Effect of aging on measures of visual attention using dual tasks and visual search

by

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Abstract

In Canada, as baby boomers age, there will be an increase in the percentage of seniors within the general population (Statistics Canada, 2006). Seniors often have difficulty in performing certain everyday tasks and have greater risk of having health issues. As such, it becomes increasingly important to understand factors that pose difficulty for this group of people. As people get older, many visual functions such as visual acuity, contrast sensitivity, and glare are known to deteriorate (Haegerstrom-Portnoy, 2005). However, when considering activities that aid mobility such as driving and walking, vision related variables are not the only ones that create difficulty for older individuals. A sensory variable such as attention, in conjunction with vision, has been shown in previous studies to be a good predictor of difficulties encountered by the elderly (McGwin, Owsley, & Ball, 1998; Owsley, McGwin, Sloane, Stalvey, & Wells, 2001). Moreover, inattention and distraction seem to be common causes of automobile accidents as well as falls. The work load imposed on the working memory can impact distractibility and inattention.

In mobility related activities such as driving and walking, individuals perceive objects that are increasing in size. Experiments were designed to investigate the factors that affect the perception of targets that are enlarging in size. Size matching of expanding targets to a previously presented static target, was investigated in a group of younger participants with normal vision using central or peripheral vision. The results show that size estimates differ depending on whether the target appears in the central visual field or in the periphery. The participants respond faster to targets that appear in the periphery compared to those in the centre/midline.

In the subsequent set of experiments we compared the performance of younger and older participants using a dual task paradigm where individuals had to perform two tasks concurrently, one of which was to match the size of an enlarging target. Attention was modulated in the dual tasks by varying the difficulty of the secondary task. It has been found that older individuals have difficulty processing multiple visual tasks or performing multiple tasks in general (Pashler, 1994a, 1994b, 1998; Verhaeghen et al., 2003). Compared to younger individuals, older individuals were found to have greater performance difficulty in the highly demanding dual tasks. These results are compared to those observed in studies of psychological refractory period effects. The differences between the young and older individuals are discussed with respect to limited capacity and bottle neck models of attention. Furthermore, eye movement measures in the dual tasks seem to provide evidence of difficulty in task switching for the older observers.

The thesis also investigated the functional field of view of younger and older individuals. By assessing the functional field of view (FFOV) using a method employed earlier by Coeckelbergh et al., (2004a), significant overall age related differences were found. Multiple characteristics of what might affect the FFOV as measured by the attended field of view (AFOV) were also investigated (e.g., impact of a pop out distracter and divided attention). It was found that differences between the two age groups occurred in all conditions. The presence of irrelevant distracters had a greater impact on the older individuals compared to the younger group, whereas divided attention or the presence of the pop out distracter did not affect either age group. Attention processing seemed to be similar for both the younger and older individuals and, therefore, the differences between the age groups appear to be at a quantitative level rather than a qualitative level.

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Dedication

To my loving parents who have supported me all my life.

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1. Introduction

The population of Canada as per the 2006 census was approximately 34 million and 13.7% were individuals over the age of 65. The percentage of individuals over 65 has risen from 7.7% in 1956 to 13.7% in 2006 (Statistics Canada, 2006). This percentage is expected to double in the next 25 years. The baby boom generation is comprised of individuals born between 1946 and 1965 and represents a large proportion of the total population. By 2011, individuals born in 1946 will become 65. This change will result in a demographic represented by an increased senior population that will impact the country in a variety of ways, such as, the labor force, public pension and health care. One way to minimize the social and economic impact is to ensure that older adults age in a healthy way, reducing health care costs due to debility and disease (Healthy Aging in Canada: A New Vision, A Vital Investment, 2006).

At risk situations for older individuals arise when they are moving around in their surroundings to perform everyday tasks. Mobility within their own environment (e.g., their house), as well as the environment through which they navigate either as a pedestrian or as a driver, poses a certain amount of risk to themselves and to others. Falls are common in the elderly and often result in serious injuries that require hospitalization and occasionally result in death. (Healthy Aging in Canada: A New Vision, A Vital Investment, 2006; Report on seniors' falls in Canada, Public health agency of Canada. 2005.)

In order to maintain independence, many older persons continue to drive as part of their daily routine. Restrictions on driving, limit independence and have been found to impact general mental well being (Anstey, Wood, Lord, & Walker, 2005). However, driving has to be safe. It is not only the life of the individual at stake but also that of the other people who are driving or walking in the same environment. The Canadian traffic collision statistics of 2006 (Canadian Motor Vehicle Traffic Collision Statistics, 2006) show that the number of injuries that occurred due to collision on the road was 199,347. Of these injuries, 2,889 were fatal injuries. The highest fatality rate was for the age group over 65 with 462 deaths. Of the total fatalities, 13.3 % occurred when individuals over 65 were driving. The number of licensed drivers over 65 was 2,950,695 in 2006 and this number is expected to increase as the individuals from the baby boom generation turn 65. As there are a significant number of fatalities due to automobile crashes in the older population and also a significant number of crashes that occur due to an older individual driving, age 65 and older can be considered a factor that elevates crash risk.

Not all older drivers are poor drivers. Therefore, it becomes important to determine those that are a greater risk. Similarly, it is important to identify factors that result in difficulty for the older individual while moving within their environment. Assuming that some of the factors that pose difficulty for the older individual can be reduced or eliminated with training, it becomes vital to understand how these factors elevate risk in situations such as driving or walking.

1.1. Visual requirements for driver licensing

In most mobility tasks, vision is considered to be one of the major factors that aids an individual when moving around. How important is vision per se? It is obvious that it is impossible to drive with the eyes closed. Similarly, walking without any vision is very difficult, particularly without using special aids. Therefore, vision definitely plays a major part in such activities. Giving credibility to the role of vision in activities such as driving, licensing of drivers includes a number of vision tests. One is a visual acuity test which requires participants to recognize letters, decreasing in size, on a standard visual acuity chart. Most provinces in Canada require the participant to have a visual acuity of 6/12. In Ontario, the cut off is slightly lower at 6/15. Another visual factor assessed as a standard test is the "visual field" which refers to how much area an individual can see in the periphery without moving their eyes. Most provinces require an individual to have a visual field of 120 degrees along the horizontal. In Ontario, in addition to this requirement, the vertical extent must be at least 15 degrees above and below fixation. Table1-1 shows the various licensing requirements of the provinces in Canada and is taken from a report on Low Vision and Driving which was submitted as part of an evidence based review of vision rehabilitation. (Strong, Jutai, Hooper, Evans, & Minda, 2005).

Table 1-1: Visual acuity and visual field requirements for provinces in Canada.

Province	Visual Acuity (both eyes)	Visual Field
Alberta	6/12 (20/40)	120° horizontal
British Columbia	6/12 (20/40)	120° horizontal
Manitoba	6/12 (20/40)	120° horizontal
New Brunswick	6/12 (20/40)	120° horizontal
Newfoundland	6/12 (20/40)	120° horizontal
Nova Scotia	6/12 (20/40)	120° horizontal
Ontario	6/15 (20/50)	120° along horizontal 15° continuous above and below fixation
Prince Edward Island	6/12 (20/40)	120° horizontal
Quebec	6/15 (20/50)	100° horizontal 10° vertical
Saskatchewan	6/12 (20/40)	120° horizontal
Northwest territories, Yukon and Nunavut	No information	No information

Licensing authorities in Canada use input based on the Canadian Medical Association Document: Physician's Guide to Driver Examination, the Canadian Council of Motor

Transportation National Safety Code, the Canadian Ophthalmological Society, and the Canadian Association of Optometrists in order to set the visual standards required for driving. Vision standards for driving in British Columbia, Ontario, and Quebec also use the recommendations of provincial ophthalmologic and optometric associations (Strong et al., 2005).

With the older driver in mind, many jurisdictions require a medical review at age 70 (Yukon), 75 (Alberta, Nova Scotia, Quebec) or 80 years (Ontario, Quebec). In Ontario mandatory annual retesting is required for individuals over 80 years of age. The driver retesting involves vision testing, written tests and participation in a driver education session. It should be noted that these are not evidence-based standards but primarily based on recommendations and expert opinion.

1.2. Vision and Aging

Physiological and Structural changes

Many physiological changes occur in the eye with age, affecting the relationship between structure and function. The change in function results in changes in the skills and abilities of an individual. In this section the structural changes that occur on the basis of the normal aging process are discussed.

Corneal changes: With the normal aging process, the shape of the cornea changes, resulting in a change from with-the-rule astigmatism (steeper vertical meridian than horizontal) to against-the-rule astigmatism (steeper horizontal meridian than vertical) (Morgan, 1993). Curvature of the cornea was studied in Asian eyes and both the horizontal and vertical meridian of the cornea were found to be steeper with increasing age (Hayashi, Hayashi, & Hayashi, 1995). There is greater steepening of the horizontal meridian compared to the vertical meridian resulting in against-the-rule astigmatism (Hayashi et al., 1995). Haegerstorm-Portnoy and colleagues (2002) also report that the increasing prevalence of against-the-rule astigmatism is most likely due to the change in corneal curvature.

Anterior Chamber changes: The depth of the anterior chamber is shallower in the elderly (Fontana & Brubaker, 1980). A recent study (He, Huang, Zheng, Alsbirk, & Foster, 2008), which included 1248 eyes, found that the depth of the anterior chamber decreases by 0.009 mm per year and that the thickness and position of the lens plays a role in determining the anterior chamber depth.

Changes in the Iris and Pupil: Senile miosis refers to the decrease in the size of the pupil with age. Reduced pupil size is one of the most common findings in the elderly (> 65 years). There is a linear decrease in the size of the pupil with age, decreasing at a rate of 0.043 mm per year at the lowest luminance (2.25 lumens/m^{-2}) and 0.015 mm per year at the highest luminance (1050 lumens/m^{-2}) (Winn, Whitaker, Elliott, & Phillips, 1994). The reduction in pupil size is attributed to factors such as the weakening of the iris dilator muscle on account of atrophy, reduction in parasympathetic inhibition, decrease in sympathetic tone, chronic fatigue and iridal rigidity (Winn et al., 1994). Sloane and colleagues (1988) report that in conditions of reduced illumination such as 0.1 cd/m2, the young adult's pupil is typically around 6 mm in diameter, whereas the older adult's pupil is typically around 2-4 mm.

Changes in the Crystalline Lens: The lens becomes thicker with increasing age as the lens fibers are compacted. Lens fibers are not lost but more and more fibers get deposited on top of each other. Moreover, the lens fibers become less transparent and the lens structure itself becomes less pliable. The diameter and curvature of the lens also change with increasing age (Jorge L. Aliò, Anania, & Sagnelli, 2008). There is a high prevalence of lens opacities and age-related cataract in the aging population. In the Beaver Dam Eye study, which included a population of adults from United States of America ranging in age from 43 and 84 years (n = 4926), the prevalence of nuclear sclerosis, cortical opacities and posterior subcapsular opacities was 17.3%, 16.3% and 6.0% respectively (Klein, Klein, & Linton, 1992). A similar prevalence of age related cataracts was also reported in the Blue Mountains eye study that included a population from Australia ranging in age from 49 to 96 (Mitchell, Cumming, Attebo, & Panchapakesan, 1997). In a Canadian clinic population (6397 clinic files including all ages 0 to 93 years), it was observed that 99% of the cataracts were related to age (Machan, Hrynchak, & Irving, 2009). The prevalence of cataract in their clinic population increased steadily after 40 years of age with a prevalence of 100% observed after 73 years of age. The distribution of the age related cataract was as follows — 49.5% nuclear sclerosis, 33.2% mixed, 2.4% cortical and 0.8% posterior subcapsular cataracts.

Retinal Changes: The normal cone mosaic of the retina is not seen to undergo much change with age even until 90 years (Spear, 1993). On the other hand with increasing age, about 30% of rod photoreceptors are lost within the central 28 degrees. The remaining rods enlarge in size and fill the gaps left by the dying rods (Spear, 1993). There have also been reports of loss of retinal ganglion cells with age, exceeding 0.3% (counting the cell body and axons) loss/year (Harwerth & Wheat, 2008)

Lateral Geniculate Nucleus (LGN) & **Cortex:** Visual information from the retina to the cortex is mainly relayed by the LGN. Spear (1993) reports that there is not much loss of neuronal cells at the level of LGN, at least in monkeys, with increasing age. The slight decrease in LGN density that was observed with age was counteracted by an increase in volume pertaining to the increase in neuron cell body size, glial cells and blood vessels. The decrease in LGN density was due to an insignificant loss of few neuronal cells. Similarly, minimal loss of cells in the striate cortex was observed (Spear, 1993).

Changes in visual function:

Visual Acuity: Reduction in visual acuity (VA) in normal healthy eyes is observed with increasing age. Elliot and colleagues (1995) report from their analysis of 223 subjects ranging from 18 to 80 years that the change in VA could be represented by a "bilinear function". The function shows an improvement in VA from 18 to 29 years with a change from -0.13 mean LogMAR (Snellen equivalent = 6/4.5) to –0.16 mean LogMAR (Snellen equivalent = $6/4^{-1}$). After 29 years, VA becomes worse with age to -0.01 mean LogMAR (Snellen equivalent = $6/6^{+1}$) for subjects over 75 years of age. They also present data from other reports that show similar and much higher rates of VA reduction (2 to 3 log units) with increasing age (see Figure 1-1). Haegerstrom-Portnoy et al., (1999) report that high contrast VA is not seen to be affected by age until about 70 years of age. Then VA is seen to drop after 70 years, reducing at a rate of 5.5 letters per decade (Haegerstrom-Portnoy, 2005; Haegerstrom-Portnoy, Schneck, & Brabyn, 1999). Low Contrast VA is seen to drop at a much higher rate with age at a rate of 8 letters per decade. High and low contrast VA correspond to points on the Contrast sensitivity function (CSF), described below.

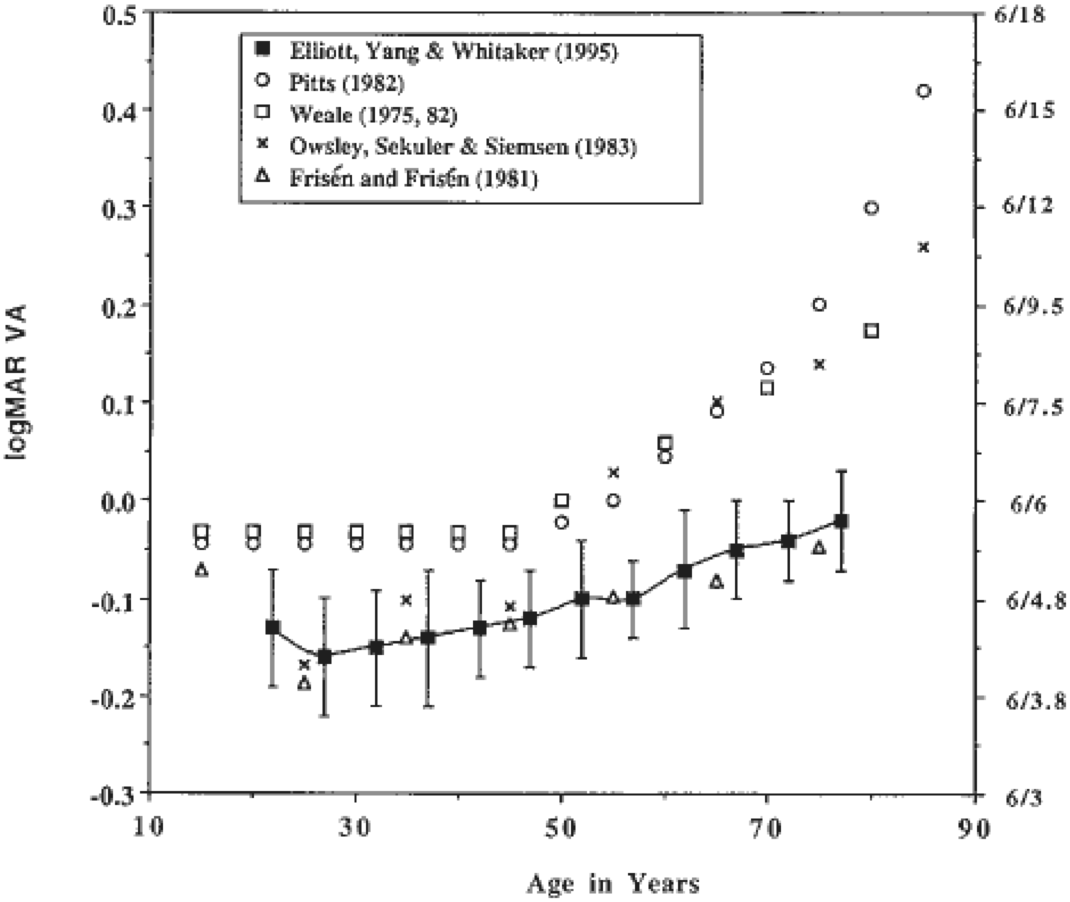

Figure 1-1: Visual acuity reduction with age, from Elliot et al., (1995) showing comparison of data from other studies. Figure used with permission from Wolters Kluwer Health.

Dynamic Visual Acuity: Dynamic VA (DVA) refers to the acuity obtained when a target is moving at a particular velocity. Dynamic VA is reduced in older individuals (Burg, 1966; Morgan, 1993). Long and Crambert (1990) studied DVA at different velocities (30, 60, 90 and 120 degree/sec) as a function of age. They found that there were only slight or no differences between age groups in resolving capacity for the slower velocities. The differences between the groups increased at the higher target velocities with better dynamic VA for the younger participants (differences up to 15 minutes of arc – obtained visually from graph) (Long & Crambert, 1990). Reading (1972) reports a difference of 10 minutes of arc resolution capacity between younger and older participants for higher angular velocities (180 degree/ sec).

Visual fields: The area in the environment perceived by the stable eye is called the visual field (Smythies, 1996). According to many studies the sensitivity of the visual field is reduced as a function of aging (Drance, Berry, & Hughes, 1967; Haas, Flammer, & Schneider, 1986; Jaffe, Alvarado, & Juster, 1986; Katz & Sommer, 1986; Spry, 2001). A generalized depression of the entire visual field has been reported by these studies. In a cross sectional data analysis of 562 normal eyes, a negative non-linear relationship was found between age and mean visual field sensitivity (Spry, 2001). The reduction in sensitivity was also greater with increasing eccentricity (distance from the centre) and this effect was found to greater for the elderly (Jaffe, Alvarado, & Juster, 1986).

Contrast sensitivity: The effect of age on contrast sensitivity (CS) is seen particularly for the middle and higher spatial frequencies (2-3 cycles/degree and above) and shows a decrease in sensitivity with increasing age (Owsley, Sekuler & Siemsen, 1983). For spatial frequencies of 1 cycle/degree and less, the contrast sensitivity function remains unchanged with increasing age. Other studies show a loss of sensitivity at all spatial frequencies with a shift of the peak towards lower frequencies (Mei, Leat and Hovis, 2007). Reduction of contrast sensitivity with age (as measured with a Pelli – Robson chart) started almost 12 years earlier compared with a similar reduction observed for high contrast VA (Haegerstrom-Portnoy, 2005; Haegerstrom-Portnoy et al., 1999). Reduction in contrast sensitivity with age may be due to optical characteristics, reduced retinal illumination or changes at the retinal or cortical level. The factors responsible for reduced illumination include pupil miosis and reduced transmission of the crystalline lens due to an increase in lens density (Elliott, Whitaker, & MacVeigh, 1990; Spear, 1993). Intra ocular light scatter could also be responsible for reduced contrast sensitivity (Berg, 1986; Elliott et al., 1990) without resulting in reduced retinal illumination. The amount of scatter created by the ocular media is higher in older individuals compared to younger groups (Steen, Whitaker, Elliott, & Wild, 1994) and therefore scatter could also explain the reduced contrast sensitivity observed in older individuals. Spear (1993) reviews studies that have observed a reduction in contrast sensitivity with age even after controlling for optical factors. This was done either by controlling pupil size (Sloane et al., 1988), including participants who have undergone cataract extraction (Owsley, Gardner, Sekuler, & Lieberman, 1985) or using laser interference fringes to create the retinal image (Burton, Owsley, & Sloane, 1993). Spear (1993) and others (Crassini, Brown, & Bowman, 1988; Elliott et al., 1990) report that neural changes, such as degeneration of cells in the areas from the retina to the cortex, particularly of the parvocellular pathway, could be responsible for the changes in CS function found with increased age.

Dark Adaptation: Robertson and Yudkin (1944) report progressive reduction in average dark adaptation with increasing age with almost 0.15 log units of increase in threshold between the age of 50 and 60. Others have also shown that the rate of dark adaptation also decreases with increasing age (Jackson, Owsley, & McGwin, 1999) and give evidence that the increase in time constant for rhodopsin regeneration with age is responsible for the decrease in dark adaption rates.

Glare: Older individuals have been found to be more affected by glare than younger individuals (Collins & Brown, 1989; Haegerstrom-Portnoy, 2005). The amount of stray light in the eye is partly responsible for the effect of glare as the scattered light imposes a veiling luminance over the retinal image resulting in reduced visual function. Between the age of 20 and 80 the amount of stray light increases by a factor of 3 (Steen et al., 1994). A study by Haegerstrom-Portnoy et al. (1999) shows that a significant number of letters on a visual acuity chart are lost in older individuals in the presence of a glare source. Similarly the time to recover from glare is also seen to be greater in the elderly (Collins & Brown, 1989; Haegerstrom-Portnoy, 2005).

Stereopsis: There is evidence for reduced stereopsis in old age. Haegerstrom-Portnoy's (2005, 1999) data show that only 20% of 90 year olds have stereopsis better than 85 arc seconds. Garnham & Sloper (2006) report a slight decline in stereopsis with age using various tests of stereopsis. They suggest that the decline in stereopsis is probably not the result of difficulty in cortical disparity detection but due to the fusional demands imposed by the various tests of stereopsis.

Motion perception: Motion detection and direction discrimination have been found to be affected by age (Tran, Silverman, Zimmerman, & Feldon, 1998; Trick & Silverman, 1991). Motion thresholds measured using random dot kinetograms (Atchley & Andersen, 1998; Ball & Sekuler, 1986) have shown elevated thresholds with age. Speed discrimination thresholds were affected by age in a psychophysical setting (Raghuram, 2004) as well as in simulations and real world situations (Scialfa, Guzy, Leibowitz, Garvey, & Tyrrell, 1991).

Motor system: Saccades are rapid eye movements used to change fixation from one point to another in visual space. Pursuit eye movements are used to track or follow moving objects and vergence eye movements help to align the two eyes at different positions on the anterio-posterior axis (Z axis). The dynamics of all these movements show some variation with age. For saccades, latency and peak velocity depict a U shape function with age, with the lowest values before adolescence and for ages over 80 years (Irving, Steinbach, Lillakas, Babu, & Hutchings, 2006; Moschner & Baloh, 1994; Pitt & Rawles, 1988; Sharpe & Zackon, 1987). This means that slower initiation times with respect to the stimulus and slower velocity of saccades are observed in individuals over 80 years of age. The gain of smooth pursuit is reported to be significantly reduced in older individuals (70+years) compared to younger and middle aged individuals (Moschner & Baloh, 1994; Zackon & Sharpe, 1987). The latency of disparity vergence, especially for the transient component (responses elicited by step stimuli), was reported to be greater in older individuals and peak velocity was found to be lower when compared to their younger counterparts (Rambold, Neumann, Sander, & Helmchen, 2006). Yang & Kapoula (2009) report a change in vergence duration with age only in the closed loop part of the response that is driven by visual feedback.

Most of the studies described above consider changes in visual function with normal aging, that is, they exclude individuals with known disease. The presence of disease such as diabetes, macular degeneration, cataracts that are more prevalent in the older age group would add to and increase these differences between the young and the old.

1.3. Attention and visual efficiency

Visual function refers to how the eye and the visual system perform whereas functional vision describes how a person functions using various sensory modalities. In this thesis, the term “visual efficiency” is used to describe the use of attention in conjunction with vision. The use of the term “visual efficiency” is based on the assumption that visual performance may be affected by attention. Therefore, first I will provide a general description of attention and various components of attention following which I will discuss how attention is affected by age.

What is attention?

The question has been asked and studied by many researchers, employing a multitude of methods. As quoted by William James (1890) “everybody knows what attention is…” William James’s (1890) definition of attention includes how we disregard other things so that we stay focused on what is important in the current state of affairs. Terms such as “focus”, “concentrate”, “stay fixed”, “alert”, “all ears” are all used loosely to imply attending to something exclusively.

Harris and Jenkin (2001) report four types of attention:

Directing attention: This type of attention refers to something in the environment calling for an immediate response. This is analogous to a prey/predator situation such that, when a predator is spotted in the vicinity, all the senses of the prey are directed to the predator in order to perform an evasive action. Directing attention is beyond the normal behavioral circumstances as it is an “emergency response”.

Parsing attention: This refers to attention that is involved in grouping objects to form a perceptual object. For example, recognition of a face calls for identifying the features in a face such as eyes, ears, nose, mouth etc., and binding all of these features together to give a complete percept.

Alertness attention: This refers to attention that requires a certain degree of arousal required to perform a task. In many monotonous tasks we can assume that a certain level of arousal is required to perform the task. This kind of vigilant behavior is referred to as alertness attention.

Selective attention: This refers to the situation where an object in the environment demands attention by a certain attribute present in the object such as color, shape etc. It could also be goal directed; to perform a certain task we might be looking for a particular object. All the things that we see or hear at a particular instant do not enter our conscious domain. At any instant only a few objects can be remembered from a particular scene due to limited capacity of our processing resources (Kahneman, 1973). Selecting particular objects on account of attention represents the role of selective attention. In this thesis I will be mostly dealing with selective attention.

1.3.1.1. How is selection achieved and when can we say we are attending?

Various models have been proposed to explain selective attention. These models can be categorized as "Early selection models" "Late selection models" and "Attention resource theories" (Pashler, 1998; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977, Wickens, 1991). According to early selection models, the selection of the attended object occurs early in the processing stream. Broadbent (1958) proposed the filter theory, according to which physical attributes of the stimuli in the environment are processed to a certain stage, but a filtering device determines which stimulus has to be attended, processed and identified. According to this theory the attention system is protected from a sensory overload by this filter, which is applied early in the processing stream. The filter theory suggests that the unattended stimuli do not enter the processing stage. If more than one stimulus is to be attended then, both the stimuli enter the processing stage and processing takes place one after the other. Treisman (1960) modified the filter theory by proposing that the unidentified stimuli are not discarded but partially identified. Those stimuli that reach a certain level of activation are identified.

According to the late selection models, the process of selection occurs at a much later stage in the processing stream. These models suggest that all the stimuli are processed unselectively to a semantic level (with respect to language) but only the attended stimuli enter awareness or memory. According to the late selection models, the decision regarding stimulus selection is based on the response that has to be initiated. Such selection helps provide a coherent response to the stimulus. Late selection models also suggest that the unattended stimuli affect the outcome of the attended stimuli (Pashler, 1998). Duncan (1981) suggests that the unconscious stage of processing transfers the stimuli obtained from sensory input to a higher processing centre. This transfer process is what determines which stimulus is to be attended.

The multiple resource theory of selective attention considers attention to be a fixed quantity (Wickens, 1991; Kahneman, 1973). The selection of the stimuli is based upon the availability of resources. If a particular task utilizes all the available resources then no other stimuli are selected for analysis. Shriffin and Schnedier (1977) presented a theory of information processing that included automatic and controlled processes. The automatic information process occurs for learned tasks that are encoded in long term memory. Such a process is unaffected by load and does not require attention. For example, response to a person’s name will be dealt with an automatic process. In a controlled process, attention is required and the various components of a task are compared serially to specific nodes present in both the long term and short term store. Such a process is affected by the information that enters the processing domain and is therefore limited in capacity.

1.3.1.2. Divided attention

Division of attention is required when multiple stimuli have to be attended simultaneously. It is clearly evident that the entire stimulus impinging upon the sensory system cannot be attended. Is there a mechanism involved in gating the attention system when multiple tasks have to be performed? In one model, the working memory which is responsible for temporary storage of information is considered to comprise a central executive (Baddeley, 1986, 1996; Baddeley & Della Sala, 1996). The central executive recruits input from two “slave systems”, one responsible for auditory information (phonological loop) and the other responsible for visual information (visuo - spatial sketchpad). In another model, Norman and Shallice (1986) suggest the presence of a supervisory attention system that controls coordination of different tasks. Such resources in the brain responsible for attention might have important involvement when multiple tasks have to be performed concurrently. When two tasks are performed simultaneously, one of the tasks will either require greater time to perform or the quality at which it is performed will most likely deteriorate (Tsang & Shaner, 1998; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). These decrements in performance can be explained by various theories.

1) Limited capacity model: According to this model, the mental resources have limited capacity (Kinsbourne, 1981; Pashler, 1994a, 1998, Kahneman, 1973) and hence when more than one task is performed, both are accessing the same resource that has only “x” amount of capacity. This is analogous to a computer processing unit that has only 1Megabyte (MB) of resource. If one task is performed at a time, all of the 1MB is available to do the task. If more than one task is performed, then all the tasks are accessing the same 1MB of available resource. The degree of arousal determines how much of the processing resource is utilized by a particular task (Kahneman, 1973).

It is also possible that there are multiple resources available for the performance of dual tasks. Processing of visual information could be carried out by a limited capacity resource that deals exclusively with visual input. Similarly there could be a processing resource solely devoted to auditory information. Wickens (1991) proposed such separate pools of resources for different sensory modalities such as vision, audition, touch etc. He also suggested that there might be multiple resources based on the type of processing required, such as whether the task involves only encoding or whether a response is required. The different resources that exist can be used independently or in conjunction depending on the demands of the task. A greater performance decrement is observed when two visual tasks are coupled, but not when one task is visual and the other is auditory and this suggests that such multiple resources exist (Wickens, 1991; Tsang & Shaner, 1998).

