The Effect of Age on Dark Focus Distance and Visual Information Transfer Rate

Nantakrit Yodpijit

Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State
University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Industrial and Systems Engineering

Thurmon E. Lockhart, Chair
Brian M. Kleiner, Member
Karen A. Roberto, Member
Woodrow W. Winchester III, Member

October 14, 2010
Blacksburg, VA

Keywords: Age, Autorefractor, Dark Focus, Visual Information Transfer Rate

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ABSTRACT

Although the static measure of accommodation is well documented, the dynamic aspect of the resting state (dark focus) of accommodation is still unknown. Previous studies suggest that refractive error is minimal at the intermediate resting point of accommodation – i.e., at the dark focus distances. Additionally, aging is closely linked to increased refractive error. In order to assess the effects of age on dark focus distance and its utility in enhancing the visual information transfer rate, two experiments were conducted under nighttime condition (scotopic vision) in a laboratory setting. A total of forty participants with normal vision or corrected to normal vision were recruited from four different age groups (younger: 26.9±5.0 years; middle-aged: 50.7±4.8 years; young-old: 64.6±2.8 years; and old-old: 79.8±6.1 years). Each age group included ten participants. In Experiment I, the accommodative status of dark focus at the fovea was assessed objectively using the modified autorefractor, a newly developed method to continuously monitor the accommodation process. The mean dark focus distances for younger, middle-aged, young-old, and old-old adults were 64.5±6.6, 73.4±20.6, 84.4±29, and 92.1±33.4 cm, respectively. There was a significant difference between the dark focus distances among different age groups. Post-hoc analysis indicated that there were statistically significant differences among young and old-old, young and young-old, and middle-aged and old-old age groups. In Experiment II, the information transfer rate was determined while viewing a target at three different distances: 52 cm, 73 cm (current recommended reading distances) and the individual's dark focus. A set of randomized alphabet characters were presented on a visual display with a luminance level of 20 cd/m^2 and ambient illumination level of 4 lux. To assess the information transfer rate, participants were asked to read a set of characters aloud with their fastest rate for three seconds. Three measurements of inforamtion transfer rate at each viewing distance at random were made. Results obtained from each viewing distance were collected and averaged. The results showed that the mean visual information transfer rate for younger, middle-aged, young-old, and old-old adults were 14.27±1.43, 10.58±2.25, 9.35±2.13, and 7.73±2.36 bits/sec, respectively. There were statistically significant differences at $\alpha < 0.05$ in means and standard deviations of visual information transfer rate in young and old-old, young and young-old, young and middle-aged, and middle-aged and old-old age groups. The mean visual information transfer rate at 52 cm, 73 cm and individual dark focus were 11.08±3.10, 10.14±2.97, and 10.22±3.42 bits/sec, respectively. There were statistically significant differences at $\alpha < 0.05$ in means and standard deviations of visual information transfer rate at different viewing distances at 52 cm and 73 cm, and 52 cm and individual's dark focus. However, there were no statistically significant differences in the interaction between age and viewing distance ($F = 1.6818$, $P = 0.1378$) on the amount of visual information transfer rate. In summary, the visual information transfer rate was not greater when presenting visual stimulus at the individual's dark focus as compared with two fixed recommended viewing distances (52 cm and 73 cm). The greatest amount of visual information gained was at 52 cm. Actual and potential applications of this study including specifications for designs were also discussed.

ACKNOWLEDGEMENTS

I would like to thank my major advisor, Dr. Thurmon E. Lockhart, for his guidance throughout this research, and the freedom to conduct this research in a way that allowed me to further my development both academically and professionally. I am grateful to him for sharing his knowledge, expertise and skills with me, and I really appreciate his patience, confidence and optimism that I needed and looked for during the past few years. It is my great pleasure to also acknowledge and thank my committee members, Drs. Brian M. Kleiner, Karen A. Roberto and Woodrow W. Winchester. Their comments, criticism, and varied perspectives were genuinely helpful in shaping this research.

Special thanks go to my sweetheart Manutchanok Jongprasithporn (MJ) for being my greatest support and being an invaluable source of advice and an open ear when I needed it. Many thanks also go to my great American friends at Virginia Tech, Courtney A. Haynes and Jay E. Clasing for their time on proofreading. All of my friends here in the US and back home in Thailand deserve my thanks for their assistance and being a source of fun when it was needed. I could not have completed this dissertation without financial support from the Royal Thai Government.

Finally, I owe thanks to my parents (I know they would be proud of my academic success) and family for their patience, always having faith in me as I have pursued my degrees in the US.

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CHAPTER 1

INTRODUCTION

1.1 Rationale

The human ability to deal with the environment relies heavily on the capacity to process sensory information (Kline & Scialfa, 1997). Our senses are sensitive to external stimuli in order to extract critical information from the world around us (Boyce, 1973). Of all our senses, vision gives us the most detailed and accurate information about our position and the position of other objects in the environment (Anshel, 2006; Steinman, Steinman, & Garzia, 2000). Additionally, age-related physiological changes generally result in a decline in visual performance (Garg, 1991; Schieber, 2006). In terms of visual performance, accommodation is one of the initial responses of the visual system to maintain a clearly focused image on the retina (Mordi & Ciuffreda, 1998, 2004; Wang & Ciuffreda, 2004). The accuracy of this process determines how much information is extracted from visual stimulus and is therefore essential to virtually every visual task (Leibowitz & Owens, 1975a; Lockhart & Shi, 2010).

Accommodation represents the ability of the eye to change its power to bring objects of interest at different distances into focus (Ciuffreda, 1991; Marran & Schor, 1997). As such, it makes an essential contribution to visual performance. The amplitude of accommodation[1] is affected by age (Duane, 1912; Glasser & Kaufman, 2003; Hamasaki, Ong, & Marg, 1956) . It probably reaches a peak early in the second decade of life, and then gradually declines to become zero at approximately the middle of the sixth decade (Atchison & Smith, 2000; Goss & West, 2002). The decline in amplitude of accommodation occurs when the range of accommodation is

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[1] Amplitude of accommodation is the difference between the convergences of the far and near points (Atchison & Smith, 2000). If distances are measured in meters (m) the vergence unit is the diopter[2] (D) (Goss & West, 2002).

[2] Diopter is an expression of focal power – mathematically the reciprocal of the focal length in meters (Simonelli, 1979). Example: an eye (or lens) focused at 1 m has a power of 1 diopter (D).

reduced so that near objects of interest cannot be seen clearly. This is called “presbyopia” and is usually age-related (Charman, 1996; Glasser & Campbell, 1998; Strenk, Strenk, & Koretz, 2005).

The dark focus or resting level of visual accommodation (Ebenholtz, 1992) is the refractive state that the eye tends to return to the absence of visual stimulation, as in complete darkness (Allen & O’Leary, 2006; Simonelli, 1979; Toates, 1972) . Previous studies suggest that refractive error is minimal at the intermediate resting point of accommodation (Leibowitz & Owens, 1975a, 1978; Owens, 1979), and thus minimizing visual fatigue (Wesner & Miller, 1986). Visual fatigue has a wide range of visual symptoms, including eyestrain, headache, and tiredness (Ukai & Howarth, 2008). Viewing distance between the user’s eyes and the visual display is a robust treatment variable in studies reporting visual fatigue symptoms (Dillon & Emurian, 1996).

Current recommendations of viewing distances lack theoretical and empirical support. Results obtained from a number of previous studies suggest that the preferred viewing distance from a visual display, the distance that produces the least reports of visual fatigue symptoms, should be greater than 50 cm (Grandjean, Hünting, & Nishiyama, 1984; Jaschinski-Kruza, 1990, 1991), while the Human Factors Society recommends a minimum of 30 cm (ANSI, 1988). Furthermore, greater visual comfort at 100 cm than at 50 cm was reported (Jaschinski-Kruza, 1988). However, musculoskeletal discomfort may ensue with a greater viewing distances since resolving characters will be difficult leading to forward head posture and ultimately neck symptoms (Rempel, Willms, Anshel, Jaschinski, & Sheedy, 2007). As such, future work is needed to provide better guidelines for viewing distances.

Viewing distance is an important factor leading to reading errors. Determination of optimal viewing distance may be more complex than the simple definition of display quality and characteristics (Trautman, Trautman, & Moskal, 1995). For example, viewing text too closely could induce myopia (Angle & Wissmann, 1978). On the other hand, monitoring a display at a far distance may lead to a loss of critical information. In this study, the optimal viewing distances of different age groups will be established utilizing the dark focus measurement. Using the optimal viewing distance may reduce musculoskeletal and visual symptoms and disorders (Jiang, Schatz, & Seger, 2005; Rempel, et al., 2007).

The main objective of this study is to investigate the individual's dark focus while considering the effects of age and viewing distances on information transfer rate. It is hypothesized that age-related visual performance (as measured by information transfer rate) will be better at the individual's dark focus distance versus a fixed recommended viewing distance. Based upon the completion of this study, the author anticipates that the age-related changes in dark focus associated with information transfer rate can be determined. The findings obtained from this study will lead to a better understanding of age-related dark focus, may be used in the design of visual work at various distances and, may lead to a reduction of accommodative errors for both young and older individuals.

1.2 Research Objectives

This study focuses on investigating the natural decline in accommodative power with increasing age and the implications of readability of the visual display (alphabet characters) as function of dark focus. It utilizes a newly developed method to continuously monitor the dark focus of the visual accommodation process. Specifically, the main objectives of the study are as follows:

1.2.1 To dynamically record the dark focus of visual accommodation via the modified Shin-Nippon SRW-5000 autorefractor.

1.2.2 To investigate the effects of age on readability of the visual display (as measured by number of correct character identified – bits of information gained) when presenting visual cues at dark focus distance and fixed recommended viewing distances (52cm and 73cm).

1.2.3 To investigate the interaction between age groups and target distances.

1.3 Hypotheses

The hypotheses of the study are:

1.3.1 The dark focus distances (as measured by the modified autorefractor) will be greater for older participants than younger participants.

1.3.2 Transfer of information (as measured by the number of correct characters identified in bits of information gained) will be greater when presenting visual stimulus at the dark focus distance for all participants.

1.4 Relevance

The aging population of the United States is changing dramatically and rapidly (Jamshidi, Oppenheimer, Lee, Lepar, & Espenshade, 1992; Schneider & Guralnik, 1990). In 2003, 35.9 million people were aged 65 and older, or 12 percent of the total population. Among the older population, 18.3 million were aged 65 to 74 years old, 12.9 million were 75 to 84 years old, and 4.7 million were 85years and older. Today's Americans are living longer and the US population continues to age. Based upon US Census Bureau projections, the number of older people will substantially increase during the 2010 to 2030 period as the first Baby Boomers turn 65 in 2011. The US aging population in 2030 is estimated to be twice as large as in 2000, growing from 35 million to 72 million, representing about 20 percent of a total of US population (He, Sengupta, Velkoff, & DeBarros, 2005).

Upon the completion of this study, the results will lead to a better understanding of the mechanisms of the dark focus and visual accommodation process and, increase the body of knowledge in this domain. The effects of age and dark focus distance on visual performance can also be used to improve the quality of life for the older person. In most instances, work operations that are designed to be easy to use by older adults may also be easy to use by other user groups. Older adults can help designers quickly identify usability problems that might arise for younger adults (Fisk, 1999). For examples, if a specific dark focus distance is found to be beneficial for a variety of age groups in term of their dynamic visual performance, the manufacturing industry may use these results to increase their operators' performance. This could be accomplished by redesigning the workplace that has workers of different age groups engaged in a variety of visual tasks. This study may also have practical implications in automobile design which could ultimately enhance the comfort and safety of older drivers by applying the results to the placement of information displays in order to enhance visual performance of drivers of different ages as well as reduce visual fatigue. As such, an explicit assumption of this study is that the quantification of dark focus distances associated with aging is an important and critical first step towards optimizing readability of the information according to the location of the in-vehicle visual displays. Understanding these critical factors will help focus our attention towards developing the most relevant and optimal in-vehicle visual display distance for both young and older populations.

CHAPTER 2

LITERATURE REVIEW

This chapter provides a brief introduction of aging, human vision, function of the eye with an emphasis on accommodation process, and information transfer theory. The literature review is divided into two sections. The first section briefly introduces aging effects on visual systems, including structure of the eye, accommodation, and dark focus or resting state of accommodation. The second section focuses on human factors/ergonomics and occupational issues related viewing distance and reading in the dark. The third section summarizes visual information transfer theory relating to reading tasks.

2.1 Human Vision and Aging Effects

Vision plays a significant role in human life. The eye is responsible for one of our vital senses and is one of the most important organs in the body (Cassel, Billig, Randall, & Farrell, 1998). The visual system begins with the eye and ends with the brain. The eye forms a sharp image of the object being viewed on photoreceptors. The photoreceptors function as transducers converting the incident electromagnetic quanta into electrical discharges. The signals produced by photoreceptors are then analyzed by the neural system before being transferred via optic nerve to the brain where they are interpreted on the basis of previous experience (Boyce, 1982).

Age-related changes occur in sensing and perceiving information (sensation and perception), processing of that information (cognition), and physically responding to the information (movement control). Changes associated with aging, known as aging characteristics, are generally considered to start around 40 to 50 (Glasser & Kaufman, 2003). However, it is important to keep in mind that such changes are not always so straightforward. There are no definitive boundaries between what is considered young and what is considered old; thus age is not easily represented as a nominal variable. As a result of reporting differences across databases, some of the research findings represent aging adults as older than age 50 or older than age 65. The initiation and severity of changes will vary between individuals. Examples of changes include (1) reduced ability to perceive contrast and to focus at different distances, (2) decreased speed in adapting to changes in light, (3) increased color perception of yellow due to decreased ability to distinguish blues and greens, (4) impairment of near vision, (5) increased reaction time, (6) reduced ability to divide attention between tasks (Hitchcock, Lockyer, Cook, & Quigley, 2001).

2.1.1 Structural changes in the visual systems

The human eye is in a bony socket within the skull and is likely spherical with a diameter of approximately 22 mm. The eye contains light-sensitive receptors, protected within a disklike structure, through which light enters by way of lens. The outer of the eye, which can be seen as the white around the eye, is a strong elastic membrane, called the sclera. However, the eye is not made of the rigid material; its shape is maintained by the pressure of interior fluids. In terms of physiological structure, the major parts of the eye include cornea, aqueous humour, iris, pupil, lens, vitreous humour, and retina (see Figure 2.1).

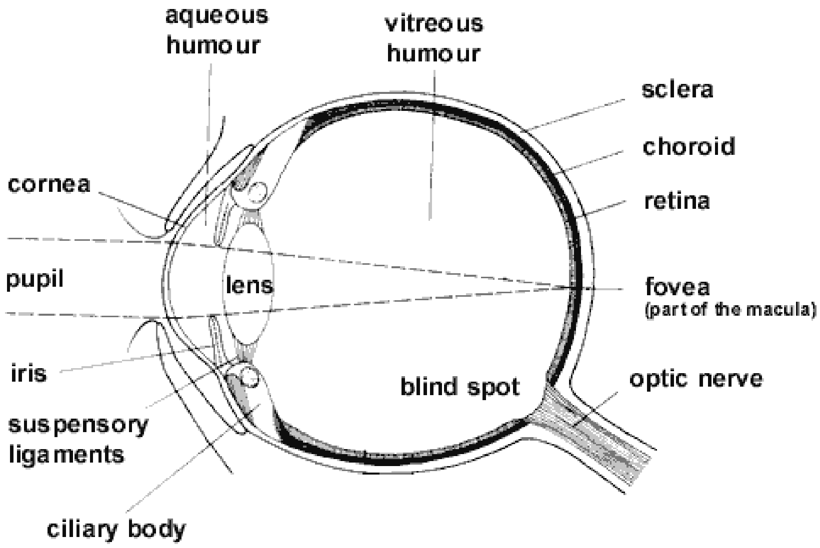

Figure 2.1 Structure of the eye

As people grow older, the age-related changes that occur in the eye, retina, and ascending visual pathways in the nervous systems can be described as follows.

