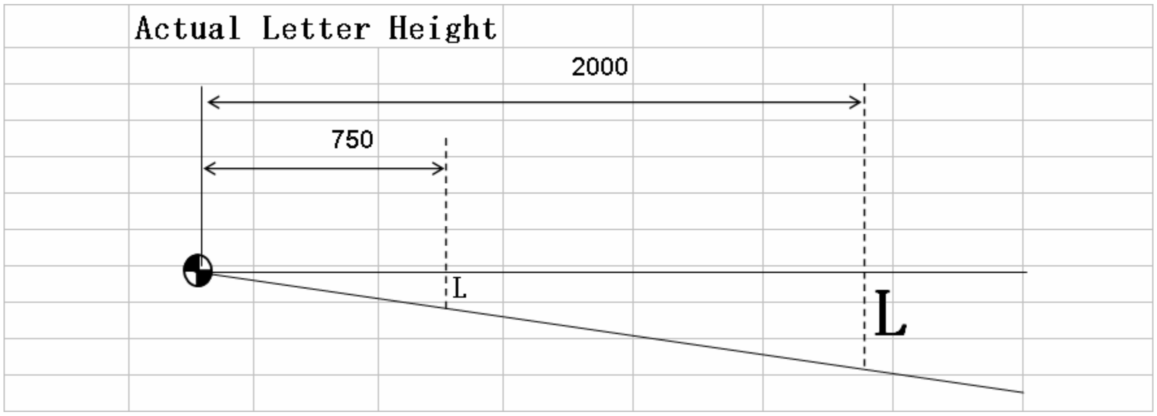

Figure 6: The letter L

3.7 Experimental Procedure

3.7.1 Daytime Condition

1. Ambient illumination was set at 1000 lx (measured horizontally – on a flat surface) using the light meter. A luminometer was used to check whether the brightness level of the target is set at 100 cd/ sqm.
2. The participant was asked to position his/her head on the chin rest and lean a little forward so that his forehead could rest against the provided support. The chin rest was adjusted so that eye line coincides with the marked level on the chin rest.

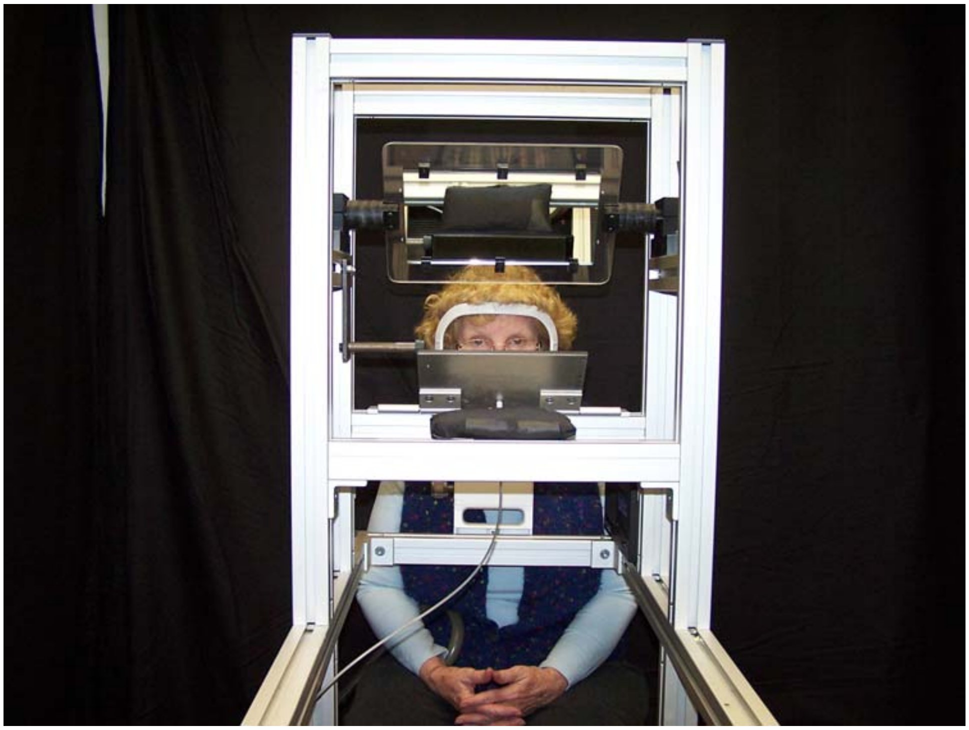

Figure 7: Participant's head and chin rest position

3. The participant was asked to look straight so that the mirror adjustment for the far target could be checked. Care was taken to check that the line of sight of the participant is perpendicular and in line with the target on the laptop screen. When necessary, the chair height of the participant was adjusted to achieve the purpose of alignment.
4. Nine random alphabets were presented to the participant at two distances (75 and 200 cms). The alphabets were presented in white color against a black background on the laptop. PowerPoint software was used for presentation and the slide transition was set at three time intervals (1, 2 and 3 seconds). The alphabets were designed using Microsoft Word as per the letter sizes (at 75 and 200 cms) and type (Gothic).

5. Initially, the participant looked at the far target.
6. The lower mirror was triggered by using pneumatics. When the mirror went down, the letters were presented to the participant on the laptop. The mirror was down for six seconds.
7. The participants simultaneously verbally called out letters of the alphabets presented. The participants were instructed to call out the letters loudly and clearly without moving their jaw too much.
8. A tape recorder was used to record the data.
9. Before triggering the next mirror movement, the experimenter waited for seven seconds. The participant looked at the far target during these seven seconds.
10. The experiment was conducted till all the treatment combinations were completed at each of the two distances (75 and 200 cms). The treatment combinations were randomized using JMP software.

3.7.2 Nighttime Condition

Ambient illumination will be set at 5 lx. Similar procedure as daytime conditions will be followed.

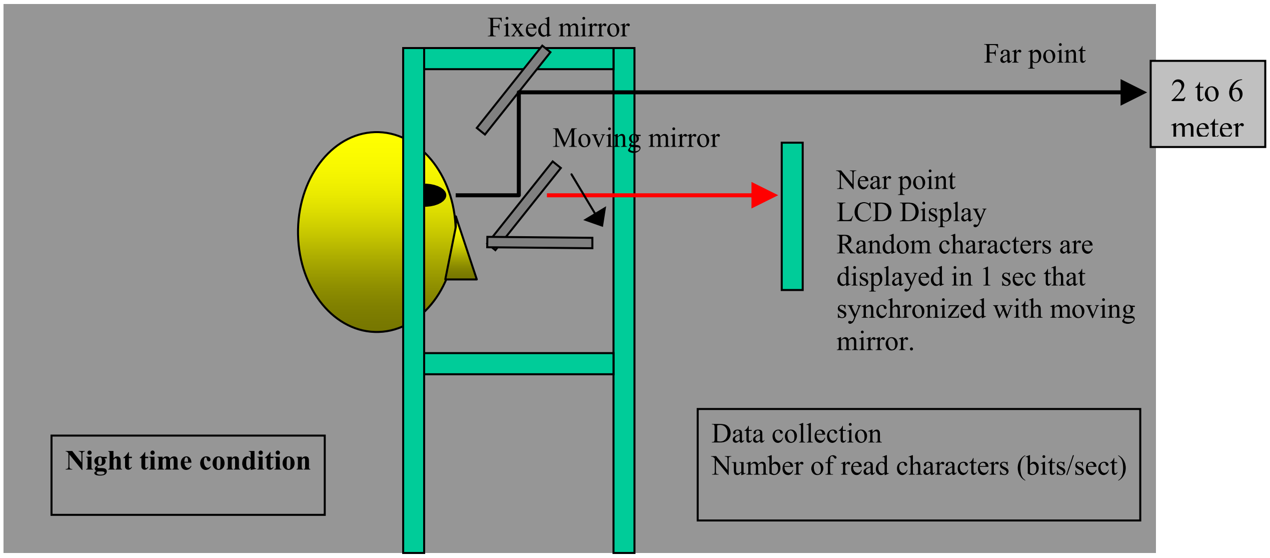

Figure 8: Schematic Setup for Nighttime Condition

3.8 Experimental Design and Data Analysis

There were five independent variables in our design, i.e., age of the subjects (2 levels), display time (3 levels), size of text (3 levels), distance of stimulus (2 levels) and ambient illumination (2 levels). The dependent variable was the reading score, i.e., the number of letters correctly identified. It is a mixed factorial design with age as between subjects and the other independent variables as within subjects. There were a total of 3x3x2x2 treatment combinations within each age group, with each subject being exposed to all the treatment combinations. The order of treatments was randomized for each subject, to minimize the order effects.

A mixed design Analysis of Variance (ANOVA) was used to test for the main effects and the interaction effects, at a significance level of (α = 0.05). The null and alternative hypotheses can be stated as follows:

$H_0 = \mu_1 = \mu_2 = \ldots \mu_i$, where μ_i represents the level mean,

$H_a = \mu_1 \neq \mu_2 = \ldots \mu_i$

Tukey's Honestly Significant Difference test will be used to test all pair wise comparisons among means with ($\alpha = 0.05$). An observed significance level of $p = 0.05$ will be used to reject the null hypothesis. Further, since higher-order interactions are very hard to interpret, the analysis will be limited to significant two and three way interaction effects.

4.0 Results

The reading scores achieved by participants, i.e., number of letters read correctly, were analyzed together with the independent variables in this section: Age group, ambient illumination, distance, display time and letter size. In general, the results indicated several statistically significant differences in reading performance. Significant differences were due to age group, distance, display time and letter size, and a minor one due to ambient illumination. These effects are described below.

Table 3: Effect Test on Reading Scores for Experiment 1 (ANOVA Table)

Source	DF	Anova SS	Mean Square	F Value	Prob>F
Age	1	1047.2267	1047.2267	46.98	<.0001
Ambient	1	1.0045	1.0045	0.40	0.5318
Age*Ambient	1	8.2545	8.2545	3.26	0.0768
Distance	1	290.2902	290.2902	70.77	<.0001
Age*Distance	1	118.6116	118.6116	28.91	<.0001
DisplayTime	2	6003.7173	3001.8586	787.46	<.0001
Age*DisplayTime	2	7.9653	3.9826	0.3553	<.0001
Size	2	557.5208	278.7604	125.35	<.0001
Age*Size	2	291.5308	145.7654	65.55	<.0001
Ambient*Distance	1	53.6910	53.6910	23.73	<.0001
Age*Ambient*Distance	1	6.3338	6.3338	2.80	0.1001
Ambient*DisplayTime	2	11.0030	5.5015	3.04	0.0521
Age*Ambient*DisplayT	2	2.4375	1.2188	0.67	0.5124
Ambient*Size	2	23.6637	11.8318	6.88	0.0015
Age*Ambient*Size	2	10.0387	5.0193	2.92	0.0584

Distance*DisplayTime	2	9.4018	4.7009	2.06	0.1321
Age*Distanc*DisplayT	2	11.9673	5.9836	2.63	0.0770
Distance*Size	2	191.2768	95.6384	33.89	<.0001
Age*Distance*Size	2	114.9494	57.4747	20.37	<.0001
DisplayTime*Size	4	12.9762	3.2440	1.84	0.1214
Age*DisplayTime*Size	4	44.1389	11.0347	6.28	<.0001
Ambien*Distan*Displa	2	3.6915	1.8457	0.92	0.4018
Age*Ambi*Dista*Displ	2	0.9117	0.4559	0.23	0.7972
Ambient*Display*Size	4	2.9583	0.7396	0.42	0.7926
Age*Ambie*Displ*Size	4	6.5774	1.6443	0.94	0.4424
Distanc*Display*Size	4	25.5179	6.3795	3.68	0.0063
Age*Dista*Displ*Size	4	21.3155	5.3289	3.08	0.0171
Ambi*Dist*Displ*Size	6	18.1220	3.0203	2.04	0.0602
Age*Amb*Dis*Dis*Size	6	9.0089	1.5015	1.01	0.4164

4.1. Main Effects

4.1.1 Age Group Main Effect

Overall, the difference between scores across age groups was statistically significant ($F_{1,54} = 46.98$, $p < .0001$) (Table 4, Figure 9). A score of 9 is the highest that is attainable and denotes that the participant was able to read all the letters correctly. Younger individuals, with corrected vision, had higher scores than the elderly participants.