2) Bottle neck models: According to the bottle neck model (Pashler, 1994a, 1994b, 1998), deterioration in the performance of of multiple tasks arises when bottle necks occur during the processing stages. This assumes that two tasks can be performed simultaneously to a certain point but after they require access to a resource that is limited in capacity and can only process the information for one task at a time. This leads to a situation where one task has to wait until the other task is completed. Using the same example of the computer, let us suppose that the 1MB of processing is adequate to perform both the tasks, but the tasks both require display of an image. The image display requires access to a graphic card that is limited in available processing resource. This is an example of a bottle neck that can occur, because at this stage, one of the tasks has to wait for the other to be completed due to limited capacity of the graphic card.

1.3.1.3. Attention and Visual search:

Researchers have used visual search to understand the mechanisms involved in selective attention. Visual search is a perceptual task that requires an active scan for a target that is unique amidst distracters. A real life example would be searching for pen on a disheveled desk. In such cases the distracters are referred to as “clutter” and are not quantifiable. Most visual search experiments involve providing a “target present” or “target absent” response on a given trial and the reaction time and accuracy are noted (Meinecke & Donk, 2002; Smilek, Frischen, Reynolds, Gerritsen, & Eastwood, 2007; Trick& Enns, 1998; Treisman. & Gelade, 1980; Wolfe, 1998). The numbers of distracters (set size) is varied for various trials ranging from 2 to 100 or more. Search slope refers to the variation of reaction time with increasing set size. It is used to understand the nature of attention processing. If the search slope is zero with respect to set size, then it means that the target is identified relatively quickly and is not affected by the number of distracters. On the other hand if search slopes are greater than zero with respect to the set size, then the number of distracters affects the identification of the target. Based on this, Treisman & Gelade (1980) proposed the “feature integration theory” where they suggested that if the target has a feature that is unique from all the distracters (e.g., red horizontal lines among green vertical lines) then the target would “pop out” and search slopes would be zero. Such a search, called a parallel or preattentive search process (Neisser, 1967) is unaffected by capacity limitations of the attention system. On the other hand, if the target shares two or more features with the distracter, it is referred to as a conjunction search (e.g., red horizontal line among red vertical lines and green horizontal and vertical lines) and the detection of the target is more difficult. This type of search is considered to use serial processing wherein each item or group of items is processed individually. The search slope functions with respect to set size are usually greater than zero for conjunction searches. Thus feature searches were considered parallel searches and conjunction searches were considered to involve a serial process. Further research in visual search showed that all conjunction searches were not strictly serial search processes. Some searches were relatively quick and efficient and the search slopes with respect to set size were only slightly greater than zero. Similarly not all feature searches were strictly parallel. The similarity between target and distracters seemed to affect the outcome in feature searches (Olds, Cowan, & Jolicoeur, 2000). For example, the saliency of a target oriented at 90 degrees among distracters oriented at 180 degrees is much higher than the case where the target is oriented at 50 degrees among distracters oriented at 70 degrees. The same analogy regarding target saliency applies when we compare target and distracter colors (Nagy & Sanchez, 1990). Wolfe (1998) in his analysis of search slopes from a large number of visual search trials found that the search slope functions were not dichotomous but more on a continuum. He suggested that visual searches should not be considered as parallel or serial but rather as “efficient” or “inefficient”. He proposed the “Guided search model”. According to this model (Wolfe & Horowitz, 2004), there is an initial parallel stage where the entire area is searched and items are compared based on basic features. In the second stage, the results of the parallel search guides attention to a particular area where the target is most likely to be present and comparisons with neighboring objects are made. Such a model is seen to explain the different search slopes obtained on a multitude of visual search experiments.

Role of cues that guide selection: The object to which an individual attends could be based on various cues available in the environment. The main distinction in this regard is the role of "bottom up" or "top down" processing (Harris & Jenkin, 2001; Hodsoll & Humphreys, 2001; Treisman. & Gelade, 1980). Bottom up influences also referred to as "exogenous cues" are based on the salience of the object wherein the object captures the attention to that location. The processing is "stimulus driven" and independent of the observer's inattention. In the case of top down influences, also referred to as "endogenous cues", the selection of the stimulus is based on goal directed behavior. The salience of the object has little impact in the case of top down processing (Poiese, Spalek, & Di Lollo, 2008).

1.3.1.4. Visual Attention and Eye movements:

Eye movements and attention are considered to be closely related. One of the many ways people examine whether we are attending to something is by determining the person's point of gaze. For example, in a typical road test for driving, the examiner notes whether the driver is looking at the mirrors, looking at signs on the road and so on. Eye movements definitely can be helpful in determining whether a person is attending to something. However, we do know that we can attend to something without making an eye movement to that particular location (Posner, 1980). Overt attention refers to orienting attention with the aid of eye movements (Posner, 1980). Covert attention refers to orienting attention by not fixating at the particular location of interest or object (Posner, 1980). In common language this is referred to as attending by "looking out the corner of the eye". Many visual search studies have used very brief presentation times (less than the latency of saccadic eye movements) that involve detecting the target among distracters. These have clearly shown that detection of the target can be achieved with relatively high accuracy without making any eye movements (Wolfe, 1998). This suggests that eye movements are not strictly necessary in order to attend to an object in the environment. However, if there is a coupling or interaction between eye movements and attention, then it should not be possible to make an eye movement without shifting attention. When we consider shifting of attention we have to invariably assume that the attention system is somewhat like a "spot light" or a "zoom lens" with a narrow focus at the cued location (Eriksen & St James, 1986; Pylyshyn & Storm, 1988). If the eye movement system and attention system are independent then 1) we will be able to make an eye movement in one direction while attending to a target in a different direction ,and 2) there are no costs associated with the production of eye movements or the detection of objects when the attention locus and eye movements are in different spatial positions (McFadden & Wallman, 2001).

Hoffman and Subramaniam (1995) investigated target identification accuracy in conjunction with eye movements. Participants had to move their eyes to a particular location in the display and report two of the four targets present in the corners of the display. Their results showed that there were higher target detection rates when the eye movements were made to the same location as the target. A discrimination task was used by Deubel and Schneider (1996) to understand the coupling between saccades and attention. They found that target letters were discriminated efficiently when the saccade target location was in the same location as the discrimination task. Kowler et al. (1995) used a circular array consisting of 8 letters and a cue to direct saccades to a particular direction. Identification of the letter was only accurate when it was also the saccadic goal. In the same experiment when a saccade was cued to be made in a direction that was not in the direction of the target to be identified, a significant increase in saccadic latency was observed. In this case, the instruction was to always report a target letter at the rightmost location, irrespective of where the cue directed the saccade. This experiment suggests that there is a shift of attention before an eye movement and this is plausible as the attention shift latency is in the order of 60-80msecs which is much shorter than saccadic latency (McFadden & Wallman, 2001).

1.3.1.5. Attention and aging

A number of factors involved in attention are negatively affected by increasing age (Groth & Allen, 2000). The changes in attention that result on account of aging are theorized in many ways. One view is that all of the impairment in attention could be due to a generalized slowing that affects most cognitive operations (Cerella, 1985; Salthouse & Somberg, 1982b; Scialfa, 1990). Reduced inhibitory functioning could be another reason that an older individual is at a disadvantage (Groth & Allen, 2000; Darowski, Helder, Zacks, Hasher, & Hambrick, 2008; Grady, Hongwanishkul, Keightley, Lee, & Hasher, 2007), although some suggest that this may be an advantage in certain situations (Kim, Hasher & Zacks, 2007). The impairment of the filtering mechanism that eliminates the processing of irrelevant information is considered responsible for the reduced inhibition. When considering the effect of age on attention one must consider age related selective attention deficits. In Rabbit’s work (1965), participants were required to sort cards that had a varying number of stimuli printed on them. In comparison with younger individuals, older participants took more time to sort the cards with a greater number of stimuli. He suggested the decrement in performance with increasing number of stimuli was due to the inability of the older individual to disregard irrelevant stimuli. Similarly, in another study, targets were presented in such a way that more than one target could appear at any of the four corners of an imaginary square and the remaining locations were occupied by irrelevant distracters (Allen, Madden, Groth, & Crozier, 1992). This condition gave rise to a greater performance decrement for the older individuals relative to a condition where the non-target locations were left unoccupied.

Effects of age are also observed on the functional field of view. The functional field of view is defined by Mackworth (1965) “as the area around the fixation point from which information is briefly stored and read aloud during a visual task”. Ball et al. (1988) describe the functional field of view as the total visual field area from which information can be extracted without eye and head movements and refer to it as the “Useful field of view”. Coeckelbergh et al. (2004a,2004b), use the term “Attended field of view” described as a measure of viewing efficiency in terms of “time” as eye and head movements are allowed to locate a target. In general, these measures are distinct from the normal visual fields in that they include more variables that can be manipulated. There are variations based on factors such as cognitive load or the presence of distracters. These factors cause a reduction in visual efficiency either in terms of a reduction in size of the functional field of view (as suggested by Ball and co-workers; 1988) or affect the viewing efficiency (correlate of time to detect a target) as described by Coeckelbergh et al (2004a, 2004b). The effects of age are also found in studies investigating the functional field of view (FFOV) where a reduction in its size or a poorer viewing efficiency is observed with increasing age (Ball, Beard, Roenker, Miller, & Griggs, 1988;Coeckelbergh, Cornelissen, Brouwer, & Kooijman, 2004; Haegerstrom-Portnoy et al., 1999; Roge, Pebayle, Campagne, & Muzet, 2005). Studies that assess the functional field of view find that the older individuals have greater difficulty in ignoring irrelevant distracters (Ball, Owsley, & Beard, 1990a; Leat & Lovie-Kitchin, 2006). Scialfa, Kline, and

Lyman (1987) suggest that young adults can tolerate more visual noise before the size of the functional field of view is reduced compared to the older adults. The effect of increasing noise on target identification was investigated in younger and older age groups. The level of noise was heightened by increasing the number of flanking distracters. The target also appeared at one of four possible eccentricities in addition to the central location. The older participants had higher error rates with increasing levels of noise and this effect was more pronounced with greater eccentricity.

Older individuals also find it difficult when two or more tasks have to be performed simultaneously (Hartley & Little, 1999; Korteling, 1991; Verhaeghen et al., 2003). Some argue that greater divided attention or attention sharing costs observed due to aging might be nullified if the single task measures are equated based on processing speed (Salthouse & Somberg, 1982a, 1982b). There is also the suggestion that performance deteriorates with increasing age as the complexity of the task increases. McDowd & Craik (1988) point out that the absolute difference in performance between younger and older individuals increases with the number of mental operations performed. There are certain factors that are considered to be resistant to changes in age. Performance differences that are observed between the old and young in target identification among distracters are nullified once the target location is specified by a valid cue (Plude, 1990; Plude & Doussard-Roosevelt, 1989). In other words, the difference in reaction time is significantly reduced once the spatial position of the target is specified by a valid cue for both younger and older adults. Plude & Doussard-Roosevelt (1989) and Plude (1990) report that the performance of older and younger individuals with respect to reaction time was identical in feature search tasks wherein the target was unique in all aspects with respect to the distracters. Trick and Ennns (1998) also find no age differences in feature search tasks where the presence or absence of the target on a display with varying numbers of distracters was to be reported. Studies which assess the FFOV also utilize feature identification and require the identification of a target that is unique in a particular feature. An age effect is found in those studies even though the task is based on feature identification. Such a result contradicts the findings of Plude (1990) and Trick and Enns (1998). The most likely reason is the salience of the target compared to distracters. D’Aloisio and Klein (1990) compared age effects on three paradigms that were designed to investigate selective attention. The Eriksen’s paradigm (D'Aloisio & Klein, 1990) requires participants to respond to a target flanked by distracters and the position of the target is specified by cues such as arrows. Laberge tasks (D'Aloisio & Klein, 1990) require participants to identify the middle letter in a string of five letters. In the second stage of a Laberge task, participants have to identify whether the word presented was a noun, name or verb, etc. In the same study, D’Aloisio and Klein (1990) also investigated the performance on traditional visual search tasks where the participants had to report the presence or absence of a target stimulus. Older individual were found to be at a disadvantage compared to younger individuals only for the visual search tasks. In the visual search tasks they required more time to identify the target. Since D’Aloisio and Klein (1990) did not find any change in performance for either the Eriksens or Laberge tasks, they suggested that older participants are no more affected by distracters than the younger participants if the position of the target is specified either by an externally (e.g arrow on the screen) or internally (memory) triggered cue. They speculate that the difference observed in the visual search task is most likely due to the inability of older individual to disengage from a previously searched location.

Hence, there are discrepancies regarding the exact forms of a task which give rise to age effects and the theories regarding the stage of processing at which the deficits occur. There is general agreement that there are age effects on selective attention and that the complexity of the task, target distracter similarity etc., are factors in these effects.

1.3.1.6. Attention and everyday activities

Attention effects influence performance in activities such as walking and driving. One of the common examples would be how driver inattention (due to fatigue, drowsiness etc) and driver distraction result in automobile crashes (Hendricks, Fell, & Freedman, 1999; Stutts, Reinfurt, Staplin, & Rodgman, 2001). Distraction in this case refers to shifting of the driver's attention away from the driving task. The result is a delay of recognition of information needed to perform the driving task. Such a distraction can be a function of many factors such as an activity outside the vehicle, a person in the car, or devices such as cell phones, radios or other gadgets that shift the attention from the primary task of driving (Chaparro, Wood, & Carberry, 2005; Strayer, Drews, & Johnston, 2003; Stutts et al., 2001). The type of distraction that results in crashes may vary with different populations. For example, an older individual may be more affected by a distraction outside the vehicle such as a complicated road sign whereas a younger individual may have a greater distraction from operating a music device present in the vehicle. The effect of distraction can also be observed in other situations of hazard avoidance such as those occurring during walking (Weerdesteyn, Schillings, Van Galen, & Duysens, 2003). Older individuals have a filtering problem where they find it difficult to disregard irrelevant stimuli and therefore seem to process more stimuli. The inhibitory mechanism which suppresses the processing of distracting information is affected by increasing age (Darowski, Helder, Zacks, Hasher, & Hambrick, 2008; Grady, Hongwanishkul, Keightley, Lee, & Hasher, 2007). However, the inability to suppress irrelevant stimuli was observed to be a benefit in certain tasks (Kim, Hasher and Zacks, 2007). This finding suggests that increased distractibility in older individuals might occasionally be useful. The question remaining is whether such filtering deficits found in older adults help in everyday activities such as driving or walking.

Measures of attention can also predict performance in everyday activities (Owsley & McGwin, 2004; Owsley, McGwin, Sloane, Stalvey, & Wells, 2001). The assessment of FFOV on older participants using UFOV® was shown by Owsley and colleagues (2001) to be associated with their performance on tasks of daily living such as dealing with communication, finances, food, shopping and taking care of medication. Performance on such tasks was best predicted by visual acuity, contrast sensitivity and the UFOV® scores. Similarly UFOV® scores were seen to predict balance and gait performance assessed by Performance Oriented Mobility Assessment, version II (POMA) (Owsley & McGwin, 2004). The POMA score is based on the performance of 16 mobility maneuvers. Another study (Broman et al., 2004), investigated how the UFOV® scores predicted bumping while walking. Participants over 72 years of age had to walk a circuitous mobility course and the number of bumps was counted. A decrease in processing speed on the divided attention task by 50msec was associated with a 4.9% increase in the number of bumps made while walking. Leat and Lovie- Kitchin (2008) assessed mobility performance in a group of individuals with low vision and the scores obtained on a mobility course were associated with measures on the FFOV. These studies show the association of attentional measures on daily activities and assert their functional importance.

Studies that have assessed FFOV using tests such as UFOV® also show that these measures play an important role in identifying the “at risk driver”. The size of the useful field of view was shown to be a strong predictor for crash risk (McGwin, Owsley, & Ball, 1998; Owsley, 1994; Owsley, McGwin, & Ball, 1998; Sims, McGwin, Allman, Ball, & Owsley, 2000). In a model developed by Ball et al. (1993), the UFOV® scores were directly related to crash frequency (r =0.46). The model accounted for 74% of the variance when other variables such as eye health, central vision, peripheral vision and mental status were incorporated. All of these variables were significant predictors of crash frequency even though direct effects were observed only for UFOV® and mental health status. Similarly, a study by Wood and Troutbeck (1995) showed a significant correlation (r =0.55) of the UFOV® scores with driving performance in a closed road circuit. A model for predicting driving performance using attention measures obtained on the AFOV test, combined with vision related variables such as contrast sensitivity, was observed to have a sensitivity of 84% and a specificity of 64% (Coeckelbergh et al., 2004b). Sensitivity relates to the percentage of drivers who were identified by the AFOV as not fit to drive as a percentage of those who failed a driving road test as scored by an examiner on a 4 point scale. Specificity relates to those who were declared fit to drive by the AFOV as a percentage of those who passed the driving road test. The road test employed in the study assessed aspects of lane positioning, steering control, car following, speed, viewing behavior, detection of traffic signals, anticipatory behavior, making left turns and merging into traffic lanes.

Judgments of time to collision (TTC) and aging:

The judgments of when an object would intercept with another object or self could be thought to be particularly important in everyday tasks such as walking and driving. Such judgments are referred to as time to collision judgments. Looming or isotropically expanding targets refer to targets that appear to come towards the observer. In situations where an object is coming towards the observer's eye or when a person moves towards another object, the retinal image enlarges, creating a percept of motion in depth.

The effect of age has been studied on TTC judgments either using targets that were looming or simulated to move in the transverse plane (DeLucia, 2004; DeLucia, Kathryn Bleckley, Meyer, & Bush, 2003; DeLucia & Novak, 1997; Kiefer, Flannagan, & Jerome, 2006). Older observers overestimate speed and underestimate time when making judgments of time to collision (DeLucia et al., 2003; Schiff & Oldak, 1990). This strategy should actually put the older driver at a lower risk with respect to automobile crashes. However, DeLucia and colleagues (2003) in their study observed that older individuals had difficulty in determining if a collision would occur or not. A 15% difference in accuracy of judging the occurrence of a collision was found between the older and younger groups. In another study (Raghuram, 2004), older observers were found to have higher thresholds for a relative judgment task of TTC. The relative judgment task required the person to indicate which of two targets would reach the destination first. The older observers required greater differences in TTC between the objects than younger observers to obtain accuracy in their judgments.

Looming targets are known to capture attention similar to targets that appear abruptly in a visual scene (Franconeri & Simons, 2003). The behavioral urgency created by a looming stimulus is considered responsible for the attentional capture (Franconeri & Simons, 2003).

Constraints on the working memory have been shown to affect the estimation of the TTC of looming targets (DeLucia, 2004; DeLucia & Novak, 1997). In this study, participants made relative TTC judgments when 2, 4, 6 or 8 objects were simulated to approach the observer. The participants indicated which of the objects would reach the observer first. The mean reaction times obtained were higher when there were more than 2 objects. As the number of objects present in a scene affects the estimation of TTC, it would imply that when there are attentional constraints the judgments of TTC are affected. It is then possible that, when there are constraints on attention, the judgments of TTC made by the older observer would be less accurate than younger observers. To my knowledge this possibility has not been addressed in the literature.

1.4. Rationale for the current studies

Considering both vision and attention related variables, a distinction can be made between visual function and visual efficiency. Visual function refers to how the eye and visual system perform while visual efficiency will be used to refer to how attention impacts the performance of vision related activities (e.g. driving, walking etc.). This means that even though the visual function may be at a certain level (e.g. 6/6 acuity, no visual field defects, normal stereopsis etc), the degree of attention a viewer directs to the visual scene influences the visual efficiency. In the presence of distracters greater presentation times are often required to find the target or targets remain unnoticed, resulting in incorrect responses at more peripheral locations (Ball et al., 1988; Coeckelbergh, et al., 2004a, Leat and Lovie-Kitchin., 2006). This occurs irrespective of good visual acuity and other visual function measures thereby suggesting the importance of visual efficiency.

Dual task refers to tasks involving attending to two targets at the same time either by sharing attention between the two tasks or by dividing attention. Visual efficiency is affected by dual task situations. When several tasks are performed at the same time, it is possible that there are costs associated with performing one or more of the tasks. In dual task scenarios visual efficiency will be dependent upon how the attention is shared between the tasks. Performance on one task may be sacrificed in competing tasks.

As mentioned previously, many visual functions deteriorate with age. Age may also impose greater difficulty with regard to attention processing which could affect visual efficiency, in turn affecting everyday activities.

1.5. Objectives for the current studies

The objectives of this thesis will be two fold; 1) to understand the performance of older individuals in dual task situations that involve some estimation of time by making visual judgments, 2) to determine the change in functional field of view in terms of viewing efficiency with aging in a variety of situations that could affect attention.

In the 2nd chapter we will investigate how the use of central or peripheral retina affects the size matching of an isotropically expanding target to a previously shown target, in a group of younger individuals. In the 3rd chapter, we study the effect of attention using a dual task on size matching judgments of an isotropically expanding target to a previously shown target, for a group of young and older individuals. Similarly, in the 4th chapter the task is to estimate the rate of expansion in order to predict the size of the target at a future instance and the effect of attention is studied. In Chapter 4, eye movements are also investigated to provide evidence with respect to how attention is shared between two tasks. The studies described in the 3rd and 4th chapter use the similar experimental protocol in that both require judgment of size of an expanding target in dual task conditions. In the 3rd chapter the target has to be matched to a previously shown size whereas in the 4th chapter, the target expands in size and has to be matched to a visible object. In the 5th chapter, the effects of age, pop out and divided attention on the functional field of view are investigated.

The hypotheses are that: 1) size matching will not be the same when using the central and peripheral retina, 2) older individuals will have greater difficulty with increasing task complexity (size matching in dual tasks), 3) viewing efficiency (AFOV) will be reduced for older individuals compared to younger individuals, 4) the presence of a pop out distracter will affect viewing efficiency, resulting in a greater time being required to locate the target in the presence of the pop out distracter, 5) division of attention will affect the viewing efficiency resulting in a greater time being required to locate the target, and 6) the effect of the pop out distracter and divided attention on viewing efficiency will be greater in older individuals than younger individuals.

2. Chapter 2: Size matching: Influence of speed, location and retinal eccentricity

The ability to estimate the time at which an object, either on collision course or otherwise, intercepts with the self or another object is vital to the survival of any organism. Interceptive tasks such as hitting, catching, or navigating through cluttered environments, all involve some estimation of time (Lee, 1976; Lee & Lishman, 1977; Regan, 1997; Schiff & Detwiler, 1979). Time can be estimated by knowing either the distance or speed at which the object is travelling. This information is not always available and hence observers are thought to be using some other form of information to estimate the time at which objects will reach a specific destination or collide. The time required for objects travelling at uniform velocity to reach the destination is referred to as the time to collision (TTC) or time to contact (Lee, 1976; Lee & Lishman, 1977; Regan, 1997; Schiff & Detwiler, 1979).

In the laboratory, the estimation of TTC can be done either by using a prediction motion task wherein an object that is simulated to move at a certain speed disappears and participants have to judge when the target would have a reached a certain distance, usually defined by a line or marker (Schiff & Detwiler, 1979; Schiff & Oldak, 1990). Such a task is similar to coincidence anticipation timing (Fleury, Basset, Bard, & Teasdale, 1998), wherein the position of the stimulus at a future instance is predicted using information such as velocity or motion of a stimulus. Another method to measure TTC is to use relative judgments tasks wherein the participants have to denote which of two moving objects would reach the destination first (Delucia, 1991; DeLucia, 2004; Regan & Hamstra, 1993; Regan & Vincent, 1995).

The question investigated in the current study is whether the size at a future instance in time can be predicted for a target expanding at uniform velocity, i.e., can size be predicted from an estimation of time. In order to do such a task, the observer can use information similar to a TTC estimate as utilized in a prediction motion task. To accurately match the size of a target expanding at uniform velocity to a previously shown target, the reaction time has to be factored in. For example consider a scenario wherein the size of the target to be matched is 10 cm in length. Assume that the target takes 1 second to become 10 cm in length from 1 cm (assuming uniform rate of expansion). From the time information the participants can make their responses such that they compensate for their reaction time by responding early enough to make an accurate size match. If the target takes 2 seconds to become 10 cm in length from 1cm then, based on their estimate of time, they have to respond much later to make an accurate size match.

The functional application of using size matching as an outcome measure is that in many situations, such as driving, people have to judge gaps available for making a lane change and these gaps are continuously changing either at uniform speeds or otherwise. While judging gaps, the observer is thought to be using the information such as the size of the gap and the rate of constriction of the optical gap (Bootsma & Oudejans, 1993. In situations such as driving, there is no real perceptual measure of the gap other than one’s own mental imagery of it. This thinking resulted in a similar study design, that is, to show the participant a particular size and ask them to remember this size and make a size match for an enlarging target. However, the motion in depth variable was not required to make a size match in this experiment.

Another question asked is whether size matching responses made using the central and peripheral retina are different. On one hand it might be reasonable to expect that there would be differences in visual functions when comparing the foveal and peripheral retina. For example, visual acuity is seen to fall off 10 fold at 20 degrees of eccentricity and contrast thresholds are seen to be 20X higher at 20 degree for a 2 cycle per degree spatial frequency (Regan & Vincent, 1995). However Regan and Vincent (1995) report that discrimination thresholds for TTC or rate of expansion are less affected by eccentricity than other visual functions. If size matching is done based on time estimation then there may not be much difference in the size matching between the central and peripheral retina. Alternatively there may be even less difference in size matching if the fovea is directed to the peripheral stimulus by allowing eye movements. This aspect was also investigated in this study.

Our experiment did not involve estimation of TTC as employed by many of the early mentioned studies. The question that was posed was whether people can estimate the time at which an object becomes a particular size if it expands at a fixed rate, either based on obtaining information about the speed or by sampling the size at every instant. As the task involves a coincidence anticipation judgment the participants have to react to the stimulus before the target actually becomes the particular size in order to adjust for their reaction time. The illusion of motion in depth occurs as the stimulus is enlarging in size uniformly. However, as the size match has to be made to a target shown in two dimensions on a screen, the motion in depth variable can be ignored by the participant, when performing the size match.

2.1. Methods

Participants

Nine young participants with a mean age of 27.4 ± 4 years participated in the study. The participants were students and staff recruited from the School of Optometry at the University of Waterloo. All participants had visual acuity better than 6/9 and had no known visual field defects. They were free of systemic diseases known to affect eye movements (e.g. vestibular disease), as well as free of any known cognitive impairment. The health status of the individual was determined verbally during the recruitment process. Approval for the study was obtained from the Office of Research Ethics at the University of Waterloo. Informed consent, in compliance with the Declaration of Helsinki, was obtained from all participants.

Procedure and Stimuli

The stimuli, created using Python programming software, were rear projected (LCD Projector model: Epson EMP 82) onto a screen set 2 meters in front of the participant. The stimulus was a vertical bar enlarging in size at a uniform speed for each trial. There were five speeds in which the vertical rectangular bar expanded and they were set in speeds varying in 2 deg/sec increments. Speed 1 refers to the slowest speed and one pixel was drawn every 10 msecs, and for speed 5 (the fastest speed), 3 pixels were drawn every 10msecs. This corresponds to 4 degree/sec, 6 degree/sec, 8 degree/sec, 10 degree/sec and 12 degree/sec for speed 1, 2, 3, 4 and 5 respectively. The resolution of the projector was set at 800X600 pixels. The participants were shown a target of fixed size on the projector screen. This 276 pixel target at the 2m working distance subtended 11.08 degrees in height and 1.14 degrees in width in visual angle at 2m. Participants were instructed to keep this size in memory. The participant's task was to judge binocularly as accurately as possible when the expanding vertical rectangular bar reached the previously shown size (11.08 degree X 1.14 degree) and respond by pressing a button on the computer keyboard. The participants were instructed to match the size of the expanding rectangular bar with the previously shown size using the vertical size even though the target was proportionately increasing in size both horizontally and vertically. The target was invisible on the first frame of each trial and expanded in size in the subsequent frames depending on the speed selected for the particular trial.

There were three sessions in the experiment. In the first session, the target rectangular bar appeared only at the central location, i.e, the straight ahead position or midline. In the second session the target appeared at eccentricities of 10 and 20 degrees in either the right or left peripheral visual field. In this session the participants were instructed to hold their gaze at a fixation cross at the central location and use peripheral vision to make the size match. We will refer to this experiment as "peripheral without eye movements (EM)". In the third session, the target appeared at the 10 and 20 degree eccentricities as before, but in this session participants were allowed to make eye movements towards the target. The fixation cross also remained on the screen during this session, but participants were not required to hold their gaze on the fixation cross. We will refer to this experiment as "peripheral allowing eye movements (EM)". A total of 500 trials were presented in each session, randomized with respect to speed (session 1) and the speed and stimulus location (session 2 and 3).

In order to make sure participants were not moving their eyes for judgments using peripheral vision (session 2), an eye tracker (Series 2020 binocular CCD; El-Mar, Downsview, Ontario, Canada) was used to record eye movements.

Analysis:

The outcome measure in all cases was the size of rectangular bar in degrees. This was referred to as the size matched value. Knowing the rate of change of the expanding target, the coincidence anticipation time can be obtained from the size. The accuracy of the size match was determined by comparing the size matched estimate to the actual size shown.

These data from each session were averaged for each different speed and location, i.e., for the central location (0 degree) there were five values obtained, one for each of the 5 speeds (4, 6, 8, 10 and 12 degree/sec). For the peripheral locations, there were 5 speeds (4, 6, 8, 10 and 12 degree/sec) X 4 eccentricities (-10, 10, -20, 20 degrees) and so there was one mean value for each eccentricity and speed. A repeated measures ANOVA was performed to see whether there were differences between the size matched values for the two eccentricities i.e., differences between 10 and 20 degrees both in conditions where eye movements were allowed or not and between right and left visual field. Data were pooled if no differences were observed with respect to the variables such as visual field or eccentricity. A repeated measure ANOVA was also used to compare differences between centre (0 degree eccentricity) and 10 and 20 degree [3 eccentricities (0 degree, 10 degree and 20 degree) X 5 Speeds (4, 6, 8, 10 and 12 degree/sec)]. This analysis was used for comparing differences between size matched values obtained at centre and “peripheral without EM” and also for comparisons of central size matched values and “peripheral allowing EM”. In cases where the assumption of ANOVA with respect to sphericity was not met, the Huynh-Feldt corrected p values are reported.