2.1.1.1 Optical changes

Cornea. The front of the eye has a region where the sclera sticks out in a round shape to form a clear window, called the cornea. The cornea is formed by fixed lenses that begin gathering a light ray and concentrate it so that the image eventually appears on the rear interior surface of the eye. About two-thirds of light refraction occurs at the cornea. Small changes in the curvature of the cornea result in remarkable changes in the quality of the retinal image.

In young eyes the curvature of the anterior surface is usually greater in the vertical meridian than that in the horizontal meridian, but this tends to reverse with increase in age. Research also found that the cornea becomes more curved with age, but more so in horizontal meridian than in the vertical meridian.

Iris and Pupil. A ring of color at the eye is a membrane that surrounds a central hole, called the iris. The function of the iris is to control the amount of light ray entering the eye. The light enters through the hole in the iris, called the pupil. The size of the pupil is controlled by a reflex. When light is bright, the pupil may contract reflectively to as little as 2 mm in diameter, whereas the pupil becomes wider to more than 8 mm as darkness increases. It also varies with changes in our emotional and attentional levels. As age-related changes, the average diameter of the pupil for a given value of illumination tends to become smaller, referred to pupillary miosis condition. Age difference in pupil diameter is greatest under low-illumination conditions.

Crystalline lens. The crystalline lens is located directly behind the pupil. Even though the lens provides a small range of refractive power (about one-thirds of light refraction), it is one of the most critical parts that makes it possible to see objects at different distances clearly without changing the location of the viewer. This process is called accommodation and is mainly accomplished by two muscles surrounding the lens, called the ciliary muscles and the zonular fibers (Fisher, 1986), as shown in Figure 2.2. When the eye focuses on the far target, the muscles are relaxed and the lens is relatively flat. But, when looking at the near target, the muscle will contract so that the lens becomes thicker and increases its curvature.

The most dramatic age-related optical changes in the eye occur in the lens. Its shape, size and mass alter markedly, its ability to vary its shape (i.e. accommodation) diminishes, and its light transmission reduces considerably, particularly at short wave lengths (Atchison & Smith, 2000). In young children, the maximum amplitude of accommodation enables the lens to add approximately 20 D of focusing power to the eye, thus enabling them to focus upon objects of interest as close as 5 cm away (Schieber, 2006). By the mid-forties of age the average person has lost so much accommodative power that they can no longer adequately focus upon objects within arm's length (Hofstetter, 1965). Regard to increasing age, the lens also becomes less transparent due to increase in the optical density of lens.

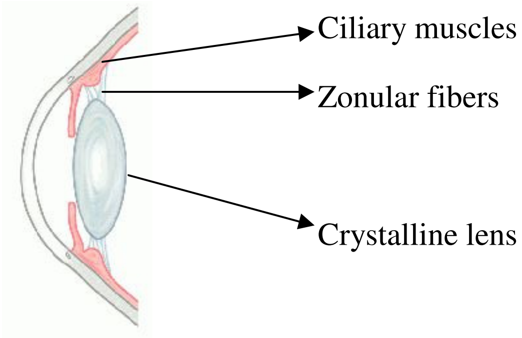

Figure 2.2 Crystalline lens: Ciliary muscles and Zonular fibers

1.1.1.2 Sensorineural changes

Retina. The retina is the most well-studied neural substrate of vision and aging is also the most accessible (Schieber, 2006). The retina is a complex structure with several layers of neurons interconnected by synapses. The only neurons that are directly sensitive to light are the photoreceptor cells. These are mainly of two types: rods and cones. Rods function mainly in dim light and provide black and white vision, while cones support daytime vision and the perception of color. Regarding diminished pupil diameter and increased optical density of lens, the combination aging effects between both conditions yield a 0.5 log unit reduction in retinal illuminance between 20 and 60 year old. It has been estimated that diminished pupil diameter accounts for a 0.3 log unit reduction in retinal illuminance. Retinal contrast also declines with advancing age due to increased intraocular scatter and generalized reduction in the modulation transfer function of the eye.

Regarding retinal photoreceptors, adult aging is accompanied by a dramatic loss in the number of rods and cones. The rod density in the central retina, 3-10 degrees, declines by 30% between 34 and 90 year old. However the cone density remains relatively stable across the same age range. The reason of this inconsistency might be due to the individual difference of cone numbers. Recent researchers have reported significant age-related reductions in the number of retinal ganglion cells subserving the macular region of the retinal. Moreover, increasing age affects losing in the number of axons in the optic nerve and thinning of the neural layer of the retina.

Initial studies of primary visual cortex reported significant cell loss by 25% as early as age 60. However, other groups of researchers claimed that the investigation have failed to observe systematic declines of neuron density in the visual cortex with aging. Rather than cell loss, the age related neural changes impacting visual function are more likely to involve extrastriate cortical areas. The neural density in the ventral visual cortex is spared with aging, human functional magnetic resonance imaging studies reveal reduced functional efficiency in this region.

2.1.2 Age-related changes in visual function

Schieber (2006) summarizes that upon eye movement, optimal performance on many tasks depends on the ability of the oculomotor system to acquire, track, and maintain stimulus images on the foveal region of the retina. The acquisition of visual stimulus is mediated by perceptual-motor systems including the smooth pursuit eye movement system, continuous motion processes that serve to track moving targets accurately, and saccadic eye movement system, ballistic excursions of the eye in visual search. As increasing age, the smooth pursuit performance declines during tracking objects in the stimulus background. Saccadic eye movement show less dramatic change with increasing age. The magnitude of this age-related increase in the latency of saccadic eye movement varies from approximately 20 ms.

In term of light sensitivity, the human retina consists of two subsystems, scotopic and photopic sensitivity that enable it to process light signal over a range of stimulus intensities. Recent studies reported that age-related changes in scotopic sensitivity declines at a rate of 0.08 log unit per decade between 20 and 90 years of age. Photopic sensitivity declines with at a rate of 0.04 log units per decade.

Visual acuity is a measure of one’s ability to distinguish differences in the spatial distribution of light in the image. Normal visual acuity defines as 20/20 vision and visual acuity also change relative to age. Several studies have reported that age differences in visual acuity are exacerbated under challenging viewing condition.

Contrast sensitivity is the ability to detect and recognize objects in the visual environment varies considerably as a function of target size, contrast, and spatial orientation. As age-related change, the contrast sensitivity function declines by approximately 0.3 log units across the latter half of the adult life span.

2.1.3 Visual accommodation and refraction

Our visual system operates as the eye forms a retina image of external objects or scenes, either distant or nearby, in dim or bright light. To achieve efficient operation, the eye takes advantage of the special function called “accommodation.” The eye “accommodates” when looking at near and far targets. The primary work of the eye is to focus light onto the retina. When the light enters the eye, it will pass through the cornea and the aqueous humour, and reach the lens. Most of the light refraction, about two-thirds, occurs at the cornea which has a fixed curvature maintained by the aqueous humour. The iris, a ring-like area of muscle fibers colored by the iris pigment placed between the lens and aqueous humour, controls the amount of light finally reaching the retina by means of its central part, the pupil. The lens, behind the iris, is a convex disc which focuses light, through the vitreous humour, onto the retina by automatically adjusting its curvature, which is known as “accommodation.” After reaching the retina, the light will arouse the firing of the photoreceptors, most of which are located near the fovea (Pedrotti, 2007).

2.1.4 Process of accommodation

Accommodation is the process in which the eye adjusts optical power to maintain a clear image on the retina. The lens accommodates (contracts or relaxes) appropriately to focus the image to the retina, depending on the distance of the object from the eye. For the far target, the ciliary muscle relaxes and the lens assumes a flatter configuration, increasing its radii of curvature and consequently its focal length, as shown in Figure 2.3 (a). As the object moves closer to the eye, the ciliary muscle contracts and squeezes the lens resulting in a decrease of radii of curvature and a shorter focal length. The smaller the radius of curvature and focal length, the higher the refractive power of the lens, precisely the condition needed to bring near objects into sharp focus, as shown in Figure 2.3 (b).

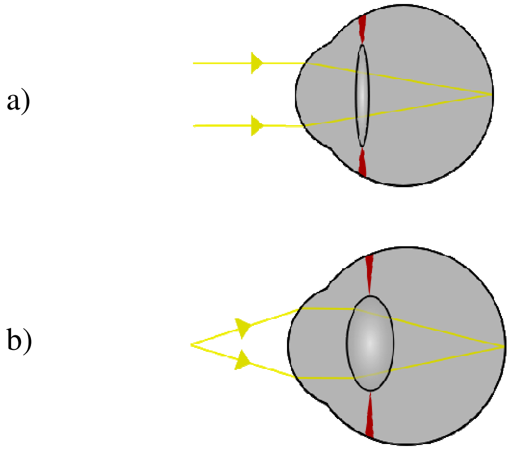

Figure 2.3 Accommodation process: a) accommodation for a far target, and b) accommodation for a near target

For normal vision and before the normal aging process influences the lens' elasticity and ability to reshape itself, accommodation provides clear images of external objects on the retina from a far target (infinity) to a near target (about one foot away). The near target (closest point of accommodation) moves further away from the eye with advancing age, starting at a position of 7 to 10 cm from the eye for a teenager, increasing to 20 to 40 cm for middle-aged adults, and extending to as far as 2 m in later years. For the average person, presbyopia (loss of accommodation) sets in during the early 40's, signaling the need for glasses to restore the near target to a comfortable position at about 25 cm or so.

It is interesting 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 360 msec ± 90 msec. Furthermore, the reaction time for far-to-near focus is about 20 msec longer than that from near-to-far focus on average (Campbell & Westheimer, 1960). The difference in the minimum and maximum refractive power of the eye is called the amplitude of accommodation. Physiological change, refractive power change, and change in conjugate distance are the three main changes involved in accommodation. In determining accommodation, refractive error, in addition to conjugate distance, should be considered.

2.1.4.1 Physiological change

Ocular changes are the most frequent physiological changes associated with aging. Common vision changes include a decrease in the ability to distinguish colors, an increased need for illumination in the workplace, a decreased ability to adapt to changing light levels, and general eye fatigue. Eyestrain is amplified with the onset of preoperative cataracts and presbyopia. People may experience a loss in color perception or some degree of colorblindness. A person with either of these conditions may be unable to distinguish two colors that look distinct to an individual with normal color vision. A third major change is the shrinking of the pupil, resulting in the need for more light and a diminished ability to adjust to changing levels of illumination (Gilmartin, 1986).

According to the American Optometric Association, a 60-year-old retina receives only 33% as much light as that of an average 20-year-old. The majority of the eye's physiological change during accommodation involves the lens (Glasser & Kaufman, 2003; Tayyari & Smith, 1997). As the eye's refractive power increases, the anterior pole of the lens moves forward and posterior lens surface increases its curvature. The lens diameter decreases, the lens capsule tension changes, and the lens sinks slightly toward the pull of gravity (Moses, 1981). Additionally, the pupil constricts, the anterior chamber becomes shallower, and the retina shifts forward. These adjustments are induced by autonomically innervated changes in the ciliary muscles (Toates, 1972).

2.1.4.2 Refractive power change

Physiological change is accompanied by alteration in the eye's refractive power. The change in the eye's refractive power is measured in diopter (D). The diopter has two distinct but related meanings with respect to the eye. In physical optics, the diopter refers to the amount of vergence or curvature of a wave front and is a measure of the refraction generated by an optical system. The number of diopters is calculated as the reciprocal of the focal length (in meters) of the system. The total refractive power of the human eye is found to be approximately 60 D at its minimum level (Gouras & Zrenner, 1981a, 1981b; Zrenner & Gouras, 1981). Therefore, accommodation is the total change in refractive power that an eye undergoes to reach its present refractive condition compared to its minimum level.

2.1.4.3 Change in conjugate distance

The refractive characteristics of the eye are difficult to assess directly. The amount of accommodation is measured as the reciprocal of the conjugate distance. Assuming the distance (in meters) between the eye and the position of a target point are focused on the retina, the amount of accommodation can be expressed. In applied vision research, the physiological and refractive power changes of the eye are generally inferred from the changes in conjugate distance.

2.1.4.4 Refractive error

A refractive error is an error of the focusing process of light by the eye, resulting in a reduction of visual acuity. There are two categories of refractive errors: spherical and cylindrical. Spherical errors occur when the refractive power of the eye is either too large or too small to focus light on the retina. People with refractive error frequently have blurry vision. In addition, when the optics is too powerful for the length of the eyeball (this can arise from a cornea with too much curvature or an eyeball that is too long), one has myopia. On the other hand, when the optics is too weak for the length of the eyeball (this can arise from a cornea with not enough curvature or an eyeball that is too short), one has hyperopia.

Cylindrical errors occur when the optical power of the eye is too powerful or too weak across one meridian. It is as if the overall lens tends towards a cylindrical shape along that meridian. The angle along which the cylinder is placed is known as the axis of the cylinder, while 90 degrees away from the axis is known as the meridian of the cylinder. When one has a cylindrical error, one has astigmatism (the unequal curvature of refractive surfaces of the eye). Refractive errors are thought to occur due to a combination of genetic and environmental factors. Also, trauma or ocular disorders may induce refractive errors.

How refractive errors are treated depends upon the amount and severity of the condition. Those who possess mild amounts of refractive error may elect to leave the condition uncorrected, particular if the patient is asymptomatic (neither causing nor exhibiting symptoms of diseases). For those who are symptomatic (with symptoms), glasses, contact lenses, refractive surgery, or a combination of the three are typically used.

Studies on accommodation have been used to investigate varied research paradigms like target detection and recognition (Dahlstedt & Svenson, 1977; Winn, Charman, Pugh, Heron, & Eadie, 1989; Winterbottom, Patterson, Pierce, Covas, & Winner, 2007), visual displays (Ciuffreda, 1991; Iavecchia, Iavecchia, & Roscoe, 1988; Ostberg, 1980; Rempel, et al., 2007; Roscoe, 1984), anomalous myopias (Hope & Rubin, 1984; Leibowitz & Owens, 1975a; Wesner & Miller, 1986), and aging and vision (Dubbelman & Van der Heijde, 2001; Dubbelman, Van der Heijde, & Weeber, 2005; Jamshidi, et al., 1992; Mordi, 1991; Pokorny, Smith, & Lutze, 1987; Schneider & Guralnik, 1990; Shi & Lockhart, 2007). But, little is known about accommodation dynamics as a function of amplitude (Bharadwaj & Schor, 2006; Ciuffreda & Kruger, 1988; Heron, Charman, & Schor, 2001; Kasthurirangan & Glasser, 2006; Schachar, 2007).

2.1.5 Dark focus of accommodation

When there is no visual input to stimulate accommodation, accommodation does not go to a zero level as one might expect, but rather to an intermediate level (Goss & West, 2002; Tan, 1986). This occurs when there is an empty visual field and also in darkness. The accommodation that occurs in darkness is known as the dark focus of accommodation. The dark focus of accommodation is responsible for the phenomenon of night myopia in which the eye tends to accommodate too much for a given object distance when lighting levels are low (Goss & West, 2002). Research shows that from 14 undergraduate students, ages 18 to 24, the dark focus of accommodation ranged from 0.37 to 2.28 D, with a mean of 1.25 D using the laser optometer (Leibowitz & Owens, 1975b).