Table 4: Descriptive Statistics of Age Group main effect on Reading Scores

Age Group	Mean	Standard Deviation
Old	5.6379	2.8222
Young	7.0794	2.2139

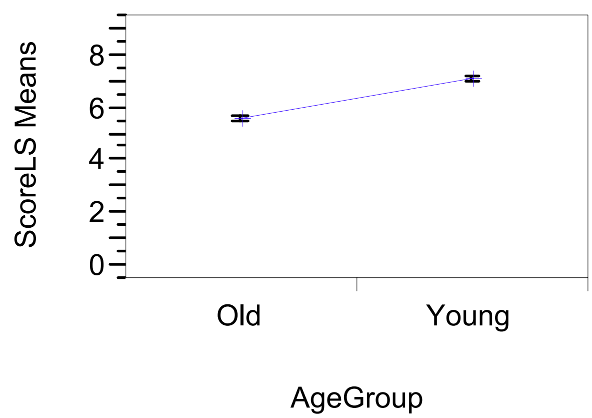

Figure 9: Age Group Main Effect on Reading Scores

4.1.2 Ambient Illumination Main Effect

In general, visual acuity performance decreased from a daytime condition to a nighttime condition across both age groups, though the difference was not statistically significant. ($F_{1,54} = 0.4$, $p = 0.5318$) (Table 5, Figure 10).

Table 5: Descriptive Statistics of Ambient Illumination Main Effect on Reading Scores

Ambient Illumination	**Mean**	**Standard Deviation**
Daytime	6.3809	2.5643
Nighttime	6.3363	2.7073

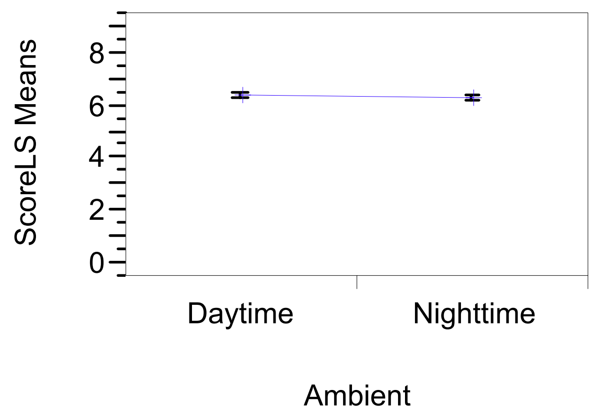

Figure 10: Ambient Illumination Main Effect on Reading Scores

4.1.3 Distance Main Effect

Overall, reading scores were significantly different for the two distance levels ($F_{1,54} = 70.77$, $p < .0001$). (Table 6, Figure 11). In general, the farther distance yields better performance.

Table 6: Descriptive Statistics of Distance Main Effect on Reading Scores

Distance (cm)	Mean	Standard Deviation
75	5.9792	2.7814
200	6.7381	2.4252

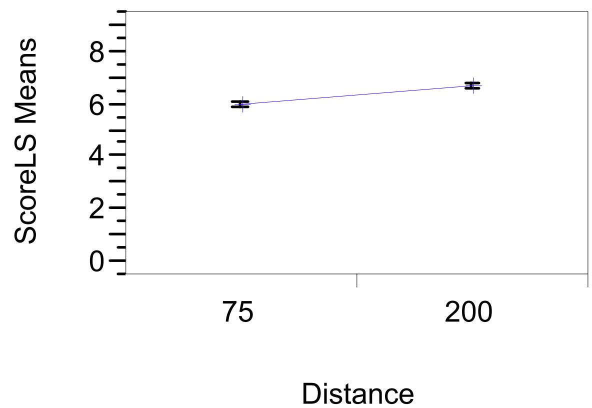

Figure 11: Distance Main Effect on Reading Scores

4.1.4 Display Time Main Effect

In general, more display time yielded better performance. The differences were statistically significant at ($F_{2,108}$ = 787.46, $p < .0001$) level (Table 7, Figure 12). A Tukey-Kramer post-hoc test indicated that there were significant differences among all the three display times ($\alpha = 0.05$) (Table 8). More specifically, the reading performance increased much more from when the time given was increased from 1 to 2 sec than 2 to 3 sec.

Table 7: Descriptive Statistics of Distance Main Effect on Visual Acuity

Display Time (sec)	Mean	Standard Deviation
1	3.9851	1.6915
2	7.0536	2.1763
3	8.0372	2.0797

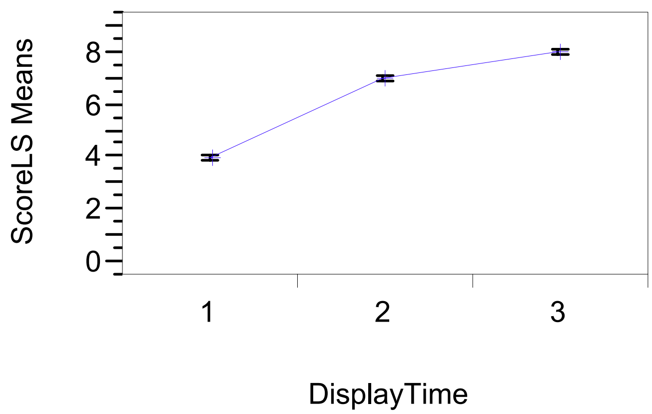

Figure 12: Display Time Main Effect on Reading Scores

Table 8: Tukey HSD of Display Time. Red and underlined signifies significant differences at alpha = 0.05

Alpha = 0.050 Q = 2.3455 LSMean[i] By LSMean[j]

Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	1	2	3
1 sec	0 0 0	-3.0685 0.08834 -3.2757	-4.0521 0.08834 -4.2593

	0	-2.8612	-3.8449
2 sec	3.06845	0	-0.9836
	0.08834	0	0.08834
	2.86125	0	-1.1908
	3.27566	0	-0.7764
3 sec	4.05208	0.98363	0
	0.08834	0.08834	0
	3.84488	0.77643	0
	4.25929	1.19084	0

4.1.5 Letter Size Main Effect

In general, scores increased with increase in size of letters. The differences were statistically significantly different ($F_{2,108} = 125.35$, $p < .0001$) (Table 9, Figure 13). Further, a Tukey-Kramer post-hoc test indicated that there were significant differences among easy and hard levels and between normal and hard levels of letter sizes, but not between easy and normal levels (hard being the smallest letter size; $\alpha = 0.05$) (Table 10). In other words, reading performance did not significantly increase when the letter size increased from normal to the easy level. This implies that reading performance does not increase significantly after a particular stimulus size (font size) has been reached.

Table 9: Descriptive Statistics of Letter Size Main Effect on Reading Scores

Letter Size	Mean	Standard Deviation
Easy	6.7961	2.3719
Hard	5.6190	2.8719

Letter Size	**Mean**	**Standard Deviation**
Normal	6.6607	2.4829

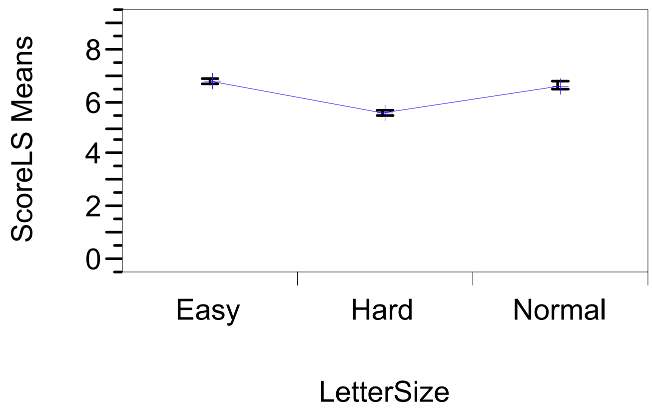

Figure 13: Letter Size Main Effect on Reading Scores

Table 10: Tukey HSD of Letter Size. Red and underlined signifies significant differences at alpha = 0.05

Alpha = 0.050 Q = 2.3455 LSMean[i] By LSMean[j]

Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	Easy	Hard	Normal
Easy	0 0 0 0	1.17708 0.08834 0.96988 1.38429	0.13542 0.08834 -0.0718 0.34262
Hard	-1.1771 0.08834 -1.3843 -0.9699	0 0 0 0	-1.0417 0.08834 -1.2489 -0.8345

Normal	-0.1354	1.04167	0
	0.08834	0.08834	0
	-0.3426	0.83446	0
	0.07179	1.24887	0

4.2. Interaction Effects

The following statistically significant (except for 4.2.1) interaction effects were observed.

4.2.1 Age Group x Ambient Illumination Interaction Effect

The younger individuals performed better than the elderly for both daytime and nighttime conditions as reflected in the means table (Table 11, Figure 14). Overall, the interaction of ambient illumination with age group level was not significant ($F_{1,54} = 3.26$, $p = 0.0768$). Hence the illumination level does not significantly influence reading performance within an age group. A Tukey- Kramer post hoc test ($\alpha = 0.05$) further signifies this finding, where the only significant differences are among mean performance between age groups (Table 12).