In order to compare the effect of speed, the data were also converted to error fractions which correspond to the fraction of the difference of actual and observed time and the actual time. For the five speeds, the actual time to become 11.08 degree X 1.14 degree was 2.76sec for speed 1, 1.84sec for speed 2, 1.38sec for speed 3, 1.10sec for speed 4 and 920 milliseconds for speed 5. This corresponds to 4 degree/sec, 6 degree/sec, 8 degree/sec, 10 degree/sec and 12 degree/sec for speed 1, 2, 3, 4 and 5 respectively.

2.2. Results

Comparison of size matched values for the two eccentricities (10 and 20 degrees) when using peripheral vision

A repeated measures ANOVA (5 speeds X 2 visual field [left, right] X 2 eccentricities [10, 20 degree] was performed. There was a main effect of speed ($p < 0.0005$), such that the largest size matched value was obtained for the fastest speed -see figure 2-1. There was neither an effect of visual field [left, right] ($p = 0.052$) nor eccentricity [10 degree, 20 degree] ($p = 0.703$). There were no interaction effects of; a) speed X visual field ($p = 0.506$), b) visual field X eccentricity ($p = .207$) or c) visual field X eccentricity X speed ($p = 0.861$). There was a significant interaction of speed X eccentricity ($p = 0.025$) that suggests a different slope for size matched values obtained for the five speeds at the two eccentricities (10 and 20 degrees) - see figure 2-2.

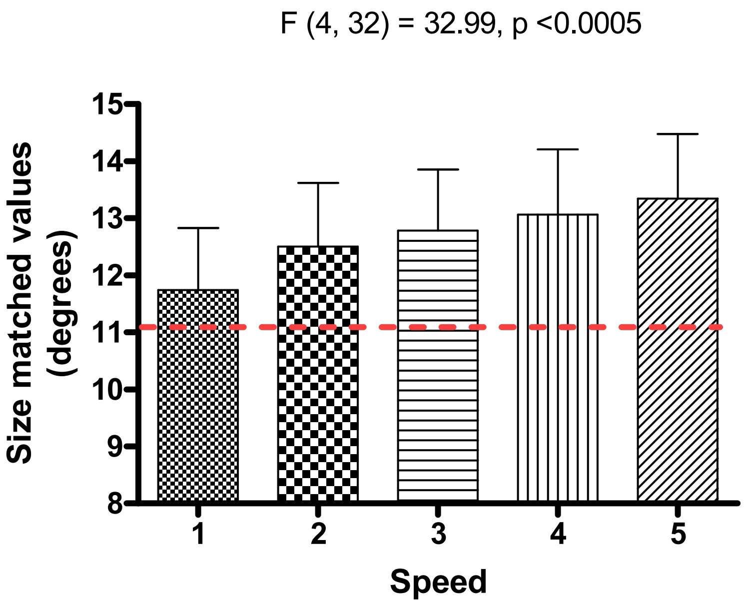

Figure 2-1: Effect of speed on the size matched values. The data is pooled from the four locations tested (two visual fields and two eccentricities). The error bars represent the standard error of the mean. The dashed line represents an accurate size match.

Even though there was a significant interaction (p = 0.025) (figure 2-2), post hoc analysis using the Bonferroni test showed that for any specific speed there were no differences between the two eccentricities 10 and 20 degrees. For example, there were no differences between the size matched values for 10 and 20 degree for speed 1 (p = 0.544) and this was similar for speeds 2, 3, 4, 5 (p values were 1.000, 1.000, 1.000 and 1.000 respectively). The interaction effect observed (p = 0.025) is because the size matched values obtained at 10 degree eccentricity for speed 1 is lower than 20 degree eccentricity while at speed 5 it is the opposite.

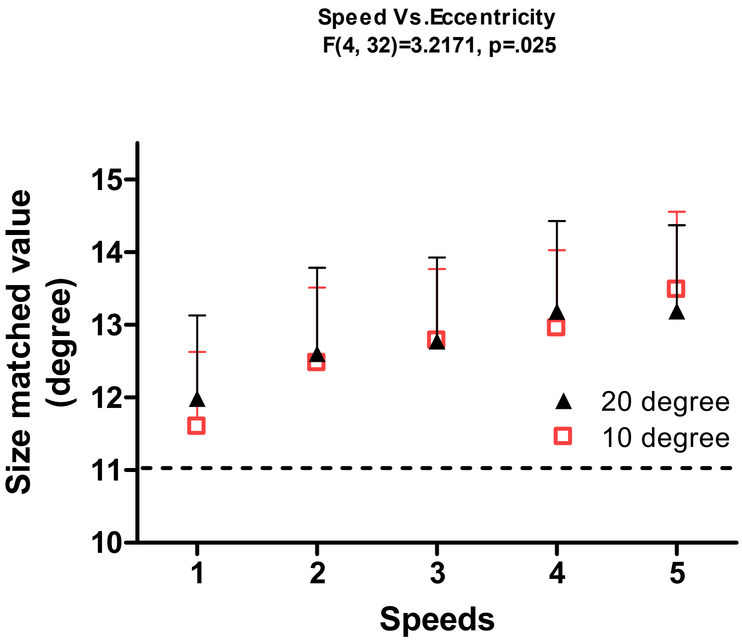

Figure 2-2: Interaction effect for the eccentricity 10 and 20 degree and speed. The error bars represent the standard error of the mean. No significant differences are observed (post hoc results) between the eccentricities for size matched values for corresponding speed. The dashed line represents an accurate size match.

Comparison of size matched values between the central and peripheral locations without eye movements

A repeated measures ANOVA was performed considering the data as three eccentricities, i.e. 0 (central), 10 and 20 degrees ([3 eccentricities (0, 10 and 20) X 5 speeds]. The results show that there was a main effect of eccentricity- [F(2, 16)=6.18, p=0.019] – Figure 2-3. The data for the 0 degree eccentricity (central) was significantly different from 10 degree eccentricity (p = 0.029) and 20 degree eccentricity (p = 0.018). There was no difference between 10 and 20 degree eccentricity (p = 1.000).

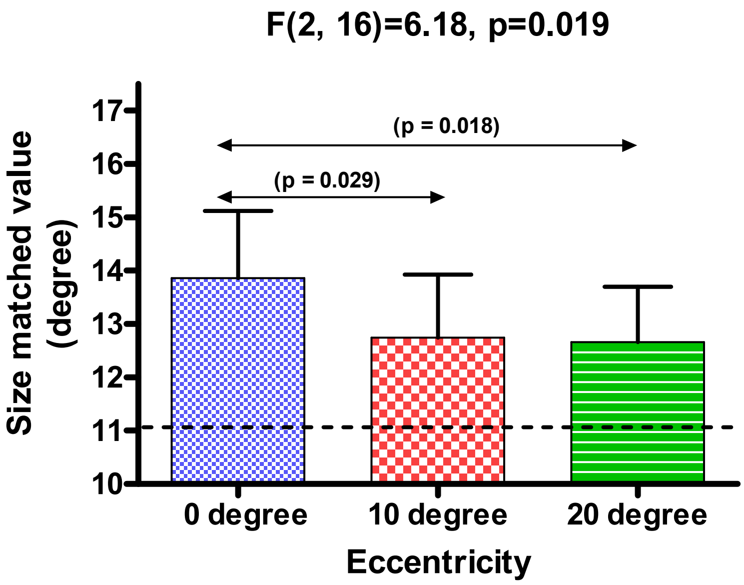

Figure 2-3: Significant differences in size matched values between the central (0 degree) and the two peripheral eccentricities (10 and 20 degree) are indicated by arrows. There were no differences between the 10 and 20 degree eccentricity in size matched values. The error bars indicate the standard error of the mean. The dashed line represents an accurate size match.

There was a significant interaction between eccentricity (0, 10, 20 degree) and speed – [F(8, 64)=2.14, p=0.043]– Figure 2-4. There were no differences between the size matched value obtained at 10 and 20 degree eccentricity for the respective speeds, e.g. for speed 1, there was no difference between 10 and 20 degree eccentricity and this was similar for speed 2, 3, 4 & 5. The interaction effect observed (p = 0.043) is because the size matched values obtained at 10 degree eccentricity for speed 1 is lower than 20 degree eccentricity while at speed 5 it is the opposite.

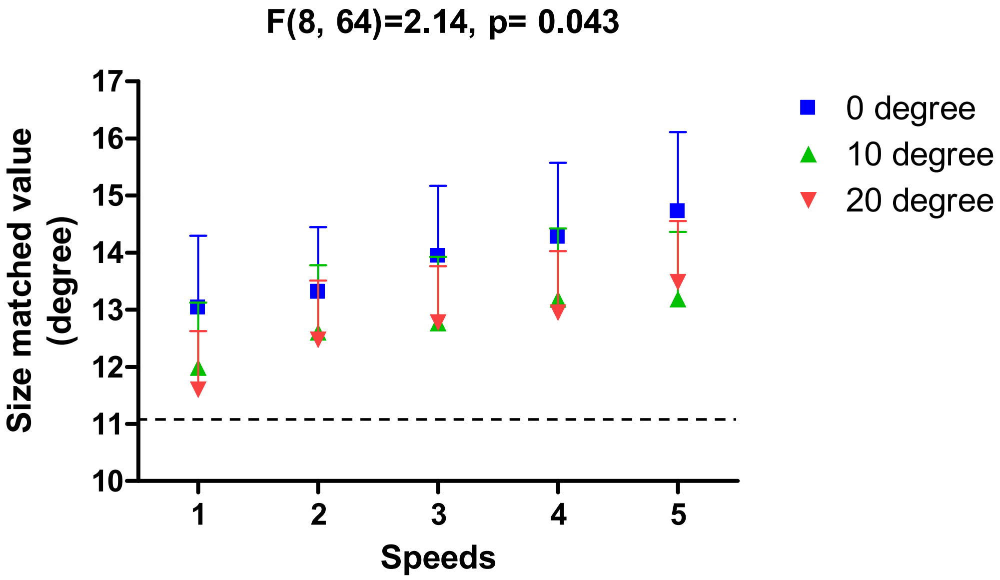

Figure 2-4: Interaction of speed X eccentricity. The error bars represent the standard error of the mean. No significant differences are observed (post hoc results) between the eccentricities for size matched values for corresponding speed. The dashed line represents an accurate size match.

Comparison of size matched values between the central and peripheral locations allowing eye movements

For the session allowing eye movements, a repeated measures ANOVA was performed considering the data as three eccentricities, that is, 0 (central), 10 and 20 degrees from the two peripheral locations ([3 eccentricities (0, 10 and 20) X 5 speeds]. The results show that there was no main effect of eccentricity- [F(2, 16)=1.1375, p = 0.318] – Figure 2-5. There was a main effect of speed [F(4, 32) = 27.704, p <0.0005] with the largest size matched value corresponding to the fastest speed. There was no interaction between speed and eccentricity – [F(8, 64)=.973, p = 0.465] – Figure 2-6.

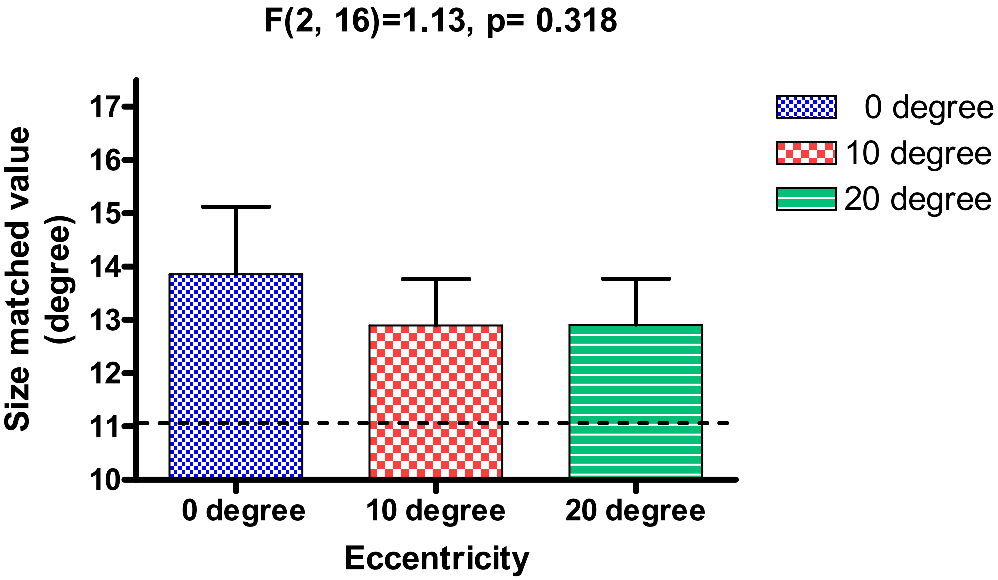

Figure 2-5: Main effect of eccentricity showing no significant differences in size matched values between the central (0 degree) and the two peripheral eccentricities (10 and 20 degree) when eye movements are allowed. Error bars represent standard error of the mean. The dashed line represents an accurate size match.

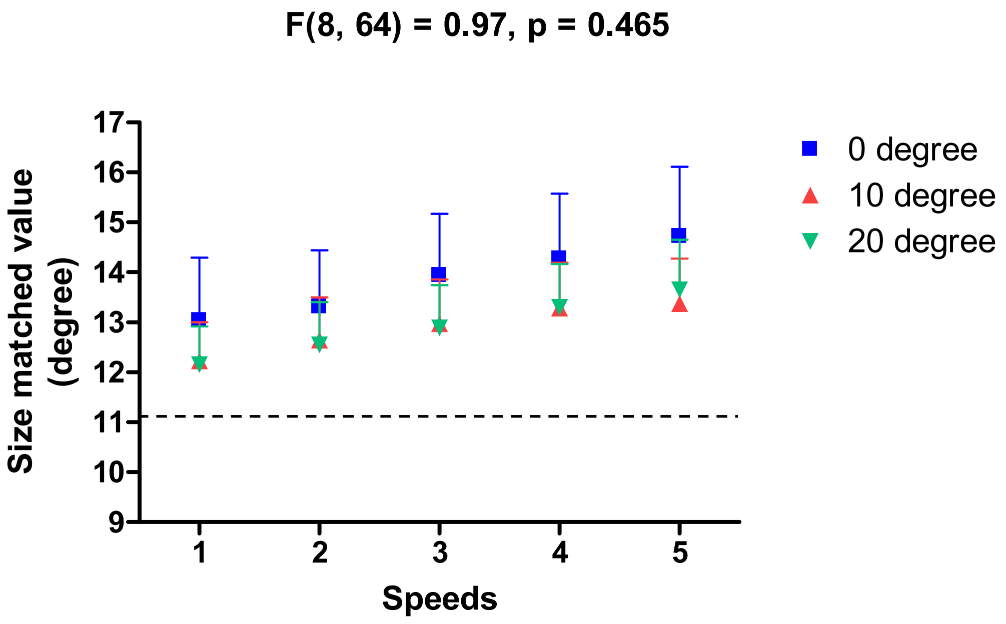

Figure 2-6: Graph showing the lack of interaction of eccentricity (peripheral allowing eye movements) and speed. The dashed line represents an accurate size match.

Comparison of all three conditions with size matched values converted to time

This analysis was done to allow the reader to understand how the size matched values compare to time. Even though time is a function of size in this case, the analysis is intended as a clarification. Figure 2-7 shows the time corresponding to the accurate size match, that is, whether the subject under- or over-estimated. Figure 2-8 shows the accuracy data for the three conditions. Accuracy in this case refers to the time difference from the accurate size match, for example for speed 1 it would be the difference from 2.76 sec for the participant. It is seen that there is greater variation on the time scale for the slowest speed (speed 1). This is because a larger error in size results in a smaller error in time in compared to speed 5. From figure 2-7 we can see that some participants appear to anticipate the size and to factor in their reaction time effectively by responding early. If we look at the raw data of all the subjects with respect to time we can see how individuals use different strategies (Figure 2-7). Some individuals anticipate the size (S2 -Figure 2-7) while others do not (S1 – Figure 2-7). Having said this, perception of the initial size shown could be a confounding factor, that is, the participants might have variation in the percept of original size. The percept of the original size could depend on the frame of reference used or other mechanism used to keep the original size in memory.

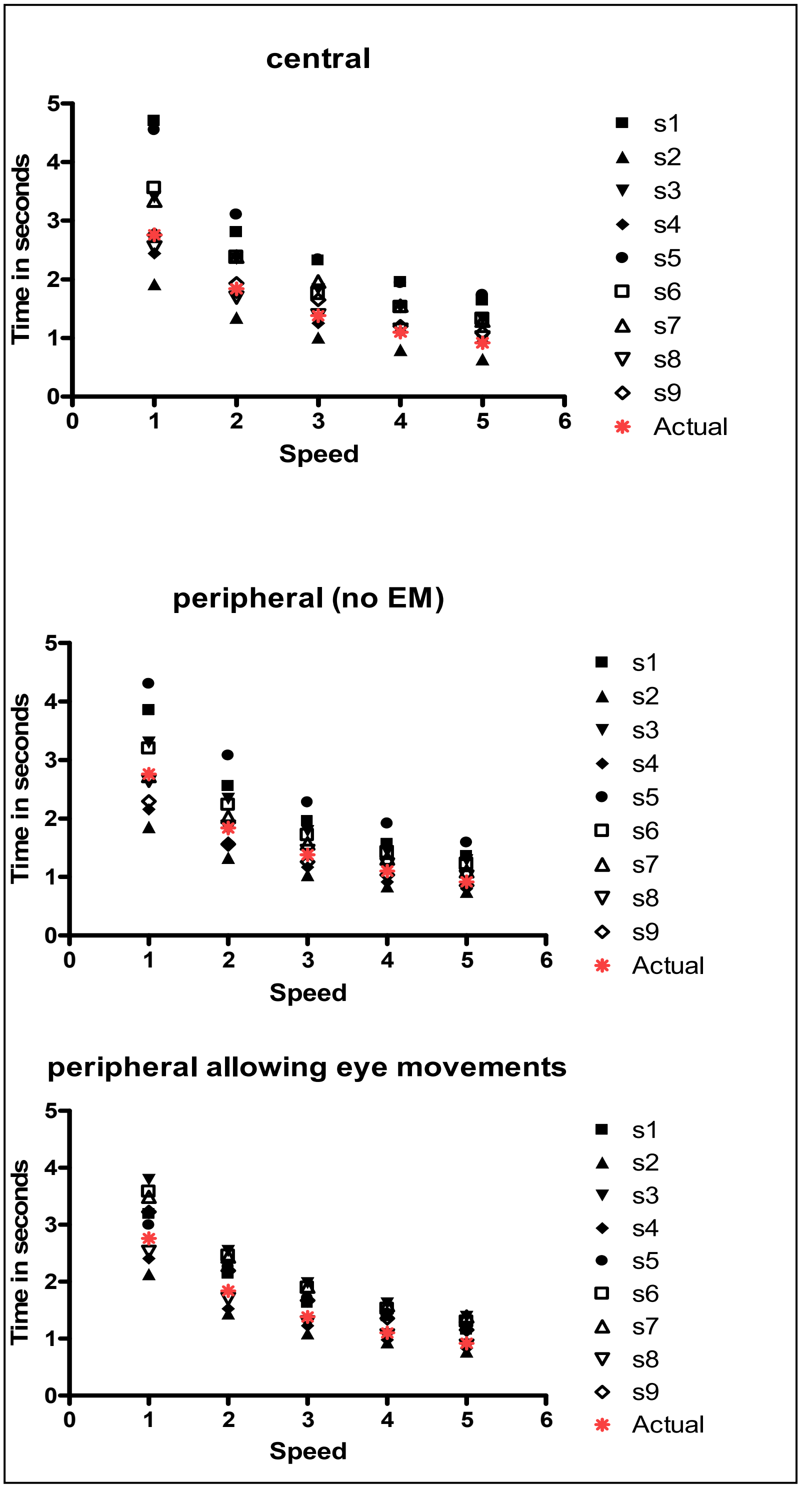

Figure 2-7: Speed plotted against time in seconds obtained from the size matched values. Data are converted to time for each speed. The stars shown in red represent the time for the target to become 11.08 degree or 276 pixels i.e. a correct response.

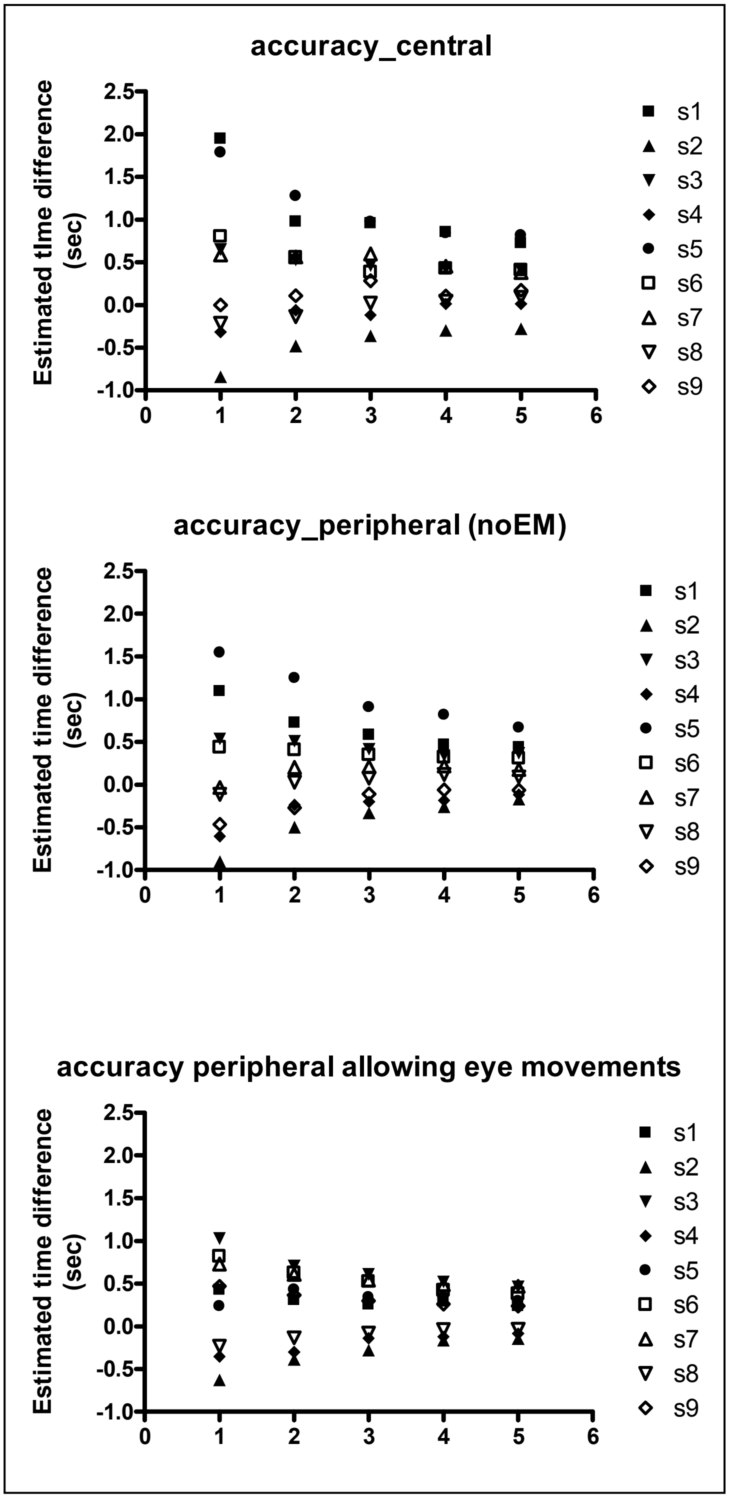

Figure 2-8: Accuracy of the estimated time for each participant.
The top figure shows data for central, the middle – peripheral without eye movements and the bottom shows the data for peripheral allowing eye movements. The zero on the graph represents 100% accuracy.

2.3. Discussion

In order to make a correct size match the participant has to correctly identify the rate of expansion and match the size to a previously shown target factoring in their reaction time. In this study a main effect of speed is observed, with the largest estimated size corresponding to the fastest speed. Reaction time would play a major role if the size matches had to be made within an assumed manual reaction time of 500 msecs (i.e., targets expands so fast that the size to be matched is reached in a time that is less than their manual reaction time). In this case, even if the participants respond as soon as they see the target, the target expanding at the fastest rate would be much larger compared to a target expanding at a slower rate. This is because there is no opportunity in such a case to anticipate the rate at which the target is expanding and make an accurate size match. However, in this study, in all the conditions, the time available to make an accurate size match was always above 700 msecs. This condition provides an opportunity for the participant to anticipate the time it would take for the target to expand to the desired size and factor in the target expansion during the reaction time.

However the following discussion indicates that the reaction time, is unlikely to be the reason for the observed effect. The target in this study was expanding uniformly such that the times to reach the desired size (11.08 degree) for the five speeds were 2.76 sec, 1.84 sec, 1.38 sec, 1.10 sec and 0.920 sec. The change in target size was linear across the five speeds (e.g. 11.08 in 2.76 sec, 11.08 in 1.84 sec etc = 4 deg/sec, 6 deg/sec, 8 deg/sec, 10 deg/sec and 12 deg/sec). For example, assuming a manual reaction time of 500 msecs, if the participants responded when the target was equal to its exact size i.e. 11.08 degrees in size, then for the 4 degree/sec stimulus the target would be 13.08 degrees; 14.08 degrees for the 6 degree/ sec stimulus; 15.08 degree for the 8 degree/sec stimulus, 16.08 for the 12 degree/second stimulus. The slope of the change in size across the 5 speed increments is 1. Thus, if the participants are not factoring in their reaction time, then the slope of the data obtained from the participants should be close to 1. However the average slope (size matched value in degrees vs. 5 speed increments for each participant) is 0. 43 (±0.18) for central size matching, 0. 33(±0.13) for peripheral no EM, and 0.37 (±0.19) for peripheral allowing EM – See figure 2 - 9.

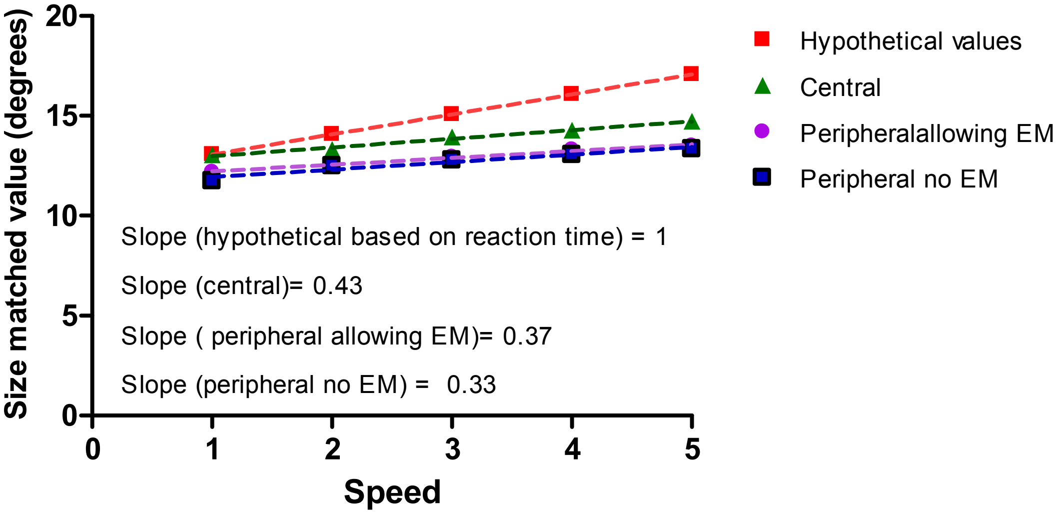

Figure 2-9: Representation of average slopes for the three conditions (central, peripheral no EM and peripheral allowing EM) compared to the hypothetical slope based on reaction time.

The result shows that the participants factor in their reaction times when matching the size of the expanding targets. As there is a speed effect it could be supposed that a perfect adjustment for reaction time is not made or they make some error in judgment of the speed.

Another result obtained was a difference observed for size matching between values obtained using central and peripheral vision. The values obtained for the matched size were smaller for peripheral vision and this difference was statistically significant. Regan and Vincent (Regan & Vincent, 1995) observed that discrimination thresholds for TTC and rate of expansion were affected by eccentricity but only slightly. They found that the discrimination threshold increased by 1.4 and 2.2 for 8 and 20 degree eccentricities respectively compared to the fovea. Similarly in their study the thresholds for rate of expansion were 1.4 and 1.8 at 8 and 20 degree eccentricities respectively compared to the fovea. The reason for differences observed between central and peripheral retina could be based on visual acuity differences between the fovea and periphery. The target may appear larger than it actually is— as a consequence of blur; when using the peripheral retina. We did not find significant differences between conditions when the target was in the centre compared to when it was eccentric if eye movements were allowed (suggesting the use of the fovea to make the judgments). This suggests that the differences observed are the result of differences between using foveal and peripheral retina. However, the finding that there was no difference in size matching values at 10 and 20 degree eccentricity (in this study), argues against the explanation that visual acuity differences (at various retinal locations) are responsible for the differences in size matching when using foveal and peripheral retina.

Another probable reason for differences in size matching between central and peripheral retina could be that targets appearing in the periphery visual field are perceived differently compared to those appearing in the midline (central). Regan (1995) suggests that a looming stimulus appearing in the peripheral vision may be more threatening ecologically. Innate behavior might cause the participant to react early for a target looming in the periphery, resulting in smaller size matches for peripheral targets. One counter argument against such an explanation would be the absence of differences between the two eccentricities 10 and 20 degrees. A reason to reject this counter explanation would be that the effect of innate behavior is observed irrespective of distance from the fovea. Perhaps there is a certain threshold eccentricity from the fovea degree (centre) to which participant responds differently than when using the fovea. The threshold eccentricity could be less than 10 degree eccentricity. This suggests that the fovea is intrinsically different from the rest of the visual field, rather than there being a continuum across the visual field.