2.1.6 Presbyopia: age-related loss of amplitude of accommodation

Accommodation is significantly affected by age-related changes in eye structure (Koretz, Kaufman, Neider, & Goeckner, 1989; Mordi, 1991). Presbyopia represents an inability of the eye to focus sharply on close objects or become difficult to maintain focusing close objects over time (Fozard & Gordon-Salant, 2001; Schieber, 2006). The term “presbyopia” derived from Greek works: presbys (means an aged person) and opsis (means vision). On the other hand, the term was used to describe the condition in which the near point has receded too far from eye as a result of a decrease in range of accommodation. In an emmetropic eye (an eye without refractive error), distant objects at or beyond what is considered optical infinity for the eye (6 m or 20 feet) are focused on retina when accommodation is relaxed. When objects are brought closer to the eye, the eye must accommodate to maintain a clearly focused image on the retina. As a result, the lens changes from a flat, thin state to a thicker, more curved state to allow a person to see a distant object versus a closer one. In individuals with presbyopia, the lens becomes less flexible.

Presbyopia is a natural part of the aging process (Glasser & Kaufman, 2003). Normal aging causes changes in the eye that lead to problems with focusing. Accommodative loss begins during childhood, with symptomatic presbyopia, or presbyopia that affects one’s day to day activities, striking during midlife. From Duane’s data, it appears that the decline in amplitude occurs at a fairly constant rate until the mid-forties when it seems to decrease at a faster rate (Goss & West, 2002). While symptomatic presbyopia has traditionally been treated with reading glasses or contact lenses, a number of surgical interventions and devices are being actively developed in an attempt to restore at least some level of accommodation (Strenk, et al., 2005).

2.1.7 Issues in measure of accommodation

2.1.7.1 Myopia: nearsightedness (inability to see far objects)

In case of myopic condition, the parallel rays coming from an infinitely far target point focus not on the retina but in front of it. The insertion of a diverging (negative) lens would move the far point of the myopic eye to infinity. The lens would serve the purpose of diverging the rays from the infinitely far target point until it approaches retinal focus.

2.1.7.2 Hyperopia: farsightedness (inability to see near objects)

In this condition, the parallel rays do not focus on the retina but at a virtual position behind it. The eye has to increase its refractive power in order to achieve retinal focus. The insertion of a converging (positive) lens would move the far point to infinity and would facilitate the convergence of the rays into retinal focus with an increase in refractive power.

2.1.8 Dynamic aspects of accommodation

Visual accommodation, in humans, has been studied extensively for more than a century. However, there is a paucity of literature on the dynamics of accommodation as a function of accommodative amplitude (Kasthurirangan, Vilupuru, & Glasser, 2003; Shirachi et al., 1978). Investigating dynamics as a function of amplitude provides important information about dynamic behavior and has been considered a powerful tool in understanding physiological changes

(Bahill, Clark, & Stark, 1975; Heron, Charman, & Gray, 2002) as well as central neural processing delay of the aging eye (Lockhart & Shi, 2010).

Accommodation is a dynamic, dioptric change in refractive power of the eye (Vilupuru & Glasser, 2002). Dynamic accommodation and the sequence of events leading to a focused image is complex, as they involve sensory, motor, neurological, anatomical, biomechanical, and perceptual components. Dynamic accommodative characteristics include latency, time constant, the peak velocity, and amplitude relationship (Mordi & Ciuffreda, 2004). Accommodative amplitude and velocity also exhibited diurnal variations. And, lastly, the dynamic response characteristics for both reflex and voluntary accommodation were found to be the same, suggesting similar lower-level control aspects despite dissimilar higher-level initiation (Mordi & Ciuffreda, 2004; Ong & Ciuffreda, 1997).

Most of the accommodation studies in the past had been performed in a static mode, which is less accurate as compared to the dynamic operation because the visual accommodation itself is dynamic (Glasser & Kaufman, 2003). While static accommodation in young adults is well documented, the findings of age-related dynamic accommodative characteristics, in particular presbyopia onset, still remain unresolved. This is because dynamics of accommodation are difficult to measure since opto-electric instantaneous measurement is required for the quantification of dynamic accommodation. Additionally, intrasubject variations make comparison of different ages complicated (Ciuffreda & Kruger, 1988; Sun et al., 1988). As such, in this study, an objective measurement device was utilized.

2.2 Occupational Issues Related to Viewing Distance and Reading

From the literature, there were several standards, recommendation, and needs associated with viewing distance and reading tasks that were used in human factors and ergonomics research as follows:

2.2.1 Standards, recommendations, and effects of viewing distance on visual performance

Viewing distance is one of the most important factors affecting visual performance and visual fatigue. There have been numerous studies relating the effect of viewing distance to visual displays (Shieh & Lee, 2007). German standard DIN 66234 (1981) suggested that the display viewing distance should be at minimum of 0.5 m. Swedish ISO Proposal (1982) suggested that the viewing distances should be between 0.5 m and 0.7 m. Grandjean et al. (1984) reported that eye-to-display distances should be from 0.61 to 0.93 m, with a mean of 0.76 m. ANSI - Human Factors Society (1988) proposed that the viewing distance should be greater than 0.3 m. Jaschinski-Kruza (1988, 1991) reported on the correlation of viewing distance and visual strain. Less feelings of visual fatigue were found at a viewing distance of 1 m versus at 0.5 m. Sanders and McCormick (1992) stated that when reading a book or paper-like material, the normal reading distance was usually somewhere between 0.31 and 0.41 m, with a mean of 0.36 m. Previous research investigated the optimal range of viewing distance of desktop monitors and recommended a minimum viewing distance of 0.64 m (Ankrum, 1996). A recent study found that the mean viewing distance was 0.42 m and screen reflections resulted in a shorter viewing distance and greater variability of viewing distance (Shieh, 2000).

2.2.2 Significance of viewing distance in human factors and ergonomics research

In human factors and ergonomics, viewing distance was one of the most frequently cited visual fatigue issues. Few studies manipulated viewing distance as an independent variable, while other studies let participants chose their viewing distance (Bangor, 2000; Jaschinski, Heuer, & Kylian, 1998). The latter likely was a practical consideration, as found in Watten, Lie, and Magnussen (1992) where participants worked up to four hours. Also, it was possible that this was done to better accommodate working conditions. However, to understand the effect of viewing distance on visual fatigue and to have a reasonable expectation of comparing data between studies, a definitive viewing distance was needed. For the single-distance experiments Tyrrell and Leibowitz (1990) used 20 cm, Ziefle (1998) used 50 cm, Goussard, Martin, and Stark (1987) and Magnussen et al. (1992) used 57 cm, and Lunn and Banks (1986) used 76 cm.

Tyrrell and Leibowitz (1990) cited studies that found viewing distances from 50 to 76 cm to be preferred by visual display terminal (VDT) users. Three of the reviewed experiments manipulated distance. Chi and Lin (1998) used distances of 40 and 80 cm in a monitoring task and Jebaraj, Tyrrell, and Gramopadhye (1999) used distances of 20 and 60 cm in their study of a visual inspection task. Both studies found greater subjective ratings of visual fatigue and lower objective performance for the nearer condition. Jaschinski, Heuer, and Kylian (1999) did not as strictly control viewing distance, but used distances of approximately 66 to 98 cm in their study and found less eyestrain and general fatigue at the distant condition. After individual adjustments by the participants, a preferred viewing distance was found at 90 cm. While this did not mean that farther is better, these studies' better range of 60 to 90 would seem to corroborate the preferred range of 50 to 76 cm cited by Lunn and Banks (1986) and the 95% preferred viewing distance range of 50 to 70 cm reported by Stammerjohn, Smith, and Cohen (1981, as reported in MacKenzie and Riddersma, 1994). However, it should be noted that Tyrrell and Leibowitz (1990) suggested that near work greatly affects only some people and not others. This would seem to coincide with the large individual differences for dark focus and dark convergence points mentioned above. It was also interesting to note that many human factors/ergonomic standards promulgated that source documents and visual displays should be at the same viewing distance. The theory here being that different viewing distances would cause frequent vergence and accommodation efforts, increasing the likelihood of visual fatigue. However, a study by Jaschinski-Kruza (1990) found that subjective ratings of visual discomfort were not different when both display and hard copy were at 50 cm and when the display was at 70 cm and the hard copy remained at 50 cm.

2.2.3 Significance of dark focus in human factors and ergonomics research

The dark focus or resting level of visual accommodation (Ebenholtz, 1992) is the refractive state that the eye tends to return to the absence of visual stimulation, as in complete darkness (Allen & O'Leary, 2006; Simonelli, 1979; Toates, 1972) . Interestingly, studies suggest that refractive error is minimal at the intermediate resting point of accommodation (Leibowitz & Owens, 1975a, 1978; Owens, 1979), thus minimizing fatigue (Wesner & Miller, 1986).

Leibowitz and Owens (1978) also addressed that the intermediate resting state is useful for correcting anomalous refractive errors, and effectively eliminates variations in visual resolution with stimulus distances. It has been known that intermediate distances have wide variations among individuals (Heuer & Owens, 1989; Iavecchia, et al., 1988; Leibowitz & Owens, 1978; Ripple, 1952; Sommerich, Joines, & Psihogios, 2001).

Predicting an individual's visual performance under adverse conditions (such as nighttime and bad weather) poses an important challenge to vision research. When an observer sits in a totally dark room, the far point of his eye accommodation is not localized in the same point in space as is obtained when his visual field is in a highly structured 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.

The distribution of dark focus is approximately normal with range approximately 4 D and mean dark focus of 1.71(0.72) D (Leibowitz & Owens, 1975a). It is evident that dark focus varies somewhat according to the observer but appears to have a mean value of around 1 D (Charman, 1995). Thus, with very weak stimulation, accommodation remains at the dark focus distance regardless of stimulus distance (Johnson, 1974, 1976). The changes in the accommodation ability of the eye at low levels of illumination are not just due to the low light level, rather, it is the reduction in contrast of objects of interest associated with the reduced light intensity which is responsible for this effect. Optical corrections based on dark focus may enhance the target detection and identification (i.e., reduction of focusing error). Johnson (1976) has demonstrated that accommodation is most accurate and visual acuity is highest when the stimulus is presented at the individual's dark focus distance. Thus, focus may be enhanced with dark focus distance at around 70 cm. This focal length is known as the "Mandelbaum Effect" (Owens, 1979). This is quite different from the visual acuity point of view, which is better at around 200 to 300 cm for older adults. Enhanced focal capability is usually seen in the nighttime condition as compared to the daytime condition.

Jaschinski-Kruza (1988) found that when the visual was near (0.5 m, as recommended in most ergonomic guidelines), visual strain in near-dark-focus subjects (0.5 m) was lower than in far-dark-focus subjects (1 m) thus, the strain of the accommodative system alone seems to be minimal when the viewing distance is made to agree with the dark focus. In both groups, visual strain was higher in the 0.5 m condition, and the longer distance of 1 m was preferred. Thus, irrespective of the individual's dark focus, visual strain can be reduced by using viewing distances greater than those recommended in some standards.

Jaschinski-Kruza (1990) found the dynamic load on accommodation and convergence due to the different viewing distances of 0.5 and 0.7 m did not produce stronger visual strain than the static load at the identical viewing distance of 0.5 m. When subjects were free to shift the screen to the most comfortable position, they preferred screen distances of 0.5 to 0.8 m (mean 0.65 m) despite gaze shifts to the display at 0.5 m every 2 seconds. These findings were evidence against the widespread ergonomic concept that viewing distances to both screen and document should generally be about 0.5 m. It was also suggested that the users may select viewing distances that they find comfortable in the range of more than about 0.5 m.

In conclusion, the evidence indicates that the resting state of the eyes may be a key factor for predicting and optimizing visual performance under a wide variety of conditions. It also allows correction of anomalous refractive errors that can seriously limit detection and identification under low visibility conditions (Fejer, 1995; Fejer & Girgis, 1992; Post, Owens, Owens, & Leibowitz, 1979). Age-related decline in amplitude of accommodation may influence individual visual performance while in the dark since older adults were seen to experience a small dark focus shift and dark focus was reported to decrease with age at approximately the rate of the far point of accommodation (Simonelli, 1983).

2.2.3 Significance of reading tasks in human factors and ergonomics research

Reading is a complex process and is essential to fully participate in daily life activities. Reading is also a critical part of many career, household, social, and recreational activities. Although reading feels like an effortless process for most people, it is a complex, multilevel cognitive process involving perceptual and cognitive inputs. As with any complex process, an error at any of the levels can lead to unsuccessful processing and comprehension. Unfortunately, reading problems are not rare. Research suggests that approximately 22% of the adult population in the United States experience reading difficulties (Mitzner & Rogers, 2006).

In some situations reading efficiency is critical, and in others reading comprehension may be more important. Whether the reader's goal is to be efficient or to be thorough, is likely determined by a number of factors, including the consequences. If a highway sign is read too quickly, a driver may exit the highway on the wrong street. However, if one's eyes are diverted from the road for a long time to read a highway sign thoroughly, the result may be a traffic accident. National Highway Traffic Safety Administration (2002) reported that approximately 7.2 million drivers were involved in a distraction-related crash from 2001 to 2006. Approximately 23% reported that they were distracted by looking for something outside the vehicle, and almost 10% reported that they were distracted specifically by looking for a building or street sign. Alternatively, if instructions and warnings for a medication are read too quickly, an individual may not take the medication correctly. In fact, it is estimated that noncompliance with drug therapy and associated adverse events contribute to approximately 28% of the hospitalizations of older adults. These examples demonstrated the significant consequences that can result from reading problems.

2.3 Information Processing

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 & Randle, 1976). Thus, it is important to consider the information processing paradigm in this study.

In general, the human-machine interface will be 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 & Fitts, 1955; Pollack & Ficks, 1954). In this study, basic sensory resolutions associated with accommodative processes are 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 will be able to control extraneous variables effectively.

Information processing is associated with encoding, transferring, and decoding. In terms of encoding, a classic study of “Information Theory” by Shannon (1951) will provide us with bit assignment of each letters. Miller’s “Information Transfer Rate” (1954) will provide us with capacity of transmission of a signal.

2.3.1 Information measurement

A study by Miller (1953) addressed valuable insights in to the paradigm of information measurement. He described the concept of amount of information by giving an example of a child who was told of picking a piece of candy lying in one of the 16 boxes. The child would be able to have 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 depends upon the fraction of the alternatives that are eliminated, not the absolute number. Every time the number of alternatives is reduced to half, one unit of information (as called as “bit”) is gained. The amount of information present in a message that reduces k to k/x, it contains 1 bit less information than does a message that reduces k to $k/2x$. Therefore, the amount of information in the message that reduces k to k/x is $\log_2 x$ bits (Miller, 1953). An example could be used to illustrate this point is when the child’s 16 boxes are reduced to two, then x is 8, and $\log_2 8$ is 3 bits of information. Thus, with 4 bits of information, the child will know exactly which box the candy is hidden.

The source selects 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. If some messages have high probability, the receiver can anticipate them and less information needs to be transmitted. Simply put, frequent messages should be the short ones. In order to take into account the differences in probability, we treat a message whose probability is p as if it was selected from a set of *1/p* alternative messages. Therefore, the amount of information that has to be transmitted from the message is $\log_2 1/p$, or $-\log_2 p$.

Since we want to deal with sources, rather than with particular messages, it is necessary to have a message represent how much information the source generates. As different messages contain different amounts of information, we have to determine the average amount of information per message that we can expect to get from the source – the average for all the different messages the source may select. Equation 2.1 defines the average amount of information per message expected to be transmitted from the source *x*, as denoted by $H(x)$:

$$H(x) = \text{the mean value of } (-\log_2 p_i) \tag{2.1}$$

$$= \sum_{1=1}^{k} pi(-\log_2 pi)$$

Given: $H(x)$ in bits per message is defined as the mean logarithmic probability for all messages from source *x.*

The situation in case of multiple sources is only partially correlated. If we know what source *x* will do, then we can make a fairly reliable guess what source *y* will do and vice versa. Some, but not all of the information we get from source *x* duplicates the information we get from source *y*, as illustrated in Figure 2.4 and equations 2.2 and 2.3. As a result, the total information is greater than either of its parts, but less than their sum.