Table 11: Descriptive Statistics of Age Group x Ambient Illumination Interaction on Reading Scores

Age Group, Ambient Illumination	**Mean**	**Standard Deviation**
Old, Daytime	5.7242	2.7029
Old, Nighttime	5.5516	2.9369
Young, Daytime	7.0377	2.2349

Age Group, Ambient Illumination	Mean	Standard Deviation
Young, Nighttime	7.1210	2.1942

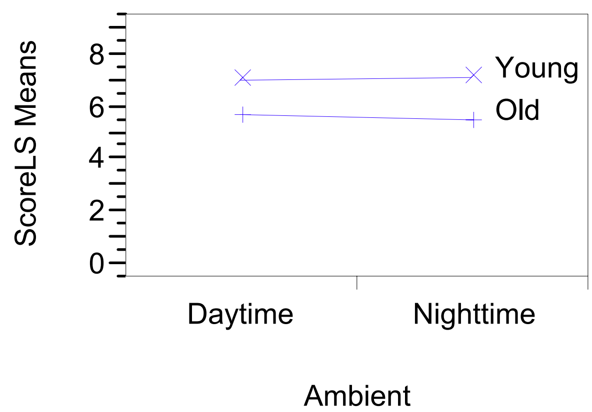

Figure 14: Age Group x Ambient Illumination Interaction Effect on Reading Scores

Table 12: Tukey HSD of Age Group x Ambient Illumination Interaction. Red and underlined signifies significant differences at alpha = 0.05

Alpha = 0.050 Q = 2.57126 LSMean[i] By LSMean[j]

Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	Old,Daytime	Old,Nighttime	Young,Daytime	Young,Nighttime
Old,Daytime	0 0 0 0	0.17262 0.10201 -0.0897 0.43491	-1.3135 0.10201 -1.5758 -1.0512	-1.3968 0.10201 -1.6591 -1.1345
Old,Nighttime	-0.1726 0.10201 -0.4349 0.08967	0 0 0 0	-1.4861 0.10201 -1.7484 -1.2238	-1.5694 0.10201 -1.8317 -1.3072
Young,Daytime	1.31349 0.10201 1.0512 1.57578	1.48611 0.10201 1.22382 1.7484	0 0 0 0	-0.0833 0.10201 -0.3456 0.17896

Young,Nighttime	1.39683	1.56944	0.08333	0
	0.10201	0.10201	0.10201	0
	1.13454	1.30716	-0.179	0
	1.65911	1.83173	0.34562	0

4.2.2 Age Group x Distance Interaction Effect

This interaction effect was statistically significant ($F_{1,54}$= 28.91, $p<.0001$). As seen in the means plot (Table 13, Figure 15), the performance across distances is influenced by the age group of the subject. Specifically, increase in distance leads to more increase in reading performance for the elderly rather than the younger age group. Further, the Tukey-Kramer post hoc test (α = 0.05) indicates that the increase in performance with increase in distance occurs for both age groups and the differences are statistically significant (Table 14).

Table 13: Descriptive Statistics of Age Group x Distance Interaction on Reading Scores

Age Group, Distance (cm)	Mean	Standard Deviation
Old, 75	5.0159	2.9149
Old, 200	6.2599	2.5833
Young, 75	6.9425	2.2654
Young, 200	7.2163	2.1548

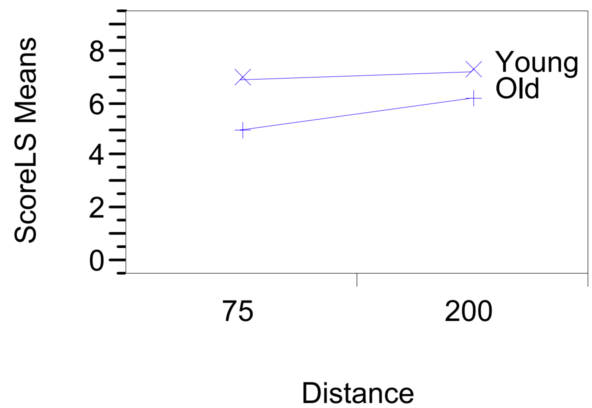

Figure 15: Age Group x Distance Interaction Effect on Reading Scores

Table 14: Tukey HSD of Age Group x Distance Interaction. Red and underlined signifies significant differences at alpha = 0.05

Alpha = 0.050 Q = 2.57126 LSMean[i] By LSMean[j]

Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	Old,75	Old,200	Young,75	Young,200
Old,75cm	0 0 0 0	-1.244 0.10201 -1.5063 -0.9818	-1.9266 0.10201 -2.1889 -1.6643	-2.2004 0.10201 -2.4627 -1.9381
Old,200cm	1.24405 0.10201 0.98176 1.50634	0 0 0 0	-0.6825 0.10201 -0.9448 -0.4203	-0.9563 0.10201 -1.2186 -0.6941
Young,75cm	1.92659 0.10201 1.6643 2.18888	0.68254 0.10201 0.42025 0.94483	0 0 0 0	-0.2738 0.10201 -0.5361 -0.0115
Young,200cm	2.2004	0.95635	0.27381	0

	0.10201	0.10201	0.10201	0
	1.93811	0.69406	0.01152	0
	2.46269	1.21864	0.5361	0

4.2.3 Ambient Illumination x Distance Interaction Effect

Another significant interaction effect observed was that of ambient illumination versus distance ($F_{1,54} = 23.73$, $p<0.0001$) (Table 15, Figure 16). As can be seen from the means plot, the performance increased with increase in viewing distance for both ambient illumination conditions (daytime and nighttime), but the increase in performance was much more during the nighttime than the daytime condition, across all subjects. The Tukey-Kramer post hoc test further illustrates that the differences in the observed means were significant (Table 16).

Table 15: Descriptive Statistics of Ambient Illumination x Distance Interaction on Reading Scores

Ambient Illumination, Distance (cm)	Mean	Std Deviation
Daytime, 75	6.1647	2.6623
Daytime, 200	6.5972	2.4459
Nighttime, 75	5.7936	2.8864
Nighttime, 200	6.8789	2.3985

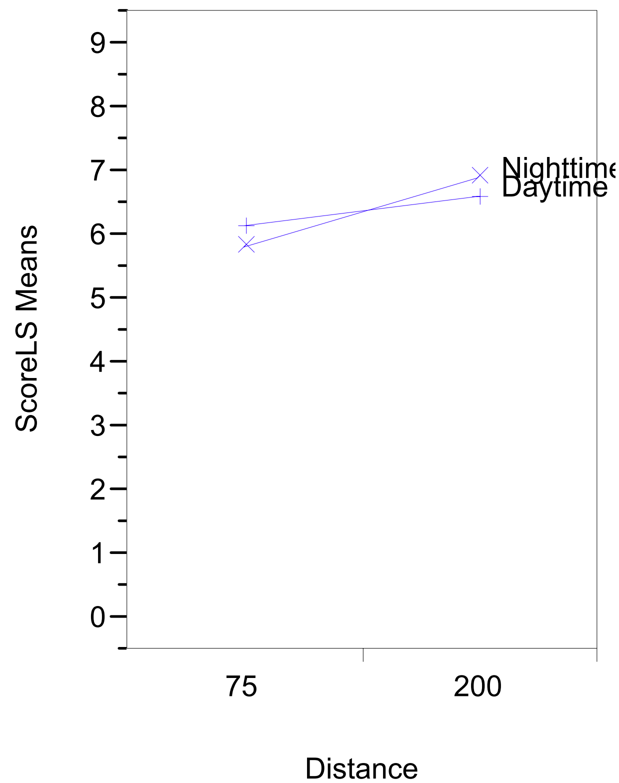

Figure 16: Ambient Illumination x Distance Interaction Effect on Reading Scores

Table 16: Tukey HSD of Ambient Illumination x Distance Interaction. Red and underlined signifies significant differences at alpha = 0.05

Alpha = 0.050 Q = 2.57126 LSMean[i] By LSMean[j]

Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	Daytime,75	Daytime,200	Nighttime,75	Nighttime,200
Daytime,75	0 0 0 0	-0.4325 0.10201 -0.6948 -0.1703	0.37103 0.10201 0.10874 0.63332	-0.7143 0.10201 -0.9766 -0.452
Daytime,200	0.43254 0.10201 0.17025	0 0 0	0.80357 0.10201 0.54128	-0.2817 0.10201 -0.544

	0.69483	0	1.06586	-0.0195
Nighttime,75	-0.371	-0.8036	0	-1.0853
	0.10201	0.10201	0	0.10201
	-0.6333	-1.0659	0	-1.3476
	-0.1087	-0.5413	0	-0.823
Nighttime,200	0.71429	0.28175	1.08532	0
	0.10201	0.10201	0.10201	0
	0.452	0.01946	0.82303	0
	0.97657	0.54403	1.34761	0

4.2.4 Age Group x Letter Size Interaction Effect

This interaction was also significant at the ($F_{2,108} = 65.55$, $p<0.0001$) level. In general, the performance decreased with decrease in letter size across all age groups (Table17, Figure 17). For the younger age group, the performance remained almost the same for the easy and normal levels, but decreased for the hard level of the letter size, although the difference in performance across the three levels of letter size was not significant for the younger age group (Tukey-Kramer HSD post-hoc test, $\alpha = 0.05$) (Table 18). For the elderly age group, the performance decreased with decrease in letter size. The performance difference between easy and normal levels was not significant, as indicated by the Tukey HSD test, but was significant for the difference between normal and hard levels. This implies that elderly have more problems associated with smaller text size, but beyond a certain letter size performance does not increase significantly. Also, the elderly had significantly lower performance than the younger individuals across all letter sizes.

Table 17: Descriptive Statistics of Age Group x Letter Size Interaction on Reading Scores

Age Group, Letter Size	Mean	Standard Deviation
Old, Easy	6.4226190	2.4821
Old, Hard	4.3690476	2.8600
Old, Normal	6.1220238	2.6710
Young, Easy	7.1696429	2.1972
Young, Hard	6.8690476	2.2818
Young, Normal	7.1994048	2.1521

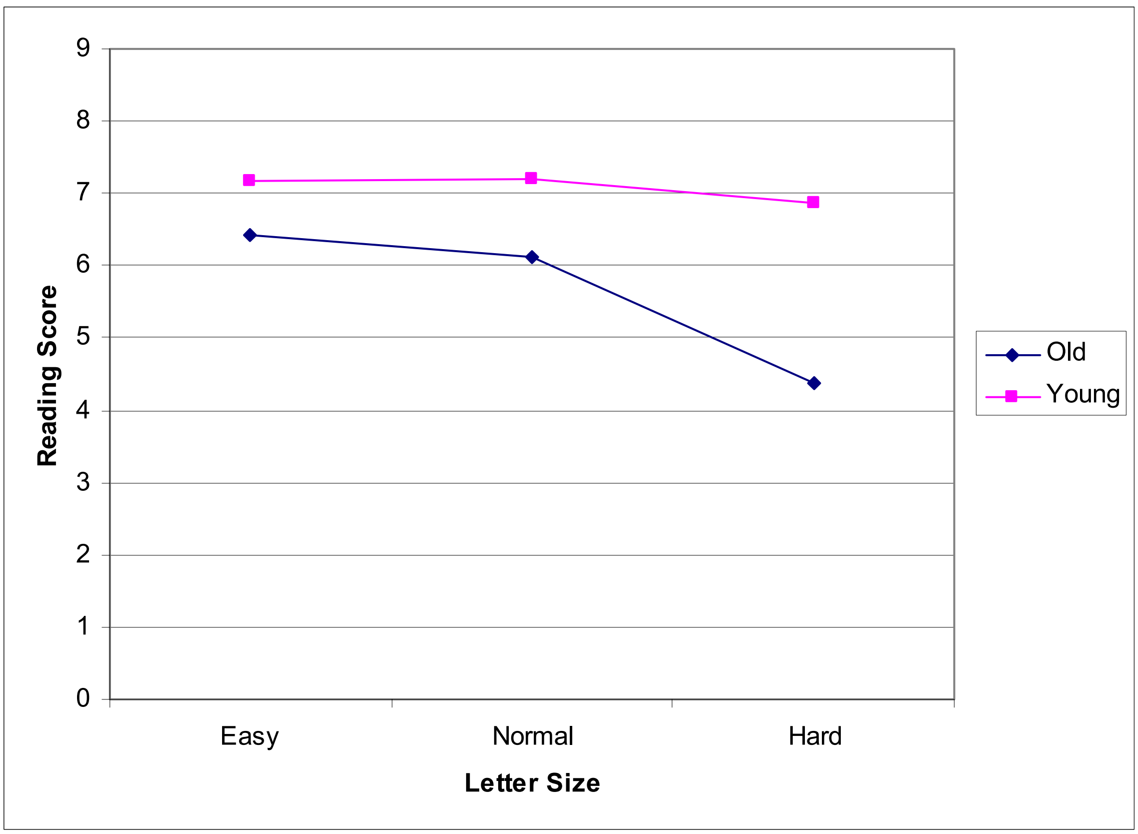

Figure 17: Age Group x Letter Size Interaction Effect on Reading Scores

Table 18: Tukey HSD of Age Group x Letter Size Interaction. Red and underlined signifies significant differences at alpha = 0.05