There is some evidence that there is a discontinuity in function between 5 and 10 degrees. Perceptual differences are observed when estimating time to arrival of an object when there are head-on approaches or when by-passing the individual (Raghuram, 2004; Schiff & Oldak, 1990). Schiff & Oldak (1990) investigated time to arrival using filmed sequences of a car moving towards an individual at uniform velocity. At a particular instance in time the car disappeared and the participants had to predict the time at which the car would collide with them or pass by them. The judgment of time to arrival was observed to be more accurate when the target was by-passing an individual compared to head-on approaches. The increase in accuracy in judging time was observed for eccentric viewing of greater than 10 degree in this study (Schiff & Oldak, 1990). The comparison of head-on versus by-pass approaches of 4 to 8 degrees did not show any significant difference. They suggest that there might be a threshold eccentricity between 5 and 10 degree that results in increased judgment accuracy for targets that by-pass the individual. In their study (Schiff & Oldak, 1990) eye movements were not restricted when making the judgments of time to arrival. In our case we can consider the size match made at the central location to be analogous to a head-on approach and the size matches made for the target appearing at peripheral locations to be analogous to TTC obtained when the target by-passes the individual. The changes in size matched values for targets that appeared in the centre as opposed to the peripheral locations (eye movement restricted) could perhaps be due to the variation in approach of the target. In our investigation there was no significant difference between the size matched values for central location (0 degree) to those in periphery when eye movements were allowed. The size matched values obtained for the targets in the periphery when eye movements were allowed or restricted were very close (12.90 ± 0.86[EM allowed] vs. 12.68 ± 1.10 [EM restricted]). This again suggests that approach differences could play a role in size matching of isotropically expanding targets. The accuracy was greater for size matches made for targets that were displayed at peripheral location compared to those appearing at the central location. Although the stimuli used by Schiff and Oldak (1990) study were more representative of the real world, our results are in agreement with their findings.

Directions for later studies

This study provides evidence that size matching of an expanding target can be used as a measure of time estimation. The assumption is that the estimates are tied to the percept of the original size shown and there would not be much inter-trial variation in this percept. These assumptions, if not true, could confound the results and hence it is important to control for such effects, for example. by having the original bar constantly present. Therefore in one of the next studies (described in Chapter 4), the effect of memory was excluded by presenting the outline of the expanding target on the screen. Studies mentioned in the next chapters investigate the time estimation and size matching in conditions of dual tasks, wherein the complexity of task is varied by manipulating the speed of one of the tasks.

3. Chapter 3: Estimating the size of isotropically expanding targets: Influence of speed, attention and age

This investigation utilizes a size matching paradigm, similar to that employed in Chapter 2 which is based on the estimation of the rate of expansion. Matching the size of an expanding target also provides us with an estimation of the time it takes to reach a given size. A target which expands at a faster rate will become a particular size in less time than a target that expands at a slower rate. In this size matching paradigm the participant is required to match the size of an expanding object to a previously shown object. This is similar to a prediction motion (PM) task (Schiff & Detwiler, 1979; Schiff & Oldak, 1990) that is used to estimate time to collision / time to contact where a target that is moving at a certain speed disappears from view and the participants have to predict the future location or time of impact to a boundary. In cases where target approach is investigated, the boundary usually refers to collision with the observer. In our size matching scenario, there is no boundary but there is an anticipated size, based on the target size initially shown to the participant. This is analogous to an approaching target reaching a certain distance from the observer.

A parameter that could affect the estimation of TTC, or any estimation of time, could be the resources available in working memory. Delucia and colleagues (DeLucia, 2004; DeLucia & Novak, 1997) found that constraints on the working memory affected the estimation of TTC. In their study, participants made relative TTC judgments (for a description of relative TTC see chapter 2) when 2, 4, 6 or 8 objects were simulated to approach them. The participant's task was to judge which object would reach them first. The mean reaction times obtained were longer when there were more than 2 objects. In another experiment (DeLucia, 2004; DeLucia & Novak, 1997), participants were to give “target present” responses when they noticed one of the objects (2, 4, 6 or 8) was moving faster than the rest and “target absent” responses when all the targets were approaching at the same speed. The reaction times were shorter for conditions when there were 8 objects compared to 2, 4 and 6 objects. Delucia et al., (DeLucia, 2004; DeLucia & Novak, 1997) suggest that, since this experiment involved ‘detection’ as opposed to ‘identification’, the number of targets in the display did not negatively affect the TTC judgments. They suggest that when identification measures are expected, constraints on working memory will affect the estimation of TTC, whereas when only detection is involved, there is not much effect on TTC estimates.

Size matching a target that is expanding at a uniform velocity involves identification and constant monitoring and therefore would be affected by the available resources in working memory. In this study, we added a secondary task in order to further tax the working memory. This allowed the investigation of how sharing the available resources in working memory affect the size matching judgments (or time estimation). The participant will have to monitor the changes in size of both targets at one instance (as both the primary and secondary task involves a change in size) to perform both the tasks. The prediction is that when tasks become more difficult as in a dual task paradigm, the amount of attention resources available for one of the tasks will be reduced. This could be due to limited capacity of the working memory and the limitations associated with the amount of information that can be held in storage (Kahneman, 1973; Kinsbourne, 1981). Another reason could be the consequence of processing bottlenecks (Pashler, 1994a, 1998) that can arise at various stages of a dual task.

Therefore, the purpose of this investigation was to see whether constraints on working memory would affect performance on the size matching task.

Secondly, difficulty in performance on dual tasks has been found to be more pronounced in elderly populations (Tsang & Shaner, 1998; Verhaeghen et al., 2003). This effect is greater when both tasks require the same working memory resource (Tsang & Shaner, 1998). In this case the visuo-spatial sketch pad, a component of the working memory (Baddeley, 1996; Baddeley & Hitch, 1996) that deals with visual information, is loaded with more than one stream of information. This could result in a processing bottle neck that could affect the older observer more than younger individuals. Based on this rationale we also investigated the effect of age on a size matching task in dual task situations.

3.1. Methods

Participants

Ten young participants with a mean age of 27.4 ± 4 years and ten older participants with a mean age of 73 ± 6 years participated in the study. The younger participants were students and staff recruited from the School of Optometry at the University of Waterloo. The older participants were recruited from the Optometry Clinic at the School of Optometry, University of Waterloo. All the participants had visual acuity better than 6/9 and had no known visual field defects. They were free of systemic diseases (based on information available from their Clinic files) known to affect eye movements (e.g. Parkinson's disease, diabetes, vestibular disease), as well as free of any known cognitive impairment. The cognitive status of the older participants was further assessed by an initial prescreening with the Mini Mental State Exam Questionnaire (MMSE) (Folstein, Folstein, & McHugh, 1975).

All the participants had a score greater than 27/30 on the MMSE and were thereby considered to be cognitively normal.

Approval for the study was obtained from the Office of Research Ethics at the University of Waterloo. Informed consent, in compliance with the Declaration of Helsinki, was obtained from all the participants. An honorarium was given to all the participants in appreciation for their time and involvement in the study.

Procedure and Stimuli

Stimuli were created using MATLAB v7. Stimuli were rear projected onto a screen located 2 meters from the participant. The resolution of the projector was set at 1024 X 768 pixels (LCD Projector model: Epson EMP 82). Participants provided responses by pressing appropriate buttons on a computer keyboard.

The study included four conditions: one focused attention condition and 3 dual task conditions. In all of the conditions participants had to match the size of an expanding target to a previously shown vertical rectangular target of 12.5 degree X 1.26 degree (300 X 30 pixels) in size. The participants were required to remember the size. The test stimulus (a vertical bar) expanded isotropically at three speeds (10.41 degree/sec - Fast, 3.47 degree/sec - Medium and 2.08 degree/sec - Slow) such that the time it became the size shown [12.5 degree X 1.26 degrees] was 1200, 3600 and 6000 msec respectively. The test stimulus was invisible on the first frame of each trial and expanded in size in the subsequent frames depending on the speed selected for the particular trial. There were a total of 100 trials for every condition with one of the three speeds randomly chosen for each trial. The vertical rectangular bar appeared at either a 10 or 20 degree eccentricity in the left or right visual field. The selection of the eccentricity and visual field was also randomized. The first condition performed by all the participants was the single task or focused attention condition. In this condition, participants were instructed to press a button on the computer keyboard when the expanding vertical bar reached the desired size (shown at the beginning of the condition). In the dual task conditions two tasks were performed simultaneously such that attention needed to be shared between them. One of the tasks was to match the size of the expanding vertical bar by pressing a button on the keyboard with the right hand to indicate that the required size was reached. The other task, which we refer to as the secondary task, required the participant to keep an enlarging square within a fixed boundary (see Figure 3-1) with the left hand. The secondary task was presented at the central location. The boundary consisted of an inner square (1 degree X 1 degree) and an outer square (4.2 degree X 4.2 degree). This manipulation required the subject to use the space bar on the computer key board. Pressing the space bar on the key board reduced the size of the enlarging square whereas releasing the space bar increased the size. The goal was to keep the size of the square within the fixed inner and outer boundary. The participants were not penalized if this goal was not met but were instructed to try their best. There were very few instances where the participants were not able to able to meet the goal of keeping the enlarging square within the fixed boundary.

The difficulty of the secondary task was varied (different sessions) and this was done by manipulating the speed of the enlarging square and was meant to vary the tax on the working memory. The three dual task conditions were labeled; Medium (70 msec refresh rate), High (40 msec refresh rate) and Mixed (random combination of 40 and 70 msec refresh rate). The time for the enlarging square to reach from the inner to outer dashed square was 5.320 sec for the medium condition and 3.04 seconds in the high condition. If the participant pressed the space bar, the size of the black square reduced at a rate of 0.60 deg/sec for the medium condition (3.2 deg/ 5.320 sec), and 1.05 deg/sec (3.2 deg/3.04 sec) for the high dual task condition. Releasing the space bar resulted in an increase in the size of the black square at the same rate as described above. In the mixed condition the increase and decrease of the size of the black square was based on the particular trial (i.e., whether it was a 70 msec refresh rate or 40 msec refresh rate and this was in random order). A new refresh rate for the black square started following a space bar press and release.

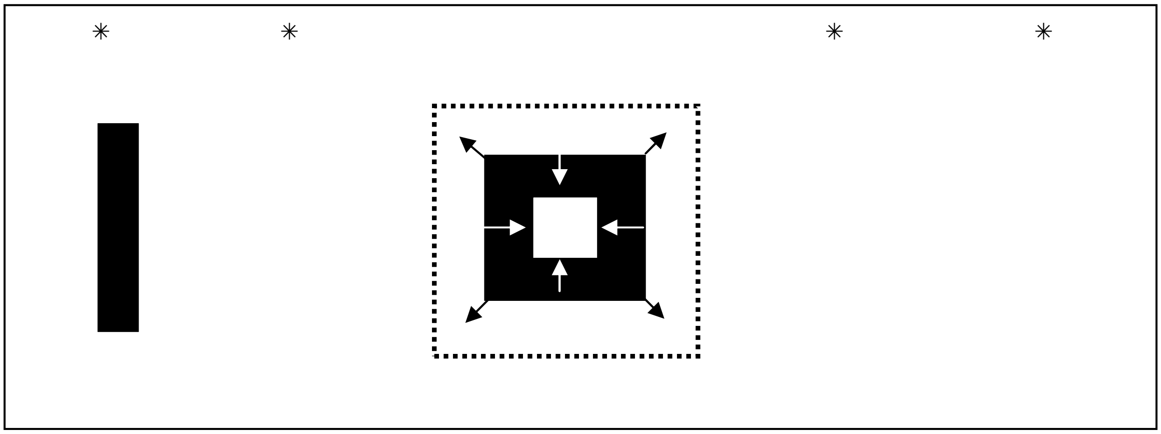

Figure 3-1: Representation of dual task paradigm.
For the dual task condition, the participant's task was to ensure that the enlarging black square stayed between the inner white square and the outer dashed square (continuous / secondary task). Pressing the spacebar on the keyboard reduced the size of the black square and releasing the spacebar enlarged it. The vertical expanding bar appeared simultaneously at one of four peripheral eccentricities (*) and participants had to judge when the target had expanded to the size shown before the start of the trials (primary task).

Data Analysis

3.1.1.1. Size matching of expanding targets

The data was sorted by the speed at which the peripheral target was expanding (10.41 degree/sec–fast, 3.47 degree/sec–medium and 2.08 degree/sec–slow) and by the two eccentricities [10 and 20 degrees] for each of the four conditions [1 focused, 3 dual task conditions]. An average value for each participant's responses at each speed and eccentricity was calculated. The main data analysis was in terms of size, but it was also transformed into an “Error fraction” (difference between the observed time and actual time ÷ actual time). The results were also expressed in terms of time which is a direct linear function of the size obtained for each speed. The data is expressed as time in the graphs and text to help the reader to follow the results better. The data was analyzed using a repeated measures ANOVA design (4 conditions [1 focused, 3 dual—medium, high, mixed] X 2 eccentricities [10, 20 degrees] X 3 speeds [fast, medium, slow]). Left and right visual field data were collapsed, since no differences were found in the previous experiment- chapter 2. The age groups were considered as the between subject variable. Bonferroni correction was used in the post hoc analyses to compare the differences between means. The data were statistically analyzed using the size matched values obtained in degrees and later converted to a time estimate. In cases where the assumption of ANOVA with respect to sphericity was not met, the Huynh-Feldt corrected degrees of freedom and p values are reported. The effect sizes for each variable are reported as partial eta squared.

3.2. Results:

The result of the repeated measures ANOVA obtained (4 conditions [1 focused, 3 dual] X 2 eccentricity [10, 20 degree] X 3 speeds [fast - actual estimate 1200msec, medium - actual estimate 3600, slow – actual estimate 6000]) with age as the between subject variable is shown in Table 3-1.

Table 3-1: Main effects and interaction of the repeated measures ANOVA

	Degrees of freedom (H-F corrected)	F value	p value	Effect sizes partial eta
AGE	**(1,18)**	**0.32**	**0.576**	**0.017**
CONDITION	**(3,54)**	**0.47**	**0.704**	**0.025**
CONDTION X AGE	**(3,54)**	**0.09**	**0.967**	**0.060**
ECCENTRICITY	**(1,18)**	**24.83**	**0.000***	**0.579**
ECCENTRICITY X AGE	**(1,18)**	**0.68**	**0.420**	**0.004**
SPEED	**(1.28,23.21)**	**59.56**	**0.000***	**0.767**
SPEED X AGE	**(1.28,23.21)**	**11.55**	**0.001***	**0.390**
CONDITION X ECCENTRICITY	**(3,54)**	**2.98**	**0.039***	**0.142**
CONDITION X ECCENTRICITY X AGE	**(3,54)**	**0.21**	**0.888**	**0.011**
CONDITION X SPEED	**(5.72, 103.12)**	**5.81**	**0.000***	**0.244**
CONDITION X SPEED X AGE	**(5.72, 103.12)**	**3.07**	**0.009***	**0.145**
ECCENTRICITY X SPEED	**(1.47,26.51)**	**0.18**	**0.765**	**0.010**
ECCENTRICITY X SPEED X AGE	**(1.47,26.51)**	**0.18**	**0.768**	**0.009**
CONDITION X ECCENTRICITY X SPEED	**(4.39,79.19)**	**1.35**	**0.257**	**0.069**
CONDITION X SPEED X ECCENTRICITY X AGE	**(4.39,79.19)**	**0.44**	**0.794**	**0.023**

Main effects and interactions that involve age; e.g. speed X age are presented in Table 3-1 (highlighted). The star represents significant differences ($p < 0.05$). There was no main effect of age [F(1,18) = 0.32; p = 0.576]. There was no significant interaction of condition X age [F(3,54) = 0.09; p = 0.969]. There was a significant interaction of speed X age [F(1.28,23.21) = 11.55; p = 0.001]. There was no significant interaction of condition X eccentricity X age [F(3,54) = 0.21; p = 0.888]. There was a significant interaction of condition X speed X age [F(5.72,103.12) = 3.07; p = 0.009]. There was also no interaction of the eccentricity X speed X age [F(1.47,26.51) = 0.768; p = 0.768].

Older participants were more affected by speed than younger participants. For the highest speed (actual estimate being 1200 msecs), the mean values were higher for older participants and for the lowest speed (actual estimate being 6000 msecs), the older participants had a lower mean than the younger participants (Figure3-2).

There is a significant interaction between the task conditions when considering both speed and age (age X conditions X speed; p =0.009) (Figure 3-2). Post hoc analyses show that there are differences between the data obtained for the older group in the focused and dual tasks conditions for the highest speed (actual estimate 1200 msecs). This showed significant differences between focused and high dual task conditions ($p<0.005$) and between focused and mixed dual task conditions (p = 0.004). For all other conditions there were no differences either between the focused or dual task conditions and neither was there an age effect.

For the medium and lower speeds, no differences in time were seen for any of the conditions. Greater accuracy was noticed for the highest speed compared to the lowest speed for both groups in terms of time estimates as seen from the graph. For example, for the fastest speed a mean difference of +50 -100 msec is observed from the actual time but for the slow speeds a mean difference of almost -600-800 msecs is observed – See figure 3-2.

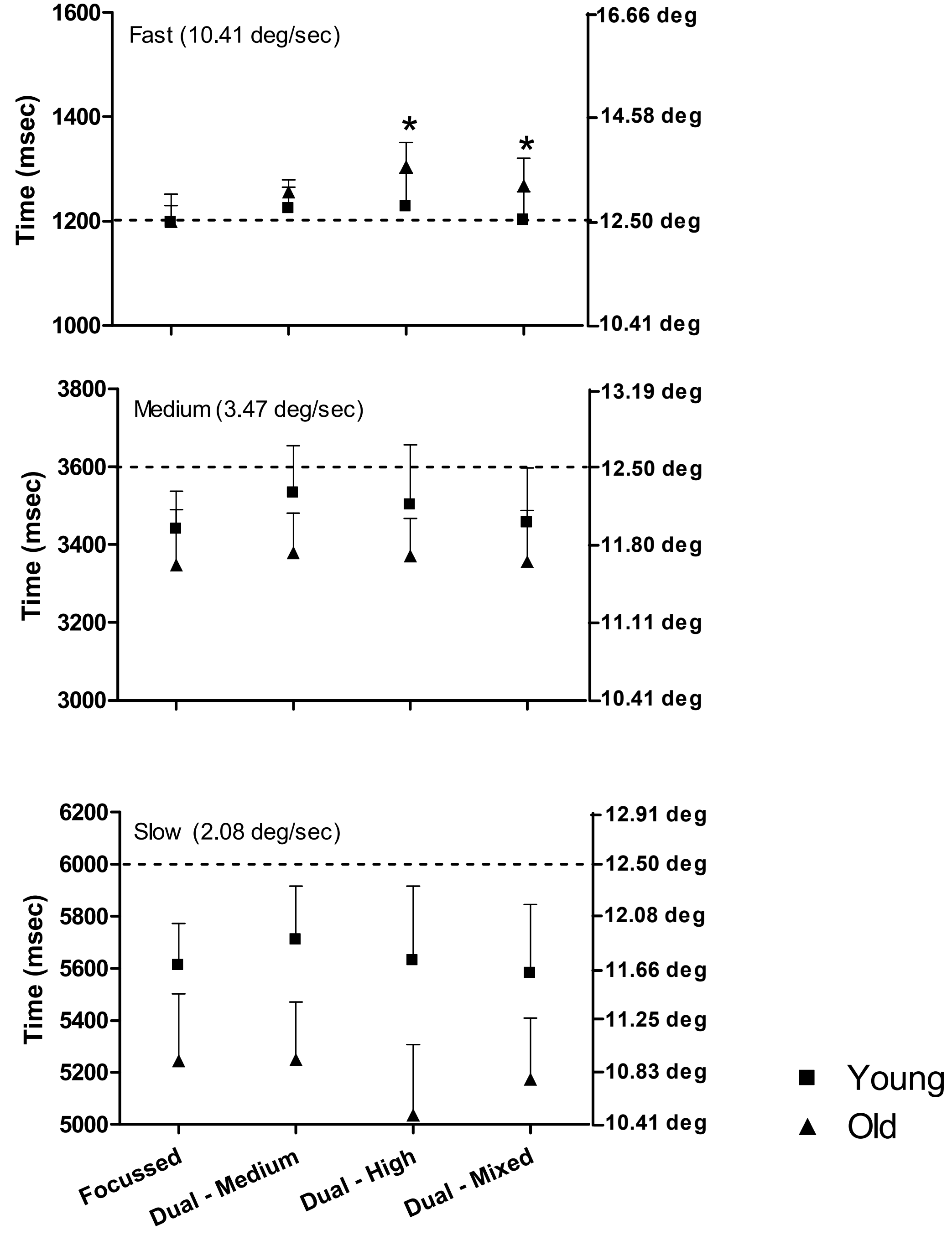

Figure 3-2: Interaction of speed, age and condition.

There is a significant interaction between speed, age and condition [F (5.72, 103.12) = 3.07; p = 0.009]. The dotted line represents the actual time required to reach the shown size. The top panel shows the fastest speed, the middle panel shows medium speed and lower panel shows the slowest speed. Significant differences are shown by star symbols and they represent differences between the focused and high and mixed dual task conditions for the older group. There were no differences between age groups. The error bars represent standard error of the mean. The size of the target that corresponds to the time is shown on the right Y axis.

The results were also compared based on accuracy by converting the values obtained to error fractions (difference between the observed time and actual time ÷ actual time). Error fractions provide a measure of accuracy and they are used to clarify the accuracy of size matching. The results of repeated measures ANOVA (4 conditions [1 focused, 3 dual] X 2 eccentricities [10, 20 degree] X 3 speeds [Fast -actual estimate 1200 msec, medium – 3600 msec, slow -6000 msec]) with age as the between subject variable using error fractions were identical (with respect to F and p values) to those shown in Table 3-1, as expected. When comparing the error fractions for the three speeds it was seen that, as the speeds increased, the error fractions become more positive. On average, all participants overestimated the speed for slower speeds. Moreover, the older participants overestimated the speed more compared to the younger participants. For example, if we look at values obtained for the slowest speed (accurate estimates being 6000msecs), the mean error fractions were -0.061 for the younger group and -0.137 for the older group. See table 3-2 & Figure 3-3 for the mean error fractions obtained for the three speeds (data pooled across different conditions).

Table 3-2: Mean error fractions for the three speeds

Speed	Young	Older
SLOW	-0.061	-0.137
MEDIUM	-0.032	-0.065
FAST	0.010	0.047

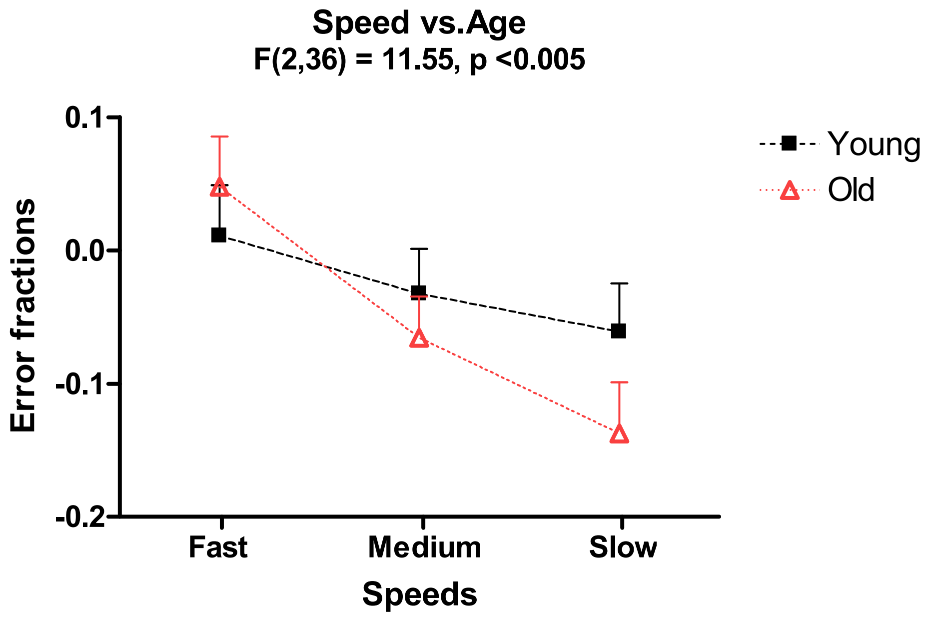

Figure 3-3: Interaction of speed X age represented as error fractions. The data is pooled across the different conditions (focused and dual task conditions). The error bars represent standard error of the mean.

3.3. Discussion

The data of the older individuals shows overestimation of sizes for the fastest speed and underestimation of sizes for the medium and slow speeds, while the young subjects tend to only show underestimation for the slowest speed. In order to make an accurate size match for a looming target the manual reaction time has to be factored in with the speed of the target. Therefore, for the fastest speed, factoring in the reaction times requires an earlier response than for either the medium or slow speed. In other words, if the participants are not considering the speed of the target when factoring in their reaction time, their size estimates would be larger for faster speeds and smaller for slower speeds. This result would be similar to that observed if participants' responded based on the size of the target, for example, when the target is 90% of the desired size. Our results suggest that younger participants are better in considering speed when factoring in their reaction times. The trends observed with the error fractions against speeds (accuracy) do show a higher slope for the older group suggesting a greater effect of speed. If the speed at which the target was expanding was not a factor then the slopes for the error fractions plotted against speed would have been zero. The result obtained here suggests that older people are less accurate and fail to adapt to the different speeds. In other words, they fail to fully recognize the variation in speed or to correctly factor in their reaction times in order to make accurate size matches.

The mean error fractions that we obtained for the respective speeds show that the smallest fractions (closest to zero) were obtained for the highest speed rather than the slower speeds. A target that is expanding faster is perceived as coming more quickly towards the person. The speculation is that in such a case “the now response factor” (referring to the impulse to respond at a particular instant) is quite high resulting in reduced uncertainty as to when to respond. For example, if it takes 1200 msec for the target to become the known size (12.5 degree X 1.26 degree), then within the first 600 msec it is half the size (6 degrees) and the decision has to be made quickly in order to adjust for the reaction time. Suppose if the person takes another 200 msec to respond and assuming a manual reaction time of 400 msec, then the selected target size would be accurate. On the other hand for medium and low speeds of target expansion, almost 2.5 seconds and 5 seconds respectively can pass before any action needs to be initiated. This gives enough time to decide when to respond, but increases the level of uncertainty. The uncertainty is due to the fact that as time progresses, the participant is unsure whether they should respond at that instant or not and this results in more decisions being made. In the case of the highest speed there is less time to make a decision and this forces the participants to react more quickly in comparison to slower speeds.

In studies using interceptive tasks it has been found that motor responses are faster when the amount of available time to react is shorter as opposed to longer (Tresilian, 2004). This means that for an interceptive task, for example in a sport like baseball, the time to move the bat from point “a” to “b” to intercept the ball is shorter for a faster moving ball than for a slower ball. In our case, we do not have any data to support this kind of a strategy usage, but it is possible that the motor planning and execution is fastest for a target expanding at the highest speed. Schiff & Oldak (1990) also reports that accuracy for time to arrival estimates reduces as the time to arrival increases. The mean time to arrival estimates reported in Schiff and Oldak’s study (1990) for 3 sec event was 2.77 sec compared to 4.01sec for a 6sec event.

At the highest speed there were significant differences in the performance of older participants between the focused and dual task conditions. The accuracy was greater in the focused attention condition compared to the dual task conditions. Delucia (2004) reports that when judging the arrival of looming targets, the reaction times of participants are found to be longer for conditions when there are more than 2 objects looming at the same time. This effect represents the constraints on working memory, when judging looming targets, as attention has to be allocated to multiple objects. The participant might be using serial processing to judge the arrival of targets when there are such constraints on working memory. The experimental paradigm that we used to study the constraints on working memory was different in that the complexity of one task (secondary task) was increased in order to investigate its affect on performance on the primary task. Thereby for dual task conditions, the working memory is loaded with more than one stream of information. This can result in processing bottlenecks wherein the processing of one task has to wait until the processing of the other task is completed (Pashler, 1994a, 1998). Processing bottle necks are explained in the work on dual task interference (see overview in Pashler, 1994a). The interference occurs when two tasks have to be performed one after the other. A larger interference is reflected by an increase in reaction time for the second task. This usually occurs when the time between the two tasks (Stimulus Onset asynchrony – SOA) is shorter. In other words, the smaller the SOA, the larger the interference observed. Our results are analogous to dual task interference effects although ours had no stimulus onset asynchrony. In conditions where a response had to be provided for a target expanding at the fastest speed (accurate estimation 1200 msec) in the focused condition, there was only one task to be performed and therefore there is no chance of interference effects. In the dual task situation, they had to switch between tasks and perform the size match as quickly as possible. In this experiment, for the target looming at the fastest speed, if they switch at the onset of the looming peripheral stimulus (i.e. from central secondary task to the peripheral primary task) then the most time they will have to make an accurate response is 1200 msec. If the participants take more time to switch from the central task then a shorter time remains to respond. If dual task interference occurs in the condition where the target is expanding at the fastest speed and the response to the primary task is delayed for a few milliseconds, the resulting judgment of the size of the expanding target will be larger. For the other two speeds at which targets were expanding, there was more time to switch between the tasks and therefore this effect would be reduced even if such bottle necks did occur. It is possible that both tasks can be processed in parallel but even then processing bottlenecks can occur.

However, it has to be noted that the accuracy for the size match appear to be more accurate for the target expanding at the fastest speed with respect to time.

In this study, a difference in the performance between the focused and dual task conditions was only found for the older individuals at the highest speed. There was no difference between the age groups. The absence of a difference between the groups may be due to the high variability in the size judgments for both groups. This variability could be due to the size judgments being based on a remembered size.

In conclusion, we observe that limitations of working memory affect the estimation of time (size matching used as a measure of time) only in conditions which are in some ways “very demanding”. Our findings show that only older individuals are affected and then only when the available time is very short. This has implications for real life situations. A befitting example would be in a driving situation where there is a sudden need to avoid a collision while travelling very fast and at the same time working memory is taxed by talking on the cell phone. The findings in this chapter have to be accepted with caution since they may be confounded because of the methodology. It is possible that the participants were unable to remember the size of the target to be matched, since it was shown only at the beginning of each session. One could argue that older participants would tend to forget the size of the target more so than younger individuals. However, there was no difference in size matching between groups in the focused attention condition, showing that both the younger and older participants are affected equally in this regard. In our next experiment, we eliminated the effect of memory, by presenting an outline to which the expanding target had to be matched (see chapter 4). The disadvantage of doing this is that the target will not be perceived as moving in depth, as there is a frame of reference for its maximum size.