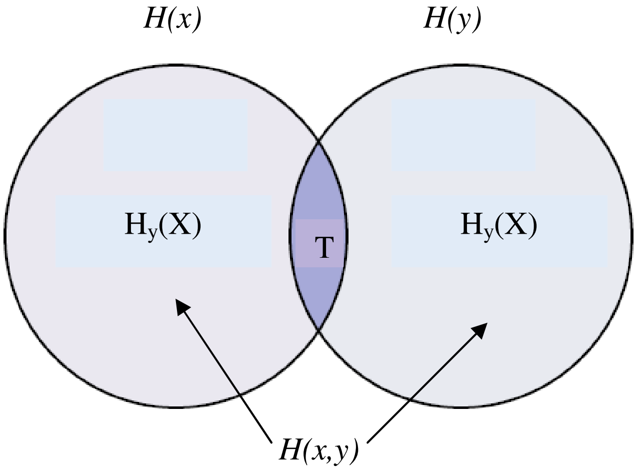

Figure 2.4 Schematic representation of the several quantities of information that are involved when messages are received from two related sources.

$$H_y(x) = H(x, y) - H(y) \tag{2.2}$$

Or

$$T = H(x) + H(y) - H(x, y) \tag{2.3}$$

Given:

H(x) is the average amount of information in bits per event expected from *x*.

H(y) is the average amount of information in bits per event expected from *y*.

T is the average amount of information in bits that represents the common information due to the correlation of *x* and *y*.

$H_y(x)$ is the average amount of information per event expected from *x* after *y* is already known.

$H_x(y)$ is the average amount of information per event expected from *y* after *x* is already known.

H(x,y) is the total amount of information in bits per event present in *x* and *y*.

Also, *T* has been seen to exhibit the properties of a measure of the correlation (contingency, dependence) between *x* and *y*. In fact, 1.3863 *nT* is essentially the same as the value of chi square that would be used to test the null hypothesis that x and y are independent, as given *n* as the number of occurrences of the event used for estimation of the probabilities involved.

2.3.2 The sequence of information transmission

Human verbal behavior is a unique and interesting example of a behavior whose 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. This 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 would give us some insight into the relationship of the variables in the sequential situation with the various quantities of information highlighted in the Figure 2.4. Let x be the source that creates the context, and y be the source that creates the successive word, thus 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, and 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 when all 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 alternatives and would carry $\log_2 26$ or about 4.7 bits of information. In other words, we only encode about one-fourth as much information per letter as we might if we used our alphabet more effectively.

A study of Shannon (1951) provided a method of calculating the entropy *H* by a series of approximations F_0, F_1, F_2, …, from the statistics of English mathematically as shown in equation 2.4. This equation can be interpreted as measuring the average uncertainty (conditional entropy) of the next letter *j* when the preceding *N*-1 letters are known.

$$\begin{aligned} F_N &= -\sum_{i,j} p(b_i, j) \log_2 pb_i(j) \\ &= -\sum_{i,j} p(b_i, j) \log_2 p(b_i, j) + \sum_{i} p(b_i) \log_2 p(b_i) \qquad (2.4) \end{aligned}$$

Where b_i is a block of *N*-1 letters [(*N*-1) – gram]

j is an arbitrary letter following b_i

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

$pb_i(j)$ 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 ignored, a twenty-six letter alphabet remains and F_0 may be considered (by definition) to be $\log_2 26$, or 4.7 bits per letter. F_1 involves 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 gives the result:

$$\begin{aligned} F_2 &= -\sum_{i,j} p(i, j) \log_2 p_i(j) \\ &= -\sum_{i,j} p(i, j) \log_2 p(i, j) + \sum_{i} p(i) \log_2 p(i) \\ &= 7.70 - 4.14 = 3.56 \text{ bits per letter} \end{aligned}$$

The trigram entropy is given by

$$\begin{aligned} F_3 &= -\sum_{i,j,k} p(i, j,k) \log_2 p_{ij}(k) \\ &= -\sum_{i,j,k} p(i, j,k) \log_2 p(i, j,k) + \sum_{i} p(i, j) \log_2 p(i, j) \end{aligned}$$

$= 11.0 - 7.7 = 3.3$ bits per letter

A similar set of calculation could be carried out including the space as an additional letter, giving a 27 letter alphabet. The results of both 26- and 27-letter calculations are given below.

	F_0	F_1	F_2	F_3	F_{word}
26 letter	4.70	4.14	3.56	3.3	2.62
27 letter	4.76	4.03	3.32	3.1	2.14

In summary, at dark focus distance, visual performance will be increased since the optical refractive error is minimal and may result in better reading performance as measured by information transfer rate.

CHAPTER 3

METHODS

This research was divided into two phases. First, dark focus measurements of individuals were made under scotopic vision. Second, the visual information transfer rates (in bits/sec) at recommended viewing distances (52 cm and 73 cm), and individual's dark focus were then determined.

3.1 Experiment 1 – Dark Focus Measurement

3.1.1 Participants

3.1.1.1 Sample size estimation

To estimate sample size, power analysis was performed on results of the pilot test and the previous study (Shi, 2007) by focusing on sample sizes that were large enough to detect differences in amplitude of accommodation with high probability between four age groups (younger: 20-44 years; middle-aged: 45-59 years; young-old: 60-74 years; and old-old: 75 years and over) (Neugarten, 1974; Settersten Jr & Mayer, 1997). The power of the F test for a single factor study (Neter et al., 1996) was used to estimate the sample size (see Equation 3.1).

$$Power = P\{F^{*} > F(1-\alpha, r-1, n_T-r) | \Phi\} \qquad (3.1)$$

Where Φ is the noncentrality parameter ($\Phi = \frac{1}{\sigma}\sqrt{\frac{\sum n_i(\mu_i - \mu_.)^2}{r}}$), or a measure of average difference of amplitude of accommodation between different age groups, σ and μ were the standard deviation and mean of the distribution of amplitude of accommodation, n was the number of participants in each age group - n_T was a total number of participants in the experiment, and r was the number of factor levels.

In this study, statistical significance was set at $\alpha < 0.05$. Results from previous research and pilot study suggested that the difference used to detect amplitude of accommodation was 0.6

with a standard deviation of 0.4. Ten participants in each age group were sufficient to detect the specified differences in amplitude of accommodation with risks of Type I error of 0.05 and Type II error of <0.2 (Power >0.8). Thus, this study included a total of forty participants of the four age groups.

3.1.1.2 Screening test

Participants were recruited from flyers placed around the Virginia Tech campus and community. Interested recruits had normal or correct-to-normal 20/40 vision, no history of binocular vision anomalies or ocular pathology (McGregor & Chaparro, 2000; Owens, Wood, & Owens, 2007). Compensation of $10/hour was supplied to participants. A maximum of $20 was paid for their participation.

The participants had signed a consent form approved by Virginia Tech Institutional Review Board: Project No. 10-495 and had completed a questionnaire regarding their personal information prior to any testing. To ensure the qualification of the participant, a screening session was held prior to the actual test session under daytime condition. In addition, a test of static visual acuity and color blindness was performed using the Bausch & Lomb Vision Tester (see Figure 3.1). Then, visual contrast sensitivity was tested using the VISTECH Vision Contrast Test System – Chart configuration B (see Figure 3.2).

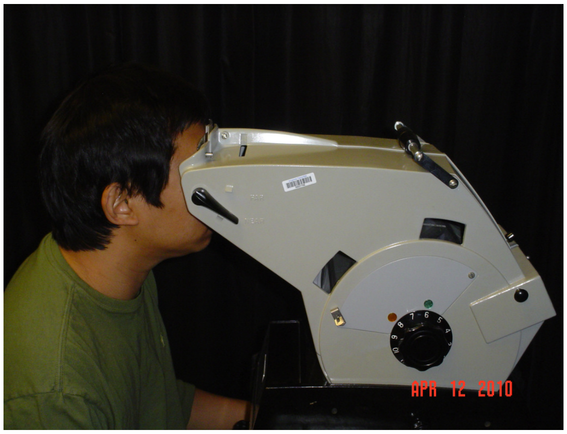

Figure 3.1 Bausch & Lomb Vision Tester

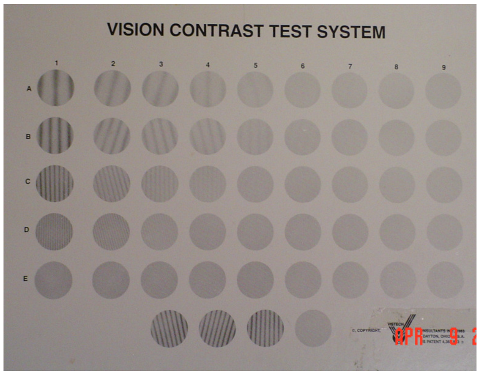

Figure 3.2 VISTECH Vision Contrast Test Chart

3.1.2 Apparatus: the modified autorefractor

The modified Shin-Nippon SRW-5000 autorefractor (see Figure 3.3), a new infrared open view autorefractor which is adjustable for proper ergonomic alignment (Wolffsohn, Hunt, & Gilmartin, 2002) was used for measuring accommodative responses (amplitude and velocity). This machine can be used to calculate refractive error of the human eye and has been found to be highly valid compared with subjective refraction and is repeatable in different age groups with pupil sizes ≥ 2.9 mm (Chat & Edwards, 2001; Mallen, Wolffsohn, Gilmartin, & Tsujimura, 2001). Different from the previous set-up and the measures, this modified autorefractor can assess scotopic vision and can thus measure dark focus. Both of the software and hardware was transformed to provide the dark-focus obtaining capability.

Figure 3.3 The modified autorefractor

3.1.2.1 Method of Measurement

In this present study, the modified autorefractor was used to give dynamic measurements of accommodation by continuous display of the measurement ring and image analysis of the video output of the instrument. This autorefractor calculates refractive error in two stages. A ring target of infrared light is imaged after reflection off the retina. On the initial measurement, a lens is rapidly moved on a motorized track to place the ring approximately in focus. Optimal focus is achieved when a peak signal is received from the light sensor. The system measures at least three meridians of the eye in order to derive the refractive power of the eye using the sine-squared function. The image size of the ring target is analyzed digitally, on initial and subsequent measurements, in multiple meridians to calculate the toroidal refractive prescription. The measurement ring width correlates with the refractive error and utilizes edge detection techniques to achieve a resolution of < 0.01 D at 60 Hz (Wolffsohn, et al., 2002). The same edge detection technique is used to measure visual accommodative amplitudes. The advantage of this system is that it provides absolute measures of accommodation – not presuming that the accommodative response matches the accommodative stimulus demand – thus providing an objective measure.

3.1.2.2 Calculation of dark focus

Knowing dark focus distance is equivalent to the inverse of accommodation amplitude (see Equation 3.2), the purpose of the present study was to determine dark focus distances by measuring accommodation amplitudes. It has been reported that the values of accommodative response and dark focus position are dependent on the method used to measure them and have a wide variation among individuals (Andre, Owens, & Owens, 1998; Bahill, et al., 1975; Mershon & Amerson, 1980). However, dark focus position is highly stable for test-retest results (Heron, Smith, & Winn, 1981).

$$\text{Dark focus (m)} = \frac{1}{\text{Amplitude of accommodation (D)}} \tag{3.2}$$

3.1.3 Workstation Setup

The experimental layout (see Figure 3.4) for the dark focus test was used to investigate the dynamic accommodative characteristics using the modified autorefractor while participants focus on the center of the fixation board (see Figure 3.5) at 4 m away from the eyes under nighttime condition (scotopic vision). For lighting setup, ambient illuminance was set at 0 lux (measured horizontally – on a flat surface) using a light meter (Extech – Model 407026), as shown in Figure 3.6.

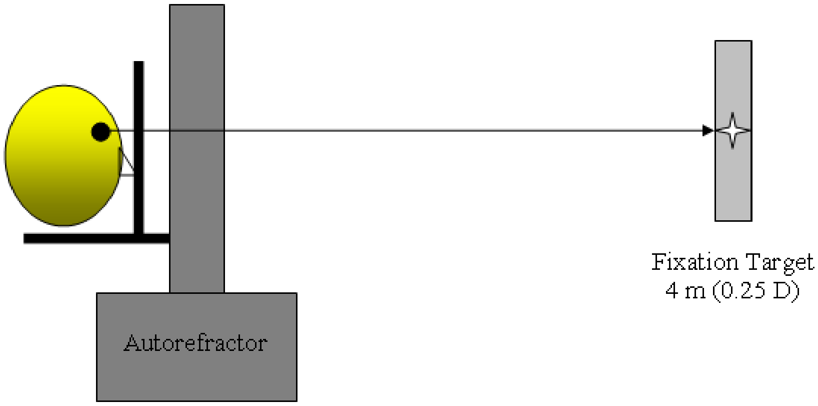

Figure 3.4 The experimental layout

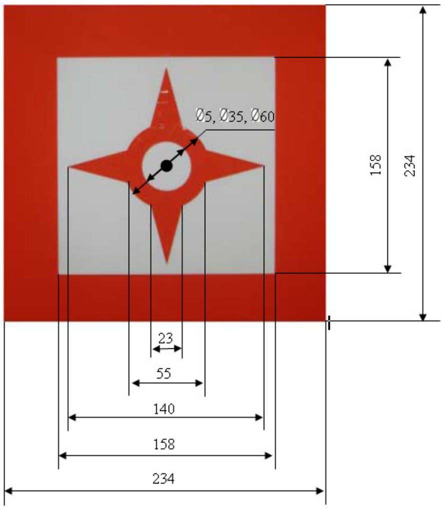

Figure 3.5 The fixation board (dimensions in millimeters)

Figure 3.6 A light meter (Extech – Model 407026)

3.1.4 Experimental Design

This was a repeated measures study design with four age groups (younger, middle-aged, young-old and old-old) of forty participants. Each age group included ten participants. All participants were asked to perform active (with attention) viewing tasks in a laboratory setting under scotopic vision. The experimental design is given in Table 3.1

Table 3.1 Experimental design for the dark focus measures

Younger	Middle-aged	Young-old	Old-old
P1-10	P11-20	P21-30	P31-40

3.1.4.1 Hypothesis

Upon completion of the study it is hypothesized that the dark focus distances (as measured by the modified autorefractor) will be greater for older participants than younger participants.

3.1.4.2 Independent variable

Age: four groups (younger, middle-aged, young-old and old-old)

3.1.4.3 Dependent variables

(a) The amplitude (D) of accommodation was determined from the experiment

(b) The velocity (D/sec) of accommodation was determined from the experiment

(c) The dark focus distance (m) was calculated from the measured amplitude of accommodation, as given in Equation (3.2).

3.1.5 Procedure

Participants were asked to sit at the modified autorefractor station with a separate desk for the PC to prevent the light from affecting the participants. The height of the chair and the chin rest of the modified autorefractor was adjusted for each individual. After paricipants found their comfortable sitting posture, the view window of the modified autorefractor was moved to the appropriate position relative to the eyes. Afterwards, participants were asked to keep their right eye open and the measurement ring of the modified autorefractor was positioned at the center of their retina. Before each trial, the participant's head was positioned upright by observing the actual head inclination angle between the horizontal and the ear-eye line, known as Reid's base line (Jainta & Jaschinski, 2002).