Alpha = 0.050 Q = 2.85258 LSMean[i] By LSMean[j]

Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	Old,Easy	Old,Hard	Old,Normal	Young,Easy	Young,Hard	Young,Normal
Old,Easy	0	2.05357	0.3006	-0.747	-0.4464	-0.7768
	0	0.12493	0.12493	0.12493	0.12493	0.12493
	0	1.69719	-0.0558	-1.1034	-0.8028	-1.1332
	0	2.40996	0.65698	-0.3906	-0.09	-0.4204
Old,Hard	-2.0536	0	-1.753	-2.8006	-2.5	-2.8304
	0.12493	0	0.12493	0.12493	0.12493	0.12493
	-2.41	0	-2.1094	-3.157	-2.8564	-3.1867
	-1.6972	0	-1.3966	-2.4442	-2.1436	-2.474
Old,Normal	-0.3006	1.75298	0	-1.0476	-0.747	-1.0774
	0.12493	0.12493	0	0.12493	0.12493	0.12493
	-0.657	1.39659	0	-1.404	-1.1034	-1.4338
	0.05579	2.10936	0	-0.6912	-0.3906	-0.721
Young,Easy	0.74702	2.8006	1.04762	0	0.3006	-0.0298
	0.12493	0.12493	0.12493	0	0.12493	0.12493
	0.39064	2.44421	0.69123	0	-0.0558	-0.3861
	1.10341	3.15698	1.404	0	0.65698	0.32662
Young,Hard	0.44643	2.5	0.74702	-0.3006	0	-0.3304
	0.12493	0.12493	0.12493	0.12493	0	0.12493
	0.09004	2.14362	0.39064	-0.657	0	-0.6867
	0.80281	2.85638	1.10341	0.05579	0	0.02603
Young,Normal	0.77679	2.83036	1.07738	0.02976	0.33036	0
	0.12493	0.12493	0.12493	0.12493	0.12493	0
	0.4204	2.47397	0.721	-0.3266	-0.026	0
	1.13317	3.18674	1.43377	0.38615	0.68674	0

4.2.5 Ambient Illumination x Letter Size Interaction Effect

This interaction effect was significant at the ($F_{2,108}$= 6.88, p = 0.0015) level. Overall, the daytime and nighttime performance was almost similar for the normal letter size across both ambient illumination conditions, but performance for easy letter size was better during nighttime than during the daytime condition, although not significantly different (Tukey HSD, $\alpha = 0.05$) (Table 20). Also, performance for the hard letter size was better during the nighttime than daytime, but was not significantly different. The only significant differences observed were between (easy versus hard) and (normal versus hard) letter sizes within each ambient illumination level (Table 19, Figure 18).

Table 19: Descriptive Statistics of Ambient Illumination x Letter Size Interaction on Reading Scores

Ambient Illumination, Letter Size	**Mean**	**Standard Deviation**
Daytime, Easy	6.7083	2.4110
Daytime, Hard	5.7887	2.7087
Daytime, Normal	6.6458	2.4670
Nighttime, Easy	6.8839	2.3324
Nighttime, Hard	5.4494	3.0209
Nighttime, Normal	6.6756	2.5023

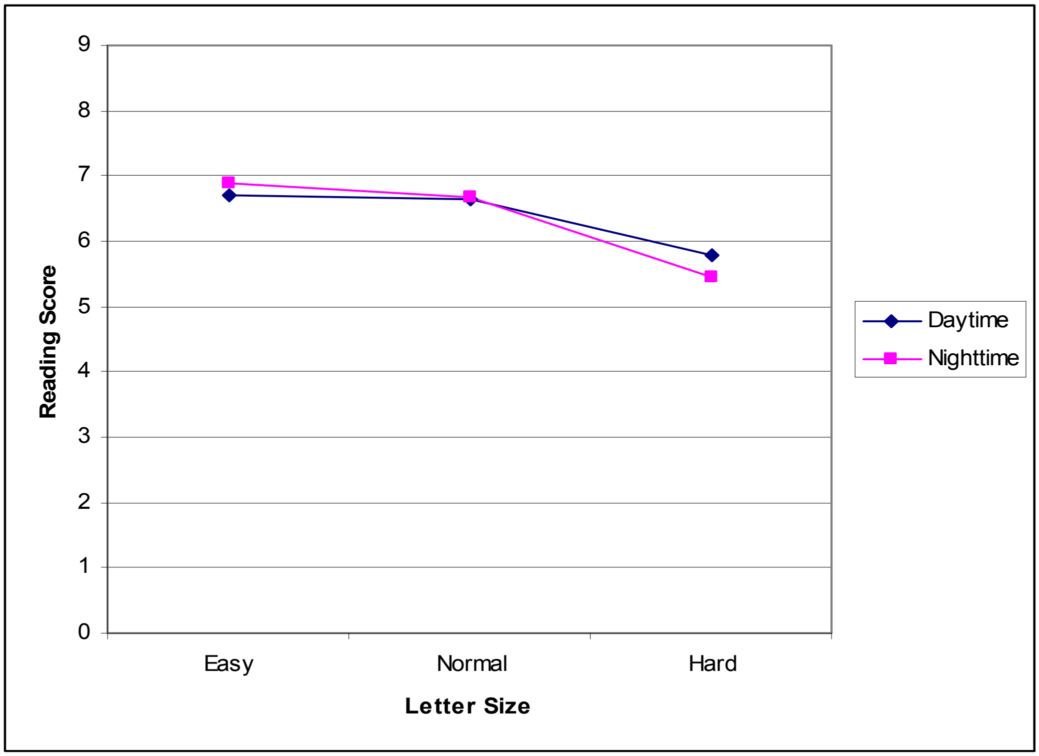

Figure 18: Ambient Illumination x Letter Size Interaction Effect on Reading Scores

Table 20: Tukey HSD of Ambient Illumination x Letter Size Interaction. Red and underlined signifies significant differences at alpha = 0.05

Alpha = 0.050 Q = 2.85258 LSMean[i] By LSMean[j]

Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	Daytime,Easy	Daytime,Hard	Daytime,Normal	Nighttime,Easy	Nighttime,Hard	Nighttime,Normal
Daytime,Easy	0 0 0 0	<u>0.91964</u> <u>0.12493</u> <u>0.56326</u> <u>1.27603</u>	0.0625 0.12493 -0.2939 0.41888	-0.1756 0.12493 -0.532 0.18079	<u>1.25893</u> <u>0.12493</u> <u>0.90254</u> <u>1.61531</u>	0.03274 0.12493 -0.3236 0.38912
Daytime,Hard	<u>-0.9196</u> <u>0.12493</u>	0 0	<u>-0.8571</u> <u>0.12493</u>	<u>-1.0952</u> <u>0.12493</u>	0.33929 0.12493	<u>-0.8869</u> <u>0.12493</u>

	-1.276	0	-1.2135	-1.4516	-0.0171	-1.2433
	-0.5633	0	-0.5008	-0.7389	0.69567	-0.5305
Daytime,Normal	-0.0625	0.85714	0	-0.2381	1.19643	-0.0298
	0.12493	0.12493	0	0.12493	0.12493	0.12493
	-0.4189	0.50076	0	-0.5945	0.84004	-0.3861
	0.29388	1.21353	0	0.11829	1.55281	0.32662
Nighttime,Easy	0.1756	1.09524	0.2381	0	1.43452	0.20833
	0.12493	0.12493	0.12493	0	0.12493	0.12493
	-0.1808	0.73885	-0.1183	0	1.07814	-0.1481
	0.53198	1.45162	0.59448	0	1.79091	0.56472
Nighttime,Hard	-1.2589	-0.3393	-1.1964	-1.4345	0	-1.2262
	0.12493	0.12493	0.12493	0.12493	0	0.12493
	-1.6153	-0.6957	-1.5528	-1.7909	0	-1.5826
	-0.9025	0.0171	-0.84	-1.0781	0	-0.8698
Nighttime,Normal	-0.0327	0.8869	0.02976	-0.2083	1.22619	0
	0.12493	0.12493	0.12493	0.12493	0.12493	0
	-0.3891	0.53052	-0.3266	-0.5647	0.86981	0
	0.32365	1.24329	0.38615	0.14805	1.58257	0

4.2.6 Distance x Letter Size Interaction Effect

This interaction was significant at the ($F_{2,108}$= 33.89, p<0.0001) level. The mean and standard deviations are listed in Table 21. Overall, the reading performance decreased with decrease in letter size across both distances. But for the 75 cm condition, the performance decreased much more than for the 200 cm condition with decrease in letter size (Fig 19). The performance was almost the same for the easy letter size across both distances. The mean levels among which significant differences exist have been represented in the Tukey HSD table below (Table 22).