4. Chapter 4: Age and the Estimation of Rate of Expansion of Retinal image in Single and Dual Task Situations

Dual tasks or divided attention tasks refer to conditions where people have to make decisions about more than one stimulus impinging on their sensory systems at the same time. Due to the limited capacity of the working memory there are constraints on the amount of information that can be held in storage and in order to perform adequately, the person must prioritize some inputs at the cost of others. Working memory is involved in keeping information for a short time so that upcoming actions can be organized accordingly (Baddeley, 1986; Baddeley & Logie, 1999). The components of working memory are considered to have a separate system for auditory (phonological loop) and visual stimuli (visuo-spatial sketch pad) (Baddeley, 1986; Baddeley & Logie, 1999). The view generally accepted is that a central executive (Baddeley & Della Sala, 1996; Baddeley & Hitch, 1996; Cepeda, Kramer, & Gonzalez de Sather, 2001) or a supervisory attentional system (Norman & Shallice, 1986; Shallice & Burgess, 1996) coordinates various tasks so that dual task costs are kept to a minimum. However, in many dual task scenarios, performance decrement is observed for one of the tasks. These decrements observed in dual task situations could be the result of the organization and the limited capacity of the working memory (Verhaeghen, Steitz, Sliwinski, & Cerella, 2003).

Tsang and Shaner (1998) coupled various dual tasks to understand how structural similarities between two tasks affect dual task costs. They observed that when two tracking tasks were coupled together greater performance decrement was seen in comparison with other tasks that were coupled; for example;. tracking task with verbal task. A greater decrement was observed when two tasks that were similar required "time sharing" such as when two visual tasks were coupled. In other cases, when the tasks were not so similar such as a visual task coupled with a verbal task, a much smaller decrement in performance was observed (Tsang & Shaner, 1998). Tasks that are similar (e.g. visual and visual) tap into the same mental resource (the visuo-spatial sketch pad) and due to limited capacity or bottle necks, performance decrements may be observed. Bottle necks refer to competition at a site that is limited in capacity wherein one of the tasks has to wait for the other to be completed (Pashler, 1994a, 1994b). Capacity limitation refers to the unavailability of adequate resources to perform both the tasks simultaneously (Kahneman, 1973, Pashler, 1994a, 1994b, Kinsbourne, 1981; Navon & Miller, 1987).

Age is found to be a factor that results in poor performance in dual task situations (Hartley, 2001; Hartley, Kieley, & McKenzie, 1992; Hartley & Little, 1999; Korteling, 1991; Tsang & Shaner, 1998; Verhaeghen et al., 2003). Is the capacity of working memory limited to a greater extent in older individuals? Many visual physiological changes occur as a result of old age (>70 years) (Haegerstrom-Portnoy, 2005; Haegerstrom-Portnoy, Schneck, & Brabyn, 1999). These changes affect functional factors such as visual acuity (VA), contrast sensitivity, and glare sensitivity, to name a few (Haegerstrom-Portnoy, 2005; Haegerstrom-Portnoy et al., 1999). Visual factors that are affected in old age are usually attributed to the reduced retinal illumination on account of pupillary miosis, increased light scatter occurring due to lenticular changes and neuronal loss at the retinal and cortical level. Factors dealing with attention are also affected by age especially the speed of processing, selective attention and divided attention (Ball, 1997; Salthouse, 1996; Salthouse & Somberg, 1982). These factors either in combination or isolation might have an effect on many everyday tasks.

Studies have also shown that decrements in dual task performance are observed with aging (Hartley, 2001; Hartley et al., 1992; Hartley & Little, 1999; Korteling, 1991; Tsang & Shaner, 1998; Verhaeghen et al., 2003). The effect of age on dual task performance is also observed in real world situations. Young and older participants were asked to walk in a pre-specified route at the same time as they were memorizing a word list (Lindenberger, Marsiske, & Baltes, 2000). The walking performance was significantly affected in the older age group in this dual task. Such detrimental performance was explained by the older participants' need for greater sensorimotor attentional resources for performance of either or both of the tasks. Similarly, the influence of secondary visual and auditory tasks on driving, in a closed road circuit, was analyzed in a group of young and older adults (Chaparro, Wood, & Carberry, 2005). There was a significant effect on the driving performance of the older group by the presence of a secondary auditory or visual task. The older participants performed much worse than the younger group in the dual task conditions (Chaparro et al., 2005). Similar differences between young and old have also been observed in studies that utilized a driving simulator (Brouwer, Waterink, Van Wolffelaar, & Rothengatter, 1991; Ponds, Brouwer, & van Wolffelaar, 1988). In effect, whenever there are multiple visual inputs age seems to be a factor that affects the response times (Bherer et al., 2005; Broman et al., 2004; Hartley & Little, 1999).

When there are multiple visual inputs, people can attend to the stimuli either overtly which refers to making an eye movement towards the region of interest or covertly wherein attention is focussed to the region without making an eye movement. It has been shown that eye movements are seen to be closely tied with shifts of attention (Crawford & Muller, 1992; Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995). Saccades refer to rapid eye movements that help to obtain information from the visual scene and are seen to be faster when preceded by a shift in attention. Hoffman & Subramaniam (1995) investigated the close coupling between saccadic eye movements and attention. In their study the participants were asked to move their eyes to a particular location in the display and report two of the four targets present in the corners of the display. Their results showed that there was higher target detection when the eye movements were made to the same location as the target. A discrimination task was used by Deubel and Schneider (1996) to understand the coupling between saccades and attention. They found that target letters were discriminated efficiently when the saccade target location was to the same location as the discrimination task. Kowler et al., (1995) in their experiment, used a circular array consisting of 8 letters and a cue to direct saccades to a particular direction. Identification of the letter was only accurate when it was also the saccadic goal. All these studies suggest that it is not possible to attend to one location and make an eye movement in a different direction.

It was also observed that once the working memory was loaded with more than one stream of information, there was an impact on generating antisaccades (saccades elicited in the direction opposite to a stimulus). The latency (initiation time) of antisaccades was found to increase with an increase in the working memory load (Irving, Tajik-Parvinchi, Lillakas, Gonzalez, & Steinbach, 2009; Meyer, Gauchard, Deviterne, & Perrin, 2007; Roberts, Hager, & Heron, 1994; Stuyven, Van der Goten, Vandierendonck, Claeys, & Crevits, 2000). The effect of attention is also observed in the generation of express saccades. Express saccades refer to saccades that have less than the normative saccadic latencies. Latencies of express saccades range from 100 msecs to 150 msecs. Normal saccadic latencies range from 200 to 250 msecs in young adults. Attention was required to be disengaged from the previous fixation location for the generation of express saccades.

In our experiment, we studied the performance in dual task scenarios by investigating the effectiveness in attention resource sharing between two tasks which both required visual judgment as well as manual responses. In order to do so we have to allocate attention so that both of the tasks can be performed. The importance of understanding the attention resource sharing capacity in such scenarios is the relevance to situations of daily living such as driving and walking. The two tasks that we used were structurally similar in nature wherein there is engagement of visual/manual responses. The outcome measure in our experiment was to make a size judgment for a peripheral target that was enlarging in size.

Previous studies have reported that attention and saccadic goals are at the same location (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995). In other words we cannot move our eyes to a position where we are not attending. In consideration of the existence of close coupling between the saccadic system and attention, eye movements were also investigated in our study to asses switching of attention between the areas of stimulus presentation in the dual task scenarios. The hypothesis was that as the level of difficulty of the dual tasks increased, the time spent on one task would also increase when compared to the second task. In this particular experiment, it would be the secondary task which was purposely made more challenging compared to the primary task. This effect was expected to be more pronounced in the older population. This is based on the hypothesis that the amount of time spent on performing the secondary task would be greater in dual task conditions due to the limited capacity of attention system.

4.1. Methods

Participants

Ten young adult participants with a mean age of 27.4 ± 4 years and ten older participants with a mean age of 73 ± 6 years participated in the study. The younger participants were students and staff recruited from the School of Optometry at the University of Waterloo. The older participants were recruited from the Optometry Clinic at the School of Optometry, University of Waterloo. All the participants had visual acuity better than 6/9 and had no known visual field defects. They were free of systemic diseases(based on information available from their Clinic files) known to affect eye movements (e.g. Parkinson's disease, uncontrolled diabetes, vestibular disease), as well as free of any known cognitive impairment. The cognitive status of the older participants was further assessed by an initial prescreening using the Mini Mental State Exam Questionnaire (MMSE) (Folstein, Folstein, & McHugh, 1975). All participants had a score greater than 27/30 on the MMSE and were thereby considered to be cognitively normal.

Approval for the study was obtained from the Office of Research Ethics at the University of Waterloo. Informed consent, in compliance with the Declaration of Helsinki, was obtained from all the participants. An honorarium was given to all the participants in appreciation for their time and involvement in the study.

Procedure and Stimuli

Stimuli were created using MATLAB version 7 in conjunction with the Eyelink toolbox (Cornelissen, Peters, & Palmer, 2002). Stimuli were back projected onto a screen located 2 meters from the participant. The resolution of the projector was set at 1024 X 768 pixels (LCD Projector model: Epson EMP 82). Participants provided responses by pressing appropriate buttons on a computer keyboard.

The experiment consisted of four sessions lasting between one and one and a half hours each. The sessions included one single task (baseline) and three dual tasks. Breaks were provided to participants upon indication by a verbal request to reduce the effect of fatigue. In the single task condition, the participant's task was to judge binocularly when an expanding vertical bar reached a fixed size as marked by an outline (12.5 degree X 1.26 degrees). When the target to be judged appeared on the screen the outline also appeared simultaneously. There were three speeds at which the target expanded (10.41degrees/ sec - Fast, 3.47 degrees/sec - Medium and 2.08 degrees/sec - Slow) with the actual times to reach the fixed size vertically set at 1200, 3600 and 6000 milliseconds.

For the baseline task the participants were asked to indicate by pressing a button on the keyboard with the right hand when the vertical bar had expanded to such an extent that it matched the size of the fixed outline. The eccentricities in which the vertical bar and the fixed outline appeared were set at 10 and 20 degrees in both the right and left peripheral visual field. The test stimulus was invisible on the first frame of each trial and expanded in size in the subsequent frames depending on the speed selected for the particular trial. A total of 100 trials were presented, randomized with respect to speed and stimulus eccentricity. Free viewing was allowed in all the conditions and no specific instruction was given as to where the participants should look. The data were obtained in terms of the actual size of the expanding bar, i.e., corresponding to when the participants indicated that it matched the outline. These values were later converted to a time estimate which is a direct linear transformation of size for a particular speed (12.5 degrees in size for the target expanding at the highest speed = 1200 msec; 12.5 degree in size for the target expanding at medium speed = 3600 msec; 12.5 degree in size for the target expanding at lowest speed = 6000 msec)

In the dual task conditions, there was an additional continuous task (which we refer to as the secondary task), where the participants had to keep an enlarging black square within the confines of an outer dashed square (4.2 degree X 4.2 degree) and an inner white square (1 degree X 1 degree) in the central visual field by pressing the space bar button on the keyboard . Pressing the spacebar on the keyboard, with the left hand, reduced the size of the black square and releasing the spacebar enlarged it. The size matching task was the same as the baseline condition where they had to judge when the target had expanded to a fixed size by pressing a button on the keyboard — Figure 4-1. In the dual task condition, free viewing was also allowed with no instruction as to where the participants should look.

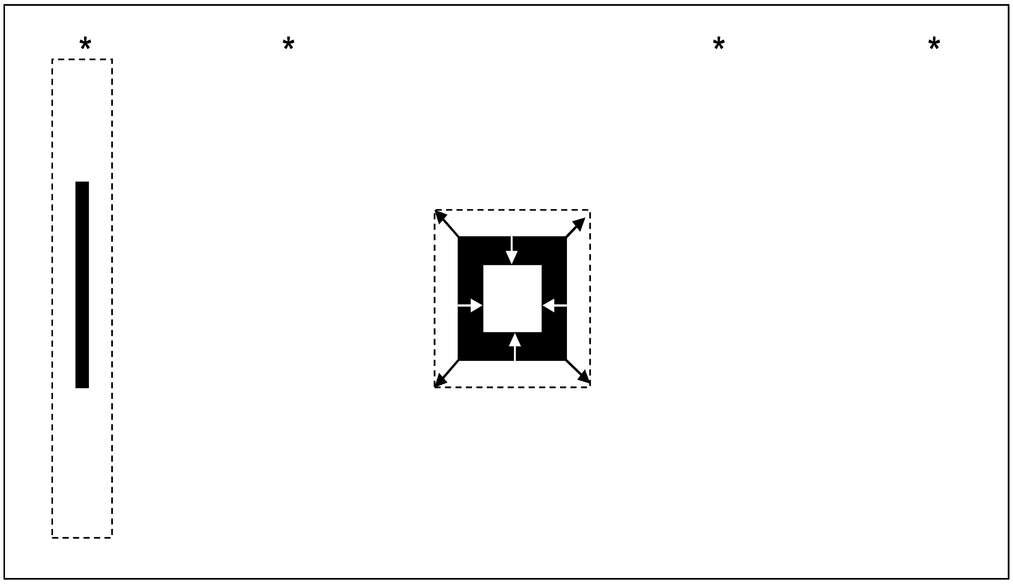

Figure 4-1: Representation of dual task paradigm.
For the dual task condition, the participant's task was to make sure that the enlarging black square stayed between the inner white square and the outer dashed square (continuous/secondary task). Pressing the spacebar on the keyboard reduced the size of the black square and releasing the spacebar enlarged it. The vertical expanding bar appeared simultaneously at one of four peripheral locations (*) and participants had to judge when the target had expanded to the dashed outer line (primary task).

In the three dual task conditions, the difficulty of the continuous central task varied. Specifically, the rate at which the black square enlarged in the central location was altered. The three dual task conditions were labelled Medium (70msec refresh rate), High (40 msec refresh rate) and Mixed (random combination of 40 and 70 msecs refresh rate) and will be referred to as such for the remainder of this paper. The time for the enlarging square to reach from the inner to the outer dashed square was 5.32 sec for the medium condition and 3.04 seconds in the high condition. If the participant pressed the space bar, the size of the black square reduced at a rate of .60 deg/sec for the medium condition (3.2 deg/ 5.320 sec) and 1.05 deg/sec (3.2 deg/3.04 sec) for the high dual task condition. Releasing the space bar resulted in increase in the size of the black square at the same rate as described above. In the mixed condition the increase and decrease of the size of the black square was based on the particular trial (i.e., whether it was a 70 msec refresh rate or 40 msec refresh rate and this was in random order). A new refresh rate for the black square started following a space bar press and release.

The first session for all participants was the single task or baseline condition. The order of the three dual tasks was randomized. In order to familiarize the participants with the keyboard buttons necessary for the appropriate responses, 50 trials were included as practice trials at the beginning of each session. The speeds (Fast – actual times 1200 msecs, Medium – actual time 3600 msecs and Slow – actual time 6000 msecs) at which the vertical bar expanded in each trial were also randomized within the 100 trials in each task. See Table 4-1 for the various possible combinations in the experiment.

Table 4-1: Possible combinations involved in single task and dual task conditions.

Tasks	Speeds	Speeds	Speeds
Single Task/Baseline	1200 msecs (10.41 degrees/sec)	3600 msecs (3.47 degrees/sec)	6000msecs (2.08 degrees/sec)
Dual task High (40msec refresh rate)	1200 msecs (10.41 degrees/sec)	3600 msecs (3.47 degrees/sec)	6000msecs (2.08 degrees/sec)
Dual task Medium (70msec refresh rate)	1200 msecs (10.41 degrees/sec)	3600 msecs (3.47 degrees/sec)	6000msecs (2.08 degrees/sec)
Dual task Mixed (40&70 msec refresh rate)	1200 msecs (10.41 degrees/sec)	3600 msecs (3.47 degrees/sec)	6000msecs (2.08 degrees/sec)

Eye Tracking

Eye movements of all participants were recorded, for all experiments, in order to investigate how participants switched their overt attention in the dual tasks. A video based eye tracker, EyelinkII®, was used to obtain gaze position. This eye tracker is comprised of three miniature cameras mounted on a padded head band – Figure 4-2. Two cameras allow for binocular eye tracking. The system makes use of dark pupil tracking wherein the cameras are mounted off axis with respect to the eye. A head-tracking camera integrated into the headband allows accurate tracking of the participant's point of gaze without the need for a bite bar. An extended marker cable with position markers for the edges of the screen was used as the stimulus was projected at 2m. These infrared position markers provide a head centric frame of reference in space. The eye tracker sampled at 250 Hz with a noise level of less than 0.01 degree.

The light levels of the cameras on the eye tracker were initially adjusted so that the pupil was detected. The eye tracker was calibrated for each participant, prior to data collection, using a nine point calibration array. Participants were asked to move their eyes to each target (dot) that appeared on the screen without moving their head. A successful calibration sequence was insured by determining how much the eye moved (as evident from the pupil marker) in response to each stimulus step in the calibration sequence. As we were using a nine point grid, the shape of the grid obtained from the gaze positions was visually inspected to confirm the status of the calibration. The use of excessive head movements or lapses in attention results in uneven shape of the grid.

Figure 4-2: The EyelinkII® eye tracker

Data Analysis

4.1.1.1. Analysis of the size matching task.

The data were sorted by the speed at which the peripheral target was expanding and the two eccentricities (10 and 20 degrees) for each of the four experimental sessions. An average value for each participant's response for each speed and eccentricity was calculated. These data were then analyzed using a repeated measures ANOVA (4 task conditions – 1single; 3 dual X 2 eccentricities -10 and 20 degree X 3 speeds – (Fast [1200 msec], Medium [3600msec], Slow [6000 msec]) with age group as the between subject variable. A post hoc analysis with a Bonferroni correction was used to compare the differences between the means of the variables (task conditions, eccentricities, speed). The ANOVA was done on size matched values obtained as degrees and not on the time estimate. This allows us to compare the differences between the three speeds of the vertical bar. In cases where the assumption of ANOVA with respect to sphericity was not met, the Huynh-Feldt corrected p values and degrees of freedom are reported. The effect sizes for each variable are reported as partial eta squared.

4.1.1.2. Eye movement data analysis

Eye movement data were analyzed using the Data viewer® (SR Research), a program specifically created for analyzing eye movement data from Eyelink eye tracker systems. In our tasks, there were five main areas to which participants fixated in order to judge the speed of the vertical bar and make a size match. For the dual task conditions, these areas were the central location (to keep the enlarging square within the boundaries) and 10 and 20 degrees in the visual field on both the right and left side (to make size judgments for the expanding vertical bar)- Figure 4-3. Dwell time percentage (time spent fixating at each location as a percentage of the total time) was obtained for each of these locations. The dwell time percentages at the central location for the dual task conditions were compared using repeated measures ANOVA with age group as the between subject variable and the task conditions as the within subject variable (3 dual task conditions).

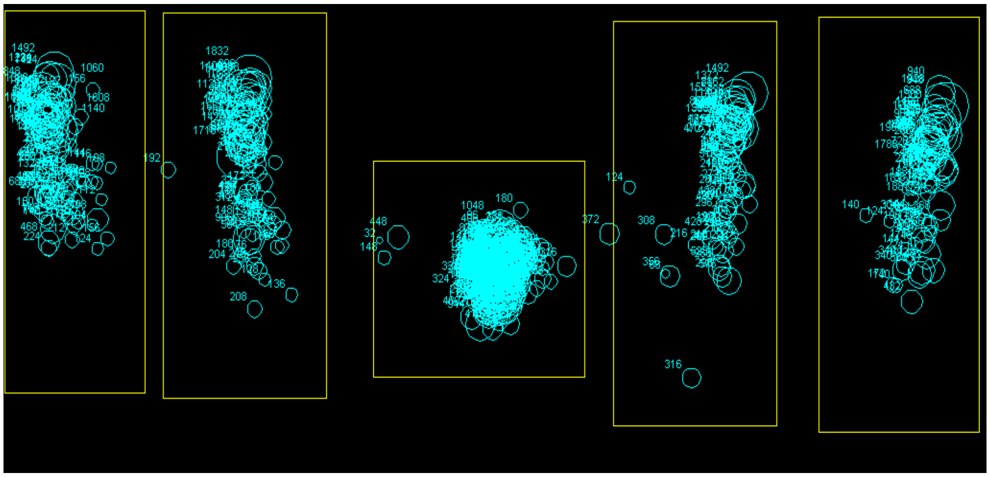

Figure 4-3: Visual areas divided into interest areas corresponding to the central and peripheral locations. The dwell time (%) refers to the time spent fixating at each location.

4.2. Results

Judgments of size of stimuli expanding at various speeds

A main effect of speed was found in all the task conditions [F(2, 36) = 23.30, p<0.0005] for size matching the vertical bar to the outline. There was a difference with respect to the two eccentricities (10 and 20 degrees) [F(1, 18) = 4.46, p = 0.048] but there were no interaction of the eccentricity effect with age or task condition or speed (p >0.05). There was a main effect of age [F (1, 18) = 6.07, p = 0.024]. There was no main effect of the task condition (F (2.38, 42.88) = 2.11, p = 0.125). There was significant interaction between task condition X age [F(2.38, 42.88) = 3.19, p = 0.019] and post hoc comparisons showed a difference in size matching for the medium dual task condition between young and old (p = 0.026). There was also a significant difference between the focused condition and medium dual task condition for the older group (p =0.005).

There was significant interaction between task condition X speed [F(1.68,30.39) = 3.91, p = 0.036] wherein differences between the single task and dual task conditions were observed at the fastest speed (10.41 degrees/sec) and not for medium (3.47 degrees/sec) and slow speeds (2.08 degrees/sec). There was also significant interaction between the speed X age [F(1.11, 20.11)=15.56, p <0.005]. See table 4-2, for the complete list of main effects and interactions of within and between subject variables.

Table 4-2: Main effects and interactions of within and between subject variables. The effect sizes of each variable are reported as partial eta squared.

	Degrees of freedom (H-F corrected)	F value	p value	Effect sizes partial eta squared
AGE	1,18	6.07	0.024*	0.252
TASK CONDITION	2.38,42.88	2.11	0.125	0.105
TASK CONDTION X AGE	2.38,42.88	3.19	0.019*	0.181
ECCENTRICITY	1,18	4.46	0.048*	0.198
ECCENTRICITY X AGE	1,18	1.35	0.258	0.070
SPEED	2,36	23.30	0.000*	0.564
SPEED X AGE	1.11,20.11	15.56	0.000*	0.463
TASK CONDITION X ECCENTRICITY	2.82,50.89	2.49	0.073	0.121
TASK CONDITION X ECCENTRICITY X AGE	2.82,50.89	1.49	0.229	0.076
TASK CONDITION X SPEED	1.68,30.39	3.91	0.036*	0.178
TASK CONDITION X SPEED X AGE	1.68,30.39	3.66	0.044*	0.169
ECCENTRICITY X SPEED	1.74,31.36	1.20	0.308	0.062
ECCENTRICITY X SPEED X AGE	1.74,31.36	0.05	0.927	0.003
TASK CONDITION X ECCENTRICITY X SPEED	3.28,59.15	0.56	0.654	0.030
TASK CONDITION X SPEED X ECCENTRICITY X AGE	3.28,59.15	0.30	0.839	0.016

Older participants were more affected by speed than younger participants with larger size matched values obtained for the fastest speed and smaller size matched values for the slower speeds. Significant effects were also seen in the interaction between speed X age X task condition (F (1.68, 30.39) = 3.66, p = 0.044). Older participants were not different from younger participants in the single task /baseline condition (p =1.000). There were significant differences between the dual task conditions and the single task condition in the older age group (p<0.0005), with the higher errors in size matched values observed in dual task conditions. There were no differences in the size matching judgments between the single and dual task conditions in the younger age group (p = 1.000).

At the highest speed at which the target expanded (10.41 cms/sec and accurate judgment being 1200 msecs), the older age group was different from the young age group in all the dual task conditions ($p < 0.0005$ for medium dual task, $p < 0.0005$ for high dual task, $p < 0.0005$ for the mixed dual task condition) — Figure 4-4. The older participants required more time to respond and the mean error was 144.02, 129.44 and 114.97 msecs for the medium, high and mixed dual task conditions respectively (+ve values represent times greater than the correct time i.e. the subject reacts too late, and vice versa for the – ve values). The mean errors for the younger participants were -2.31, 9.15 and 4.72 msecs (Table 4-3). For the trials in which the target is expanding at the highest speed this relates to an increase in size by 1.03 degrees for every 100 msecs.

There were no differences between the age groups when the targets were expanding at the medium or the lowest speeds (accurate judgments for speeds being 3600 and 6000 msecs respectively) — see Figure 4-4. The errors (Table 4-3) in the case when the target was expanding at the medium speed (accurate estimate being 3600 msec) were -9.59, 9.00 and 3.26 msecs for the younger group for the medium, high and mixed dual task conditions. For the older participants the mean error was 21.59, 7.30 and -19.49 msecs respectively in each of the dual task conditions. It has to be noted, for the medium speed at which the vertical bar expands, for every 100 msec the change in size is only 0.35 degrees.

For the slowest speed at which target is expanding (accurate estimate of 6000 msecs), the mean errors (Table 4-3) for the younger participants were 93.01, 60.18 and 29.78 msecs in the dual task conditions, medium, high and mixed conditions respectively. For the older participants, the errors were much higher, on the order of -246.27, -356.64, and -165.41 for the medium, high and mixed dual task conditions respectively. It should be noted that the change in size is 0.21 degrees/100 msec. The time error in this case only reflects a very small error in size for the slowest speed. The errors from the estimated time of 1200, 3600 and 6000 for both groups are shown in table 4-3.

Table 4-3: Accuracy of the time estimate for the vertical bar to reach fixed outline (±standard deviation). The positive values represent higher than correct time and negative values show lower than correct time.

Speeds	**Conditions**	**Mean (± SD) Young**	**Mean (± SD) Old**
Fast(10.41degree/sec) -1200 msec	Baseline	+7(±20)	17(±41)
Fast(10.41degree/sec) -1200 msec	Dual (Medium)	-2(±33)	144(±176)
Fast(10.41degree/sec) -1200 msec	Dual (High)	9(±20)	129(±83)
Fast(10.41degree/sec) -1200 msec	Dual (Mixed)	4(±36)	114(±67)
Medium (3.47 degree/sec) -3600 msec	Baseline	0 (±28)	-15(±38)
Medium (3.47 degree/sec) -3600 msec	Dual (Medium)	-9 (±37)	21(±72)
Medium (3.47 degree/sec) -3600 msec	Dual (High)	-9(±39)	7(±159)
Medium (3.47 degree/sec) -3600 msec	Dual (Mixed)	-3(±48)	-19 (±45)
Slow (2.08 degree/sec)- 6000 msec	Baseline	-39(±31)	-107(±87)
Slow (2.08 degree/sec)- 6000 msec	Dual (Medium)	-93(±81)	-246(±423)
Slow (2.08 degree/sec)- 6000 msec	Dual (High)	-60(±52)	-356(±264)
Slow (2.08 degree/sec)- 6000 msec	Dual (Mixed)	-29 (±54)	-165(±183)

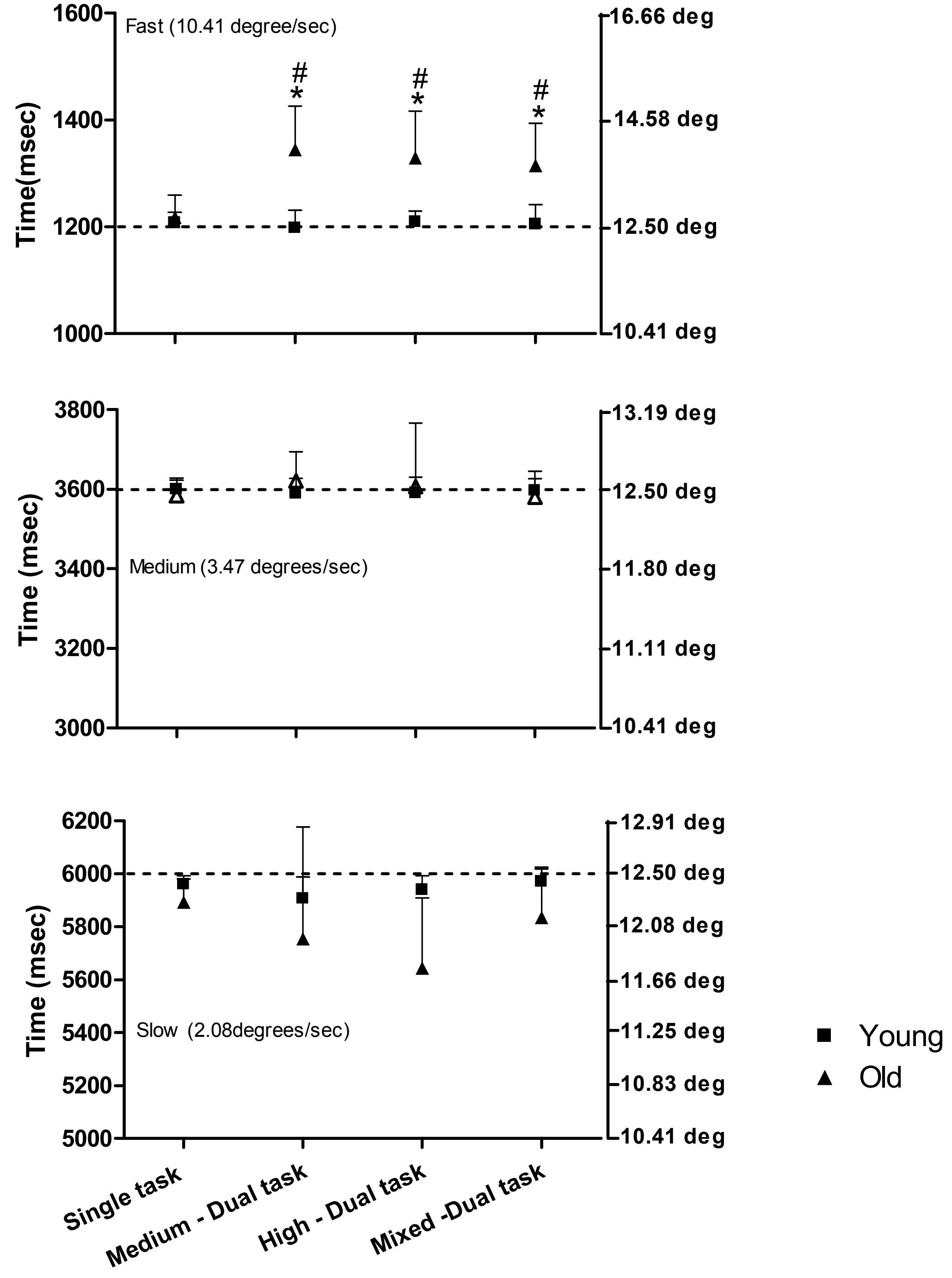

Figure 4-4: Time estimation of size of the peripheral target for the three speeds: Fast, Medium, and slow. The 4 conditions are plotted on the X axis and the Y axis represents the time at which the size matches were made. The asterisks (*) denote significant differences between the age groups and (#) sign represents differences between the focused and dual task conditions. The data represents means and SE of the two groups. The dashed line represents the time to make an accurate size match. The data shown is pooled from values obtained for both 10 and 20 degree eccentricity. The size of the target that corresponds to the time is shown on the right Y axis.