Participants completed a series of trials on the modified autorefractor as their gaze directed horizontally to a fixation target on the wall. Accommodative responses (amplitude and velocity) of each participant's right eye were measured objectively under scotopic vision with the modified autorefractor, while the other eye is covered. Dark focus was measured in the dark after a period of ten minutes so that participants were fully dark adapted. Three measurements of thirty seconds for each trial were taken. Results of three consecutive seconds out of thirty seconds on each measurement were selected and averaged. During these visual tasks, participants were asked to look at the same position: the middle spot of the fixation board at the horizontal eye level. A one-minute break was given to participants after each trial.

3.1.6 Data recording, processing, and analysis

The original use of the autorefractor was to measure the refractive errors of the human eye by locating a measurement ring target of infrared light on the observer's eye and measuring the refracted image by laterally moving the Badal lens to find the optimal focus of the ring image on the retina. In this present study, accommodative responses and the dark focus distances were calculated from the modified autorefractor.

After the shape and size of the ring image were determined from different eye conditions, the refractive error was then identified. Data was collected by a Pentium IV 2.40 GHz PC (see Figure 3.7) with a National Instrument (NI) PCI-1407 image acquisition card via the output panel of the autorefractor. Data was analyzed via threshold image analysis to obtain the diameter of the measurement ring by using LabVIEW 8.0 programming and NI Vision Module 8.0.1 software from Texas National Instrument. The diameter value was then calculated as the spherical equivalent (SE) (Shi & Lockhart, 2007). As accommodation can be observed by optical power changes, the change of SE will indicate the accommodative responses. Since SE is linearly related to the ring diameter, a conversion equation could be formed based on static and dynamic accommodative responses of the eye, which provide 60 Hz temporal resolution. The dynamic accommodation process can be calculated to an accuracy of <0.001 D (Wolffsohn, Gilmartin, Mallen, & Tsujimura, 2001).

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Figure 3.7 Computer workstation for data recording, processing, and analysis

3.1.7 Statistical analysis

JMP Statistical Software was used for the analyses. Between-subject ANOVA was performed with a model shown below (Table 3.2). In this study, statistical significance was set at $\alpha < 0.05$. The statistical model for one-factor, between-subject design was given in Equation 3.3.

$$Y_{ijk} = \mu + \alpha_i + \gamma_{j(i)} + \varepsilon_{k(ij)} \tag{3.3}$$

Here, Y was observation, μ was population mean, A was a between-subjects variable (age group: α, a, $i = 4$), S was the number of the subject in each group (γ, $k = 10$), and ε was random error. ANOVA table is provided in Table 3.2.

Table 3.2 Source and Error terms for one-factor, between-subject ANOVA

Source	df	SS	MS	E{MS}	F
<u>Between</u>					
A	a-1	SS_A	MS_A	$n\sigma_\alpha^2 + \sigma_\gamma^2 + \sigma_\varepsilon^2$	$MS_A / MS_{S/A}$
S/A	a(n-1)	$SS_{S/A}$	$MS_{S/A}$	$\sigma_\gamma^2 + \sigma_\varepsilon^2$	$MS_{S/A}/MSE$
<u>Total</u>	an-1	SS_{Total}			

3.2 Experiment 2 – Measures of the Visual Information Transfer Rate at Various Viewing Distances

3.2.1 Apparatus and experimental setup

A photometer (Minolta CS-100), as shown in Figure 3.8, was used to measure lighting luminance levels of 20 cd/m^2 at a visual display. An adjustable table, chin rest and forehead rest was used to accommodate participants while performing reading tasks.

Figure 3.8 A photometer (Minolta CS-100)

3.2.2 Visual stimulus

English alphabet characters were white on a black background, in Arial font, and all characters will be capitalized capitals, with a height of 3.3 mm (10 points). In common usage of a visual display the size of the characters remains the same, and the character sizes are not adjusted based on viewing distance (Rempel, et al., 2007). Thus, in this study the text height was held constant across all viewing distances. Random characters were displayed for three seconds timed by the Microsoft PowerPoint software.

3.2.3 Experimental design

This was a repeated measure study design with four age groups (younger, middle-aged, young-old and old-old) of forty participants. Each age group included ten participants. Participants were asked to read aloud lists of characters provided on a visual display presented at three viewing distances: 52 cm, 73 cm, and dark focus at random order.

3.2.3.1 Hypothesis

Upon completion of the study it is hypothesized that the transfer of information (as measured by the number of correct characters identified in bits of information gained) will be greater when presenting visual stimulus at the dark focus distance for all participants.

3.2.3.2 Independent variables

(a) Age: four groups (younger, middle-aged, young-old and old-old)
(b) Distances: three positions (52 cm, 73 cm, and dark focus)

3.2.3.3 Dependent variables

(a) Reading rate (characters/sec)
(b) Visual information transfer rate (bits/sec)

A 4x3 mixed-factor design (see Table 3.3) were used in this study. Age (four groups: young, middle-aged, young-old and old-old) was a between-subject variable, whereas viewing distance (three positions: 52 cm, 73 cm, and dark focus) was within-subject variables.

Table 3.3 Experimental design for the information transfer rate measures

	Younger	**Middle-Aged**	**Young-Old**	**Old-Old**
52 cm	P1-10	P11-20	P21-30	P31-40
73 cm	P1-10	P11-20	P21-30	P31-40
Dark Focus	P1-10	P11-20	P21-30	P31-40

3.2.4 Procedure

Previous studies suggested that reading aloud demonstrates the fastest rate at which a human being can transmit information, as contrasted with typing, playing the piano, or tracking (Pierce & Karlin, 1957). In this present study, the experimental procedure consisted simply of participants reading lists of characters aloud as rapidly as possible. Lists of characters were presented at three viewing distances: 52 cm, 73 cm, and the individual's dark focus distance. In each instance, the characters were chosen at random. The visual display was centered along a line that was 15° below the horizon from the participant's eyes. The visual display was positioned directly in front of the participant. Three measurements of visual information transfer rate at each viewing distance were made. Results obtained from each viewing distance were selected and averaged.

3.2.5 Visual information transfer rate measures

For all participants, the information transfer rate was measured by the number of correct characters identified in bits of information gained when presenting visual stimulus at different viewing distances.

3.2.6 Statistical analysis

A 4x3 mixed-factor design (see Table 3.3) was used to assess the effects of two factors (age and viewing distance). JMP Statistical Software was used for analysis of variance (ANOVA) with repeated measures. In the analysis, the two factors were assumed to be fixed-effect factors, while the participant was a random-effect factor. Significant findings were followed up with the Tukey post-hoc test for multiple comparisons. In this study, statistical significance was set at $\alpha < 0.05$. The statistical model for two-factor, mixed-factors design was given in Equation 3.4.

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_{k(i)} + \alpha\beta_{ij} + \beta\gamma_{jk(i)} + \varepsilon_{l(ijk)} \tag{3.4}$$

Here, Y was observation, μ was population mean, A was a between-subjects variable (age group: α, a, $i = 4$), B was a within-subject variable (viewing distance: β, b, $j = 3$), S was the number of the subject in each group (γ, $k = 10$), and ε is random error. ANOVA table is provided in Table 3.4.

Table 3.4 Source and Error terms for two-factor, mixed-factor ANOVA

Source	df	SS	MS	E{MS}	F
Between					
A	a-1	SS_A	MS_A	$bn\sigma_\alpha^2 + b\sigma_\gamma^2 + \sigma_\varepsilon^2$	$MS_A / MS_{S/A}$
S/A	a(n-1)	$SS_{S/A}$	$MS_{S/A}$	$b\sigma_\gamma^2 + \sigma_\varepsilon^2$	
Within					
B	b-1	SS_B	MS_B	$an\sigma_\beta^2 + \sigma_{\beta\gamma}^2 + \sigma_\varepsilon^2$	$MS_B / MS_{BxS/A}$
BxA	(a-1)(b-1)	SS_{BxA}	MS_{BxA}	$n\sigma_\beta^2 + \sigma_{\beta\gamma}^2 + \sigma_\varepsilon^2$	$MS_{BxA} / MS_{BxS/A}$
BxS/A	a(b-1)(n-1)	$SS_{BxS/A}$	$MS_{BxS/A}$	$\sigma_{\beta\gamma}^2 + \sigma_\varepsilon^2$	
Total	abn-1	SS_{Total}			

CHAPTER 4

RESULTS

The hypotheses of this study included: (1) the dark focus distances (as measured by the modified autorefractor) will be greater for older participants than younger participants and; (2) the transfer of information (as measured by the number of correct characters identified in bits/sec) will be greater when presenting visual stimulus at the dark focus distance for all participants. To test these two hypotheses, a two-way mixed factor ANOVA was performed to assess the effects of age, viewing distance and their interaction on dark focus distance and information transfer rate.

4.1 The ANOVA Tests

In order to provide better understanding of how the dark focus and visual information transfer rate were influenced by aging and viewing distance, each of these two variables (dark focus and information transfer rate) was analyzed separately using a mixed-factor repeated measures ANOVA.

4.1.1 The ANOVA test for the dark focus

The results of the ANOVA test for the dark focus are summarized in Table 4.1. The dark focus distance (in meters) is defined as the inverse of accommodation amplitude (in diopters) using the modified autorefractor. As mentioned earlier, amplitude of accommodation is significantly affected by age. This age-related change is known as presbyopia.

Table 4.1 ANOVA table for the dark focus

Source	**Error**	**F Value**	**Prob > F**
Age Group	Subject (Age Group)	7.2484	**0.0002**

4.1.1.1 Main effect: age group

Overall, a progressive decline in the amplitude of accommodation with aging was observed. The age effect was statistically significant (F = 7.2484, $P<0.0002$). The means and standard deviations of the dark focus of accommodation for the four age groups are given in Table 4.2 and shown in Figure 4.1. A Tukey post-hoc test also indicated that there were statistically significant differences in dark focus distance among different age groups.

Table 4.2 Descriptive statistics of age main effect on dark focus distance

Age Groups	**Dark Focus Mean (m)**	**Standard Deviation**
Young	0.645	0.066
Middle-Aged	0.734	0.206
Young-Old	0.844	0.290
Old-Old	0.921	0.334

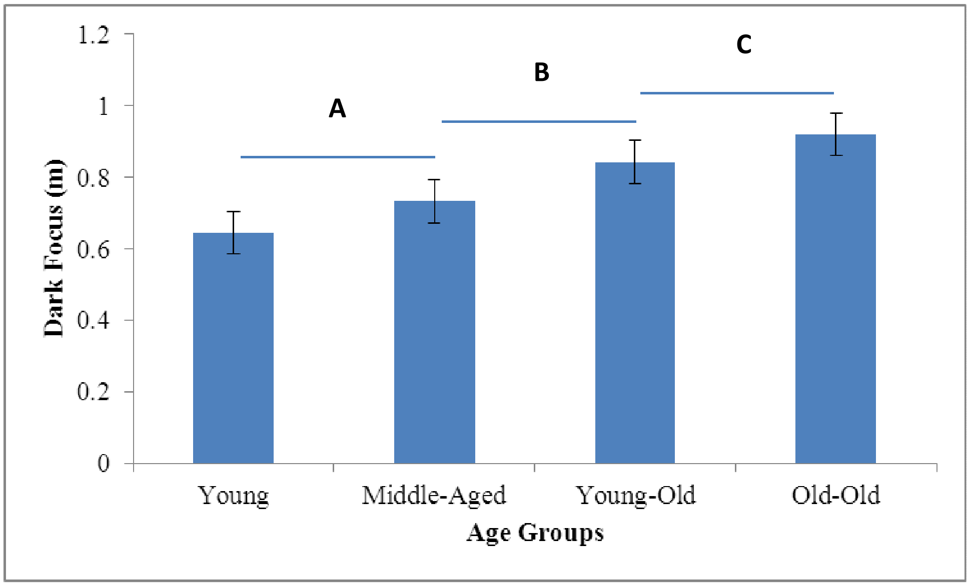


Figure 4.1 Means and standard deviations of dark focus distance across the four age groups (different letters represent statistically significant differences at the $p < 0.05$ level, see Table 4.3 for details)

Table 4.3 Tukey's HSD (Honestly Significant Difference) test of age main effect at $\alpha = 0.05$ (significant p-Value in bold print)

LSmean-LSmean	Diff	Lower CL Diff	Upper CL Diff	p-Value
Old-Old – Young	0.275	0.110	0.441	**0.0002**
Young-Old – Young	0.198	0.033	0.364	**0.0121**
Old-Old – Middle-Aged	0.187	0.021	0.353	**0.0205**
Young-Old – Middle-Aged	0.110	-0.056	0.276	0.3142
Middle-Aged – Young	0.088	-0.077	0.254	0.5074
Old-Old – Young-Old	0.077	-0.089	0.243	0.6213

Subsequent statistical analyses were also made using a one-factor (dark focus), between-subjects design of each age group. There were no statically significant differences in dark focus in young, middle-aged, and young-old age groups, however a significant difference in dark focus was found in old-old age group at $\alpha = 0.05$ (see Table 4.4).

Table 4.4 Descriptive statistics of age group on dark focus distance

Age Groups	F Value	Prob > F
Young	1.992	0.096
Middle-Aged	1.112	0.393
Young-Old	0.589	0.791
Old-Old	2.354	**0.050**

4.1.2 The ANOVA test for the visual information transfer rate

The results of the ANOVA test for the visual information transfer rate are given in Table 4.5. The visual information transfer rate is defined as the number of correct characters identified (in bits/sec) when presenting visual stimulus at different viewing distances. In general, different age groups and viewing distances influenced the reading performance as well as the visual information transfer rate. In addition, statistically significant interaction effect was not found between age group and viewing distance.

Table 4.5 ANOVA test for the visual information transfer rate

Source	**Error**	**F Value**	**Prob > F**
Age Group	Subject (Age Group)	19.6534	**<0.0001**
Viewing Distance	Viewing Distance*Subject (Age Group)	17.4081	**<0.0001**
Age Group*View Distance	Viewing Distance*Subject (Age Group)	1.6818	0.1378

4.1.2.1 The main effects

a) *The age effect*

Age-related reduction in visual information transfer rate was observed. The differences were statistically significant (F = 19.6534, P < 0.0001). The means and standard deviations of visual information transfer rate for four age groups are given in Table 4.6 and shown in Figure 4.2. A Tukey's post hoc test also indicated that the visual information transfer rates were significantly different among age groups (see Table 4.6).