Table 21: Descriptive Statistics of Distance x Letter Size Interaction on Reading Scores

Distance (cm), Letter Size	Mean	Standard Deviation
75, Easy	6.7559	2.3815
75, Hard	4.8333	3.0206
75, Normal	6.3482	2.5300
200, Easy	6.8363	2.3652
200, Hard	6.4048	2.4815
200, Normal	6.9732	2.3982

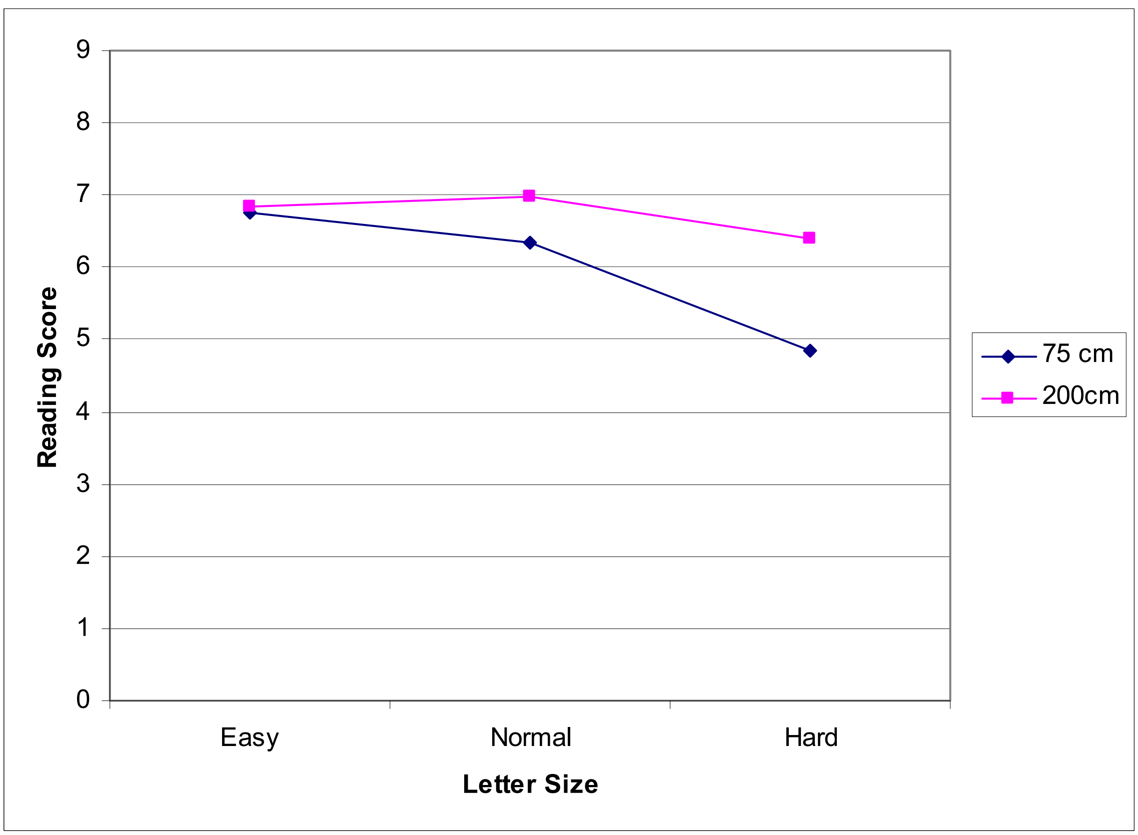

Figure 19: Distance x Letter Size Interaction Effect on Reading Scores

Table 22: Tukey HSD of Distance x Letter Size Interaction. Red and underlined signifies significant differences at alpha = 0.05

Alpha = 0.050 Q = 2.85258 LSMean[i] By LSMean[j]

Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	75,Easy	75,Hard	75,Normal	200,Easy	200,Hard	200,Normal
75,Easy	0	1.92262	0.40774	-0.0804	0.35119	-0.2173
	0	0.12493	0.12493	0.12493	0.12493	0.12493
	0	1.56623	0.05135	-0.4367	-0.0052	-0.5736
	0	2.279	0.76412	0.27603	0.70757	0.13912
75,Hard	-1.9226	0	-1.5149	-2.003	-1.5714	-2.1399
	0.12493	0	0.12493	0.12493	0.12493	0.12493
	-2.279	0	-1.8713	-2.3594	-1.9278	-2.4963
	-1.5662	0	-1.1585	-1.6466	-1.215	-1.7835
75,Normal	-0.4077	1.51488	0	-0.4881	-0.0565	-0.625
	0.12493	0.12493	0	0.12493	0.12493	0.12493
	-0.7641	1.1585	0	-0.8445	-0.4129	-0.9814
	-0.0514	1.87127	0	-0.1317	0.29984	-0.2686
200,Easy	0.08036	2.00298	0.4881	0	0.43155	-0.1369
	0.12493	0.12493	0.12493	0	0.12493	0.12493
	-0.276	1.64659	0.13171	0	0.07516	-0.4933
	0.43674	2.35936	0.84448	0	0.78793	0.21948
200,Hard	-0.3512	1.57143	0.05655	-0.4315	0	-0.5685
	0.12493	0.12493	0.12493	0.12493	0	0.12493
	-0.7076	1.21504	-0.2998	-0.7879	0	-0.9248
	0.00519	1.92781	0.41293	-0.0752	0	-0.2121
200,Normal	0.21726	2.13988	0.625	0.1369	0.56845	0
	0.12493	0.12493	0.12493	0.12493	0.12493	0
	-0.1391	1.7835	0.26862	-0.2195	0.21207	0
	0.57365	2.49627	0.98138	0.49329	0.92484	0

4.2.7 Age group x Distance x Letter Size Interaction Effect

This three way interaction was found significant at $F_{2, 108} = 20.37$, $p<0.0001$. The means and standard deviations for this interaction are listed in Table 23. Clearly, from the means plot (Figs. 20 and 21), age is an influencing factor in the "distance x letter size interaction". The performance of younger individuals was better for all distances and levels of the letter size than the elderly. Moreover, the change in distance from 75 cm to 200 cm improved the performance of the elderly more than it did for the younger individuals. Also increase in letter size led to much greater performance improvement for the elderly.

Table 23: Descriptive Statistics of Age Group x Distance x Letter Size Interaction on Reading Scores

Age Group, Distance, Letter Size	Mean	Standard Deviation
Old, 75, Easy	6.3869	2.4395
Old, 75, Hard	3.0178	2.4846
Old, 75, Normal	5.6428	2.6768
Old, 200, Easy	6.4583	2.5309
Old, 200, Hard	5.7202	2.5616
Old, 200, Normal	6.6012	2.5854
Young, 75, Easy	7.1250	2.2698
Young, 75, Hard	6.6488	2.3449
Young, 75, Normal	7.0536	2.1619
Young, 200, Easy	7.2143	2.1281
Young, 200, Hard	7.0893	2.2019
Young, 200, Normal	7.3452	2.1388

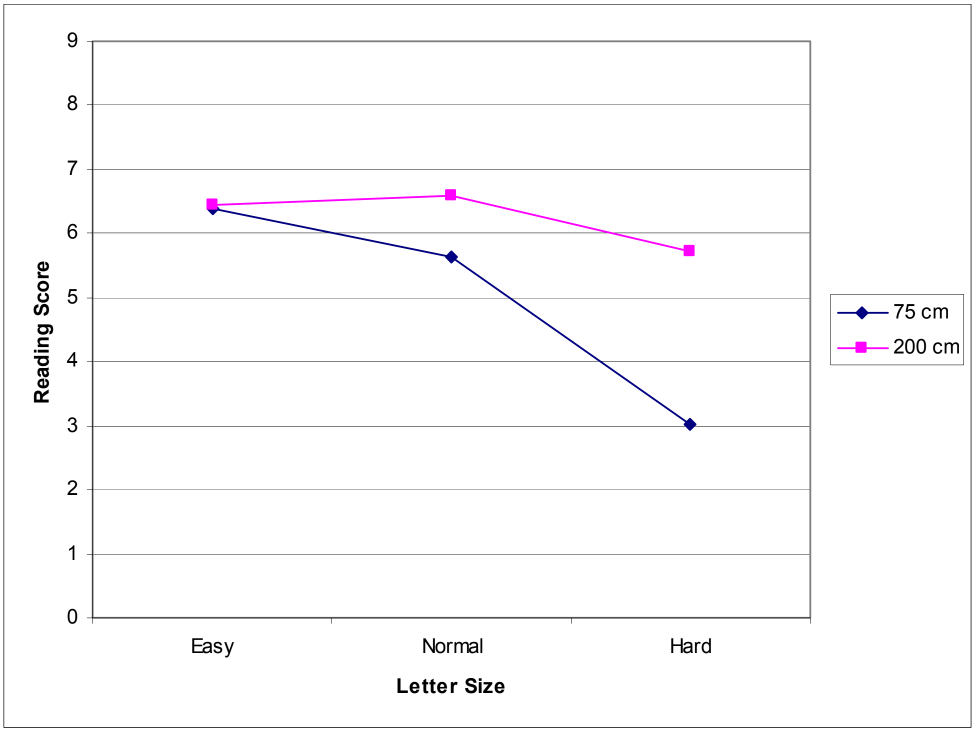

Figure 20: Distance x Letter Size Interaction Effect on Reading Scores for the Elderly

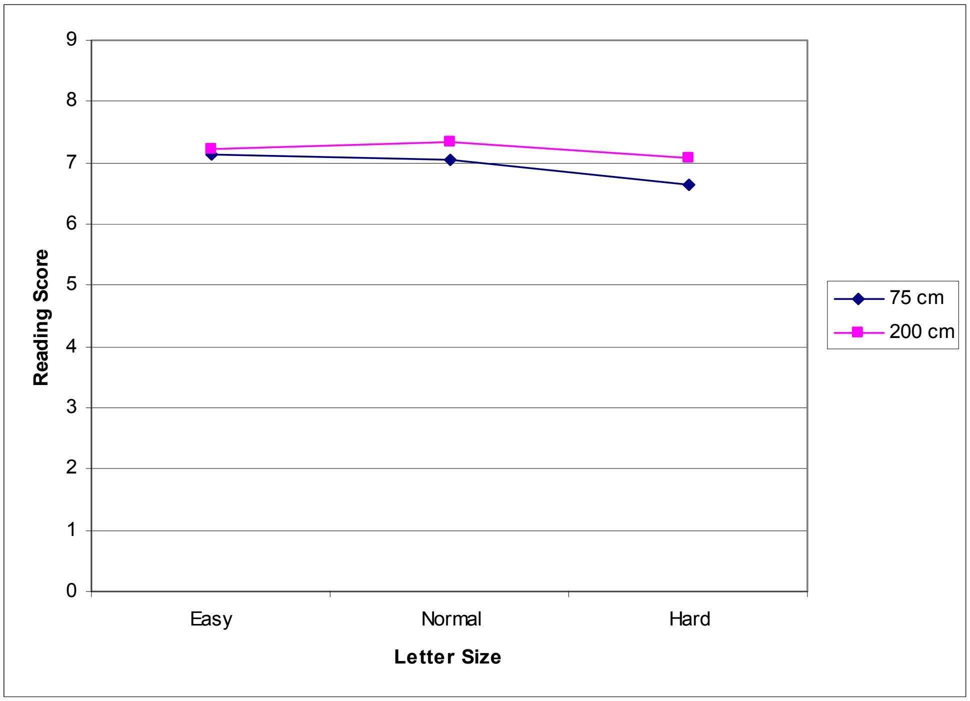

Figure 21: Distance x Letter Size Interaction Effect on Reading Scores for the Younger Individuals

4.2.8 Age group x Display Time x Letter Size Interaction Effect

This interaction effect was found to be significant at $F_{4,216} = 6.28$, $p<0.0001$ level. From the means plots (Figs. 22 and 23 it is clear that age has an influence on the "display time x letter size" interaction. Not only is the performance of the younger individuals higher for all combinations of display time and letter size than the elderly individuals, the variation in reading scores across the levels is significantly different. For example, the performance of younger individuals across the easy, normal and hard levels in the display times of 2 and 3 seconds does not vary as much as it does for the elderly participants. Also, the performance increase for the elderly individuals across the normal and hard levels is much more significant, for all levels of the display time, than for the younger individuals. It is also pertinent to note here that the 2 and 3 second performance level means, though significantly different, are closer to each other than the 1 second performance level means.