Eye movement analysis: A comparison of the dual task conditions

Dwell time, as a percentage of total time, spent fixating the central location (continuous task) for the three dual task conditions was analyzed using repeated measures ANOVA (3 dual task conditions – Medium, High, Mixed). For the repeated measures analysis, the task condition was the within subject variable and age was between subject variable. There was a main effect of age [$F(1, 18) = 5.26$, $p = 0.034$] with the older participants having a higher percentage dwell time at the central location. There was a main effect of task condition [$F(2, 36) = 8.07$, $p = 0.001$] with the highest dwell time percentage seen for the high dual task condition. There was no significant interaction between age X task condition [$F(2, 36)=1.71$, $p = 0.194$]. Overall the older participants were spending more time at the central location in all the three dual task conditions compared to the younger age group — Figure 4-5. The dwell time percentage at the central location also varied with the complexity of the task such that the highest percentage dwell times were observed for the high dual task conditions (40 msec refresh rate) followed by medium (70 msecs refresh rates) and mixed dual task conditions (combination of 40 and 70 msec refresh rates) — Figure 4-5.

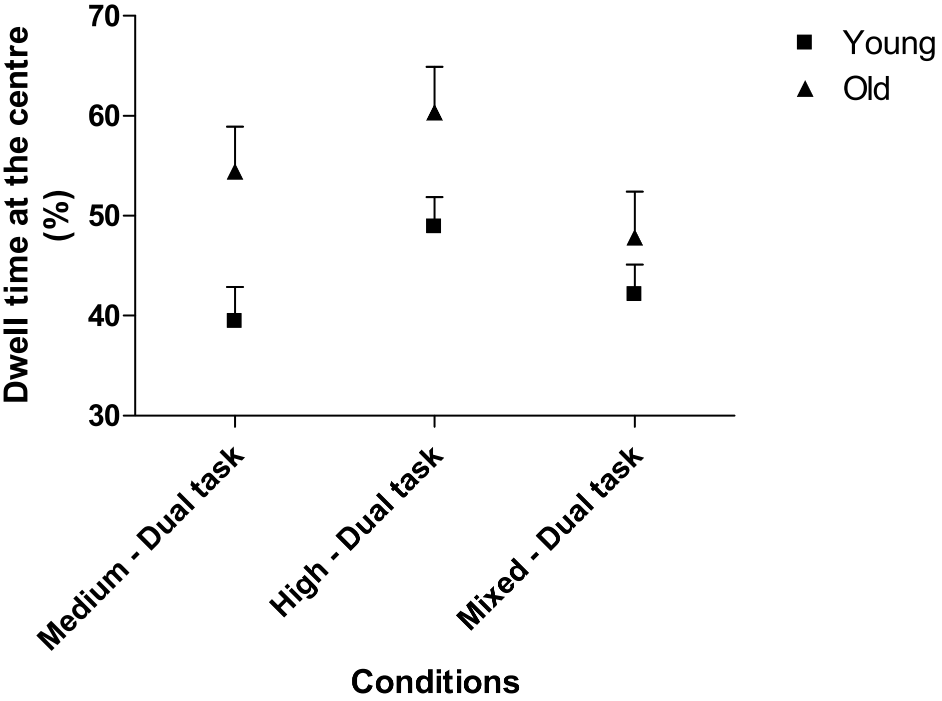

Figure 4-5: Means and SE of the two groups for dwell time %. Data is pooled from the two eccentricities (10 and 20 degrees) and the 3 speeds (Fast, medium, and slow).

4.3. Discussion

The results of our experiment show that the judgments of the size of the enlarging target (peripheral) are not different between the younger and older age group for any of the three speeds at which the vertical bar expanded in the single task/baseline condition. The older individuals were able to make the size match as accurately as younger individuals, when there was no additional task. Although, slowing of reaction time with increasing age (Der & Deary, 2006) could be a possible confound that could affect the results pertaining to the analysis of speed, the baseline results show that simple differences in reaction time between the groups, if any, cannot explain the rest of the results. For faster speeds than those utilized in this study it is quite possible that manual reaction time differences might have confounded the results when studying dual task situations. As there are no differences for the three speeds in the baseline conditions, the effect of the rate at which target is expanding is not solely responsible for the effects obtained in the experiment.

Differences between the age groups were observed in the dual tasks. The dual task paradigm utilized in our experiment required attention resource sharing between two locations, one being at the central location and other being at the peripheral location. As indicated by the results, the difference observed between the two groups was greatest when the speed of the vertical bar at the peripheral location was the fastest (10.41 degrees/sec). The current results may be explained by the work on dual task interference effects (Levy, Pashler, & Boer, 2006; Pashler, 1994a). These are observed when the time between two tasks, usually referred to as stimulus onset asynchrony or SOA is smallest. In such cases the interference is reflected by an increase in reaction time in response to the second task. This increase in reaction time to the second task is referred to as the psychological refractory period (PRP) effect (Levy et al., 2006; Pashler, 1994a). In our experiment we have two tasks to be performed simultaneously, wherein one of the tasks is continuous in nature and requires constant visual attention and manual manipulation. The second task (peripheral task) involves anticipating the correct size based on the judgment of the speed. Considering the two tasks, we assume that the time interval between them (usually referred to as SOA) is smallest when the peripheral target is expanding the fastest. At the fastest speed, the amount of available time for an accurate response is 1200 milliseconds. In dual tasks, if the participants switch their attention to the peripheral target at the onset of the stimulus, then 1200 msecs is available, but if more time is taken to switch from the continuous central task, the available time to respond decreases. As observed in other studies of dual task interference especially PRP experiments (Hartley & Little, 1999; Korteling, 1991; Pashler, 1994a, 1994b), as the time between the two tasks becomes smaller, greater performance decrements are observed. Now consider conditions for slower speeds. If the participants switch attention at the onset of the stimuli, there is either 3600 msecs (medium speed) or 6000 msecs (low speed) available. Therefore, if we consider the continuous central task as one task and the peripheral task as the second task, then we can assume that there is more time between the two tasks when the peripheral task expands more slowly. As suggested before, if the time between the two tasks is greater then there is less chance of dual task interference.

Why is the interference in our case observed only in older individuals? The absence of a difference for the younger population between the single and dual tasks might relate to their ability to more effectively switch their attention between the two tasks (central and peripheral task in dual task conditions). Age related differences have been observed in dual task performance, with aging (> 60 years of age) resulting in greater dual task costs (Hartley, 2001; Hartley & Little, 1999; Korteling, 1991; Tsang & Shaner, 1998; Verhaeghen et al., 2003). In a study (Tsang & Shaner, 1998) that required participants to track both the horizontal and vertical components of a moving cursor concurrently (the horizontal component of the moving cursor was controlled by the right hand and the vertical component was controlled by the left hand), it was observed that older participants had greater performance decrement in comparison to younger individuals. Our study also requires maintaining attention on two parameters wherein both require manual manipulation of targets judged visually. A greater resource allocation on one task will lead to poor performance on the other. Age related decline in dual task performance has been found to go beyond the effects caused by generalized slowing with age, as shown by a meta analysis study of age related differences in cognitive tasks (Verhaeghen et al., 2003). They found that a single linear function cannot explain the differences in single and dual tasks when comparing the latency differences between young and older participants. Dual tasks were shown to involve an additional stage of processing resulting in increased latency differences when comparing young and older individuals. This additional processing required by the older individuals might explain the difference in performance between the young and old age groups that we observed in our experiment. Also this might explain the difference between the single and dual task differences observed in the older individuals but the lack of difference between the different dual task conditions.

The results also suggest that even though dual task interference is usually observed with shorter time between two tasks, the older adults appear to experience interference with much greater time between two tasks than young adults (Hartley & Little, 1999). For example, if an SOA of 50 msecs is required to result in dual task interference in young adults, a 200 msecs difference between two tasks might result in dual task interference in older adults. In other words, older individuals require greater processing resources for performing either task and hence once the working memory (in this case the visuo - spatial sketch pad) is loaded with more than one stream of information, it results in reduced processing resources to perform the second task (Baddeley, 1986; Baddeley & Logie, 1999).

It could be argued, based on the fact that there is no baseline for the central task that the differences observed between young and old are due to the complexity in performing the continuous central task. However, if this was the case then a difference between young and old should have been observed for all three speeds of the peripheral target, which was not the case. There should also have been differences between the three dual task conditions for all the different speeds of the peripheral target. The fact that this was not the case indicates that the central task was not preventing the performance of the easiest peripheral tasks and therefore, presumably, performance of the central task alone would also not be different between the groups.

There is also a possibility that the effects we are observing are not due to dual task interference but related to the strategy that is employed. If the participants always respond to the target when it is, for example, 90 % the final size, then for a reaction time of 400 msecs (assumed), a target that is expanding at 10.41 degree/sec (fastest speed) will become much bigger in that time frame compared to the target that is expanding at 2.08 degree/sec (slowest speed). This still does not explain the differences between the single and dual task and hence we conclude that there is most likely a dual task interference effect. However, it could be argued that such a strategy is employed in the case of dual task but not in the baseline conditions as there are more attention resources available when performing the baseline task.

One other question we posed was whether eye movement data, specifically dwell times, indicate difficulty in attention switching between multiple locations in dual task conditions. Attention is known to be in close interaction with the eye movements (Bichot, 2001; Crawford & Muller, 1992; Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995). In an eye movement study (Eizenman, Harbluk, & Noy, 2002), the changes in search behavior of participants were studied when a cognitive load was introduced by a cell phone conversation task. They found that due to the additional processing required to carry out the cell phone conversation, visual search was restricted to the central visual field region. Miura (1990), analyzing the role of eye movements while driving, also showed that as the driving difficulty increased due to situational demands (highly crowded route, expressway driving etc), a greater proportion of fixations were in the central location in comparison to the peripheral locations (looking for signs etc). Thus the analysis of eye movements in the study of Eizenman, Harbluk, & Noy. (2002) & Miura (1990) report changes in visual search behavior of participants when cognitive load is increased.

Similar to the above mentioned studies (Eizenman, Harbluk, & Noy, 2002; Miura, 1990), a change in eye movement pattern was observed in our experiment for the dual task conditions. Our analysis of the dual task conditions showed that there was more time spent at the central location in comparison to the peripheral location in the older group compared to the younger age group. This suggests the use of greater attention resources for performing one task, resulting in higher dwell time percentage in that location. The results also show that, as the difficulty of the continuous central task was increased by manipulating the rate, there was an increase in dwell time percentage for both the groups. If we observe how the dwell time percentage varies with the complexity of the task then we can see that the highest percentage dwell time is for the dual high conditions (40 msec refresh rate) followed by mixed (combination of 40 and 70 msec refresh rates) and then for medium dual task conditions (70 msecs refresh rates). Importantly, the result suggests that the older participants spend more time at the central location and thereby could be switching to the peripheral location at a later instance. Such an event reduces the time between the central and peripheral task (shorter SOA), and thus results in a greater chance for dual task interference.

Why is it important to study dual task interference? The importance of investigating dual task interference is that dual tasks exist in real world situations and are particularly common in driving. In general, driving encompasses a complex environment wherein individuals have to make decisions about the distance of the lead car as well as the presence of pedestrians and other vehicles in traffic. Also, while driving, the person has to judge distances while making lane changes at the same time maintain a safe distance with the lead car. Hence in many situations while driving, a dual task behavior is observed. Dual task interference effects were investigated in an experiment designed to resemble a driving situation (Levy et al., 2006). The reaction time for braking was studied on a driving simulator (Levy et al., 2006), where participants also had to respond to whether a visual or auditory stimulus was presented once or twice. Presentation times for the stimulus for braking (in this case braking by the lead car) and the secondary visual or auditory stimulus were varied to create various SOA's. The braking reaction times at shorter SOAs between the stimulus for braking and secondary visual or auditory task were found to be slower.

The stimulus used in our study was designed to resemble a driving situation where the person has to maintain a certain distance from the lead car. The central continuous task in our study requires the participant to make sure an expanding stimulus stays within a fixed boundary can be considered similar to maintaining a safe distance from the lead car when driving. The task of judging the speed and making a size match may be similar to avoiding a collision with a peripherally moving target.

In summary, we observe difficulty in attention switching in elderly in dual task scenarios. Analyzing eye movements as employed in this study might help in predicting the difficulty in attention switching.

5. Chapter 5: Experiments on the Attended Field of View

Visual search refers to searching for objects in the visual field, an activity that is part of daily life. The search can be effortful, where a person has to search hard for a single object in a clutter—like looking for a missing pen on a disheveled desk. In other cases, the object seems to appear almost immediately from the background clutter due to certain characteristics of the object such as colour, size, shape etc (Smilek et al., 2007). This is referred to as “pop out” in visual search (Treisman & Gelade, 1980; Wolfe, 1998; Wolfe & Horowitz, 2004). Pop out effects have been observed in visual search experiments, where the reaction time to locate the object does not change with an increase in the number of distracters or the display size (Meinecke & Donk, 2002; Smilek et al., 2007; Treisman & Gelade, 1980; Trick & Enns, 1998; Wolfe & Horowitz, 2004). Such pop out effects are said to be due to pre-attentive or parallel processing (Bergen & Julesz, 1983; Plude & Doussard-Roosevelt, 1989) where the characteristic of the stimulus on account of its salience (difference from other objects for e.g., colour, onset, motion) results in attentional capture to that location.

Visual search forms the basis of some tests that measure the functional field of view. The term functional field of view (FFOV) is used here as a generic term and is described differently by various authors. Mackworth (1965) defines it “as the area around the fixation point from which information is briefly stored and read aloud during a visual task”. Ball et al. (1988) describe the FFOV as the total visual field area from which information can be extracted without eye and head movements in situations of divided attention or clutter and refer to it as the “Useful field of view” (UFOV) (Ball & Owsley, 1993; Ball, Roenker et al., 1990; Roge et al., 2005; Scialfa, Thomas, & Joffe, 1994; Sekuler & Ball, 1986; Sekuler, Bennett, & Mamelak, 2000). Standard visual field measurements, as obtained with perimetry testing, assess the overall visual field as well as its sensitivity. Such testing, only requires the detection of a change in luminance at a point within the visual area (Ball, Owsley, & Beard, 1990b). On the other hand, the functional field of view represents the area from which information such as the location and identity of a target can be detected (Ball, Owsley et al., 1990b). The size of the functional field of view is usually less than the size of the overall visual field. This measurement is shown to be more useful for real world situations where there are multiple inputs that need to be processed simultaneously (Ball, Owsley et al., 1990b; Owsley, 1994; Owsley & Ball, 1993).

Various tests exist that attempt to measure FFOV. Some research groups have used the UFOV® test wherein a target (e.g., a smiley face) is to be localized and identified, with or without distracters, with a presentation of approximately 100 msec and in a 30 degree binocular visual field (Ball et al., 1988; Leat & Lovie-Kitchin, 2006; Myers, Ball, Kalina, Roth, & Goode, 2000; Owsley & Ball, 1993). Coeckelbergh et al. (2004a; 2004b) used a similar paradigm but in their test, the target had to be detected and identified amidst distracters, but the use of eye and head movements were allowed. Coeckelbergh et al. (2004a; 2004b) call this the attended field of view (AFOV) and define it as the area from which information can be extracted with the use of eye and head movements. The authors use the term “viewing efficiency” to represent the time taken to locate the target amidst distracters to describe the functional field of view. The rationale for creating this new test was that, in real life, we seldom perform visual search without moving our eyes and head. In studies that utilize the UFOV® test, the presentation time for which targets are displayed is always less than the latency of eye movements (i.e., less than 200 msecs).The studies that use UFOV® and AFOV tests are utilizing the attentive processing capabilities, such that, when the target is dissimilar from the distracters by one feature, it should pop out from the background, making target identification relatively easy. If the target always pops out from the distracters, the accuracy would be near 100% and very short presentation times would be needed to detect the target. The dynamic nature of the functional field of views is demonstrated by using different target and distracter similarity/dissimilarity (Bergen & Julesz, 1983; Scialfa et al., 1987).

In a study by Coeckelbergh et al., (2004a) longer presentation times were required to localize and detect a target at farther eccentricities (reduced viewing efficiency at more peripheral locations) in comparison to presentation times required to detect targets near the centre. This was probably because the task was more complex than many studies of pop-out that tap into the preattentive mechanisms and suggests poorer attentional selectivity in the peripheral visual field. The eccentricity effect remained even after the target and distracters were scaled in size for compensating for the visual acuity decrease in the peripheral visual field.

The functional field of view is found to be affected in conditions of divided attention (Ball et al., 1988; Ball, Roenker et al., 1990). When performing more than one task simultaneously, there is engagement of the working memory that is separated into a part responsible for visual stimulus (visuo-spatial sketch pad) and a part responsible for dealing with auditory information (phonological loop) (Baddeley, 1996; Baddeley & Della Sala, 1996; Baddeley & Logie, 1999). The limited capacity of these resources necessitates prioritization of some inputs at the cost of others. Moreover, if performing two visual tasks at the same time requires tapping into the same mental processing resource (visuo-spatial sketch pad) then it can result in a processing "bottle neck". This refers to competition at a site that is limited in capacity wherein one of the tasks has to wait for the other to be completed. Another possibility that could occur when two tasks are performed simultaneously is "cross talk" (interference arising because of unintentional coupling between information from the two tasks) of the information resulting in increased delay in performing the task (Kahneman, 1973; Kinsbourne, 1981; Navon & Miller, 1987; Pashler, 1994b). In the context of visual search, all information available from the visual scene cannot be attended to simultaneously. When divided attention is required, the FFOV, as described by its size, is different than when attention sharing is not required (Ball, Roenker et al., 1990; Murata, 2004; Sekuler et al., 2000). Various methods have also been used to investigate the functional field of view in conditions of divided attention. The UFOV® (Ball, Roenker et al., 1990; Sekuler et al., 2000) includes this variable as well as the distracters mentioned above. Here central targets, such as a schematic of two faces (smiling/frowning), are displayed and participants are required to judge whether they are similar or dissimilar. At the same time as they are performing this task they are also required to detect the location of a smiley face in the peripheral visual field. Other researchers have used a perimeter with the addition of a central task. In this case the participants count the number of times a light flashes at the central location while also detecting peripherally appearing luminance defined targets (Haegerstrom-Portnoy et al., 1999; Brabyn, Schneck, & Haegerstrom-Portnoy, 2001). The amount of attentional resources spent performing one task affects their ability to detect other targets in the visual field (Haegerstrom-Portnoy et al., 1999; Murata, 2004). There are discrepancies regarding the results obtained when tasks that involve dividing attention were performed. Sekuler &Ball (1986) in one of their experiments had a UFOV® condition that included a central task and distracters. Peripheral target localisation errors were considered as the outcome variable. The peripheral localisation errors obtained were not different when compared to a condition where they only had distracters without the additional central task.

Age is another factor that has been shown to affect the functional field of view. Similar to the many physiological visual changes that occur with old age (>70 years) (Haegerstrom-Portnoy, 2005; Haegerstrom-Portnoy et al., 1999) attentional factors are also affected (Ball, 1997). The ability to selectively attend to relevant stimuli and disregard irrelevant information decreases with age. Older participants are unable to disregard irrelevant information (Ball, Roenker et al., 1990; Rabbitt, 1965). Such changes in attention result in a reduction in performance for measures of functional fields that require participants to locate a target amidst distracters. Furthermore, these changes have important functional implications which relate to everyday activities (Owsley, 1994; Owsley & Ball, 1993; Roge et al., 2004; Wood, 2002; Wood et al., 2006). A greater number of "at fault" crashes involving the elderly occur at intersections (Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998). This might relate to the increased number of potential distracters at intersections and the inability of elderly drivers to ignore such distracters. There are greater opportunities to crash at an intersection, where decision making regarding turning or giving way etc is required.

In our study, the AFOV test was used to measure the functional field of view and the effect of eccentricity was investigated. The AFOV test describes the performance over the field as "viewing efficiency" and represents the time taken to locate the target amidst distracters. We also introduced an additional distracter in the AFOV test. The additional distracter was dissimilar in one feature, namely colour, from all the other distracters. In doing so, our assumption was that this particular distracter would attract more attention than the target (due to its greater dissimilarity from the target and other distracters) and therefore make target identification more difficult. We investigated the viewing efficiency, as measured by the AFOV, in conditions with and without divided/dual attention and how the viewing efficiency changes with the presence of an additional "pop out distracter".

The effect of age was also investigated by comparing the result with a group of young adults. The question we posed was whether there is reduction in viewing efficiency in the elderly as measured by AFOV test. Secondly, do older people find it harder to ignore an irrelevant pop out distracter resulting in reduced viewing efficiency? Thirdly, do older people perform more poorly in conditions of divided attention on the AFOV, both with and without the presence of a pop out distracter?

5.1. Methods

Participants

Nine young adult participants with a mean age of 25±6 years and 9 older participants with a mean age of 72±4 years participated in the experiment. The younger participants included students and staff, recruited from the School of Optometry at the University of Waterloo. The older participants were recruited from the Optometry Clinic at the University of Waterloo and were screened for dementia and general mental well being using a standard MINI mental state exam questionnaire (Folstein et al., 1975). During the testing, the older participants were either provided with their near correction in a trial frame or asked to wear their own single vision near spectacles to allow for good visual acuity at the testing distance. All participants had corrected visual acuity better than 6/9 and no known visual field defects.

Approval for the study was obtained from the Office of Research Ethics at the University of Waterloo. Informed consent, in compliance with the Declaration of Helsinki, was obtained from all the participants.

Apparatus

A 19 inch LG monitor connected to a 2.4Ghz Intel Core PC was used to display the stimuli. Custom software for the attended field of view test was made using the Experiment Builder (SR Research®) after Coeckelbergh et al. (Coeckelbergh et al., 2004 a, 2004b). The participants were seated 50 centimeters from the screen with the eye level aligned to the centre of the screen. A standard keyboard and mouse were used to respond to the stimuli.

Procedure

The AFOV test designed following Coeckelbergh et al.,(2004a) involves binocular localization and detection of a white target (Landolt C) that at 50 cms subtends 1.1 degrees with a gap of 0.2 degrees from an array of 24 white rings that are positioned on a grid along eight radii (oriented at 0, 45, 90, 135, 180, 225, 270, and 315 degrees) and at three eccentricities (4, 8, and 12 degrees from the centre of the screen). The target and the distracter rings appear on a grey background giving 50% contrast. One white ring also appears in the central location, although the target never appears at this location. The target (Landolt C) oriented in one of the four possible directions (up, down, left, right) is displayed at 9 of the 24 possible locations (3 locations at each eccentricity) presented in random order, except that the location of the target was never at the same location as in the previous trial.

This was set such that the target could appear at any of the nine locations to be tested; that is, the order of presentation was randomized. The participants were not informed that only nine locations were tested. The time taken to perform the test would be considerably more if all the available 24 locations are tested and there are chances that participants might be fatigued. In order to reduce the amount of time required to perform the test only 9 of the available 24 locations were tested. The target and the other elements appear simultaneously in the display— Figure 5-1.

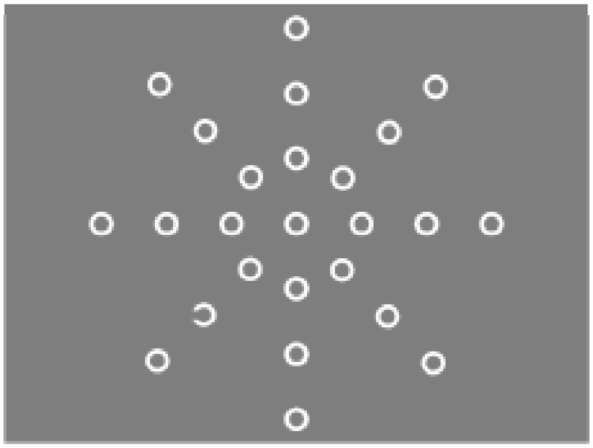

Figure 5-1: Representation of the stimulus used in the AFOV test (standard).

The experiment began with a central fixation cross being displayed for one second. Following this, the display containing the target at one of the nine locations and the other white circles (distracters) appeared (see Figure5-1). The initial presentation time was set at 350 msec. Following this, a mask (a combination of black, white and grey squares) appeared for 800 msec. The purpose of the mask was to eliminate any afterimages of the target and distracters. After the mask, the response screen appeared and the participants had to move the mouse and click at the location where the target was observed. If the target was not observed, the participants still had to guess the location. In the next screen, the orientation of the target was indicated by pressing the up, down, left or right arrow key on the key board. Following this, the fixation cross appeared at the central location and the procedure was repeated for the next trial. Those individuals who had difficulty with the mouse and keyboard were asked to point to the location and verbally report the orientation. The experimenter entered these responses using the mouse and keyboard for every trial. An independent staircase for the presentation time was run at each of the nine target locations. The presentation time was increased if localization of the target was incorrect and decreased if it was correct, in a weighted up-down manner (.2 log unit up and .1 log unit down), such that the percentage of increase was higher than the decrease. The presentation time of the display was varied such that for each position at which the target appeared, 67% correct localization of the target was to be achieved. A total of 40 trials were run at each location and in all cases more than 8 reversals were obtained. The average of the response reversals, excluding the highest and lowest reversal values, for each eccentricity was taken as the measure of time to locate the target. Although the orientation of the Landolt C was to be judged, this judgment did not affect staircase presentation time. We will be referring to the first experiment as the "standard AFOV".

In the second experiment, the effect of a single pop out distracter on the performance on the AFOV was investigated. The experimental task remained the same, but in this case, one of the white rings was replaced with a red ring (pop out distracter). The locations of the red pop out distracter varied with every trial randomly occupying one of 23 available positions. The participants were instructed to ignore the red ring and still search for the target (Landolt C)—Figure 5-2. The location of the target and the orientation of the "C" were identified as described in the first experiment. Experiment two will be referred to as "standard AFOV with pop out distracter".

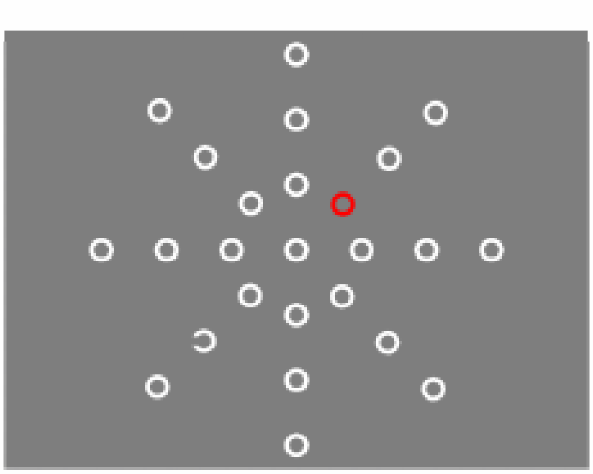

Figure 5-2: Representation of the stimulus in experiment two "standard AFOV with pop out distracter".

In the third experiment the AFOV test was modified to study divided/dual attention. The central target was replaced with an arrow oriented in one of four orientations (up, down, left or right). The experiment started with the display of a central fixation cross lasting for one second. After this the stimulus containing the target (Landolt C) at one of the nine locations and the distracters (other white circles) appeared along with the central arrow oriented in one of the four directions (up, down, left, or right)—Figure 5-3. This display was followed by a mask lasting for 800 msecs, as before. The responses, in this case, required the participants to first report the direction of the central arrow (using the arrow keys on the keyboard) and then indicate the location of the target. A response regarding the orientation of the Landolt C was not required in this case. This was done to avoid confusion between the orientation of the central target and the direction of the Landolt C.

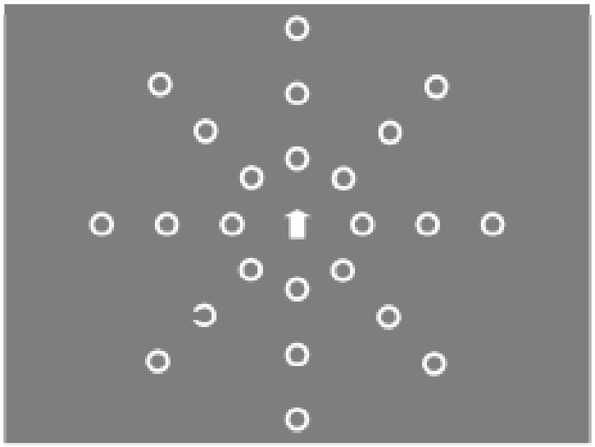

Figure 5-3: Representation of the AFOV stimulus in the divided/dual task conditions ("divided/ dual AFOV").

As in the standard AFOV, 9 locations were tested (3 at each eccentricity). Participants were not informed of the fact that some locations were not tested. A total of 40 trials were run at each location and in all the cases more than 8 reversals were obtained. In cases where the response for the direction of the central arrow was wrong, the trial was put back into the sequence of the staircase for that location. The number of trials increased if there was an error for the direction of the central target. Details regarding the staircase run at each location remained the same as described in experiment one. Experiment three will be referred to as "divided/dual AFOV".

The pop out distracter effect on the divided/dual AFOV was investigated in experiment 4. One of the distracter locations was replaced with a pop out distracter (red ring)—Figure 5-4. This experiment will be referred to as "divided/dual AFOV with pop out distracter".