Table 4.6 Descriptive statistics of age group main effect on visual information transfer rate

Age Group	**Information Transfer Rate Mean (bits/sec)**	**Standard Deviation**
Young	14.274	1.434
Middle-Aged	10.584	2.249
Young-Old	9.348	2.126
Old-Old	7.729	2.361

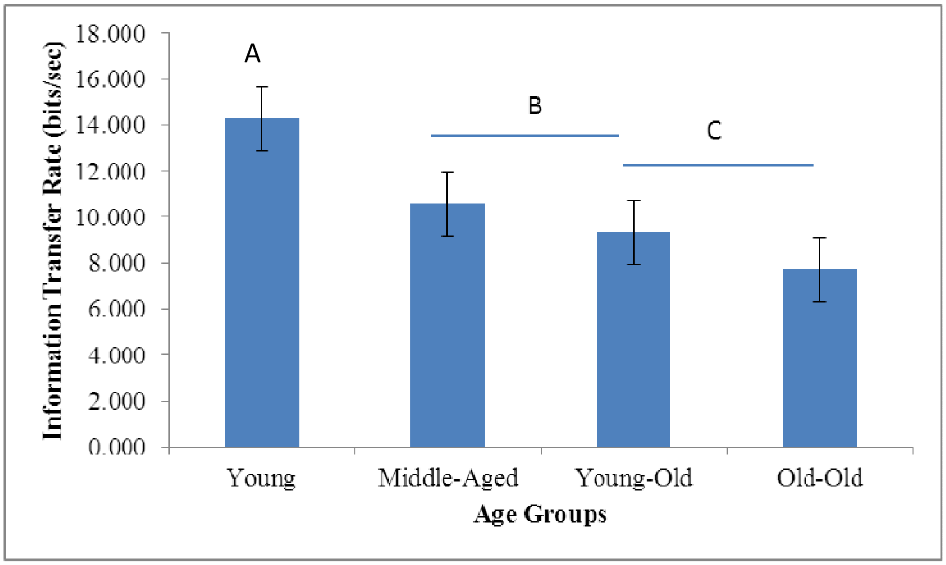


Figure 4.2 Means and standard deviations of visual information transfer rate across the four age groups (different letters represent statistically significant differences at the $p < 0.05$ level, see Table 4.7)

Table 4.7 Tukey's HSD test of age main effect at α = 0.05

LSmean-LSmean	**Diff**	**Lower CL Diff**	**Upper CL Diff**	**p-Value**
Young – Old-Old	6.5454	4.1533	8.9376	**<.0001**
Young – Young-Old	4.9263	2.5341	7.3185	**<.0001**
Young – Middle-Aged	3.6904	1.2982	6.0825	**0.0011**
Middle-Aged – Old-Old	2.8550	0.4629	5.2472	**0.0140**
Young-Old – Old-Old	1.6191	-0.7731	4.0113	0.2795
Middle-Aged – Young-Old	1.2359	-1.1562	3.6281	0.5127

b) Viewing distance effect

In general, the visual information transfer rates were significantly different at different viewing distances (F = 17.4081, P < 0.0001). The closer viewing distance (52 cm) resulted in a greater amount of information gained, as shown in Table 4.8 and Figure 4.3.

Table 4.8 Descriptive statistics of viewing distance main effect on visual information transfer rate

Viewing Distance	**Information Transfer Rate Mean (bits/sec)**	**Standard Deviation**
52 cm	11.084	3.101
73 cm	10.144	2.973
Individual Dark Focus	10.222	3.417

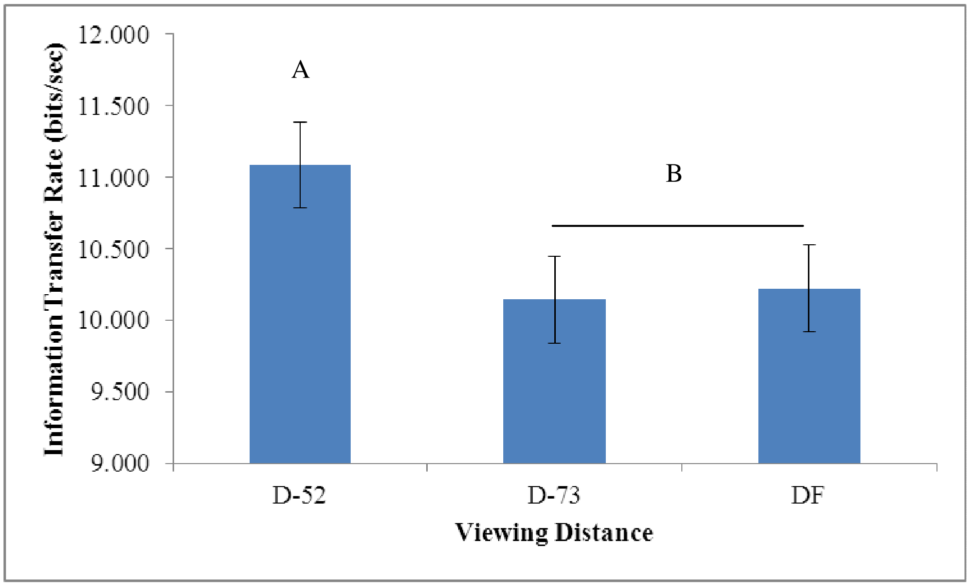


Figure 4.3 Means and standard deviations of visual information transfer rate across the three viewing distances (different letters represent statistically significant differences at the $p < 0.05$ level, see Table 4.9 for details)

Table 4.9 Tukey's HSD test of viewing distance main effect at $\alpha = 0.05$

LSmean-LSmean	**Diff**	**Lower CL Diff**	**Upper CL Diff**	**p-Value**
52 cm – 73 cm	0.9401	0.5170	1.3632	**<.0001**
52 cm – Individual Dark Focus	0.8618	0.4386	1.2849	**<.0001**
Individual Dark Focus – 73 cm	0.0783	-0.3448	0.5014	0.8976

4.1.2.2 The interaction effect: age group ^{x} viewing distance

The interaction between age group and viewing distance was found to be not statistically significant ($F = 1.6818$, $P = 0.1378$). The visual information transfer rate changed across the four age groups at different viewing distances, as shown in Table 4.10 and Figure 4.4 and 4.5.

Table 4.10 Descriptive statistics of the interaction between age group and viewing distance on the visual information transfer rate

Interaction	**Information Transfer Rate Mean (bits/sec)**	**Standard Deviation**
Young x 52 cm	14.727	1.514
Young x DF	14.466	1.256
Young x 73 cm	13.630	1.424
Middle-Aged x 52 cm	11.384	1.872
Middle-Aged x DF	10.288	2.663
Middle-Aged x 73 cm	10.079	2.147
Young-Old x 52 cm	9.922	2.074
Young-Old x 73 cm	9.348	2.066
Young-Old x DF	8.773	2.294
Old-Old x 52 cm	8.303	2.575
Old-Old x 73 cm	7.520	2.351
Old-Old x DF	7.363	2.289

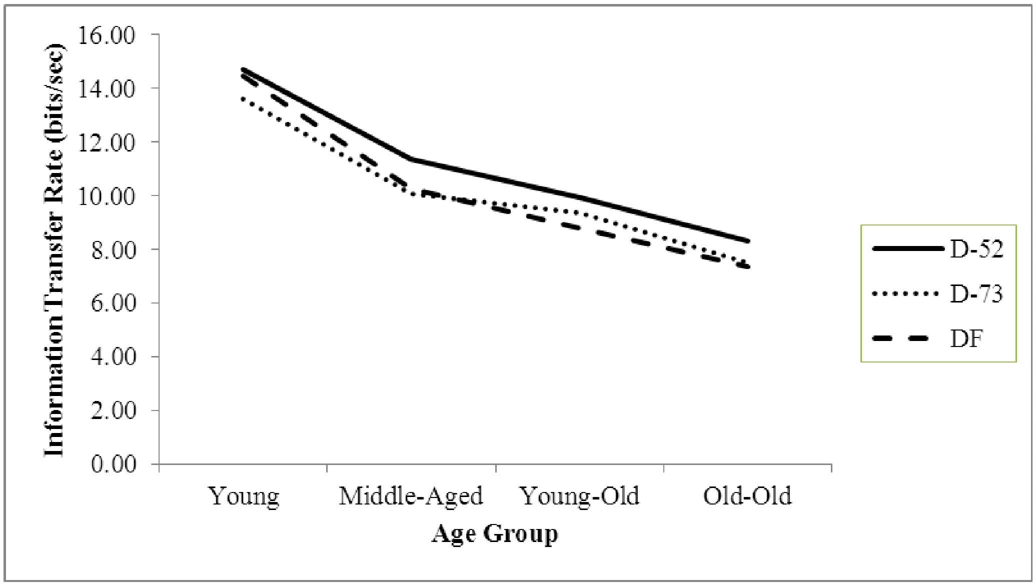


Figure 4.4 The interaction between age group and viewing distance on the visual information transfer rate.

4.1.2.3 Summary of the ANOVA test on the visual information transfer rate

Overall, with advancing age and greater viewing distance there was a progressive reduction in the visual information transfer rate.

4.2 Regression Analysis

Regression analyses were performed to describe and predict the relationships between the independent (predictor: X) and dependent (response: Y) variables. In general, simple regression assumes a linear relationship between the two correlated variables. In this present study the predictor variables were age and viewing distance. The response variables (Y) included dark focus and visual information transfer rate. These analyses were used to predict dark focus distance given age (in years) and predict visual information transfer rate at 52 cm, 73 cm, and an individual's dark focus distance given age (in years).

4.2.1 Regression model for predicting dark focus

A regression line and a simple linear regression equation for predicting dark focus given age was illustrated in Figure 4.5

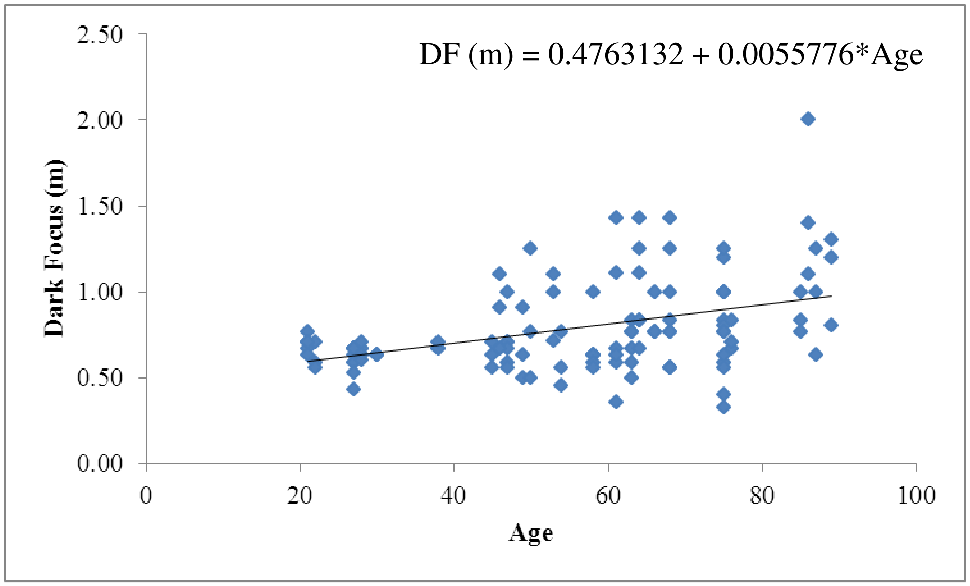


Figure 4.5 Plot of age versus dark focus with a regression line and a simple linear regression equation for prediction of dark focus

4.2.2 Regression model for predicting visual information transfer rate at 52 cm

A regression line and a simple linear regression equation for predicting the visual information transfer rate at a viewing distance of 52 cm is illustrated in Figure 4.6

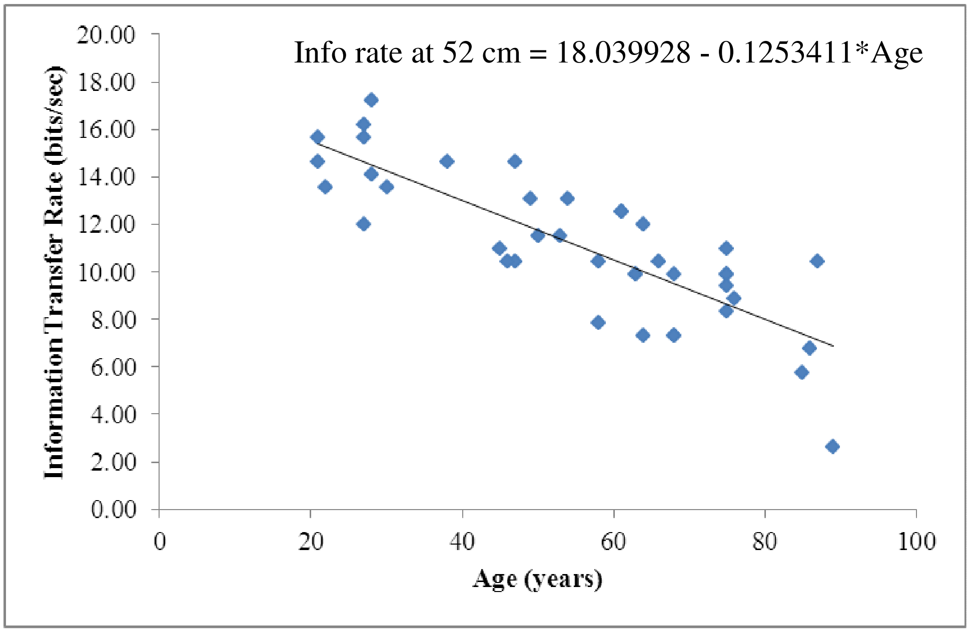


Figure 4.6 Plot of age versus visual information transfer rate with a regression line and a simple linear regression equation for prediction of visual information transfer rate at 52 cm.

4.2.3 Regression model for predicting visual information transfer rate at 73 cm

A regression line and a simple linear regression equation for predicting the visual information transfer rate at a viewing distance of 73 cm is illustrated in Figure 4.7

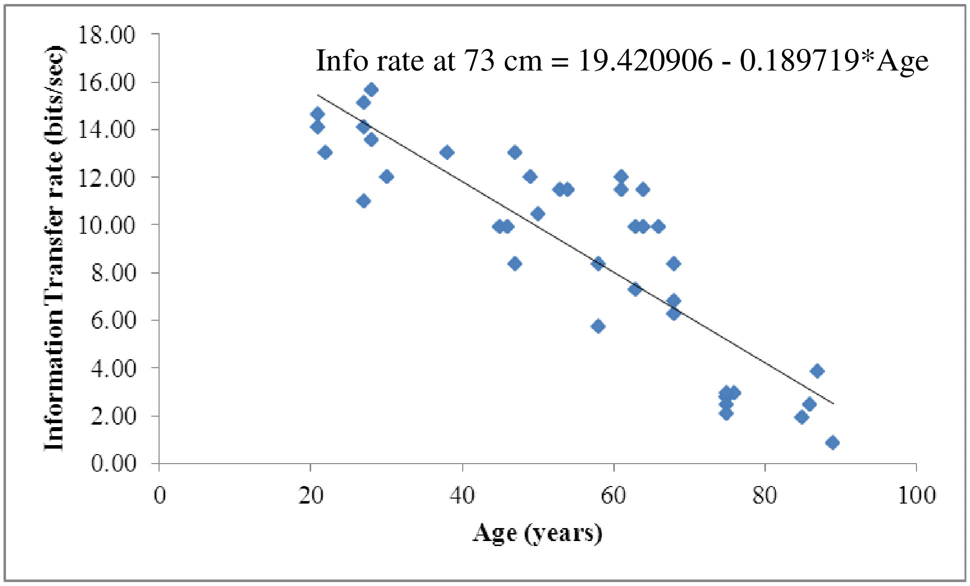


Figure 4.7 Plot of age versus visual information transfer rate with a regression line and a simple linear regression equation for prediction of visual information transfer rate at 73 cm.