Table 24: Descriptive Statistics of Age Group x Display Time x Letter Size Interaction on Reading Scores

Age Group, Display Time, Letter Size	Mean	Standard Deviation
Old, 1, Easy	3.8036	1.3612
Old, 1, Hard	2.4732	1.5937
Old, 1, Normal	3.6607	1.6360
Old, 2, Easy	7.1696	1.7598
Old, 2, Hard	4.8393	2.6357
Old, 2, Normal	6.7232	2.1019
Old, 3, Easy	8.2946	1.6199
Old, 3, Hard	5.7946	3.0495

Age Group, Display Time, Letter Size	Mean	Standard Deviation
Old, 3, Normal	7.9821	2.1138
Young, 1, Easy	4.7857	1.3717
Young, 1, Hard	4.3036	1.4385
Young, 1, Normal	4.8839	1.5052
Young, 2, Easy	7.9375	1.6510
Young, 2, Hard	7.6964	1.4694
Young, 2, Normal	7.9553	1.4789
Young, 3, Easy	8.7857	0.9993
Young, 3, Hard	8.6071	1.0514
Young, 3, Normal	8.7589	1.0419

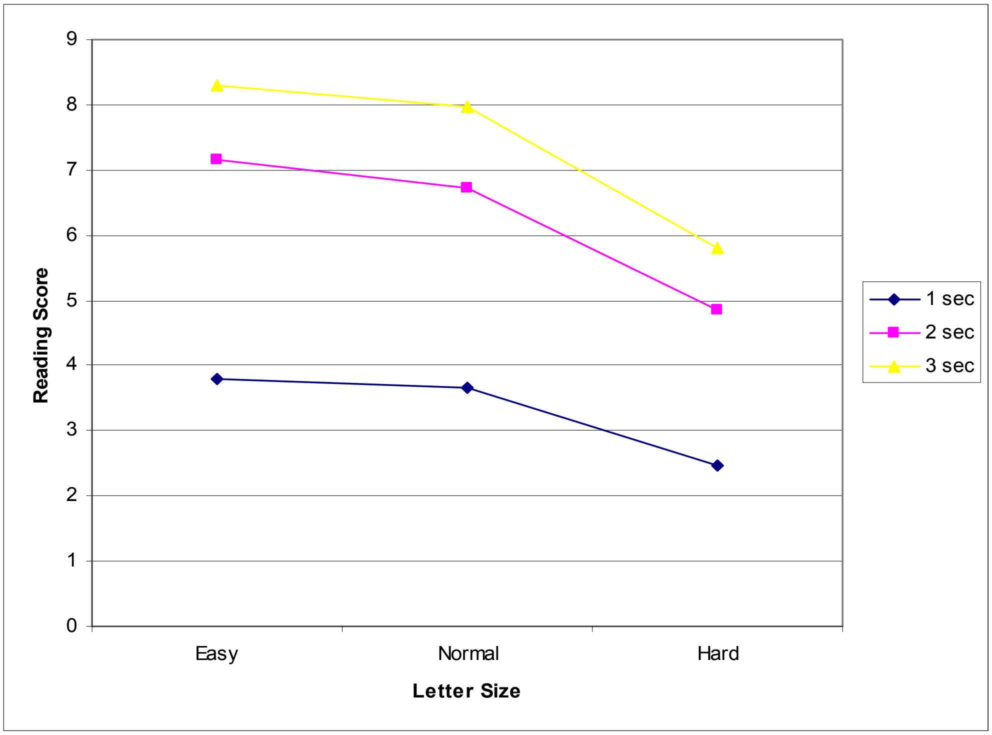

Figure 22: Display Time x Letter Size Interaction Effect on Reading Scores for the Elderly

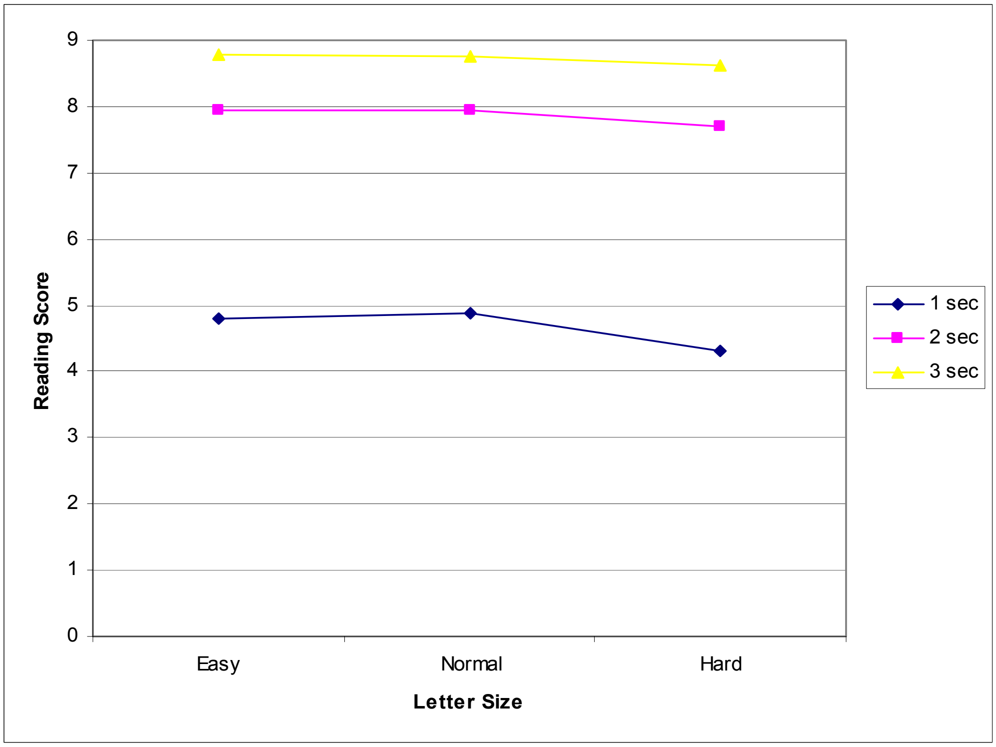

Figure 23: Display Time x Letter Size Interaction Effect on Reading Scores for the Younger Individuals

5.0 Discussion

5.1 Summary of Results

The present study was conducted to explore the effect of different parameters related to in-vehicle visual display design on the reading and information processing capability of elderly individuals and compare their performance with the younger population. The parameters whose effect was analyzed in this study (independent variables) were letter size, ambient illumination (daytime versus nighttime), distance (far versus near), age of the subject and display time. All of these parameters had significant effects on the reading performance of the participants, except ambient illumination, which had a minor effect. As expected, younger individuals had, overall, higher reading scores than the elderly participants. The ambient illumination, on the other hand, did not significantly affect reading performance, though the reading scores decreased slightly from daytime to nighttime. Between the two distance levels (200 cm and 75 cm), the farther distance yielded better performance. Also, the differences between performance of the participants for all the three display times were significant, with more display time resulting in better performance. More specifically, the reading performance increased much more when the time given was increased from 1 to 2 sec than 2 to 3 sec. This means that the time period for which information is displayed reaches a limiting value, beyond which increasing the time period does not result in significant performance gain. For the letter size independent variable, as expected, scores increased with increase in size of letters. There were significant differences among easy and hard levels and between normal and hard levels of letter sizes, but not between easy and normal levels (hard being the smallest letter size). In other words, reading performance did not significantly increase when the letter size increased from normal to the easy level. This implies that reading performance does not increase significantly after a particular stimulus size has been reached.

Also, there were several significant interaction effects observed between the independent variables. The age group of the subject influenced the reading performance across distances. Specifically, increase in distance led to more increase in reading performance for the elderly rather than the younger age group. Also, age of the subject influenced reading performance for a particular letter size and across letter sizes. For the younger age group, performance remained almost the same for the easy and normal levels, but decreased for the hard level of the letter size, although the difference in performance across the three levels of letter size was not significant. For the elderly age group, the performance decreased with decrease in letter size, for all letter sizes. Though the performance difference between easy and normal levels was not considerable, the difference between normal and hard levels was significant. This means that elderly have more difficulty reading smaller text size, but beyond a certain letter size performance does not increase significantly. Another significant interaction effect observed was that of ambient illumination versus distance. In this, the performance increased with increase in viewing distance for both ambient illumination conditions (daytime and nighttime), but the increase in performance was much more during the nighttime than the daytime condition, across all subjects. Interestingly, the ambient illumination level had an effect on performance across letter sizes. Though, the daytime and nighttime performance was almost similar for the normal letter size, performance for easy letter size was better during nighttime than during the daytime condition. Also, performance for the hard letter size was better during the daytime than nighttime. Another significant interaction was between distance and letter size. As expected, the reading performance decreased with decrease in letter size. But for the 75 cm condition, the performance decreased much more than for the 200 cm condition. Also, performance across both distances was the same for easy letter size. This means that the increase in performance afforded by the easy letter size overcomes any advantage offered by increase in distance.

Furthermore, the performance of elderly varied significantly on account of the letter size and the distance at which information was presented. More specifically, the reading performance reduced significantly with decrease in letter size at 75 cm, but did not vary as much for the 200 cm condition. On the other hand, for the younger individuals there was no significant reduction in performance on account of decrease in letter size and distance. This means that the reduction in performance observed on account of reduced letter size and distance, observed for the subject population on the whole, can be mostly attributed to the elderly. The performance of the elderly population was also different than the younger segment for the different letter size and display time combinations. Overall, the performance worsened with reduced display times and letter sizes for both age groups, but the drop was much more significant for the elderly. Specifically, the elderly experienced more problems than the young when the letter size was reduced for different display times, especially across normal and hard letter sizes.

5.2 Interpretation of Results

The overall information processing ability of the elderly subjects, as measured by the reading scores, was significantly less than younger individuals. This result supported the first hypothesis, where we said that the readability of the visual display will be reduced with advancing age. This can be attributed to the decline in visual, perceptual and cognitive functions which occur with age (Baltes, Cornelius, Spiro, Nesselroade, and Willis, 1980,; Retchin et al., 1988; Shinar and Schieber, 1991; Marottoli et al., 1993). Indeed, there may exist a causal relationship between decline in perceptual and cognitive functions (Fozard, 1990, Schaie, Baltes and Strother, 1964), where sensory loss leading to sensory deprivation may result in cognitive decline (Birren, 1964). Numerous studies have documented the decline in the visual system which can be attributed to decrease in both the accommodative amplitude (Atchison et al., 1994) and the speed of accommodation, both far-to-near and near-to-far (Beers & Van Der Heijde, 1996; Schaeffel, Wilhelm & Zrenner, 1993) due to stiffening of the eye lens. Also, deficits in visual acuity may have led to incorrect reading of the letters, thus reducing performance (Frisen and Frisen, 1981; Pits, 1982). For example, elderly people were more likely to need corrective lenses (19 vs. 11 participants). Hence this finding corresponded with existing research regarding decline of elderly perceptual and information processing abilities.