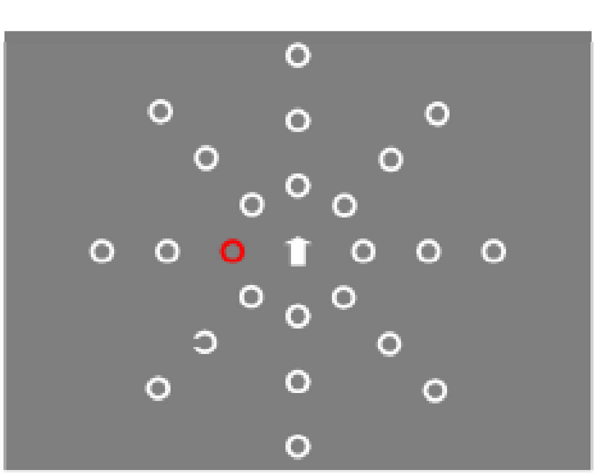

Figure 5-4: Representation of the stimulus in the AFOV test with divided/dual task conditions and the pop out distracter.

The order of the experiments was not counterbalanced based on the assumption that it would be too difficult to perform the pop out distracter condition as the first experiment. The effect of learning would play a role as the order of the experiments was not randomized or counter balanced, but the opportunity to learn remained identical for all the participants in this experimental design.

The inverse of the average presentation time in seconds for each eccentricity was log transformed and reported in terms of "viewing efficiency" (Coeckelbergh et al, 2004 a, 2004b).

$$Viewing\ Efficciency = Logarithm\ (\frac{1}{Average\ presentation\ time\ in\ seconds})$$

The logarithmic transformation, as suggested by Coeckelbergh et al., (2004a), made the distribution normal and allowed us to use parametric statistics to perform the analysis. The Kolmogorov-Smirnov tests also confirmed that the distribution was normal ($d = 0.1$, $p > 0.05$).

Statistical Analysis

A repeated measures ANOVA was performed on the log transformed data (Coeckelbergh et al., 2004a) ([2 tasks; pop out distracter vs. no pop out] x Eccentricity [4, 8 and 12 degrees]) for the standard AFOV and divided/dual attention AFOV. Comparison between standard AFOV and divided AFOV was also done using a repeated measures ANOVA ([2 tasks; standard AFOV without pop out distracter vs. divided/dual AFOV without pop out distracter] x Eccentricity [4, 8 and 12 degrees]). Similarly the same type of analysis was used for conditions comparing the standard AFOV with pop out distracter and the divided/ dual attention AFOV with pop out distracter. Age was considered the between subject variable in all cases. A post hoc analysis with a Bonferroni correction was used to compare the differences between the means. The p values reported are Huynh-Feldt corrected in cases where the assumption of ANOVA with respect to sphericity is violated.

5.2. Results

Results of Experiment 1 & 2 (standard AFOV and standard AFOV with pop out distracter)

There was a main effect of age [F(1,16) = 28.35, $p < 0.001$] and a main effect of eccentricity [F(2,32) =68.55, $p < .001$]. With increasing eccentricity, the viewing efficiency decreased. This was the case for both groups. There was no main effect of pop out distracter on the viewing efficiency [F(1,16) = 0.52, p = 0.478]. There was a significant interaction of pop out distracter X age [F(1,16) =0.067, p = 0.049] and a significant interaction of pop out distracter X eccentricity [F(2,32) = 8.04, p = 0.002]. A significant interaction was also observed for eccentricity X age [F(2,32) = 4.38, p = 0.021]. Post-hoc analysis on significant higher order interaction terms ($p<0.05$) showed that there was a significant effect of pop out distracter at the 4 degree eccentricity for the younger group (p = 0.014) wherein reduced viewing efficiency was observed in the presence of the pop out distracter. There was no impact of the pop out distracter at other eccentricities for either group with p values > 0.1 (figure 5-5). It can be seen that, at the 12 degree eccentricity, the viewing efficiency of the older group appears better with the pop out distracter than without, even though the difference was not statistically significant. The data were also plotted on a linear scale, depicting presentation times, as is common in other studies of functional field of view. Figure 5-6 shows this data on a linear scale. On this scale much greater differences may be observed. As we are only interested in relative differences that are depicted on log scale and the statistical analysis was also performed on log transformed data, we will base the discussion on Figure 5-5.

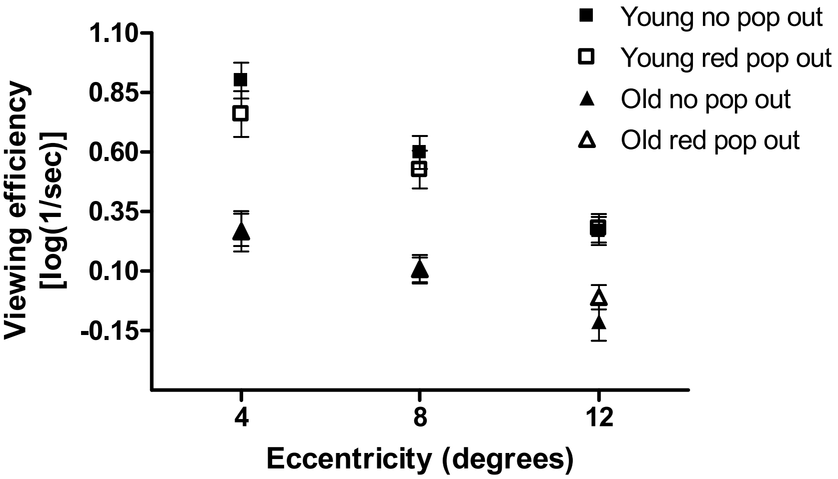

Figure 5-5: The graph represents the data for both groups from experiment 1 (standard AFOV without the pop out distracter) and experiment 2 (standard AFOV with the red pop out distracter). Viewing efficiency (logarithm of inverse of threshold presentation time in seconds) is plotted against eccentricity. The error bars represent standard error of the mean.

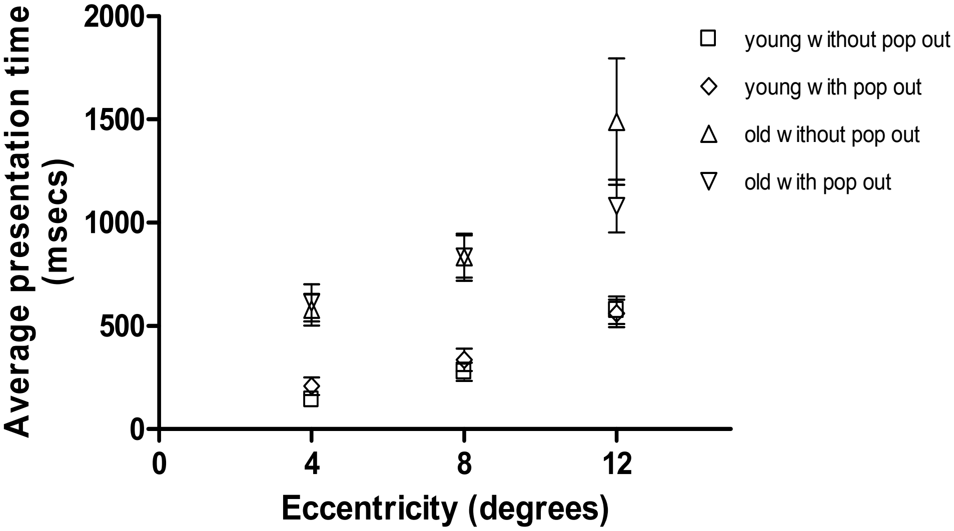

Figure 5-6: The data from figure 5-5 is represented on a linear scale. Average presentation time in milliseconds is plotted against eccentricity.

Results of Experiment 3 & 4 (divided /dual task AFOV and divided/dual with pop out distracter)

There were main effects of age F [(1,16) = 27.32, p <0.001] and eccentricity [F (2,32) = 68.55, p < 0 .001]. With increasing eccentricity, viewing efficiency decreased. This was the case for both groups. There was no main effect of pop out distracter on viewing efficiency [F(1,16) = 0.11, p = 0.748]. There was no interaction of pop out distracter X age [F(2,32) = 0.43, p = 0.519] nor for pop out distracter X eccentricity [F(2,32) = 0.42, p = 0.664]. Thus there was no impact of the pop out distracter at any eccentricity for either group, p values > 0.1 (figure 5-7). Figure 5-8 represents the threshold data on a linear scale.

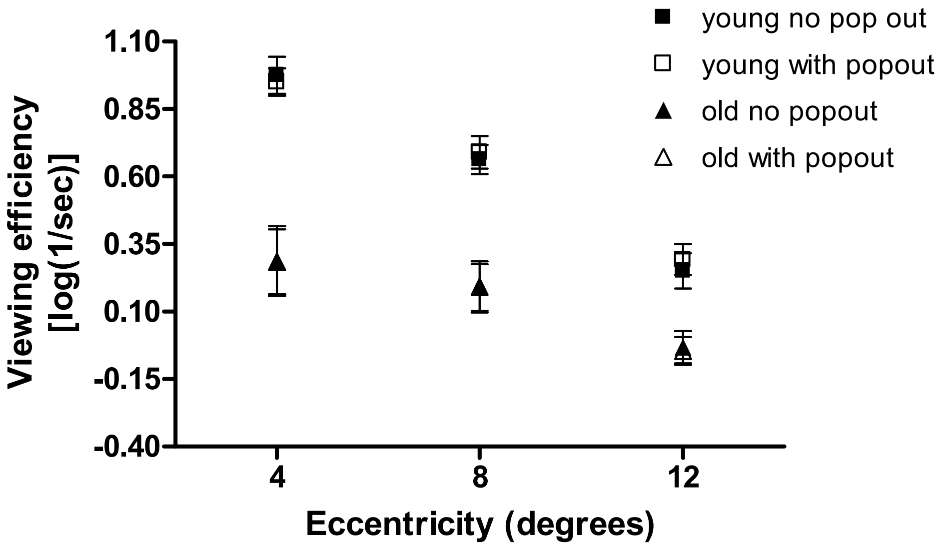

Figure 5-7: The graph represents the data for both groups from experiment 3 (divided/dual AFOV without the pop out distracter) and experiment 4 (divided/dual AFOV with the red pop out distracter). Viewing efficiency (logarithm of inverse of threshold presentation time in seconds) is plotted against eccentricity for both age groups.
The error bars represent standard error of the mean.

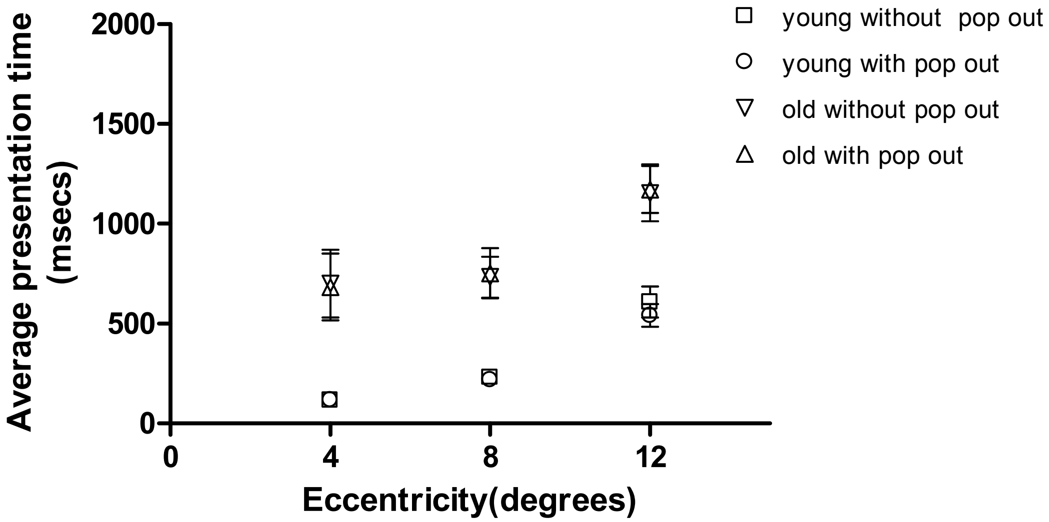

Figure 5-8: The data from figure 5-7 is represented on a linear scale. Average presentation time in milliseconds is plotted against eccentricity. The errors bars represent standard error of the mean.

Comparison of Experiment 1 (standard) and 3 (divided/dual AFOV)

There was a main effect of age [F(1,16) = 35.75, p <0.001] and a main effect of eccentricity [F(2,32) = 70.10, p <0.001). There was no main effect [F(1,16) = 2, p = 0.176) for the type of experiment (Standard vs. Divided/dual AFOV). There was no interaction [F(1,16) = 0.07, p = 0.797] between age and type of AFOV experiment (Standard vs. Divided/dual AFOV) and the trend was the same for both age groups – Figure 5-9.

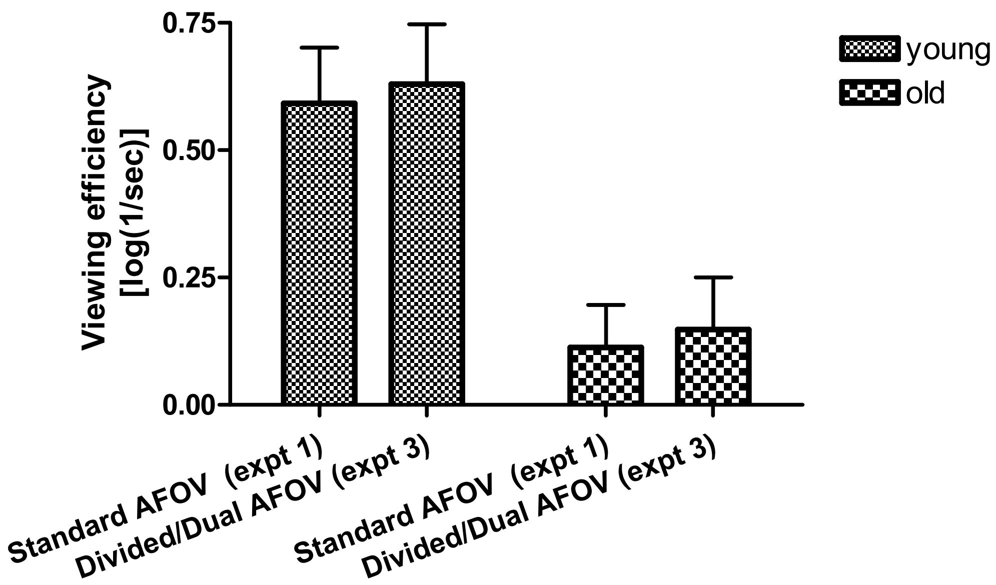

Figure 5-9: Comparison of data pooled for eccentricities for both standard AFOV and divided/dual AFOV. Viewing efficiency (logarithm of inverse of average presentation time in seconds) is plotted against type of AFOV for two age groups. The error bars represent standard error of the mean.

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Comparison of Experiment 2 (standard AFOV with pop out distracter) and Experiment 4 (divided/dual AFOV with pop out distracter).

There was a main effect of age [F(1,2) = 25.97, p <0.001]. There was also a main effect of eccentricity [F(2,32) = 62.52,p <0.001] and condition (whether it was standard or divided/dual AFOV) [F (1,16) = 5.25, p = 0.036]. Better viewing efficiencies were observed in divided/dual AFOV conditions. There was no interaction of this effect with age [F (1,16) = 2.62, p = 0.125] – Figure 5-10.

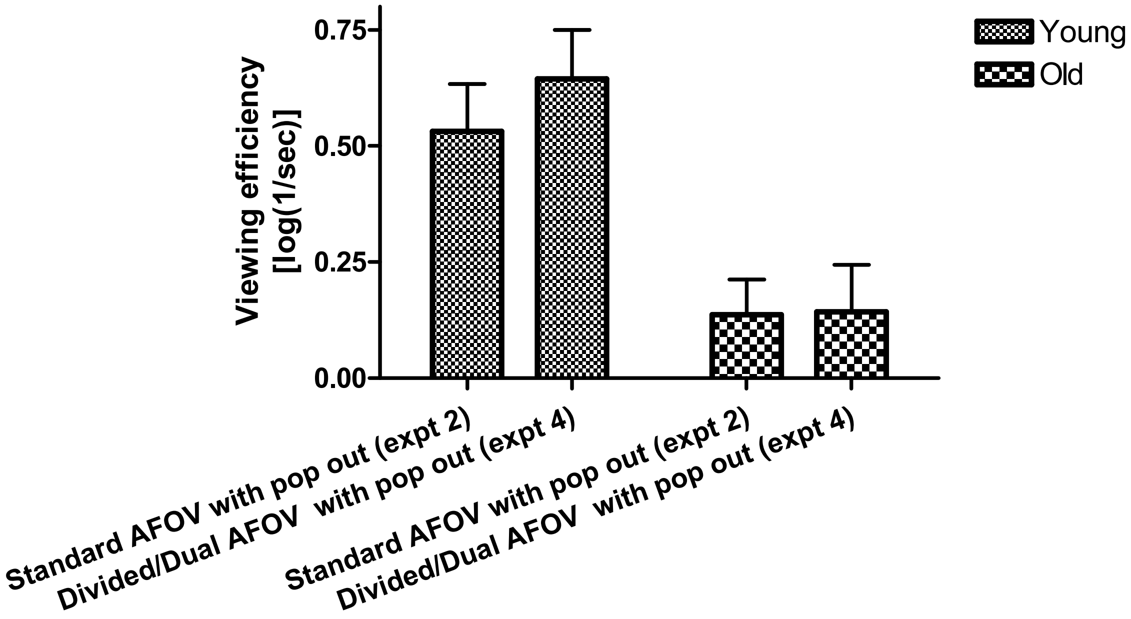


Figure 5-10: Viewing efficiency (logarithm of inverse of average presentation time in seconds) is plotted against type of AFOV for two age groups when the pop out distracter is present. Data is pooled for the three eccentricities.

Effect of pop out distracter location in Experiment 2 (standard AFOV with pop out distracter) and Experiment 4 (divided/dual AFOV with pop out distracter).

It is possible that the location of the pop out distracter in some cases might help in identifying target (Landolt C) location, by capturing attention to it. For example, if the pop out distracter is at a neighboring location to the target it might help to locate the target. In order to test this possibility, we investigated the location of the pop out distracter when wrong response reversals occurred in the staircase of presentation time. For the targets at 4 degree and 12 degree eccentricity, 5 locations were considered as neighboring locations. For the targets at the 8 degree eccentricity, 8 locations were identified as neighbors. The percentage of wrong response reversals when the pop out distracters were at neighboring locations was calculated and compared to the expected value. The expected percentage in this case was defined as 5 out of 22 (22 refers to the total number of available locations for the pop out distracter to appear) which corresponds to 22.72%, and 8 out of 22 which corresponds to 36.36%. The data obtained for the standard AFOV with pop out distracter and divided AFOV with pop out distracter are shown in figures 5-11 and 5-12. .

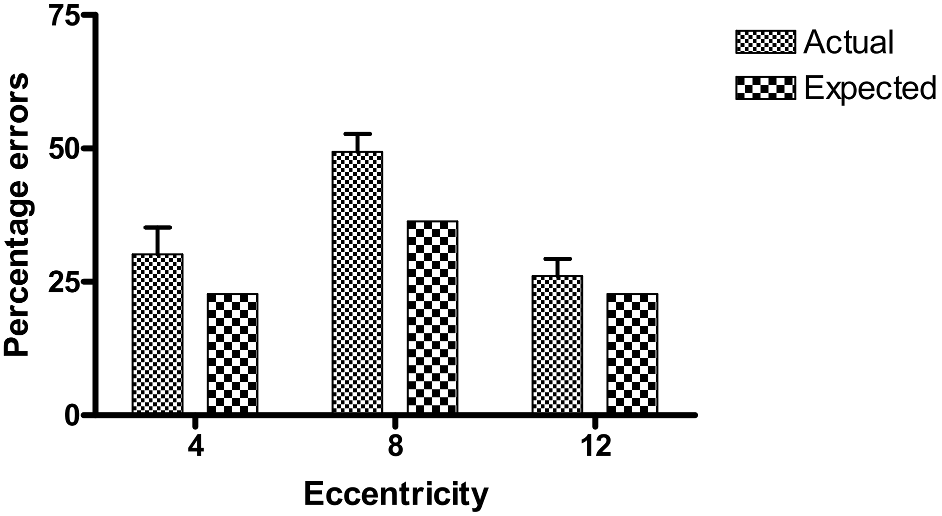


Figure 5-11: Pop distracter location effect on standard AFOV with pop out distracter – Experiment 2. Actual number of errors is shown against the expected.

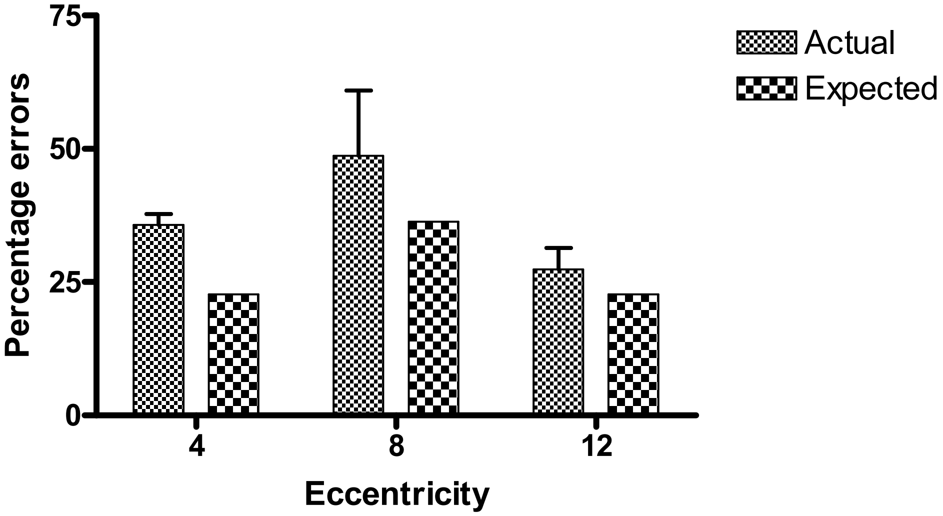


Figure 5-12: Pop distracter location effect on divided/dual AFOV with pop out distracter – Experiment 4. Actual number of errors is shown against the expected.

In all the cases, a higher than expected number of errors occurred when the pop out distracter was at a neighboring location. It was observed that about 30 % of the time, the pop out distracter was at a location near the target, for the 4 and 12 eccentricities. An even higher percentage was obtained for the 8 degree eccentricity, which was close to 50%. This indicates that incorrect response reversals did not occur only when the pop out distracter was far away from the target. This analysis should be considered qualitative only as there as other variables such as number of times that the target might have appeared at a particular location etc. that we have not taken into consideration.

5.3. Discussion

One of the main advantages of using the AFOV and UFOV® is that reaction time does not affect the outcome. Visual search experiments typically use the reaction time as the index to study search efficiency (Duncan & Humphreys, 1989; Meinecke & Donk, 2002; Smilek et al., 2007; Treisman & Gelade, 1980; Wolfe, 1998; Wolfe & Horowitz, 2004).

Generally, reaction times are found to be slower with age (Der & Deary, 2006; Welford, 1977). Therefore, when reaction times in visual search tests are used to measure the efficiency of older individuals it might be a confounding factor. In our study, the presentation times did not include a manual reaction time and variations in these times were based on response reversals in the staircase. As such, the problem of reaction time influencing the results was eliminated.

The results of the first experiment (standard AFOV) show that younger participants have better viewing efficiency than the older individuals' at all three eccentricities. Different search strategies utilized in identifying targets could be one of the reasons for the differences in viewing efficiency between groups. Parallel processing strategy refers to visual search where all the information is processed in parallel and involves the preattentive stage (Neisser, 1967; Treisman & Gelade, 1980). Such processing usually occurs when the target has one feature that is unique from all the distracters (Treisman & Gelade, 1980). The target pops out from the background resulting in very low reaction times required to identify the target and low presentation times to terminate the visual search. In serial processing, each item in the display is scanned (or an area is scanned) sequentially. Serial processing occurs when some features of the target are also shared by the distracters and the search is referred to as conjunction search (Treisman & Gelade, 1980; Treisman & Sato, 1990). The similarity of the target and distracters plays a role in characterizing whether the search is parallel or serial. More recent models of visual search (Wolfe, 1998; Wolfe & Horowitz, 2004) propose that there is no strict dichotomy as to whether a search is parallel or serial and should be characterized as "efficient searches" and "inefficient searches". Efficient visual search occurs when the target is identified quickly mostly by parallel processing. Inefficient searches start out with a parallel search but if the targets are not identified then serial processing starts. In this guided search theory of attention the proposition is that there is an initial parallel stage where the entire area is searched and compared based on basic features (attributes such as colour, shape etc). In the second stage the results of the parallel search guides attention to the particular area where the target is most likely to be present. In essence, an efficient search is not necessarily strictly parallel but the parallel processing stage is able to guide the attention appropriately so that very few locations are required to be searched using serial processing to identify the target. Inefficient searches are those where the initial parallel processing stage is not able to guide the attention to a particular location and hence results in many more areas being searched before the termination of the search. In a visual search task, certain attributes of the stimulus such as colour, motion, orientation, and size are known to be "undoubtful attributes" that guide attention (Wolfe & Horowitz, 2004). "Undoubtful attributes" in this case refer to characteristics of the stimulus that are certain to capture attention or guide the attention processing to locate a target. Other attributes such as shape, closure, and vernier offsets are considered "probable attributes". This refers to characteristics of a stimulus that may capture attention, although not always (Wolfe & Horowitz, 2004). Our AFOV test consists of a Landolt C target that is distinct from the distracters (white rings). Therefore, it is possible that the target pops out from the distracters and all items are processed in parallel and this results in efficient searches. The AFOV stimulus might also require a conjunction search as the target shares a colour feature with the distracter (white target and white distracters). Thus it is also possible to result in inefficient visual searches.

In the AFOV (standard), the target is different from the distracters in shape and closure, and since these are "probable attributes", the identification of the target can be the result of parallel processing or a combination of both parallel and serial resulting in either efficient or inefficient visual searches. It is possible that the younger participants are able to make more efficient visual searches and identify the stimulus quicker when compared to older individuals. As efficient searches have a greater contribution of parallel search and involve the preattentive stage (Neisser, 1967),thereby processing all the information at the same time, they require a lower presentation time (i.e., greater viewing efficiency on the AFOV).

We can also be certain that younger people are not always identifying the target using parallel search or making efficient visual searches since the viewing efficiency decreases with increased eccentricity. One of the many ways to distinguish the nature of the processing used in visual search is the finding of unaltered reaction times with increasing set size (i.e., the number of items in the display) and increasing eccentricity in parallel search. In other words, an eccentricity effect should not be observed if all the items are searched in parallel. Thus, the greater viewing efficiency that is observed with our central stimuli is likely to occur when there is a successful parallel search or, in other words, the target pops out from the distracters or is identified quickly—after scanning a very few items (serial processing) suggesting an efficient visual search. Reduced viewing efficiency is probably the result of unsuccessful parallel searches and the need for a greater number of elements to be scanned (serial processing) in order to identify the target and this points to an inefficient visual search. The differences observed between the two age groups tested could perhaps be due to older individuals resorting to a serial search more readily than the younger ones.

We also investigated whether the presence of the pop out distracter (the red ring) would result in reducing viewing efficiency on the AFOV (Experiment two – standard

AFOV with pop out distracter). Our results showed that the presence of the pop out distracter reduced viewing efficiency only in the younger individuals for targets near the central location. This could be the result of younger participants starting out using a parallel search and being successful in target identification or making more efficient searches near the central location without the pop out distracter. In conditions where the pop out distracter was presented in the visual field, the parallel processing ended when the pop out distracter was located resulting in less efficient visual search. This would be true as the colour attribute is considered to have stronger influence than the shape attribute in attracting attention or guiding attention (Wolfe & Horowitz, 2004). If this were the case then we could ask why the pop out did not have an impact at eccentricities of 8 and 12 degrees. The probable reason is that at these eccentricities the younger participants were not so successful in identifying the target as a result of the parallel search process even without the pop out distracter and might have already switched to using serial processing resulting in less efficient searches. A speculation is that in conditions where there is a greater role of serial processing resulting in inefficient visual searches, the pop out distracter will have little or no effect on the total time taken to identify the target. It is even possible that the pop out distracter improves viewing efficiency by eliminating one of the locations that needs to be searched to locate the target.

Another result we observed was that older individuals were not affected by the pop out distracter. If the older individuals are already making inefficient visual searches characterized by greater role of serial processing in the standard AFOV, then the presence of the pop out distracter will not result in increased presentation times as both the searches are relatively inefficient. Colcombe et al.,(2003), also found that the presence of an onset (target appearing abruptly) or coloured distracter did not affect their older group more than the younger individuals.

The results of experiments 3 and 4 assess viewing efficiency of the AFOV in dual/divided attention conditions with and without the pop out distracter. Similar to experiments 1 & 2, a significant impact of age was observed. The older group had reduced viewing efficiency compared to the younger individuals. The inclusion of the central task ensures that participants are starting their search from the central location. Moreover, if the participants were inaccurate on the central task, the trial was put back into the sequence of the staircase. Therefore, the differences observed between the groups can be explained on the basis of search process differences as suggested earlier (experiment 1 - standard AFOV). Again, the younger individuals may be successful on a greater number of trials because of the greater contribution of the parallel search process and that there is greater guidance from the feature to locate the target resulting in more efficient visual searches compared to the older individuals.

It is also possible that younger participants are able to process the information at the central location (dual task) and the location of the Landolt C at the same time or an efficient search characterized by greater contribution of parallel search. The older participants may be utilizing all their parallel processing resources just identifying the direction of the central arrow. To determine the location of the Landolt C, they might be required to perform a serial search. Their reduced viewing efficiency represents the time taken to identify the target and is of the order of 300 msecs per item at the farthest eccentricity. This strategy difference resulting in inefficient searches would result in reduced viewing efficiency for the older group.