4.2.4 Regression model for predicting visual information transfer rate at the individual's dark focus

A regression line and a simple linear regression equation for predicting the visual information transfer rate at the individual's dark focus distance is illustrated in Figure 4.8

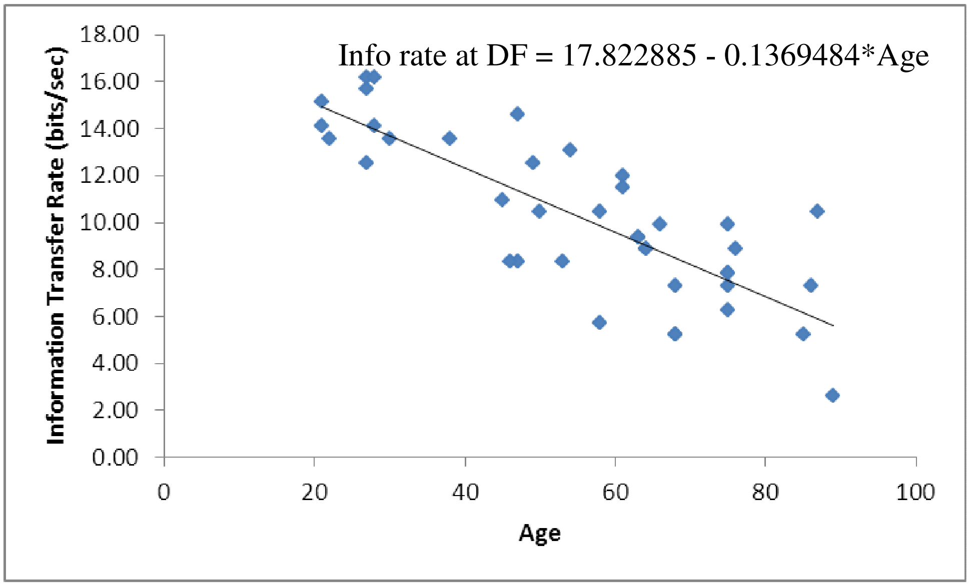


Figure 4.8 Plot of age versus visual information transfer rate with a regression line and a simple linear regression equation for prediction of visual information transfer rate at individual's dark focus.

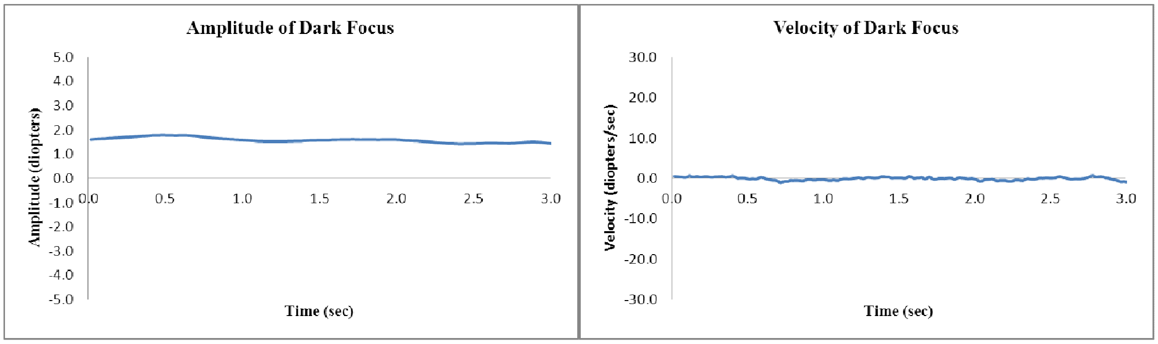
From regression analysis, correlations between dark focus distance and age, and visual information transfer rate at different viewing distances and age were given in Table 4.11

Table 4.11 Summary of the linear regressions between dark focus distance and age, and visual information transfer rate at different viewing distances and age

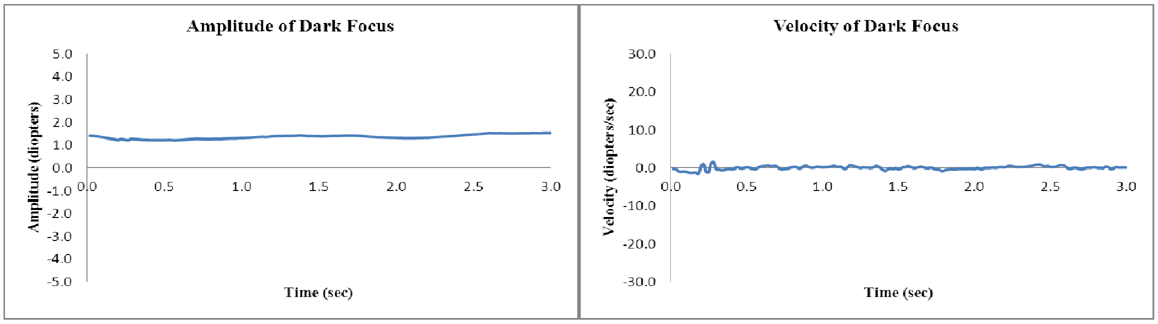
Linear Regression Equation	**R^2**
Dark Focus by Age	0.1785
Visual Information Transfer Rate at 52 cm by Age	0.6693
Visual Information Transfer Rate at 73 cm by Age	0.7649
Visual Information Transfer Rate at Individual's Dark Focus by Age	0.6580

4.3 Results from the Experiments

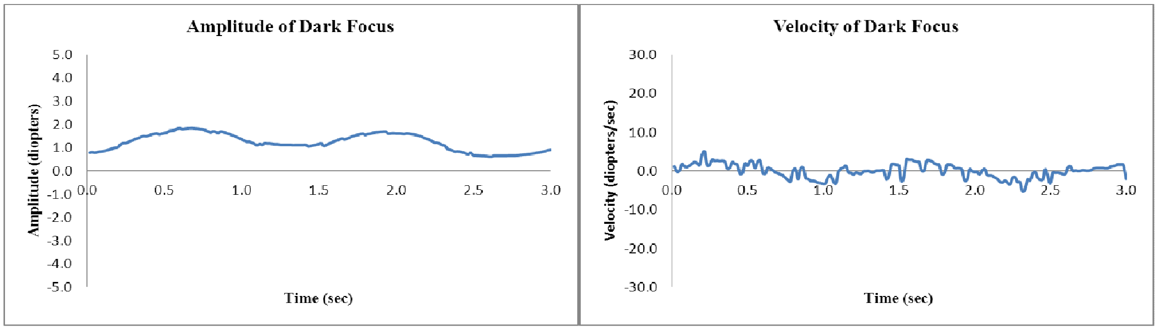
An example set of plots of amplitude and velocity of dark focus from participants in different age groups in experiments is shown in Figure 4.9.



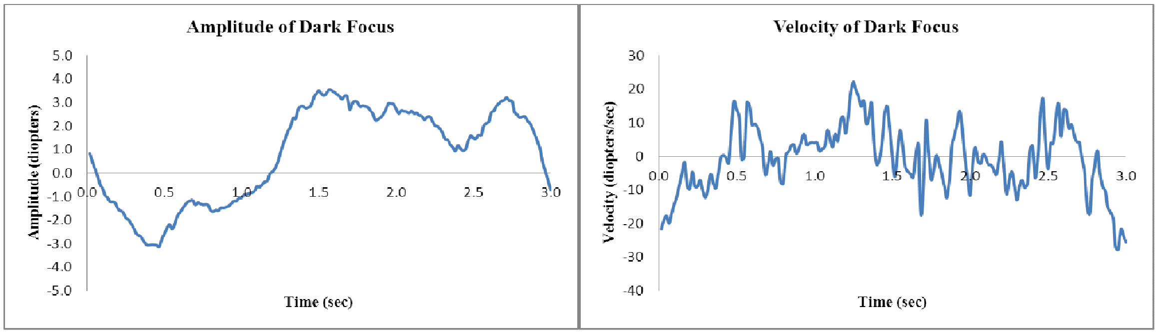
a) young adult



b) middle-aged adult



c) young-old adult



d) old-old adult

Figure 4.9 An example set of plots of amplitude and velocity of dark focus from adults in different age groups

CHAPTER 5

DISCUSSION

Based on the current study, it was evident that the decline of amplitude of accommodation was affected by age, and visual information transfer rates were significantly influenced by viewing distances.

5.1 The Effect of Age on Dark Focus

The overall objective of this study was to determine if visual information transfer rate was affected by the combination of age and viewing distance. As discussed previously, accommodation is affected by age. However, results suggested that viewing distance is also an important factor in predicting night vision reading performance. Participants gained more information when the visual display was presented at 52 cm than at 73 cm or at an individual's dark focus distance. Similarly, the loss of visual performance was found with advancing age, as evidenced in the amount of information transfer rate in bits/sec.

The first hypothesis of the study was that the dark focus distances will be greater for older participants than their younger counterparts (Experiment I). The results indicated that there were statistically significant differences in dark focus distance among the four age groups. Subsequent post-hoc analysis further revealed that with advancing age, the dark focus distance increased. This could be a result of age-related decline in amplitude of accommodation (Glasser & Campbell, 1998; Hamasaki, et al., 1956; Strenk, et al., 2005). Age-related changes in visual systems include a decrease in the elasticity of the lens and the degeneration of the Zonular fibers and the Ciliary muscles surrounding the lens (Dubbelman, et al., 2005; Mordi, 1991; Sun, et al., 1988). Additionally, the lens hardens (Pokorny, et al., 1987; Schieber, 2006), the tension of the Zonular fibers declines (Glasser & Kaufman, 2003), and the activity of the Ciliary muscles decreases (Ciuffreda & Kruger, 1988; Fisher, 1986). As a result, it has been documented that the progressive reduction of amplitude of accommodation is affected by age (Duane, 1912). Previous studies also suggested that these changes in visual systems could be a major contributing factor to age-related loss of accommodation (Mordi & Ciuffreda, 1998, 2004; Schachar, 2007). This is called presbyopia, which is the continuous loss of the ability of the eye to change its focus on objects at close distances (Atchison & Smith, 2000; Ciuffreda, 1991).

However, the findings from the present study did not support previous studies in that the dark focus distances have wide variation among individuals in the same age group (Leibowitz & Owens, 1975a, 1978; Ripple, 1952). Previous reports indicated that the measure of accommodative responses and dark focus positions were dependent on the method used to measure them (Heron, et al., 1981). Mordi (1991) addressed that most of dark focus measurements done in the past used a laser beam that resulted in an interference pattern known as the laser speckle pattern, which could have an effect on accommodation because of the cognitive aspect of deciding motion and direction that may substantially influence this response. The objective scheme of the autorefractor used in this study may have allowed more stable results in measuring dark focus distance, thereby reducing the variability within an individual. The absence of the laser speckle pattern in the autorefractor arrangement, which utilizes infrared light, may largely account for inconsistency with previous studies or the differences between results obtained from laser and infrared optometers. For example, in young adults, mean and standard deviation of dark focus distance obtained in this study from ten participants were 0.65 m and 0.07 m, respectively. As compared with the previous results of Leibowitz & Owens (1975), the mean dark focus distance from this study was slightly greater (0.65 m vs 0.58 m), however the standard deviation of dark focus distance was much smaller (0.07 m vs 1.38 m) than reported by Charman (1995). Similar findings were also observed among older adults. Their average dark focus distance was significantly increased, and can be attributed to presbyopia (Andre, et al., 1998; Simonelli, 1983).

The second hypothesis of the present study was that transfer of information will be greater when presenting visual stimulus at the dark focus distance for all participants. Experiment II was designed to explore the effects of viewing distances on younger and older adults' reading performance. Overall, younger adults read the texts significantly quicker. However, age-related differences in reading speed were evident for texts presented at different viewing distances. The mean visual information transfer rate for younger, middle-aged, young-old, and old-old adults were 14.27±1.43, 10.58±2.25, 9.35±2.13, and 7.73±2.36 bit/sec, respectively. Subsequent post-hoc analyses indicated that there were statistically significant differences in means and standard deviations of visual information transfer rate in different age groups (young and old-old, young and young-old, young and middle-aged, and middle-aged and old-old). Age-related changes in dynamics stability of the amplitude and velocity of dark focus became more noticeable across the older age groups in the present study.

Statistically significant differences in visual information transfer rate at different viewing distances were also observed. The mean visual information transfer rate at 52 cm, 73 cm and individual dark focus distances were 11.08±3.10, 10.14±2.97, and 10.22±3.42 bits/sec, respectively. The post-hoc test also indicated that there were statistically significant differences in means and standard deviations of visual information transfer rate at different viewing distances with 52 cm being the best. This could possibly be a result of night myopia, a temporary increase in myopia (the condition of nearsightedness) due to darkness (Koomen, Scolnik, & Tousey, 1951; Rayleigh, 1883). Many investigators have observed that the normal eye becomes nearsighted at low light levels or under low contrast conditions such as night driving (Charman, 1996; Fejer & Girgis, 1992). Night myopia may be as high as 6.0 D. This increase in myopia can cause significant difficulties with night driving due to blurring of vision, glare and loss of contrast sensitivity. Individuals with 20/20 day time vision may incur this problem, and more importantly, about one-third of young adults have night myopia and do not realize that they have this problem until questioned (Hope & Rubin, 1984; Ryosa, 1992). Statistics showed that 17% of observers aged 16 to 80 years were found to have night myopia of 0.75 D or more. The rate for those aged 16 to 25 years was 38%, with 4% having night myopia of 2.5 D. The prevalence and magnitude of night myopia decreased steadily with increasing age and were insignificant by the age of 65 years (Fejer, 1995).

According to the result of this experiment, there were no statistically significant differences in the interaction between age and viewing distance (F = 1.6818, P = 0.1378) on the visual information transfer rate. Additionally, the visual information transfer rate changed across the four age groups at different viewing distances. These results suggested that within these viewing distances, visual information transfer rate associated with reading may not be different even for the elderly individual. It was therefore concluded that the transfer of visual information among individuals in these four age groups was greatest when presenting the visual stimulus at 52 cm.

5.2 The Potential Use of Dark Focus

For a practical application, the knowledge of dark focus distance leads to potential strategies and techniques for the design of corrective lenses, typically using a negative (concave) lens. Prior research found that the dark focus of an individual correlated highly with the magnitude of night myopia (Leibowitz & Owens, 1975a). Studies also suggested that these myopias could be corrected on the basis of the dark focus of accommodation (Leibowitz & Owens, 1978; Post, et al., 1979).

However, general guidelines for night vision and night myopia have not been completely satisfactory due to the variability in dark focus (Simonelli, 1979). Also, little has been done to address this challenge. Part of the reason may be that, until recently, there has not been a standard way of measuring night myopia (Ryosa, 1992). However, using individualized corrections equivalent to dark focus would be an additional correction resulting in higher sensitivity in detecting a target under low illuminance, such as while driving at night (Fejer, 1995).

Statistics showed that automobile driving at night is a common situation that places people with night myopia at a greater risk for accidents (Dahlstedt & Svenson, 1977; Ward, Shepherd, Robertson, & Thomas, 2005). It has been anticipated that night myopia accounts for some of the increase in road accidents at night (Cohen et al., 2007). If some degree of uncorrected myopia exists, night myopia will make the vision proportionately worse. Night myopia is a correctable cause of decreased visual acuity under conditions of decreased illumination. Corrections of the decreased visual acuity in darkness may be especially important in certain occupations. Recognition of night myopia is important both for general safety and for occupational considerations. For example, truck drivers, police officers, pilots and others must have good visual acuity under conditions of decreased illumination (Seymore, 1985). Thus, availability of corrective lenses for night myopia could be very important and should be required for individuals while driving at night (Fejer, 1995).

Dark focus may also play a significant role in visual training. A study reported that aviators were significantly less myopic than the student population and this dramatic difference in reduced refractive error of accommodation resulted from the night vision accommodation training (Temme & Ricks, 1987). Prior study investigating the eye training showed that people with normal focusing responses could be taught to accurately control accommodation and offers the possibility of overcoming the adverse effects of night myopia using dark focus techniques (Roscoe, 1985).

5.3 Recommendations for Future Research

The findings of the current study consistently supported prior studies that there was a progressive reduction of accommodation amplitude with increased age (Glasser & Kaufman, 2003; Mordi & Ciuffreda, 1998). Results also showed that the visual information transfer rate gained at 52 cm was significantly greater than the visual information transfer rate gained at 73 cm, which was relatively close to the distance from the eye to the dashboard (Shi, 2007). Therefore, a further study might be needed to investigate if the dashboard position and clutter design influence the driver's visual performance under scotopic visual conditions. Also, these results should be sufficient to justify modifications to current in-vehicle/workplace standards that would need a better design or a choice of corrective lens for users in different age groups under low lighting conditions since the combination of age group and viewing distance was especially problematic for certain visual performance conditions.