The reading scores for all subjects increased, albeit asymptotically, with an increase in presentation time, validating the second hypothesis. Since the time period available for reading must be shared between accommodation, perception and processing (Atsumi, Kanamori and Miyao, 2003), increase in time leads to better scores. The asymptosy can be explained since we did not increase the number of letters with increase in presentation time. Based on Miller's theory of information measurement and other well established work in human information transfer rates (Pierce and Karlin, 1956) we presented stimuli ranging from the maximal capacity of human information processing channel (9 letters/sec equivalent to 43 bits/sec) to successively easier levels (9 letters/2 sec and 9 letters/3sec). The fact that younger individuals not only performed better than elderly at all three levels, but also there was a lack of significant performance improvement across the three levels for the young as opposed to the elderly, points to the decrease in accommodative speed of the elderly, and longer processing times. This finding also agrees with the results of a study conducted by Cerella and Hale (1994) where information processing rates over the lifespan follow an inverted U-shaped curve. The reduced information processing rate may also be related to longer speaking times for the elderly, since the participants were instructed to read the letters aloud. In a study conducted by Morris and Brown (1994), testing reading rates between younger and older populations; it was found that the elderly users had an average speaking rate that was about 14% slower than younger users. This effect is significant because it reduces the time for which perceptually perceived information is available in the working memory. Working memory is the precursor store of information before final processing in the brain, and has a very short decay period (Just and Carpenter, 1992; Kareev, 2000). It enables the person to store, manipulate and retrieve information for later use and is an important aspect related to everyday driving (USDOT, Federal Highway Administration Technical Report), and moreover, it also declines with age (Norman, Kemper, Kynette, 1992). Hence reduction in time for which information is available in working memory along with age-related declines leads to loss of information actually available for processing, and therefore reduced performance.

With regard to size of the stimulus, i.e., letter size, three different letter sizes were presented for each distance condition, namely; easy, normal and hard, which subtended an angle of 0.45˚, 0.3˚ and 0.15˚ at the eye respectively. The overall performance increased with increase in letter size which supports our third hypothesis. Tinker (1963) reported very small differences in reading speed and accuracy for several sizes of newspaper type, but the study did not control for viewing distance, and hence the angle subtended at the eye. Howell and Kraft (1960) measured the legibility of alphanumeric symbols for four letter sizes ranging from 0.1˚ to 0.6˚, in which they found optimal legibility for 0.4˚ characters. Bouma et al. (1982) measured oral reading rates for characters ranging from 0.3˚ to 2.8˚ and found a slight increase in reading rate with letter size. In a comprehensive study investigating the effect of letter sizes on reading performance, character sizes ranging from 0.06˚ to 24˚ were investigated (Legge, Pelli, Rubin and Schleske, 1985), and maximum reading rate was obtained for characters in the range 0.3˚ - 2˚. Also, a fairly rapid decline in reading rate was observed for characters smaller than 0.3˚ and greater than 2˚, albeit the rate of decline was slower in the latter case. These results agree with the findings of this study where, a size transition from hard (0.15˚) to normal (0.3˚) represented a significant increase in performance, for both age groups. Beyond that, increasing the size (0.3˚ to 0.45˚) improved the performance but not by as much. The rapid decline in performance for characters smaller than 0.3˚ is most likely associated with acuity limitations. Also, even though we controlled for distance by using angles subtended at the eye, it was found that performance was greater at 200 cm than 75 cm for hard and normal letter sizes, but the same for easy letter size (distance x letter size interaction effect) for both age groups. This may be due to the larger time for accommodation needed for looking at the 75 cm target than the 200 cm target. Furthermore, the elderly experienced a greater decline in reading performance from normal to hard letter size than the younger individuals which may be a consequence of their much worse visual acuity (Gittings & Fozard, 1986; Pits 1982). Additionally, for a given display time, performance was seen to increase with increase in letter size. This effect is due to changes in apparent distance induced by letter size which reduce the required accommodative efforts (Kruger, and Pola, 1985). Not surprisingly, this effect was more pronounced for the elderly.

Another design parameter considered in this study was related to designing for daytime versus nighttime ambient illumination conditions. No significant differences were found between the two conditions for both age segments, and therefore did not support the fourth hypothesis, i.e., readability would be better during daytime than nighttime. To explain this counterintuitive result, we have to consider the phenomena of contrast ratio (CR) and visual acuity. Contrast ratio is the luminance ratio between a brighter state and a darker state on a display screen, and greater contrast ratio leads to better visual acuity. Ambient illumination reduces the CR of a display screen due to reflection from its surface, consequently reducing the afforded acuity. In this study, we used two different inherent LCD CR values for the daytime and nighttime condition. Specifically, we used a greater inherent LCD CR value for daytime than nighttime, and this may have resulted in similar overall CR values for the two conditions, and consequently similar visual acuity resulting in similar reading performance. An interesting conclusion that can be drawn from this is that by designing displays which adjust their inherent contrast ratio according to daytime and nighttime, we can cancel out the differences in reading performance which may result from differences in contrast ratio produced by the two ambient illumination conditions. Another effect that we expected to observe was whether if when the pupil dilates during the nighttime condition, reading is enhanced due to more light reaching the retina, or diminished due to optical imperfections of the lens (Sloane, Owsley and Alvarez, 1988). Again, no conclusive findings were observed in this study.

The distance at which letters were presented significantly influenced performance, and this effect was almost entirely due to the older individuals. This result supported our fifth hypothesis. This finding may be attributed to the onset of presbyopia in elderly individuals, which results in longer accommodation times for closer distances and errors associated with focusing at closer distances due to decrease in accommodative amplitude (Tsui, Atsumi, Kanamori, and Miyao, 2002). In a previous study conducted by Lockhart et al. (2004), static visual acuity was positively correlated with viewing distance for the elderly subjects (Figure 1). In this study the subjects were required to focus, perceive and process the information presented in a limited amount of time, and therefore better visual acuity at greater distances may have reduced the amount of errors for the 200 cm condition. Also, since the performance was much better at 200 cm than at 75 cm, it may be reasonable to conclude that the tonic position (Jachinski, 2000; Leibowitz and Owens,

1978) for the elderly as a group overall lies closer to 200 cm. Another factor to be considered in this regard is related to cues which help an individual perceive distance such as stereopsis (i.e., binocular vision) and vergence. Previous studies have examined age differences in stereopsis, but there is no consensus regarding the magnitude of this difference or even if it exists (Owsley and Sloane, 1990). But, some existing evidence suggests that distance judgments may become distorted at nighttime luminance levels and may be attributed to vergence insufficiency, and this effect may be more pronounced for the elderly (Bourdy, Cottin, and Monot, 1991). Indeed, in this study we found an interaction effect for distance and ambient illumination, where performance was worse during nighttime than daytime for 75 cm but the converse was true for 200 cm. This effect may have been due to difference in perceived distance during the two ambient illumination conditions.

5.3 Conclusion and Design Recommendations

The function of the visual display systems in vehicles is to augment the information available to the drivers regarding their surrounding environment. The goal of this is to help them improve their driving performance, make fewer errors and consequently reduce fatalities. But this source of information places increased demands on the limited attentional and processing resources, in addition to the regular demands of normal driving, especially for elderly drivers. Indeed, there is a fine line between when the benefits due to increased amount of available information are overcome by negative consequences due to information overload. Since driving is a dynamic task with constantly changing stimuli to be processed, attention must be given to designing in-vehicle systems which minimize eyes-off-the-road-time, while enabling maximum information processing during that limited window of time. In the current study, we tried to come up with design guidelines for such systems by measuring how changes in design parameters can affect information processing. A key point in this study, which formed the basis for our dependent variable (reading score), was to capture the cumulative defects of perceptual and conceptual systems in elderly individuals, so that the design can take into account all of these factors. Various studies have been conducted to investigate the effect of parameters such as letter size, luminance, age, distance, etc. on visual performance. In many cases, these studies have not taken into account the impact of different design parameters on information processing ability, and none have explored them in such an integrated fashion as in this study. By considering these parameters in such fashion, we were not only able to find out how each affects performance individually, but also how these variables interact with each other. This is especially important since in real world design trade-offs have to be made and knowing how one design variable can affect the other can greatly improve the design process. Following is a set of design guidelines that we have derived based upon the results obtained in this study:

1. Age of the driver is an important criterion while deciding the distance at which information must be presented. Both elderly and young individuals tend to perform better at farther distances, though the performance gain for the elderly is much more. Hence information must be presented at or near 200 cm rather than 75 cm. If information must

be presented at 75 cm due to design constraints, larger letter sizes (normal or easy) should be used.

2. Information should be presented at a rate of 4-5 letters (or chunks of information) per second. A faster rate will cause the driver to miss the presented information. A slower rate will ensure processing of the presented information but will increase eye-off-the-road-time, which is not desirable. If information needs to be presented at a faster rate than that, a larger letter size should be used (easy - 0.45˚). Another factor that needs to be kept in mind is that while display time affects performance significantly for both age groups, letter size holds more importance for the elderly.

3. Letters should be presented at the normal size level (0.3˚). Sizes less than that will cause errors in the perceived information. Above that level, performance does not increase significantly. There is a tradeoff between performance gain associated with increase in letter size and display area available in the vehicle. This should be taken into account by the designer, i.e., the display area that he/she is willing to sacrifice for a given increase in performance. Also, even though one can compensate for smaller letter sizes with increase in display time, this should be avoided as it will increase eyes-off-the-road time.

4. Farther distances lead to better performance during both daytime and nighttime conditions, but this effect is more significant for the nighttime condition. Hence, information should be presented at distances close to 200 cm during nighttime.

5. Larger letter sizes have greater performance gains associated with them during the nighttime. It is therefore desirable to switch information to a larger letter size during the nighttime, while during the daytime smaller letter sizes can be used. Again, the decision depends on how much display area one is willing to sacrifice for a given performance gain. Indeed, there can be a mechanism to switch information from smaller to larger letter size when ambient illumination conditions change.

6. Screens with self-adjusting contrast, according to ambient illumination conditions, should be used so that the perceived contrast ratio remains the same. Since the ambient illumination conditions can vary greatly, this can provide a way to control for them so that the acuity afforded by a particular display does not change with them.

While implementing the above guidelines, an issue that needs due consideration is one of designing for populations with different characteristics, such as, for example, young and old. Indeed, the performance gains associated with the implementation of the above design guidelines are more significant for the elderly than the younger individuals. Should then there be different vehicle display designs for different segments of the population? An approach to be considered in this regard is “Universal Design” (The Center for Universal Design, 1997) which advocates that the design of products and environments should be such that they are usable by all people without the need for adaptation or specialized design. A design that is specialized to accommodate the needs of people with physical, sensory and cognitive disabilities is classified under “Assistive

Technologies" and attempts to meet specific needs of certain individuals, whereas universal design advocates an approach where a single design serves the needs of populations with different characteristics (e.g., elderly, individuals with disabilities, etc.). The need behind this approach lies in the fact that implementing "special" features for certain demographics not only involves higher costs, but also fosters a sense of segregation among those populations. Additionally, designs modified to meet the requirements of these segments of the population may, in some cases, benefit everyone (Design Council, 2005). In our study, the objective of testing both young and old subjects was to find out whether age has an impact on the overall performance as well as its interaction with other design parameters. As is illustrated in the results of the study, changing the parameters in question influences elderly performance much more than for the younger individuals. More specifically, parameter values that improve elderly performance are either also beneficial for the younger individuals or do not significantly affect them; for example, both elderly and younger individuals perform better at larger letter sizes whereas distance positively affects elderly performance at the same time not significantly affecting younger individuals' performance. In other words, if we design for the elderly population, it would also accommodate the needs of younger demographic, and therefore separate designs are not needed. Indeed, separate designs for elderly and young would increase the cost of buying a vehicle for both segments due to reduced economies-of-scale.