Studies that have investigated visual search with divided attention tasks have shown that older people perform more poorly than their younger counterparts (Ball et al., 1988; Ball, Roenker et al., 1990; Richards, Bennett, & Sekuler, 2006; Sekuler et al., 2000). The differences between the age groups are explained to be due to greater divided attention costs for the elderly. However, not all studies that utilized UFOV® find greater divided attention costs for the elderly. A study by Sekular and Ball (1986), found that a central task did not have a greater effect than the presence of distracters on the functional field of views. Leat and Lovie-Kitchin (2006) found that the presence of distracters had a greater impact with aging than the competing central task. The results obtained from these studies suggest that the mere presence of distracters makes it harder for older individuals to identify the target location (Ball et al., 1990; Rabbitt, 1965, Leat and Lovie-Kitchin, 2006). Our results also show that there were no greater divided attention costs for either group as the comparison between the viewing efficiency with and without the central task shows no significant differences. In both the cases, the presence of the distracters could be the factor resulting in the poorer performance of the older individuals. Once distracters are present in the field it can result in a poor performance attributed to the complexity of the test (similar to floor effects) and hence in conditions of divided attention further deterioration in viewing efficiency might not occur. Somberg and Salthouse (1982) suggest that divided attention costs may be nullified if the baseline performances are equated between younger and older individuals. In his experiment he used simultaneous displays that presented an array of letters. The participants had to report whether the target (line oriented in any direction) was present or absent. Once baseline performance was equated by adjusting the exposure duration, the older participants were seen to have no greater divided attention cost than the younger participants.

It is possible in our case (Divided/ dual task AFOV), as the presentations are not fixed at approximately100 msecs as in the above mentioned studies, that the older people are using a dual task strategy in which they use all their available resources to first identify the direction of the central arrow and then search for the target. When two tasks are performed one after the other, the reaction time for the second task is found to increase as the inter-stimulus interval decreases (Pashler, 1994a, 1994b, 1998). This reaction time increase is found to be even greater for older individuals when compared to younger individuals. These differences are attributed to capacity limitations of processing resources (Kahneman, 1973), or processing “bottle necks” (Pashler, 1994a, 1994b) occurring at various stages of response production or “cross talk” of information (Kinsbourne, 1981; Navon & Miller, 1987). The two tasks that we used were both visual in nature—the participants had to identify the orientation of the central arrow and also find the location of the Landolt C. Even though the exact processing might be different in detecting the direction of the central arrow and locating the Landolt C, both the tasks require access to the same processing resource—the visuo-spatial sketch pad and processing bottlenecks can occur. As the processing of one task is underway, the other task might have to wait. The current results, however, do not support this explanation, since the viewing efficiency is not different in conditions of divided attention when compared to conditions without the central task, for both younger and older individuals.

Surprisingly, the pop out distracter had no effect on the AFOV in conditions of divided/dual attention. A speculation is that, if participants were identifying the targets using serial processing or making inefficient visual searches, the presence of the pop out could only result in either providing a location to start their search or helping by eliminating one of the locations required to be scanned. This was the case for both the younger and older group.

The impact of top down processing (Hodsoll & Humphreys, 2001) is perhaps another reason for the absence of an effect of the pop out distracter. Top down processing in these experiments refers to the influence of goals or prior knowledge regarding the target and the pop out distracters. As the distracters (white circles) and pop out distracter (red circles) are the same colour in all presentations, participants could perhaps learn to avoid being distracted by the pop out distracter and successfully identify the target location. Comparing experiment 1 &2 (standard AFOV with and without pop out distracter) and experiment 3 & 4 (divided/dual attention AFOV with and without pop out distracter), no major difference in viewing efficiency due to the presence of the pop out distracter was observed in either the standard or divided/dual attention AFOV. An exception to this is the reduced viewing efficiency at the 4 degree eccentricity for the younger group in the standard AFOV with the pop out distracter. Perhaps the presence of the pop out distracter only has an effect in the preattentive stage of processing affecting target localization at all eccentricities. Therefore in a test such as the UFOV®, a significant effect might be observed as it is known to tap into the preattentive stages of processing.

The effect of practice, which is also part of top down processing, may have affected our outcome on these experiments. The same participants performed all the experiments which allowed us to compare between the different experiments. The order in which the experiments were done was not randomized between the participants and therefore participants might have become trained to make more efficient searches with ongoing experiments. A good example from this study would be the improved viewing efficiency observed for divided/dual AFOV with red pop out distracter compared to standard AFOV with red pop out distracter.

General statements regarding all four experiments

The presentation times required in our study are longer than those observed by Coeckelbergh et al., (2004a). In their AFOV study a backward mask was not used. The backward mask used in the present study was designed to remove after-images because they give a preview benefit when identifying the location and direction of the target. For example, if the screen with target and distracters is displayed for 200 msecs, the after-images produced might last for another 200 msecs (arbitrary value). In such a case, even though the actual display time is only 200 msecs, the participants are effectively viewing the display for 400 msecs. Thus artificially, a scenario without the mask might result in better viewing efficiency than with it.

The presentation times that were required in this study to identify the target were also longer than observed in studies using the UFOV®. The UFOV® tests are based on fixed presentation times of usually 100 msecs or less and therefore AFOV and UFOV tests can be considered similar only when the target is detected on the AFOV test in less than 100 msec. In all the cases the average presentation time to localize the target was greater than 100 msec. The only comparisons we can make with respect to studies of UFOV® are based on the presentation times. The higher presentation times in the current study could be due to the saliency relationship between the target and the distracter. The circle distracters and the target "Landolt C" (used in this study and Coeckelbergh's) are probably more similar to each other than a smiley face or triangles amongst squares as have been commonly used in the UFOV® test. The greater target distracter dissimilarity may help in identifying the target quicker as found in studies using a UFOV®. Search asymmetry (Treishman and Souther, 1985) is another factor that could also affect the detection of the target among distracters. Search asymmetry refers to the finding that presentation times required to detect the target would differ based on which stimulus takes the role of target or distracters (in the same display). Another major difference between studies of AFOV and UFOV is requiring participants to locate the target and also state its orientation in the AFOV. Even though for these experiments the staircase was not based on the accuracy of the orientation response, the participants were not informed of this and could require more attention resources to perform the task.

As observed in previous studies (Ball et al., 1988; Coeckelbergh et al., 2004a), an eccentricity effect was observed, resulting in longer presentation times needed to detect a peripheral stimulus. This effect is repeatable and was found in all four experiments. Reduced visual acuity away from the fovea could result in poor identification in the periphery and may thereby be responsible for the eccentricity effect. This could also be the reason for a switch from parallel to serial processing. The use of larger stimulus sizes at peripheral locations is referred to as spatial scaling and is used to decrease the effect of reduced visual acuities at peripheral locations. In this study, the stimulus size was not scaled (stimulus size subtended 1.1 degree and gap of 0.2 degree) and this could explain the longer thresholds at more eccentric locations (Carrasco & Frieder, 1997; Whitaker, Makela, Rovamo, & Latham, 1992). However, in Coeckelbergh et al.'s experiment (2004a), the increase in the size of the stimulus in the periphery did not negate the eccentricity effect. Furthermore the disadvantage to using spatial scaling is that increasing the size at peripheral locations also increases the effect of crowding. Although it is really not known how crowding effects the performance on AFOV, crowding decreases the performance on visual acuity tasks.

The role of eye movements in visual search (Bichot & Schall, 1999; Findlay, 1997; Findlay, Brown, & Gilchrist, 2001; Zelinsky & Sheinberg, 1997) is another factor that could be responsible for age related difference and eccentricity effects. When the target identification in visual search is dependent on the rate of eye movements, a greater time to identify target can be expected. Visual search restricted by eye movements may take as long as 300 msec per item in the visual field (Wolfe & Horowitz, 2004). If a larger number of eye movements are needed to identify the target with increased eccentricity, then greater presentation time would be required. Moreover, with advanced age, the latency of saccades is known to increase (Abel, Troost, & Dell'Osso, 1983; Carter, Obler, Woodward, & Albert, 1983; Irving et al., 2006; Yang, Bucci, & Kapoula, 2002), and therefore, with each saccade made prior to target identification, the time required would be greater when compared with the younger individuals. The role of eye movements in search tasks in dynamic displays has been studied by Becic, Kramer and Boot (2007). They showed that individuals who resorted to using fewer saccades were able to detect the target more quickly. They showed that both older and younger individuals were able to detect the onset of a stimulus quickly when they used a parallel search strategy. Even though we used static displays one might speculate that perhaps the older individuals in our study made use of more eye movements, compared to younger ones, in order to detect the target. At present we do not have eye movement data to substantiate the idea.

As shown in the results, the location of the pop out distracter did not appear to help or hinder the identification of the target location. The number of wrong response reversals that occurred when the pop out distracter was at a neighboring location was more than expected. This, at least qualitatively, indicates that incorrect response reversals did not occur only when the pop out distracter was far away from the target.

In summary, viewing efficiency as described by AFOV is affected by age and the effect is most likely due to search processing differences. The differences in visual search, which result in efficient and inefficient searches, might be the reason for differences found between groups. Also the difficulty of the older observer in disregarding irrelevant distracters might be the reason that elderly participants resort to inefficient search in most of the studies described above.

6. General Discussion and Conclusions

The age of an individual is considered a risk factor in cases of mobility as suggested by traffic collision statistics and statistics on falls (Statistics Canada). When issuing a license to operate a motor vehicle, it is important to identify how competent an individual is to drive. The current regulations, established by the various provincial Departments of Motor Vehicles in Canada, include an assessment of visual acuity and visual fields in addition to the on-road assessment. As mentioned earlier in this thesis, many visual functions deteriorate with increasing age. These include visual acuity, contrast sensitivity, glare recovery, dark adaptation, stereopsis, as well as others. The important question is how these visual functions relate to the visual efficiency that is required to perform many activities of daily living. Attention, in conjunction with visual factors, plays an important role in determining good visual efficiency. We have investigated how some aspects of attention, which might have importance in natural situations, change with age, in order to understand the added difficulty that may be imposed by age.

The first set of experiments investigated how a group of younger individuals judge the speed at which a target was enlarging such that its size, at a future instance, could be predicted. There were differences pertaining to whether the stimulus was in the central or peripheral visual field. Participants were found to be quicker to respond to a stimulus in the peripheral visual field (compared to stimulus in the centre/midline). In the subsequent set of experiments we incorporated a dual task situation wherein individuals had to perform two tasks concurrently. Attention was modulated in these dual task situations by making one of the two tasks more difficult to perform. In comparison to younger individuals, older individuals were found to have greater performance difficulty in highly demanding situations that involved dual tasks. The limited capacity of attention resources or bottle necks arising when two tasks were performed simultaneously was considered to be responsible for these outcomes. Perhaps older individuals require more processing to perform each task and therefore processing bottlenecks occur, even for larger inter-stimulus intervals compared to younger individuals. For example, if there is 1200 msec interval between two tasks, there would not be any processing bottle necks for the younger individual but a bottle neck could occur for the older individual. Note that a strict inter-stimulus interval was not present in experiments detailed in chapters 3 & 4; the maximum available time between the two tasks to make accurate size match at the fastest speed was 1200 msec. It was also observed that different dual task situations caused more difficulty for the older observers relative to the younger ones. When the primary tasks were less demanding in a dual task situation, there were no significant differences between the younger and older observers. This is probably due to the lower demands imposed on the attentional processing resources. In cases where there is enough time to switch between the two task conditions there is less likelihood of processing bottlenecks occurring.

Eye movements made to different regions of the task display showed how attention can be modulated in dual task scenarios. The analysis of dwell time percentages provided evidence that as the complexity of the task increased, more time was spent fixating at each particular location in order to effectively perform the task. Overall, time estimation was found to be affected by whether the information that was to be analyzed was presented in the centre or periphery. The constraints on working memory were also found to affect the estimation of time.

Another situation where age has an impact with respect to attention is identifying targets in the presence of distracters. By assessing the functional field of view (FFOV), in terms of viewing efficiency, significant overall age related differences were found. The viewing efficiency, as measured by the Attended Field of View (AFOV), could be affected by variables such as a pop out distracter and use of divided attention. The effects of these variables on the viewing efficiency were investigated in a group of younger and older adults. It was found that differences between the groups occurred in all conditions where there were irrelevant distracters. All assessments of the FFOV mentioned in this work included distracters in all conditions. The inefficient visual searches observed for the elderly could be due to the complexity of the test. As inefficient visual searches were already observed in the standard AFOV condition, the pop out distracter condition and divided attention condition did not provide a chance for further performance decrements. Even in studies of Useful Field of View [UFOV®] (Ball, Roenker et al., 1990) the presence of distracters were found to have a greater effect (45.59% loss in size of the useful field of view) in comparison to divided attention alone (28.30 % loss in size of the useful field of view). Similar findings were observed in the work of Leat and Lovie-Kitchin (2006) where measures of UFOV® were compared in a group of older adults with and without low vision. The presence of distracters had a greater negative impact on the UFOV measures than the conditions that included divided attention. Even though complexity of the test might have been a factor affecting some of the findings presented in this thesis, the result that the FFOV is significantly different for the older individuals is still important because of its everyday functional impact.

The findings from our study suggest that older individuals may be using the same search strategy as the younger individuals but less efficiently. All individuals most likely start out with a parallel mode of processing. However, the guidance to the target from the parallel search could be greater for younger individuals and hence results in more “efficient searches”. For the older individuals the parallel process does not provide adequate guidance to the target and therefore results in “inefficient searches”. Thus, attention processing for visual search is qualitatively similar between older and younger individuals but there are still significant quantitative differences.

Functional field of view measures using tests such as UFOV® can predict performance in activities of daily living, balance and gait performance, as well as bumping while walking (Owsley & McGwin, 2004; Owsley, McGwin, Sloane, Stalvey, & Wells, 2001; Broman et al., 2004). Attention measures obtained in the laboratory are also useful in identifying the at-risk driver as well as predicting crash risk (Owsley, 1994, Coeckelbergh et al, 2004a; 2004b). AFOV measures (similar to that used in our study) were found to be able to ascertain whether an individual would pass or fail a road test. However, the sensitivity and specificity of the test was not optimal to be incorporated into the standard regimen of licensing procedures. The FFOV measures and the dual task performance (in judging looming targets) were not intended to identify unfit drivers in our study (this was beyond the scope of this thesis); this is a possible avenue for further research.

There are some factors such as that have not been controlled in the series of experiments conducted as part of this thesis. Fatigue could have affected the outcome of our experiments. A cursory analysis of the first 20 trials and the last 20 trials showed that there was no difference in the performance in the various experiments. This shows that for the tests outlined in the thesis, fatigue was not a major factor affecting the outcome. The role of previous experience in doing attentional tasks is another possible confound. Experience in attentional tasks can affect the outcomes, especially if information processing occurs as an “automatic” or “controlled process”, as suggested by Shiffrin and Schneider (1977). Automatic processes occur for well learned tasks, where the tasks are encoded in long term memory. A good example is the response to the person’s own name. In the experiments conducted as part of this thesis, for example, persons who are video gamers may have had an advantage over other participants. The tasks involved in video games usually include attentional tasks such as dual tasks or ignoring irrelevant distracters, etc. Hence some of these tasks might become well learned and could be processed by an “automatic process”. However, of all the participants included in the study, only two younger participants were video gamers. It is unlikely that the data of these 2 individuals skewed the rest of the data. Secondly, some of the participants recruited for the first set of experiments (size matching) also participated in the AFOV studies. Three of the younger and five of the older individuals participated in both experiments. In essence, the role of experience has the potential to be confound in our experiments, although, such effects might have become balanced across the two groups.

In summary, it is important when designing any measure of FFOV, that the optimal target distracter similarity that relates to natural situations be used. Perhaps when there is very high target distracter dissimilarity (e.g., red target amidst white distracters) much of the difficulty observed in viewing efficiency may be eliminated. Therefore, it would be necessary to control target-distracter similarity when designing new FFOV tests. For divided attention tasks, it is possible that there are no costs associated with performing two tasks if adequate time is available to perform both tasks. However, in real life situations there are many cases in which information is available for a limited amount of time. If two tasks are to be performed in a limited time frame then processing bottle necks could occur which in turn could negatively affect the performance of the older individual.

The importance of understanding dual task scenarios and attention modulations is to understand how distraction affects performance in activities such as driving. Distracted or inattentive drivers pose a risk (while driving) not only to themselves but also to others. Distraction could also pose a risk in situations such as walking and could result in falls. The important point is whether “distraction” affects certain individuals more than others. Age was found to negatively affect the identification of targets in the presence of distracters in this study. Similar performance decrements were observed in dual task scenarios. It has yet to be determined whether training would help these older individuals overcome difficulties in such scenarios. On the other hand, if the neural circuits have changed significantly with age such training may not be beneficial.

Appendix: Understanding top down influences of the pop out distracter's colour on the AFOV

The attended field of view (AFOV) refers to the area from which information can be obtained allowing the use of eye and head movements (Coeckelbergh et al., 2004a, 2004b). The presence of a single pop out distracter on the AFOV was predicted to decrease the viewing efficiency in an earlier experiment (Chapter 5). The experiment showed that there was no reduction in viewing efficiency due to the presence of the pop out distracter. The null hypothesis was therefore accepted.

Top-down processing could be one reason for this observation (Hodsoll & Humphreys, 2001). Top-down processing in this case refers to the influence of goals or priority in order to avoid attending to the pop out distracter. As the target was always a Landolt C and the pop out distracter was always a red circle, this might have resulted in participants learning to avoid being distracted by the red circle. In order to see how we can reduce such top-down influences and give greater weight to the impact of the pop out distracter, we changed the colour of the pop out distracter on every trial from a set of thirteen colours. This way the influence of top down processing in terms of ignoring a particular colour will be minimized.

We studied this both on the standard AFOV and divided/dual attention AFOV, and compared it to the data obtained when the pop out distracter was always red.

Methods:

The participants who took part in this experiment were the same as those who performed the AFOV experiment as outlined in the earlier chapter (Chapter 5). The group comprised 9 young (25±6) and 9 older participants (72±4). The details of the 2 AFOV tests are given in Chapter 5. Briefly, the standard AFOV with pop out distracter involves identifying the location and direction of a Landolt C in a field of distracters made up of 22 white rings arranged in three circles at eccentricities of 4, 8 and 12 degrees. There are a total of 24 available locations of which one position is occupied by the target Landolt C and the other by the pop out distracter. In the divided/dual AFOV, the central location was replaced by an arrow that can be oriented in either up, down, left and right direction and participants were to provide a response regarding its orientation in addition to identifying the target Landolt C. The participants were in all cases instructed to ignore the pop out distracter and identify the target location.

In this experiment the colour of the pop out distracter could be black, blue, brown, cyan, dark blue, dark green, green, lilac, magenta, orange, red, violet, or yellow. The colour of the pop out distracter on each trial was randomized and could be any one of the 13 colours. The experiment will be referred to as “multiple colour pop out distracter”.

An independent staircase for the presentation time was run at each of the nine target locations (as before, only 9 locations were used). The presentation time was increased if localization of the target was incorrect and decreased if it was correct, in a weighted up down staircase. A total of 40 trials were run at each location and in all cases more than 8 reversals were obtained. For each location, the highest and lowest values were removed from the correct and wrong response related reversals. The averages of the correct and wrong response reversals for each eccentricity were taken as the measure of average time taken to identify the target. The data obtained were log transformed and reported in terms of viewing efficiency. The viewing efficiency in this case refers to the logarithm of the inverse of the average presentation time in seconds for each eccentricity. The logarithmic transformation made the distribution normal and allowed us to use parametric statistics to perform the analysis. The Kolmogorov-Smirnov tests also confirmed that the distribution was normal ($d = 0.1$, $p > 0.05$).

Repeated measures ANOVAs were performed on the log transformed data obtained for the standard AFOV with pop out distracter and the divided/dual AFOV with the pop out distracter. The within-subject variables were the 2 conditions (red pop out distracter vs. multiple colour pop out distracter) X eccentricity (4, 8 and 12 degrees). Age was considered as the between subject variable in all cases. A post hoc analysis with a Bonferroni correction was used to compare the differences between the means of each variable.

Results

Standard AFOV with red pop out distracter vs. Standard AFOV with multiple colour pop out distracter.

A main effect of age [$F(1,16) = 20.88$, $p < 0.0005$] and eccentricity [$F(2,32) = 61.78$, $p < 0.0005$] was observed as expected. The older participants had reduced viewing efficiency compared to the younger group. The eccentricity effect was also observed as expected, with the farthest eccentricity having the lowest viewing efficiency ($p < 0.0005$). There was also an eccentricity x age interaction [$F(2,32) = 3.84$, $p = 0.032$]. The younger participants were more affected by the eccentricity than the older group. This was due to the lower viewing efficiency values observed for the near central location for the older group. There was also a main effect for the type of pop out distracter [F(1,16) = 23.63, p < 0.0005) – Figure A-1. The viewing efficiency observed in the multiple colour pop out distracter condition were significantly higher than the viewing efficiency obtained for the condition when the pop out distracter was always red. There was no interaction of the pop out distracter condition and age [F(1,16) = 0.31, p = 0.583] and this suggests that both groups have better sensitivities for the condition with multiple colour pop out condition (Figure A-2).

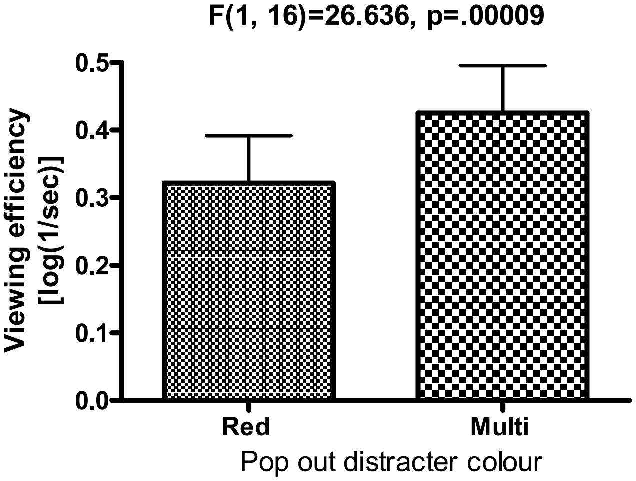


Figure A-1: Viewing efficiency (data pooled for all eccentricities) on the standard AFOV with pop out distracter in conditions where there is a red pop out distracter and multiple colour pop out distracter. The error bars represent ±SE of the mean

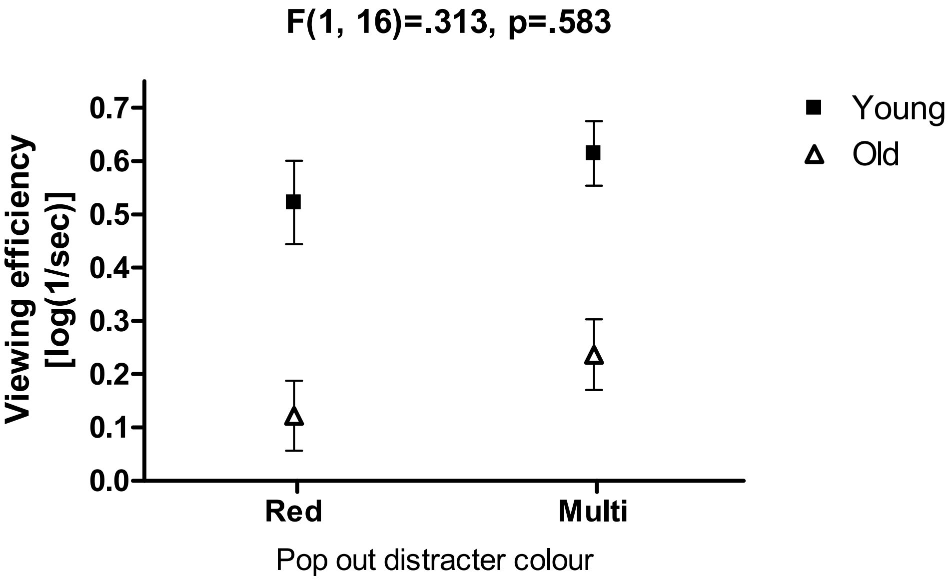


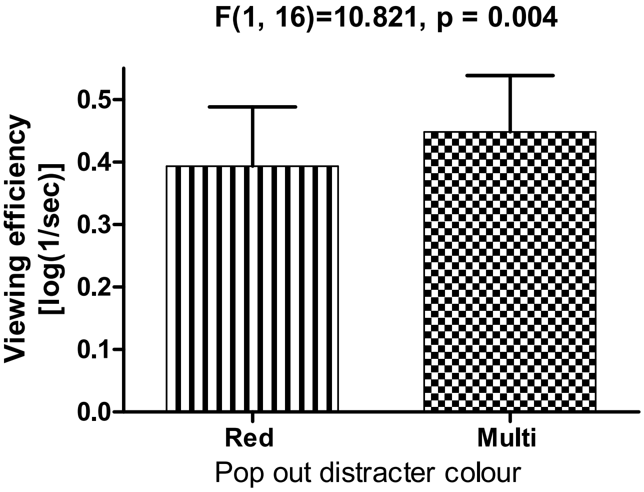
Figure A-2: Effect of age and type of pop out distracter on the viewing efficiency. The error bars represent ±SE of the mean

Divided/Dual AFOV with red pop out distracter vs. Divided/Dual AFOV with multiple colour pop out distracter.

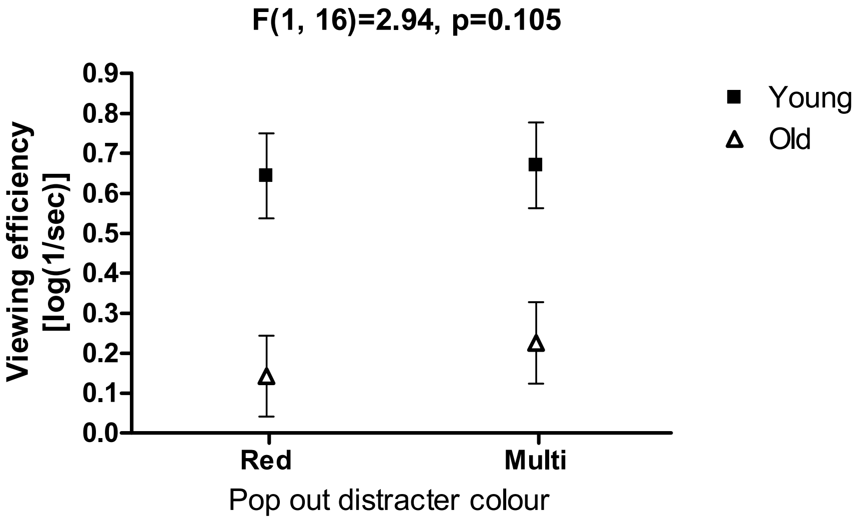
The results obtained for this comparison are very similar to those obtained for the standard AFOV with the two types of pop out distracter. Main effects of age [F(1,16) = 26.57, p < 0.0005) and eccentricity [F(2,32) = 55.96, p < 0.0005] were observed. The younger group had significantly greater viewing efficiency than the older group. Regarding the eccentricity effect, the 12 degree eccentricity had the lowest viewing efficiency values for both groups. There was again an age x. eccentricity interaction [F(2,32) = 5.6, p = 0.008] which is observed due to the reduced viewing efficiency for the 4 degree eccentricity for the older group.

There was a main effect with respect to the type of pop out distracter [F(1,16) = 10.82, p = 0.005). The viewing efficiency observed for the multiple colour pop out distracter condition was significantly higher than when the pop out distracter was always red (Figure

A-3). There was no interaction [F(1,16) = 2.94, p = 0.105] for the type of pop out distracter with respect to age, showing that both groups performed similarly with respect to the type of pop out distracter (Figure A-4).



FigureA-4: Viewing efficiency (data pooled for all eccentricities) on the divided/dual AFOV with pop out distracter in conditions where there is a red pop out distracter and multiple colour pop out distracter. The error bars represent ±SE of the mean.



FigureA-4: Effect of age and type of pop out distracter on the viewing efficiency on the divided/dual AFOV. The error bars represent ±SE of the mean

Discussion:

In our earlier experiment (Chapter 5) a reduction in viewing efficiency on the AFOV was predicted due to the presence of a pop out distracter. Our hypothesis was rejected as the pop out distracter did not reduce the viewing efficiency on both the standard and divided/dual AFOV. In those experiments the pop out distracter was always the same colour on every trial. Perhaps the participants might have learnt to avoid being distracted by the pop out distracter that was the same colour throughout the experiment. In this experiment, we investigated if the top down processing such as learning associated with the colour of the pop out distracter was the reason for the absence of impact. Contrary to our hypothesis, when the pop out distracter was a different colour in every trial, higher viewing efficiency were obtained in comparison to standard AFOV with red pop out and divided/ dual AFOV with red pop out. This was same for both groups. This was again not as predicted and therefore the top down influences based on the pop out distracter being the same colour was not found to affect the viewing efficiency. An alternate influence, which is also part of top down processing, that may have affected our outcome is that of practice on these experiments. The same participants performed all the experiments which allowed us to compare between the different experiments. The multiple coloured distracter experiments in the standard and divided/dual AFOV were the 5th and 6th experiment respectively for each participant. Hence, all the participants had a fair amount of practice at learning to locate the target. Even though the location of the target was random, it is possible that the participants had become trained to make much more efficient visual searches. Practice effects have been investigated on tests of UFOV that studied divided attention. The study by Richards et al., (2006) equated stimulus durations for younger and older individuals so that similar error rates on the UFOV were observed. Practice on divided attention tasks (judgment of central task and peripheral localization) as well as focused attention tasks (peripheral localization alone), showed significant improvement in both groups reducing the costs associated with the tasks that were observed prior to practice. Similarly practice or learning effects were evident on the AFOV (Hernandez-Luna, Babu, Strong, & Irving, 2009). The study investigated repeatability by comparing data from three repeated observations for a group consisting of 7 younger and 7 older participants. There was a significant improvement between observation 1 and observation 2 for the younger group. For the older group, there was improvement with each observation. In other words, the younger group had improvement from observation 1 to observation 2 but reached ceiling performance. The older group had on-going improvement from observation 1 to 2 and 2 to 3.

In summary, the role of practice cannot be ignored when multiple experiments on the AFOV are performed by the same participants. It is possible that the practice effects in identifying targets nullify the effect of the presence of multiple coloured distracters in each trial. This gives the appearance that top down influences regarding the colour of pop out distracter are not occurring.

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