As mentioned previously, visual requirements are critical for the safety of drivers. A prior study showed that in a model of driver information processing, vision was typically considered the primary sensory channel, which is responsible for up to 95% of driving-related information inputs. If good vision is a necessary condition for safe driving, it might be concluded that poor vision results in unsafe driving (Schieber, 2000; Shinar & Schieber, 1991). In the US, the majority of states require that drivers have a best-correct visual acuity of 20/40 to obtain a non-restricted driver's license. However, these visual standards vary from state to state. For example, Kansas will grant a restricted driver's license to individuals with a best corrected acuity of 20/90, but California will allow an individual with a best corrected acuity of 20/200 (which is the legal definition for blindness) to obtain a restricted driver's license (McGregor & Chaparro, 2000). The statistical phenomenon of a restricted range of visual impairment – such as instating an essentially worldwide requirement for driving of at least 20/40 acuity in the better eye (Charman, 1985) – would act to reduce the dramatic differences in visual acuity requirements between states and within the general population. Some of the visual requirements with high theoretical construct validity have not been evaluated in large-scale studies (ie. contrast sensitivity). Drivers with reduced capacities may compensate by restricting their driving to times when there are favorable light conditions, low density, and low-speed traffic (Shinar & Schieber, 1991). Thus, studies on night vision requirements (ie. – dynamics visual acuity test and symbol recognition) and on alternative strategies (ie. – people applying for a driver's license should be tested for night myopia and should wear corrective lenses if necessary) are needed.

Several studies have focused on the causes of highway construction and maintenance injuries and showed that night work, contact with heavy equipment and being stuck by passing vehicles were the major causes of fatalities and the injury rates continued to climb due to increasing nighttime work under traffic (Hallowell, Protzman, & Molenaar, 2010). Research found that poor lighting conditions contributed to 43% of deaths in nighttime highway construction and was the second leading factor contributing to nighttime work zone fatalities (Arditi, Ayrancioglu, & Shi, 2005). Although lighting requirements for nighttime construction have been established, many variables influence the quality of work zone lighting. These variables include lighting intensity, orientation, direction and location influence lighting quality, especially illumination, glare and shadowing. However, if the visibility is poor, workers are more likely to be placed in a higher risk of accidents such as to be struck by heavy equipment, passing vehicles or materials. Therefore, further research should heavily focus on the quality of light and individual's visual corrections.

In order to determine the information transfer rate for individuals, an in-vehicle visual display/task analysis, conducted in a realistic traffic environment, would be necessary. This type of evaluation, which would identify the relative importance of visual-related traffic controls, could clearly define the design requirements including the combination of lighting conditions, visual signal quality, additional visual displays, and visual sensitivity for safety. An evaluation of this type could lead to significant changes in future driving evaluations and requirements.

Studies indicated that the resting level of visual accommodation (Ebenholtz, 1991, 1992; Toates, 1972) and the refractive error was minimal at the intermediate resting point of accommodation (Leibowitz & Owens, 1975a, 1978; Owens, 1979) and minimized visual fatigue (Wesner & Miller, 1986). Visual fatigue has a wide range of visual symptoms, including eyestrain, headache, and tiredness (Ukai & Howarth, 2008). Viewing distance between the user's eyes and the visual display is a robust treatment variable in studies reporting visual fatigue symptoms (Dillon & Emurian, 1996). Therefore, to minimize visual fatigue and improve visual performance, a future study should focus on investigating the relationship between dark focus or resting state of accommodation and visual fatigue and the effects of fatigue on dark focus distance (Hasebe, Graf, & Schor, 2001; Owens & Wolf-Kelly, 1987; Tan & O'Leary, 1988).

Ideally, night vision research with an emphasis on dark focus evaluation to determine individual visual performance could be conducted in a simulated visual environment however, an evaluation of this type may not be realistic. A more straightforward night vision evaluation for drivers, regardless of visual constraints such as the size of the stimulus and lighting level in this present study, may be appropriate with other types of stimulus and background noise experienced by the driver while in the vehicle. A more realistic night vision test as described would provide better understanding of whether a driver meets night vision requirements to drive safely.

Additionally, more research will be needed to further explore the effects of age as well as other forms of visually degraded performance to aid in developing guidelines for designing visual materials and display or tool-presented visual stimulus that assist language processing for younger and older adults. It was evident from the current study that optimizing viewing distance for reading tasks that demand efficiency is essential, particularly under scotopic conditions if the reading tasks may include older adults. The results of this study highlighted age-related differences in reading under dark, scotopic environments. Consequently, to maximize visual performance, a new design for visual performance improvement may be necessary to accommodate older adults, particularly because age-related loss in accommodation is not always corrected by the same type of corrective lenses that may be used in the daytime condition.

This study identified the relative effects of age and viewing distance on visual information transfer rates in an effort to include factors other than visual attentional level on an individual’s reading performance. Because this study was conducted in a laboratory setting, there were factors inherent to reading in the dark that could not be accurately captured in a laboratory. A similar study conducted in a research vehicle or in actual road traffic would provide even more realism that could identify viewing distance and visual information transfer rate more realistically. Because there was only a display in foveal (central) vision used in the experiment, the effect of visual peripheral performance was not explored. Future studies should include measures of peripheral performance and studies on how the peripheral vision affects the visual information transfer rate.

5.4 Design Guidelines for Night Myopia Correction

The present study investigated the age-related dark focus and visual information transfer rate at different distances under scotopic vision. The findings from the study indicated that there were statistically significant differences in means and standard deviations of visual information transfer rate at different viewing distances, and the visual information transfer rate was greatest at the viewing distance of 52 cm. Previous study suggested that this could possibly be a result of night myopia (Charman, 1996; Fejer & Girgis, 1992).

Design guidelines for night myopia corrections as given below are especially important during times of technology growth because information is increasingly being presented in new formats, such as on electronic displays. Different formats often have different perceptual qualities, and it is necessary to understand how the various qualities affect the reading behavior of all readers to optimize communication success and efficiency.

General design guidelines: A variety of relationships exist between target size, distance to target, and lighting illuminance, so multiple design guidelines should be considered. For example, vehicles should be designed with display flexibility in mind, allowing the driver to adjust display distance (Rempel, et al., 2007), display size, and display luminance levels (Bangor, 2000) to accommodate for a variety of age ranges and individual visual abilities. Another design guideline should address the quality of target illuminance (Boyce, 1973). For example, in construction work zones, better lighting quality may enhance a driver’s ability to detect a target and possibly avoid an accident (Hallowell, et al., 2010). More specific design guidelines are given below.

Design guideline 1: The increase of the information transfer rate due to the decrease of viewing distance under darkness (Fejer, 1995) can be used to improve an individual's visual performance. Specifically, reading a visual display placed at 52 cm allowed the greatest information transfer rate for all different age groups rather than a display at 73 cm which is relatively close to the distance between the eye and dashboard. This is similar to the effect of visual accommodation on reading display while driving at night (Shi, 2007). As such, the future design of display location for drivers should be given significant consideration in order to improve individual's nighttime visual ability (Jainta & Jaschinski, 2002; Wittmann et al., 2006).

Design guideline 2: Due to age-related continuous decline of accommodation and visual information transfer rate, the optimal viewing distance should always be applied along with other visual stimulus characteristics/design techniques to create a suitable stimulus for older adults to accommodate (Kline & Scialfa, 1997). These characteristic/design techniques may include enlarging the size of the target, improving the quality of target such as increasing lighting intensity, reducing glare, and avoiding placing target at long distances (Shinar & Schieber, 1991).

In summary, based on the findings of the current study, different viewing distance may have different impacts on the age-related dynamic accommodative performance. Accordingly, the design guidelines above for night myopia correction were proposed. It must be noted, however, that since visual perception and users' satisfaction is not determined solely by good accommodative performance, the final decision on night myopia correction or target/display design must be made with the consideration of many other important factors such as personal preferences, information perception, safety, cost, and technical feasibility (Handcock, Rogers, Schroeder, & Fisk, 2004).

5.5 Limitations of the Current Study

The experiment was designed to be as realistic as possible, and factors such as requiring full dark adaptation, performing realistic visual tasks under scotopic vision, and having participants in different age groups greatly contributed to the realism and the overall external validity of the study. However, there were several limitations to the current study that should be considered. These limitations were realized during the course of data collection and data analysis. First, the dark focus that was investigated was limited to a simulated environment where the observer read information under only a scotopic visual condition (low brightness level where rods are primarily active). In other words, the study had one type and one size of visual stimulus, under one lighting level. These conditions are not usually found in the real-world visual environments. Future studies may include testing at different lighting levels to simulate driving at different times of day. Additionally, it may be more realistic if the visual target used to elicit accommodation was an image of an actual dashboard control.

Another factor that was not implemented in this study was that of background noise and/or any other sources of distractions. Under actual visual tasks, the observer usually perceives more than one information channel such as additional visual information with ambient noise, thereby increasing the amount of information gained. These factors were not added to the experiment in an effort to reduce confounds in the analyses. For this reason, visual information transfer rate may have been artificially increased in this experiment. Future work should evaluate the interventions under a range of simulated or actual occupational tasks. The visual stimulus used in this study was also controlled in terms of specific frequency, presentation manner, and content. Future studies are needed to assess other types of visual stimulus and underlying dark focus mechanisms.

Lastly, the findings of the present study were derived from ten participants in each age group. Future studies with a larger number of participants in each age group should be considered and may produce more conclusive results regarding the discriminative capacity of the dynamics of dark focus. Additionally, factors such as an individual’s stress level, physical, mental/visual/physical fatigue, target luminance level, and ambient lighting condition may play a role in one’s accommodative stability and should be considered in future studies.

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Appendix A: IRB – Informed Consent Form

INFORMED CONSENT FOR PARTICIPANTS IN RESEARCH PROJECTS INVOLVING HUMAN SUBJECTS

TITLE OF PROJECT: The Effect of Age on Dark Focus Distance and Visual Information Transfer Rate

PRINCIPAL INVESTIGATOR: Thurmon E. Lockhart, PhD, Grado Department of Industrial and Systems Engineering, Virginia Tech

I. Purpose

The purpose of this project is to examine the influence of age on dark focus distance and its relationship to the readability of the visual display.

II. Procedures and Project Information

A. Participant Selection

This study will include participants aged 20 years and older. There will be four age groups: younger (20-44 years), middle-aged (45-59 years), old (60-74 years), and older (over 75 years). Participants will be screened and excluded from participation based on the presence of eye disease, color blindness, eye surgery, or optic nerve damage that may affect sensory perception in the eye. The participants must also have normal or correct-to-normal vision in at least one of the eyes.

To ensure the qualification of the participant, a screening session will be held prior to the actual test session, which will take place after the participant has signed an IRB-approved informed consent form and completed a questionnaire regarding his/her personal information. In addition, a test of static visual acuity and color blindness will be performed for each eye, using the Bausch & Lomb Vision Tester. Then, the static contrast sensitivity will be performed, using the Vistech Contrast Sensitivity Chart.

B. Time Requirements

The study will require no more than two hours of the participant’s time.

C. Study Procedures

This research will be divided into two experiments.

In Experiment I, the accommodative status of dark focus at the fovea will be assessed objectively using the modified autorefractor, a newly developed method to continuously monitor the accommodation process. Participants will be asked to sit at the modified autorefractor station with a separate desk for the PC to prevent the light from affecting the participants. The height of the chair and the chin rest of the modified autorefractor will be adjusted for each individual. After paricipants have found a comfortable sitting posture, the view window of the modified autorefractor will be moved to the appropriate position relative to the eyes. Afterwards, participants will be asked to keep their right eye open and the measurement ring of the modified autorefractor will be positioned at the center of their retina. Before each trial, the participant’s head will be positioned upright by observing the actual head inclination angle between the horizontal and the ear-eye line. Participants will complete a series of trials on the modified autorefractor as their gaze is directed horizontally to a fixation target on the wall. Accommodative responses (amplitude and velocity) of each participant’s right eye will be measured objectively under nighttime condition (0 lux) with the modified autorefractor, while the other eye is covered. Dark focus will be measured in the dark after a period of ten minutes so that the participant will be fully dark adapted. Three measurements of thirty seconds for each trial will be taken. Results of five consecutive seconds out of thirty seconds on each measurement will be selected and averaged. During these visual tasks, participants will be asked to look at the same position: the middle spot of the fixation board at the horizontal eye level. A one-minute break will be given to the participants after each trial.

In Experiment II, the visual information transfer rate will be determined when viewing a target at three different distances: 52 cm, 73 cm, and the individual's dark focus in random order. A set of randomized English alphabet characters will be presented on a visual display with a luminance level of 20 cd/m^2 and ambient illumination level of 4 lux. Characters will be white on a black background, in Arial font, and all characters will be capitalized, with a height of 3.3 mm (10 points). To assess the visual information transfer rate, participants will be asked to read a set of characters aloud with their fastest rate for three seconds. Three measurements of inforamtion transfer rate at each viewing distance at random will be made. Results obtained from each viewing distance will be collected and averaged. The amount of information gained for individuals at 52 cm and 73 cm will then be determined and compared with the amount of information gained at their dark focus distance.

III. Risks Involved in Participation

The risks associated with this study are minimal. The participant could potentially have minor eye fatigue, as similar to that encountered while driving.

IV. Benefits from Participation

No direct benefits of participation are promised, however, the results of the research may lead to better understanding of the dynamic aspect of dark focus of the human eye. The main objective of this study is to explore the effects of age on dark focus distance and its relationship to the readability (measured as number of bits/sec gained) of the visual display. The results of the study will be applied to product design and development, and will be used to understand how viewing distance can affect the individual's reading performance.

V. Extent of Anonymity and Confidentiality

All data will be coded and will contain no personal information pertaining to the participants. Participant information will not be seen by anyone other than the researchers involved in the project.

VI. Freedom to Withdraw

Participants are free to withdraw at any time during the study.

VII. Compensation

Compensation of $10/hour will be supplied to participants. A maximum of $20 will be paid for the participation.

VIII. Participant Responsibilities

Participants will be asked to perform the experimental tasks to the best of their ability.

IX. IRB Review of Research

The Virginia Tech Institutional Review Board (IRB) for Projects Involving Human Subjects, has reviewed this proposed study, and has determined that it is in compliance with federal laws and Virginia Tech policies governing the protection of human subjects in research. However, you should recognize that the review does not constitute an endorsement of the research, and that it is up to you to determine whether you are willing to participate in the study after having been informed of the risks, benefits, and procedures involved in this study.

X. Participant's Permission

I have read the Consent Form and conditions of this project and have addressed all concerns with the research staff or the principle investigator. I have had all concerns addressed appropriately and hereby acknowledge the above and give my voluntary consent to participate in this study.

____ Date:____________________
Participant Signature

Participant Project ID Code: _________________________

The research team for this experiment is led by Dr. Thurmon Lockhart. He may be contacted at the following address and phone number:

Dr. Thurmon E. Lockhart
Associate Professor
Department of Industrial and Systems Engineering
557 Whittemore Hall
Blacksburg, VA 24061
Phone: (540) 231-9088; Email: lockhart@vt.edu

In addition, if you have any detailed questions regarding your rights as participant in University Research, you may contact the following individual:

Dr. David M. Moore
Associate Vice President for Research Compliance
Chair, Virginia Tech Institutional Review Board for the Protection of Human Subjects
Office of Research Compliance (Attn: IRB)
2000 Kraft Drive, Suite 2000
Blacksburg, VA 24060
Phone: (540) 231-4991; Email: moored@vt.edu