5.4 Limitations and Future Research

Our study had the following main limitations. These were mainly a consequence of safety considerations for the subjects, equipment available for completing the study and budget constraints:

1. The dependent variable (reading score) was based upon the fact that we were trying to measure the amount of information that is correctly processed. This task (letter reading) is not strictly generalizable to the processing ability of various other types of information (e.g., graphical, pictorial) that may be presented to the driver by the vehicle display system.

2. Since the experiment was conducted in a closed laboratory room, it did not exactly correspond with the actual dynamic conditions (rapidly changing visual stimuli such as other moving vehicles) that the driver is faced with during the actual driving task. This may also have implications on the generalizability of the study.

3. The effect of contrast sensitivity was not taken into account since a fixed level of contrast was used for all subjects during the daytime and nighttime conditions, based on what is presently being used in vehicles. Contrast sensitivity is a measure of how faded or washed out an image can be before it becomes indistinguishable from a uniform field. Existing research suggests that age differences in acuity (Lockhart, 2004) are magnified at low levels of luminance contrast (Owsley, Sloane, Skalka and Jackson, 1990). Indeed,

this may have significant implications on display design, and must be studied in future research.

4. We used only a single font type for all subjects under all conditions (Gothic). Existing research points to the fact that font type can influence performance. More specifically, it has been observed that Times New Roman, Gothic and Sabon fonts facilitate reading relative to other fonts, whereas the presence or absence of serifs does not significantly affect performance (Connolly, 1998). Future research needs to investigate the characteristics of fonts that may affect their readability such as the relationships between percentage x-height (the percent of a font's x-height to its cap-height) and font contrast (the percentage of a font's thin stroke width to its thickest stroke width).

5. Four of the participants (3 elderly, 1 young) had bifocal glasses and one person (elderly) had trifocal glasses. We did not expect this to be an issue in this study since the display was presented at eye level while the participant was looking straight ahead. But indeed, this may be an issue because in-vehicle display systems at the dash-board require the eye to move from looking straight ahead to downward direction and involve a change in focal length of the eye lens due to change in the power of the glasses for bi-and-tri-focal glasses. This may influence the accommodative efforts, associated errors, visual acuity and time required to focus. Future studies need to take into account the different locations of on-board display systems within the vehicle, and associated variability in reading performance.

This study was designed to explore the basic design parameters for an in-vehicle display system. Needless to say, display systems of the future require a very detailed blueprint. For this, studies should be conducted in an ecologically valid setting such as an actual vehicle in which both letter based and graphical types of information should be tested. Little research has been done to investigate the effect of aging upon depth/distance perception based on cues such as stereopsis, ocular vergence effects, spatial and motion parallax, etc. This can have important implications on distance at which information is presented especially under conditions of low luminance. Additionally, certain other variables such as contrast sensitivity and color are important variables that require relevant design guidelines and should be investigated.

In addition to the above, since we have discussed statistically significant or non-significant differences in performance, a question which needs to be addressed is how much of a difference is “practically” significant, i.e., whether a particular increase or decrease in visual display reading performance has any measurable impact on the driving performance. To address this question we need to look at the importance of the additional information provided by the visual display as compared to the sources of information about the environment normally available to the driver. As has been pointed out in the literature review section, elderly people are prone to greater fatality rates because of various underlying degenerative factors. In addition to this, certain studies have reveled that failure to yield and making left turns are the top two crash scenarios for the elderly (Cooper et al., 2001). Arguably, additional information about approaching vehicles can reduce these types of crashes. Also, most accidents are likely to take place in complex driving conditions where there may be a deficiency of information about the surroundings. In this case every additional chunk of information can be effective in reducing the crashes. Of course, the effectiveness of the presented information eventually depends upon its relevance and the way in which it is presented. Additionally, time is also an important factor. If the design of the display is such that less time is required to process a given amount of information, it can compensate for reduced reaction times in the elderly (Luchies et al., 2001), especially for a complex task such as driving. Further research is required to determine exactly how much of an increase in driving performance is associated with a given increase in processing capability for the in-vehicle display, and what information to display in a given driving situation. This will most certainly require the driver to be performing an actual driving task while the information is presented on the display.

Also, while the detrimental effects of aging cannot be completely overcome with the use of guidelines suggested in this study, recent research has suggested that elderly drivers have well developed heuristics for the driving task and they escape the effects of advanced aging (Salthouse, 1991). Many of the visual and motor skills of experienced drivers fall into this category. These require very little attentional resource and processing capacity and present a significant advantage in designing for the elderly. It is therefore extremely important to direct a considerable research effort in identifying and designing for them.

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Appendices

Appendix A. Data Sheet

For each PowerPoint slide presented to the subject, in each experiment, the data was collected in the following format:

Subject Number	**Age Group**	**Experiment Number**	**Ambient Illumination**	**Distance (cm)**	**DisplayTime (sec)**	**Letter Size**	**Color**	**Score (bits of information)**
1 - 56	Young/ Old	I, II or III	Daytime/ Nighttime	200/75	1/ 2/ 3		Red/ Blue/ White	0 - 9

Appendix B. Driving History Form

Personal Driving Data and Medical History

Virginia Tech, ISE Department

Dynamic visual performance of Elderly Drivers

Date ______________

Name _____________________Phone_____________________ Age _____________
Sex __________ Height (ft in) _______________ Weight (lb) _____________
In case of emergency contact: Name ______________________ Phone ____________

1. Do you have a valid driver's license? Yes________ No________
2. How long have you had your driver's license? ___________________________
3. How often do you drive each week? ____________________________________
4. What type of vehicle do you currently drive? _____________________________
5. Have you been involved in any accidents within the past 2 years? If so, please explain.
____
6. Do you drive during the night? Yes _________ No __________ If no, please explain.
____
7. If you do drive at night, how often do you drive at night? Every day____________
At least twice a week _____________ Less than twice a week _______________
8. Do you drive in an area that does not have overhead lighting at night? If so, please explain. ____
9. Do you usually drive in an area that does have overhead lighting at night? ________
10. Do you have any vision impairments that restrict your night driving? If so, please explain.
____
11. Do you have normal or corrected to normal vision? If no, please explain.
____

Check if susceptible to:
Shortness of breath _____ Dizziness _____ Headaches _____ Fatigue _____
Pain in arm, shoulder or chest ______
If you checked any of the items above, please explain: ___________________________
____

Are you currently taking any type of medication ? ______ If so, please explain:
____

Have you had or do you now have any problems with your blood pressure ? _______ If so, please explain: ____

Appendix C. Informed Consent form

Virginia Polytechnic Institute and State University

Informed Consent for Participants of Investigative Projects
Grado Department of Industrial and Systems Engineering
Virginia Tech

TITLE OF STUDY: Dynamic Visual Performance of Elderly Drivers

PRINCIPAL INVESTIGATORS: Pankaj Raj and Thurmon E. Lockhart

I. PURPOSE

The purpose of this study is to explore the nature of decline in accommodative power with increasing age and its implications on overall driving performance (i.e., visual performance and information processing). This study is aimed at exploring the design attributes and parameters of in-vehicle displays characteristics and usability that are needed to accommodate the older population, and ultimately enhancing the comfort and safety of the elderly drivers.

II. PROCEDURE

1. Read and sign this Informed Consent Form.
2. Participate in pre-experimental Visual Acuity Test using Bausch and Lomb Vision Tester.
3. Participate in the main experiment.

Visual Acuity Test - Bausch and Lomb Test

You will be asked to sit in a chair and place your eyes on the instrument. You will repeat this procedure until it is completed. You may stop at any point of the session, and ask any questions necessary. The experimenter will answer all necessary questions. You will be asked to continue wearing your corrective glasses or lenses during the study.

I. Daytime Condition

1. Ambient illuminant will be set at 1000 lx (measured horizontally – on a flat surface) using the light meter. A luminometer will be used to check whether the brightness level of the target is set at 100 cd/ sqm.
2. You will be asked to position your head on the chin rest and lean a little forward so that your forehead can rest against the provided support. The chin rest will be adjusted so that your eye line coincided with the marked level on the chin rest.
3. You will be asked to look straight and the mirror adjustment for the far target will be checked. Care will be taken to check that your line of sight is perpendicular and in line with the target on the laptop screen. If necessary, your chair height will be adjusted to achieve the purpose of alignment.

4. Nine random alphabets will be presented to you at two distances (75 and 200 cms). The alphabets will be presented in white color against a black background on the laptop. Powerpoint software will be used for presentation and the slide transition will be set at three time intervals (1, 2 and 3 seconds). The alphabets will be designed using Microsoft Word as per the letter sizes (at 75 and 200 cms) and type (Gothic).
5. Initially, you will look at the far target.
6. The lower mirror will be triggered by using pneumatics. When the mirror goes down, the letters will be presented to you on the laptop. The mirror will go down for double the duration of the display time.
7. After, the mirror comes back up again, you will be asked to verbally call out letters of the alphabets presented.
8. Your Responses will be recorded using a tape-recorder.
9. The experiment will be conducted till all the treatment combinations are completed at each of the two distances (75 and 200 cms). The treatment combinations will be randomized.

II. Nighttime Condition

1. Ambient illumination will be set at 5 lx. Similar procedure as daytime conditions will be followed. The luminance level of the white colored letter will be set at 10 cd/ sq m.

You may stop at any point of the session, and ask any questions necessary. The experimenter will answer all necessary questions.

You will be allowed to rest after each session.

III. RISKS OF PARTICIPATION

Minor irritation of the eyes, and momentary blur vision: Risks will be minimized through resting of the eyes.

IV. BENEFITS

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Your participation may provide a better understanding of your visual characteristics during daytime and nighttime conditions.

V. COMPENSATION

Monetary compensation will be provided ($10.00 per hour).

VI. ANOYNMITY AND CONFIDENTIALITY

The data from this study will be kept strictly confidential. No data will be released to anyone but the principal investigator and graduate students involved in the project without written consent of the subject. Data will be identified by subject number.

VII. FREEDOM TO WITHDRAW

You are free to withdraw at any time from the study for any reason. Circumstances may come up that the researcher will determine that you should not continue as a subject in the study. For example, an illness could be a reason to have the researcher stop your participation in the study.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Tech, and by the Grado Department of Industrial and Systems Engineering. You will receive a copy of this form to take with you.

VIIII. SUBJECT PERMISSION

I have read the informed consent and fully understand the procedures and conditions of the project. I have had all my questions answered, and I hereby give my voluntary consent to be a participant in this research study. I agree to abide by the rules of the project. I understand that I may withdraw from the study at any time.

If I have questions, I will contact:

Principal Investigator: Thurmon E. Lockhart,
Assistant Professor,
Grado Department of Industrial and Systems Engineering,
Phone: 231-9088.

Chairman, Institutional Review Board for Research Involving Human Subjects: David Moore,
Phone: 231-4991

Signature of Subject ____ Date:

Signature of Project Director or his Authorized Representative:
____ Date:

Signature of Witness to Oral Presentation:
____ Date: