EXAMINING THE DIFFERENTIAL AGING OF THE AMBIENT AND FOCAL VISUAL SYSTEMS: AN APPROACH USING THE PERIPHERAL DETECTION TASK DURING SIMULATED DRIVING

By

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Abstract

The purpose of this project was to investigate the recently popular peripheral detection task (PDT) in an attempt to further understand the true nature of its diagnosticity. Rather than measuring attention in the traditional sense, an alternative approach was used which explains information processing in terms of two unique, yet non-exclusive visual systems; referred to as the "ambient and focal systems." The focal system is used for object identification while the ambient system is responsible for object localization and visuomotor functions. Ambient system abilities were operationalized by temporally modulating the signal strength of peripherally located LED targets in an attempt to test the recently suggested *ambient insufficiency hypothesis* for explaining age-related changes in visual system sensitivity. Sixteen young (*M*=23 years) and eighteen older (*M*=72 years) subjects were required to operate a simplistic driving simulator during conditions of varying workload and target location predictability while receiving targets of differing ambient ability (low, moderate, or high). Older subjects exhibited significantly lower PDT hit rates as a function of increasing simulator workload demands and decreasing target location predictability. However, the failure to observe any additional age-specific interactions with the ambience manipulation suggests that all subjects, regardless of age, were relying on top-down periodic scanning of the target area using focal vision to detect peripheral targets. These results bring into question the validity of the *ambient insufficiency hypothesis*. On the contrary, after reassigning the older group of subjects to performance-based groups, *post hoc* analyses revealed that those with poorer overall detection rates exhibited a decline in sensitivity for targets theoretically designed to maximally stimulate ambient system processing. In addition, those older subjects with better overall detection rates remained indistinguishable from those of the younger group. This suggests that a select group of senescent individuals in the current sample were no longer able to reliably capitalize on targets specifically designed to trigger preemptive, ambient processing. Such findings indicate a change in ambient system sensitivity for some, but perhaps not all aging persons; thereby providing preliminary support for the *ambient insufficiency hypothesis*.

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Prologue

Over the years, a considerable amount of research has been performed in an attempt to better understand the changes in behavior which occur as a result of the normal aging process. This effort is in response to the simple fact that people are living longer. As our society continues to exhibit life spans of increasing longevity, it's critical that the proper steps be taken to understand the potential consequences of such aging trends. Developing a better understanding as to the sources of such changes in behavior can ultimately help us to better meet the needs of this senescent population in the future. Ultimately, through the use of empirical research, techniques can be developed which help to identify those members of this population with the most critical needs, as opposed to simply relying on metrics based solely on the chronological aspects of age.

The following document will present a research question which requires the integration of four unique branches of information, each of which could stand alone as the foundation for entire research projects. First, the reader will be introduced to traffic data which reveal some interesting, yet consistent crash patterns specific to the aging driver. Second, a wealth of empirical research is presented to further the reader's understanding as to what is already known about the visual and attentional capabilities of an aging society that might be contributing to their information processing difficulties. The third section of this introduction will then present a body of evidence which supports the existence of two unique, yet non-exclusive visual information processing systems utilized by humans to create a visual experience rich in both detail and awareness; a focal system used for object identification and an ambient system used for object localization and visuomotor functions. A thorough examination of this literature suggests that as a

result of the normal aging process, not only do the mechanisms which mediate the aging person's information processing abilities become slower and less efficient; but such a decline also appears to be the result of the differential aging of the ambient visual system compared to the focal system. From a traffic safety vantage point, it might be a weakening or malfunctioning ambient system which contributes to the overrepresentation of senescent drivers in certain types of collisions. Finally, in the fourth section of the introduction, a recently successful secondary task paradigm known as the peripheral detection task will be reviewed. The primary objective of the current research project will then involve further examining the aging driver's ability to perform the peripheral detection task, as the characteristics of this task allow the systematic manipulation of both ambient and focal channel functions.

The Aging Population & its Susceptibility to Crashes

Demographics

The Aging Population

In 2005, there were 36 million adults age 65 and older living in the United States, making up approximately 12% of the entire population (NHTSA, 2005). This is an increase of roughly 10 million people from just 3 years prior (NHTSA, 2002). From 1992 to 2002, the population of Americans aged 70 years and older increased at a rate 27% higher than that of the overall population's growth rate (NHTSA, 2002). Other researchers have confirmed similar trends with regard to population growth rates, showing that the sheer number of adults aged 65 years and older continues to steadily rise

in relation to younger age groups, with those over 75 years of age having the most rapid growth rates (Ostrow, Shaffron, & McPherson, 1992). This data suggests that a continually growing number of Americans are living further into their later years of life. Ahmed & Smith (1992) suggest that the population trends associated with our aging society is quite possibly the most important demographic event taking place. As researchers, it is important to understand where the consistently rising numbers of individuals over age 65 might have significant influence. One such area which denotes further scrutiny is the potential impact of age on an individual's ability to safely operate a motor vehicle.

The Aging Driver Population

In 2004, there were 28 million licensed drivers over the age of 65, 17% more than ten years prior in 1994 (NHTSA, 2005). For the year 2001, NHTSA (2002) reported that there were 19.1 million older licensed drivers in the United States, an increase of approximately 9 million older drivers in only three years. Researchers predict that by the year 2025 there could be as many as 50 million people over age 65 that qualify to drive (Waller, 1991), making up approximately 21.8% of the entire population (McGwin & Brown, 1999). The current generation of individuals over the age of 65 is thought to rely on the automobile as their primary source of transportation more so than any other previous generation; a reliance which is expected to be even more dramatic for future generations. It is likely that the elderly drivers of tomorrow will not only continue to rely on the automobile well into their later years of life, but actually continue driving throughout these years. This will undoubtedly lead to an increase in the total number of

licensed drivers over age 65, as well as an increase in the total number of miles driven annually (Jette & Branch, 1992; McGwin & Brown, 1999).

Crash Statistics

Rate of Crash Occurrence

Previous data show that older driver crash rates are no worse than other age groups when considered in terms of the number of licensed drivers (Waller, 1991). As drivers begin the transition into their later years of life, they begin to exhibit certain characteristic changes in both driving behavior, as well as the environments in which they prefer to drive. Typically, this segment of the driving population has a tendency to restrict their vehicle use to low-risk situations during daylight hours (Ball & Owsley, 1991); thereby avoiding situations associated with higher risks such as severe weather, dense traffic, complicated roadways, and nighttime driving (Schieber, Fozard, Gordon-Salant, & Weiffenbach, 1991). This restriction of driving to primarily low-risk situations is viewed by some researchers as a form of self-selection or compensatory behavior resulting from age-related perceptual and/or cognitive deficits (Kosnik, Sekuler, & Kline, 1990). Survey results of Kosnik et al. (1990) also suggest that elderly drivers are indeed aware that they are developing problems which could potentially compromise their driving abilities, and most behave accordingly. Given these circumstances, it would appear that the older driver poses no more of a risk to the driving community than any other age group, with the exception of novice drivers who have little to no experience (Cerrelli, 1989).

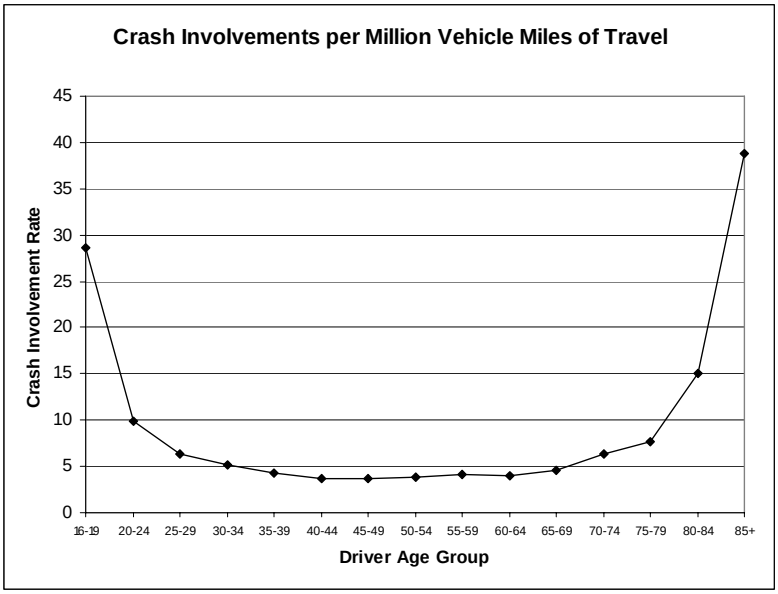


Figure 1. Crash involvement per million vehicle miles of travel (Cerrelli, 1989)

Simply looking at crash rates relative to the number of licensed drivers for a given age group however, might not be telling the entire story. When analyzed in terms of the number of crashes per mile driven, the data suggests that older drivers are involved in considerably more crashes than their middle-aged counterparts (Carr et. al, 1992; Cerrelli, 1989; Waller, 1991; & Massie, Campbell, & Williams, 1995). A number of studies, both in the United States and abroad, have shown that vehicle crash rates begin to significantly rise as a driver progresses into their later years of life, eventually resembling crash rates as high, if not higher than novice teenage drivers (Gebers & Peck, 1992; Hakamies-Blomqvist, 1994a; Hakamies-Blomqvist, 1994b; Massie et. al, 1995; Stamatiadis & Deacon, 1995, Stamatiadis, 1996). Driver crash involvement relative to actual miles driven typically reveals a U-shaped function (Figure 1); showing higher rates during the early years of driving where experience is minimal, lower rates as experience is gained throughout the middle-years, followed by rising crash rates during the later years of life.

According to Cerrelli (1989), drivers beyond the age of 85, despite having a lifetime of experience behind the wheel, have crash rates higher than those of 16-19 year old teenage drivers who have little to no driving expertise.

Driver Fatality Rates

When the accident data is scrutinized in more depth, researchers have consistently shown that the chances of being seriously injured or killed in an automobile crash increase substantially as a function of increasing age (Figure 2) (Cerrelli, 1989; Evans, 1988; Waller, 1991). In 2005, NHTSA reported that 191,000 elderly persons suffered injuries as a result of involvement in traffic crashes, up nearly 40,000 from only three years prior (NHTSA, 2002). Older drivers also made up 15% of all traffic fatalities during this year (NHTSA, 2005). According to Cerrelli (1997), drivers over the age of 65 are nearly two and a half times more likely to be involved in a fatal traffic accident when compared to younger drivers. Researchers agree that this increased overall fatality risk is most likely a result of the aging drivers increased probability of suffering from both the immediate, as well as delayed consequences which result from a crash (Cerrelli, 1989 & Waller, 1991). As senescent individuals proceed into the later years of life their muscles and bones become progressively weaker and less dense. This increased frailty suggests that the aging body's ability to withstand the physical trauma associated with the impact of a crash becomes increasingly unlikely, thus making the aging driver much more susceptible to suffer a fatal outcome (Waller, 1991). Given the demographic trends outlined up to this point, it is expected that as the number of licensed drivers over the age of 65 continues to rise, the number of miles driven by this aging population will also increase which, unfortunately, will most likely lead to an overall increase in driver

fatality rates for these senescent individuals (Barr, 1991; Ball & Owsley, 1991; Waller, 1991).

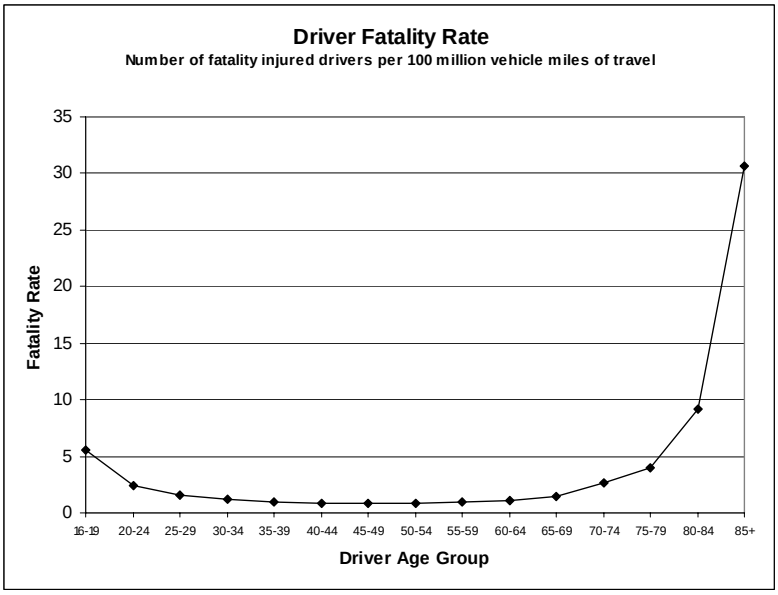


Figure 2. Crash Involvement driver fatality rate by age (Cerrelli, 1989)

Types of Crashes

Further investigation of crash data also reveals important clues indicating the type of accidents the aging driver is typically involved in. According to NHTSA (2005), 79% of the fatal crashes involving older drivers occurred during the daytime, 73% took place during weekdays, and 73% involved other vehicles. When involved in accidents with other vehicles, older drivers are more likely to be operating the vehicle that is initially struck (Hakamies-Blomqvist, 1994a), as well as be considered responsible for the collision (Hakamies-Blomqvist, 1993, 1994b; Stamatiadis & Deacon, 1995; Stamatiadis, 1996). With regard to two vehicle fatal crashes, older drivers are two times as likely to be operating the vehicle that was initially contacted (NHTSA, 2005). A common finding in the literature involves the over-representation of older drivers in collisions which occur

during cross traffic maneuvers such as turning left across oncoming lanes of traffic or negotiating intersections (Figure 3) (Cerrelli, 1989; Hakamies-Blomqvist, 1993, 1994b, 1994c; Stamatiadis & Deacon, 1995; Stamatiadis, 1996).

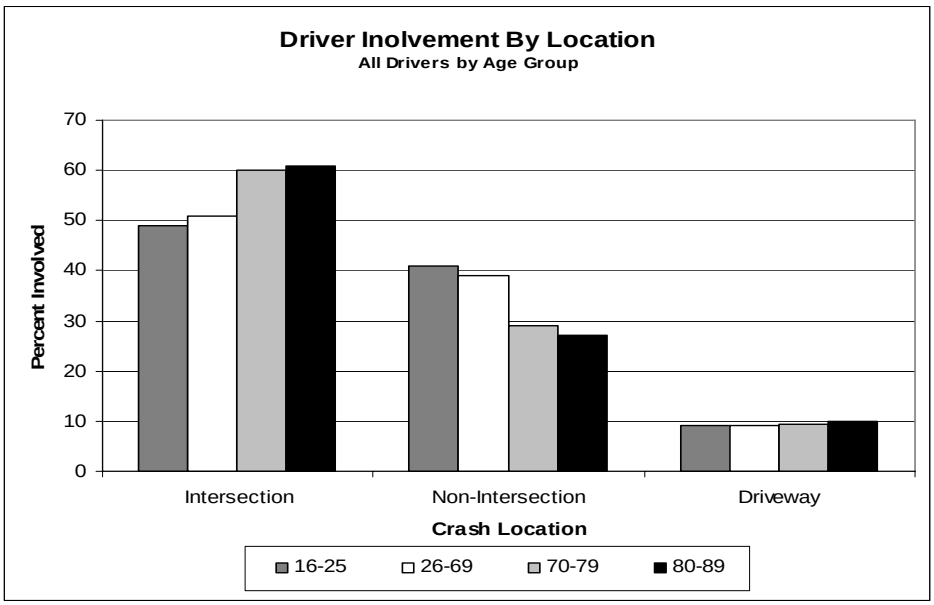


Figure 3. Location of crash involvement (Cerrelli, 1989)

In addition to analyzing national and state accident record data, Cerrelli (1989) also examined the types of infractions for which drivers of different age groups were cited (Figure 4). This data showed that younger drivers typically received citations involving excessive speed violations while such infractions were rare for older drivers. The opposite trend occurred for citations involving traffic sign or right-of-way violations. Older drivers appear much more likely to be cited for violations which occur during traffic situations which demand high levels of visual information processing.

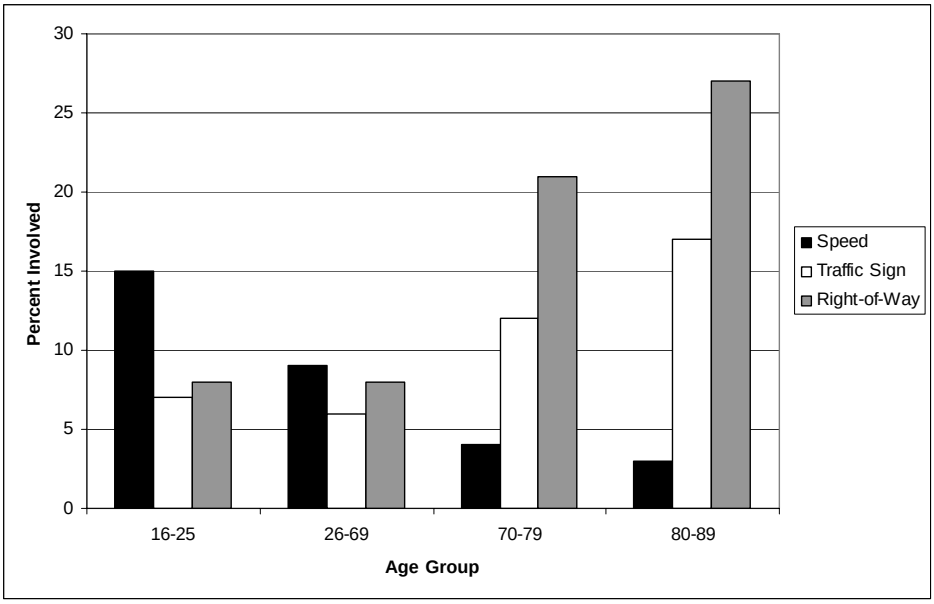


Figure 4. Types of violations for different driver age groups (Cerrelli, 1989)

Similar findings were reported by Schieber (2000) with respect to the types of intersections where older drivers appear to have the most problems (Figure 5). Consistent with the previously reported findings, there is a clear change in the accident trends of older drivers at intersections compared to non-intersections. Interestingly, when an intersection is controlled by a traffic signal the differences in aging trends disappear. In this instance, the accident rates of younger and older drivers are indistinguishable from one another. However, when the intersection is no longer controlled by a traffic signal, but rather a stop sign; the relative percent of accident involvement increases as a function of driver age. According to Schieber (2000), it is the presence of the traffic signal which minimizes the visual information processing demands of the older drivers as it tells them when to safely proceed. But in the case of intersections controlled by stop signs, the visual information processing demands are placed solely on the abilities of the driver.

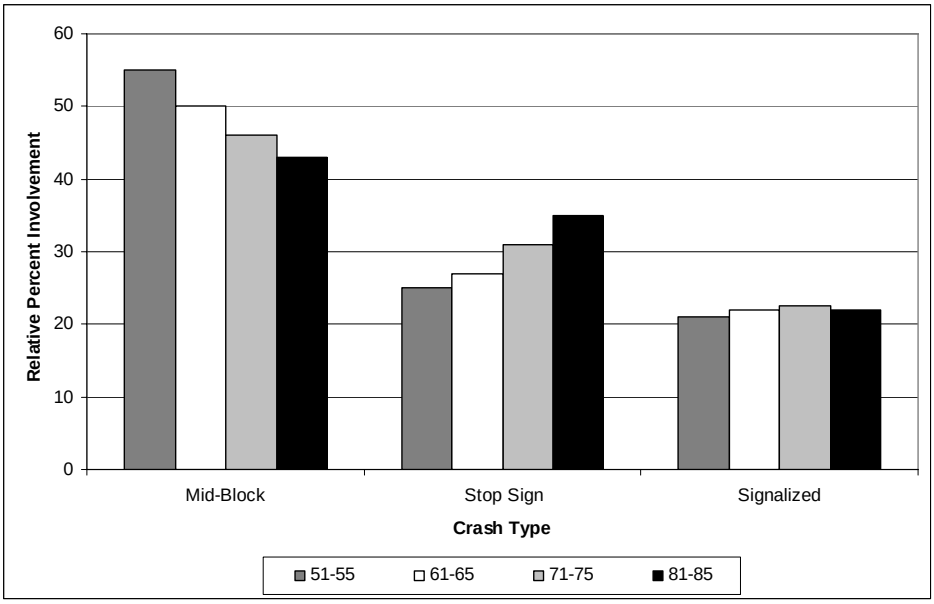


Figure 5. Crash type involvement compared by age (Schieber, 2000)

Analyzing accident records are indeed a useful tool in helping to better understand the various causes for different types of transportation problems, especially with regard to the aging driver. Keep in mind though, that accidents are rather infrequent events. This is especially true when we consider the thousands of miles most people drive each year without experiencing so much as a minor fender-bender. In most cases, accidents are the result of many different factors. As Owsley and colleagues (1991) point out, many of these factors are intrinsic to the driver such as vision and information processing, but many others are extrinsic factors like weather conditions or construction. Using these highly improbable events as the only metric to understand driver information processing is unlikely to be telling the entire story. In addition to examining vehicle accident data from a number of driver age groups, several researchers have used more empirical methods to try and further understand the difficulties experienced by the aging driver during cross traffic maneuvers. When asked to indicate the last possible moment to

execute a safe left-hand turn across traffic during real world conditions, Staplin (1995) reported that older drivers were relatively insensitive to an oncoming vehicle's speed, estimating the same safe turning gaps for a vehicle traveling 30 mph compared to 60 mph. Similar results were reported by Parsonson, Isler, and Hansson (1999) who found that drivers over the age of 59 were the least consistent when asked to estimate safe turning gaps across traffic at rural T-intersections. These older drivers also took the longest amount of time to clear the lane of oncoming traffic when actually negotiating a turn. These findings, combined with what has been learned from accident records suggest that as a driver advances into the later years of life, they are much more likely to experience problems during traffic scenarios which place high demands on the visual information processing abilities of the driver. More specifically, engaging in cross traffic maneuvers appears to be of particular concern for the aging driver. From the perspective of transportation science, it is important to further examine such acts in more controlled settings so that we can begin to understand why senescent drivers are overly represented in such crashes. Once this is accomplished, the field can then move on to developing methods which allow the identification of potentially problematic drivers during the re-licensing procedure in hopes that they be either retrained or restricted from driving if their behavior is deemed unsafe.

Basic Visual Function, Aging, & Driving

Most researchers would agree that the task of driving relies heavily on the processing of visual information. Other senses are involved as well, but without a doubt the majority of information immediately necessary for safe vehicle travel is acquired

through visual perception. Accident records and turning gap estimation studies suggest that the aging drivers' ability to successfully navigate a vehicle during highly visual demanding traffic situations is potentially suspect. This is of particular concern considering that the majority of older individuals only drive under the most optimal conditions; for example during the daytime, on weekdays, in low traffic congestions, and under pleasant weather conditions. To examine the effects of visual aging on driving, Kline et al. (1992) surveyed drivers of various age groups with regard to the visual problems they encounter. Five different visual dimensions were reported as increasing in difficulty as a function of driver age; detecting unexpected vehicles in the periphery, speed judgments of self and others, reading dim in-vehicle displays, windshield issues, and reading signs (Figure 6). According to Kline and colleagues (1992), these findings suggest that "older persons have problems with stimuli that are dimly illuminated, near to them, rapidly changing, or embedded in more complex arrays." The self-report results of this study are consistent with what is known about the types of crashes typically experienced by older drivers. Such findings have led many researchers to suggest that the decreasing sensitivity of the aging drivers' visual capabilities is a significant contributing factor to their over-representation in cross traffic accidents (Waller, 1992; Evans, 1988).

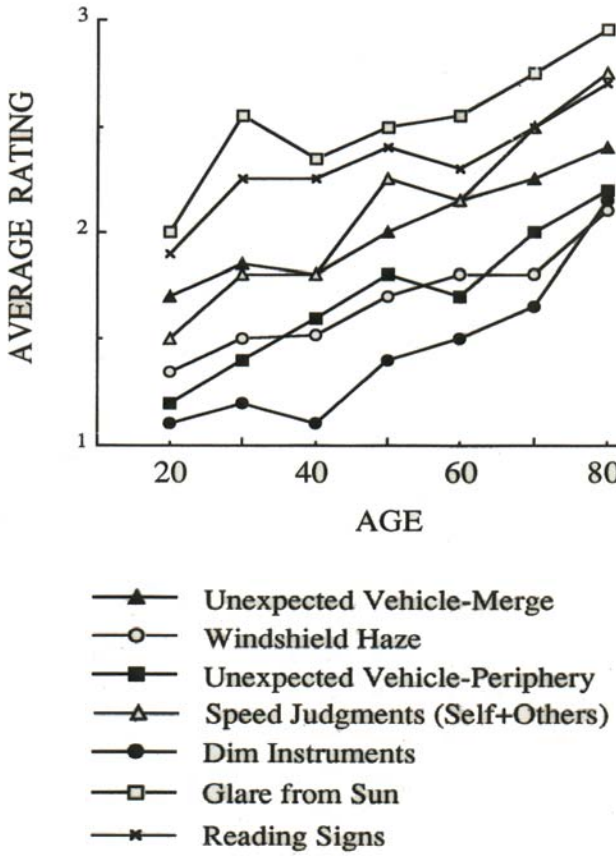


Figure 6. Visual problems of the aging adult (Kline et al., 1992)

There also exists some extremely large sample size correlational studies that have been performed in an attempt to identify relationships between visual performance measures and accident involvement, yet most of these relationships have been quite small at best, accounting for less than 5% of the total variance (Burg, 1964; Johnson & Keltner, 1983). Keep in mind the overall complexity of the driving environment and the many factors which potentially can contribute to automobile accidents. Shinar and Schieber (1991) explain the weak link between pure visual performance metrics and accident involvement using the following reasons:

(1) Accidents most often have multiple causes rather than being attributable to one specific human impairment.

(2) In detailed accident analyses, the most frequently cited human causes of accidents are either attentional or higher-order perceptual failings such as improper lookout, misjudgment, and distraction (Treat et al., 1977; as cited in Shinar & Schieber (1991).

(3) The statistical phenomenon of a *restricted range* of visual impairments – attributable to the essentially worldwide requirement for driving of at least 20/40 acuity in the better eye (Charman, 1985; as cited in Shinar & Schieber, 1991) – would act to reduce the strength of a relationship that may in fact exist in the general population.

(4) Many large-scale studies (e.g. Burg, 1964; Council & Allen, 1974; Davison, 1985; as cited in Shinar & Schieber, 1991) rely on relatively unreliable vision data obtained from gross driver screening devices

(5) Some of the visual requirements with high theoretical construct validity have not been evaluated in large-scale studies (e.g. functional field of view, contrast sensitivity).

(6) The highway traffic system is a very forgiving one, with compensatory mechanisms for human errors and deficiencies.

(7) Drivers with reduced capacities may compensate by restricting their driving to times when there are favorable light conditions and low-density, low-speed traffic (p. 507).

Shinar & Schieber (1991) go on to suggest that a more appropriate practice would be to study specific visual impairments in terms of unique driving tasks or certain behaviors which are related to accidents. For example, Shinar, McDonald, & Treat (1978) reported that drivers suffering from reduced vision exhibit improper lookout techniques which ultimately increase their chances of being in an accident nearly three fold. That being said, it is still important that we understand the visual capabilities of the aging driver using traditional techniques, as this information tells us what visual information is actually detected by senescent individuals in experimentally controlled settings.

Spatial Resolution

Visual Acuity

Visual acuity is essentially a persons' ability to resolve fine spatial detail. According to Schieber (2006) visual acuity is typically represented using the *minimum angle of resolution* (MAR) in minutes of arc with the average persons' visual acuity subtending 1 minute of arc, the equivalent of what most refer to as 20/20 vision. When a person goes to apply for a driver's license, Snellen letters are frequently used to determine their visual acuity. The charts most commonly used consist of multiple lines of Snellen letters which are larger at the top and progressively smaller towards the bottom. The critical details of these letters (the stroke width and gap width) always subtend 1/5th of the overall letter height (Figure 7).

Figure 7. Stroke width &gap width of Snellen letters for viewer with 20/20 vision (http://webvision.med.utah.edu/KallSpatial.html)

The visual acuity of a person is measured by determining the smallest row of letters on a Snellen chart that can be accurately reported (Kolb, Fernandez, & Nelson, 2007). Contrary to what some might believe, when we say a person has 20/20 vision, this essentially means that his or her vision is average. To clarify, the first number in this relationship refers to a persons' actual performance, while the second number refers to the average persons' performance. Thus, to say your vision is 20/20 simply means that you can determine letters with 1 minute of arc line separation at a distance of 20 feet whereas the average person could do the same. But to say your vision is 20/15 means

you can see from 20 feet what most would have to be at a distance of 15 feet to see. Most states use 20/40 as the visual acuity cutoff for obtaining a drivers license. According to Owsley & Sloane (1990), most states use these high contrast, high luminance Snellen charts to measure visual acuity because they are easy to both administer and perform.

In a review of the literature regarding visual function and aging, Pitts (1982) reported that after age 60, corrected visual acuity begins to decline dramatically. More recent research using large, representative samples and more modern techniques has confirmed this claim. Figure 8 from Schieber (2006) depicts the data from three studies (Haegerstom-Portnoy, et al., 1999; Bergman & Sjostrand, 2002; Weymouth, 1960) which found that the aging persons corrected visual acuity decreases from 20/24 at age 70 to 20/71 at age 95.

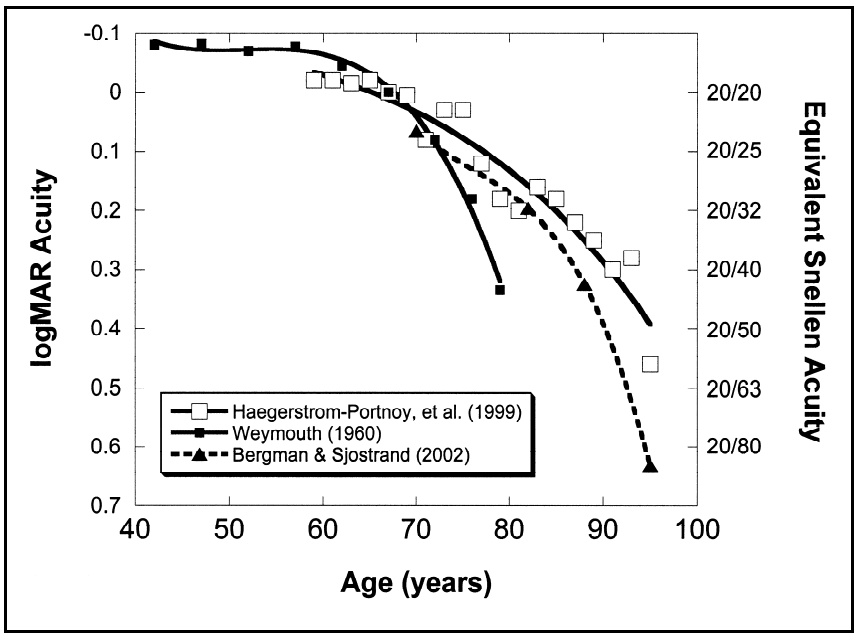


Figure 8. Findings from three studies of aging and visual acuity (Schieber, 2006)

According to Schieber (1991), some of the optical characteristics of the pupil that influence an aging persons' visual acuity are changes to the surface of the cornea which

lead to increases of intraocular scatter (Kuwabara, 1979), as well as a reduction in pupil size (senile miosis) which restricts the amount of incoming light able to reach the retina (Birren, Casperson, & Botwinick, 1950). Schieber (1991) goes on to suggest that the most likely factor occurs at the level of the lens and involves its ability to accommodate. Research suggests that as a person grows older, their lens becomes less transparent (Sample, Esterson, Weinreb, & Boynton, 1988) and more rigid, thus making it increasingly difficult to bring near objects into focus on the retina. However, even when such optical factors are corrected for, there still exists a decline in acuity with advancing age, a finding which implicates a strong neural component as well (Weale, 1975; 1982).

It is noteworthy that, most standard tests of visual acuity are conducted during conditions with both high contrast and high luminance levels. When we drive however, it is not always during such optimal conditions. Oftentimes, people choose to operate a vehicle when visibility is actually quite poor (rain, snow, fog, etc…) and little light is available (nighttime, dusk, dawn, etc…). Some might wonder how a drivers' visual acuity changes as a result of suboptimal conditions. A large sample study performed by Heagerstrom-Portnoy and colleagues (1999) set out to measure the visual acuity of different age groups under conditions of varying background luminance (low=15 cd/m^2 vs. high=150 cd/m^2) and contrast (low=16% vs. high=90%). The results of this study show that with increasing age, visual acuity scores are significantly worse under conditions of both low contrast and low luminance with the average 80 year olds' acuity measuring 20/126 (Figure 9). When the luminance level was raised, visual acuity improved to only 20/50 for this age group, a value well beyond the standard 20/40 cutoff used by most states to restrict a person's driving privileges. The fact that the slope of

each viewing condition was significantly different from the next is an important finding as it suggests that current tests of visual acuity for licensing purposes might not be informing us about the true visual capabilities of the aging driver during real world situations, as these tests are performed under the least taxing of environmental conditions (i.e. high luminance & high contrast). Many researchers agree that poor performance on measures of visual acuity might be helpful for identifying drivers with extreme visual deficits, but these measures have yet to show promise as reliable predictors of future accident involvement (Ball & Owsley, 1991; Owsley et al., 1991).

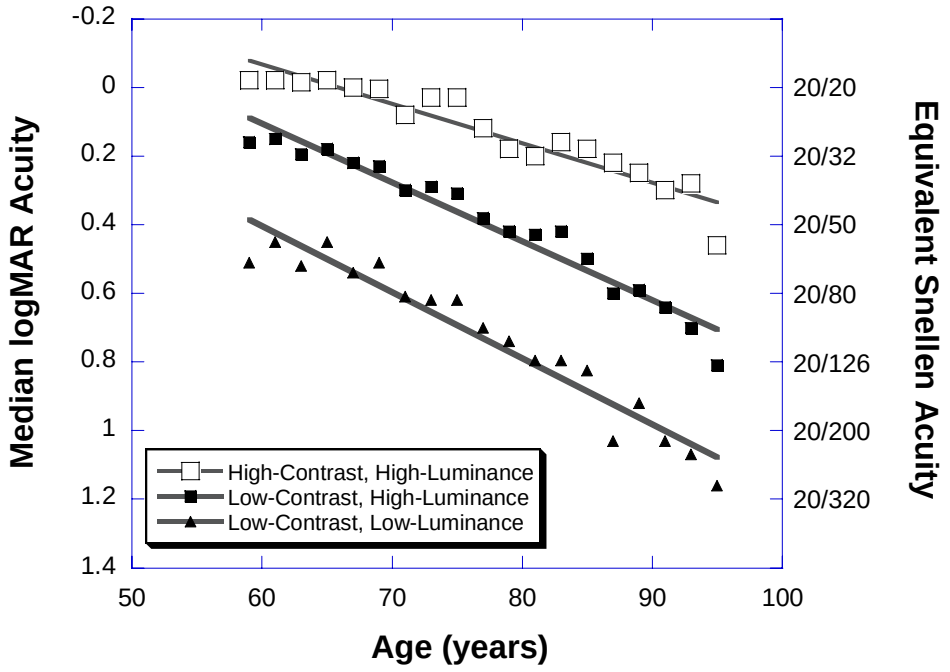


Figure 9. Visual acuity as a function of age and varying stimulus contrast and luminance (Schieber, 2006)

Contrast Sensitivity

When one considers the types of tasks performed by a driver, very few actually rely on the drivers' ability to resolve fine spatial detail. Discriminating fine print on the buttons of a radio or reading nearby road signs are some examples which might hinge on

the driver's visual acuity. However, most highway signs actually rely minimally on the drivers' ability to resolve fine spatial detail because they consist of large letters or symbols which can be discriminated from rather lengthy distances. When we think about the driving environment, the critical component hinges on the drivers' ability to establish and maintain a safe pathway of travel, detecting and avoiding other vehicles that could potentially interfere with their route. A driver does not need to identify the make, the model, or the style of rims on a vehicle that is nearby, but rather the critical factor has to do with detecting whether or not a vehicle is actually present. According to Shinar & Schieber (1991), "the ability to distinguish large targets against their low-contrast backgrounds is much more relevant to the visual requirements of driving than is the ability to distinguish small details under optimal illumination." Fortunately, a number of vision researchers have developed techniques which extend the information gained from simple measures of visual acuity by establishing what is known as the *contrast sensitivity function* (CSF) (Schieber, 2006).

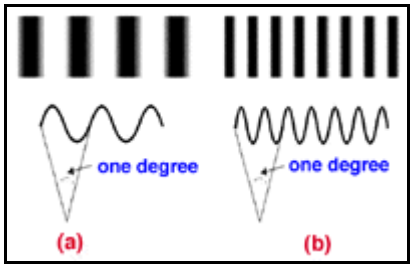


Figure 10. Spatial frequency is a measure of the number of cycles per degree subtended at the eye. (a) one cycle per degree (b) two cycles per degree (http://webvision.med.utah.edu/KallSpatial.html)

Establishing a person's contrast sensitivity function is a tool which allows measurement of the minimum amount of contrast needed to detect targets of various sizes from their background. Targets are typically represented by sine wave gratings that vary in spatial frequency (cycles per degree of visual angle or c/deg) (Schieber, 2006). Sine-

wave gratings are used because they can be created mathematically (Ginsburg, 1978) and are believed to be used by the visual system early in information processing as fundamental image building blocks (Maffei, 1978). The spatial frequency of a given target is determined by the number of cycles subtended within a single degree at the eye (Figure 10) and typically range from 0.5 c/deg (very wide) to 16-32 c/deg (very narrow) (Schieber, 2006).

A person's sensitivity to target contrast over a wide range of spatial frequencies is typically represented using an inverted U-shaped function (Figure 11). This is because the relationship between contrast threshold and spatial frequency is reciprocal (1/threshold contrast). The more sensitive a person is to a given spatial frequency target, the lower their contrast threshold will be. In Figure 11 we can see that the younger age groups are most sensitive around 6 c/deg, need slightly more contrast to detect a lower frequency 1.5 c/deg target, and considerably more contrast to detect a high frequency 20 c/deg target.

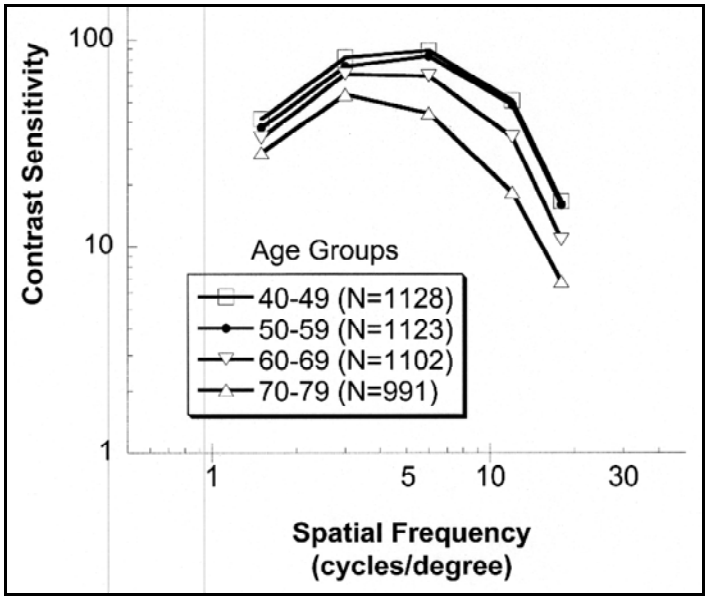


Figure 11. Contrast Sensitivity functions of four age groups (Schieber, 2006)

Research to date has consistently reported an age-related decline in contrast sensitivity for both intermediate and high spatial frequency targets which are stationary (Owsley, Sekuler, & Siemsen, 1983; Elliott, 1987; Elliott & Whitaker, 1992). The results of a large sample study conducted by Nomura and colleagues (2003) confirm such age-related deficits (Figure 11), finding that participants aged 60-69 years begin to exhibit a decline in contrast sensitivity on the order of 0.1 log units for targets greater than 3 c/deg, while those aged 70-79 years display a much more dramatic sensitivity loss for intermediate and high spatial frequencies needing approximately 0.3 log units more contrast to detect a target (Schieber, 2006). Self-reported visual problems of senescent individuals age 65 and older have also shown a significant relationship with declines in contrast sensitivity for both intermediate and high spatial frequencies (Schieber, Kline, Kline, & Fozard, 1992). Sloane, Owsley, & Alvarez (1988) measured the contrast sensitivity for a sample of older subjects who were free from any ocular pathology under three levels of decreasing luminance. The results of this study showed that not only did the older observers' sensitivity decrease at higher spatial frequencies, but such deficits became even more dramatic as luminance levels decreased. These findings suggest that as a person proceeds into the later years of life, their visual system will require increasingly higher levels of contrast to reliably determine the difference between a target and its background.

Despite the fact that visual acuity is typically the only metric used to establish a persons visual capabilities when applying for a driver's license, its relationship with contrast sensitivity is not particularly impressive. Nomura et al. (2003) reported that for participants whose visual acuity was measured as being 20/20 or better, 21.1% of those in

their seventies could not detect an 18 c/deg target with the highest level of contrast available. It appears that measures of visual acuity alone are not indicative of a person's ability to detect objects, even when substantial contrast is available. Along similar lines, Evans and Ginsburg (1985) found that measures of contrast sensitivity were a better predictor of the aging person's ability to differentiate highway signs than were measures of visual acuity. It is likely that the decline in contrast sensitivity with age might also make it more difficult to judge the location of road symbols such as edge lines, lane markers; or perhaps even detect pedestrians (West et al., 2003). In a study of both visual and cognitive correlates with crash involvement for older drivers, contrast sensitivity was significantly related to many other measures of visual performance (stereoacuity, central 30^{o} visual field, night acuity, etc.), but showed no convincing relationships with accident involvement, number of citations, or driving avoidance (Owsley et al., 1991). Along similar lines, Decina and Staplin (1993) found that poor contrast sensitivity performance on at least three spatial frequencies was related to higher crash involvement for older drivers only when this metric was combined with visual acuity and horizontal visual field measures. It appears that measures of contrast sensitivity suffer from many of the predictive constraints similar to those of visual acuity mentioned previously. Contrast sensitivity is measured in the laboratory under highly controlled conditions. Although this metric does allow the manipulation of contrast level, an event which undoubtedly occurs quite frequently during real world driving, it appears to lack the critical components which mimic the highly dynamic qualities of actual driving, and by itself, is of limited utility for identifying potentially problematic drivers.

Peripheral Visual Fields

Determining the actual size of a driver's visual field is considered by many researchers to be another useful tool for identifying potentially problematic drivers. In theory, the larger the visual field of view, the larger the contribution of peripheral vision to a driver's abilities. The average young adult can reliably see approximately 175^{o} of visual angle, losing about 2^{o} with each additional decade after the age of 45 (Bell, 1972; Wolf, 1967). Johnson and Keltner (1983) conducted a large sample study on 10,000 volunteers and found that persons over the age of 65 had a visual field loss of nearly 13%, compared to only 3% for those aged 16 to 60 years. Alarmingly, of those persons identified as suffering from "severe visual field loss," over half (57.6%) were unaware of their shrinking peripheral visual fields. This study also found that drivers with severe binocular visual field loss had both accident and conviction rates twice as high as persons with normal visual fields. Similar findings were reported by Owsley and colleagues (1991), who found that despite not being significantly correlated to accident involvement, persons with declining visual field sensitivity were involved in twice as many accidents as those with unimpaired visual fields.

In a closed-course field study, Wood & Troutbeck (1992) reported that subjects whose visual field was restricted via a pair of goggles showed significant impairments in driving performance. With increasing field of view restrictions, subjects took longer to complete a driving course, successfully avoided fewer obstacles, and failed to detect significantly more roadside targets located in the periphery (pedestrians & road signs). Along similar lines Brooks, Tyrrell, & Frank (2005) reported that for a group of healthy young drivers, steering performance in a driving simulator remained relatively stable

until monocular field loss was experimentally degraded below 11^{o}. With further reductions in visual field size down to 1.7^{o}, steering performance declined dramatically. A study by Coeckelbergh, Cornelissen, Brouwer, and Kooijman (2002) looked at the eye movement behavior of persons with visual field defects under both highly controlled laboratory conditions and during an actual on-road driving test. Compared to a group of control subjects, during the laboratory tasks subjects with peripheral visual field defects had longer search times, made more fixations, and had shorter fixation durations; however none of these behaviors was predictive of eye movement strategies used during the actual driving test. As a whole these findings suggest that a shrinking visual field has the potential to seriously restrict a person's ability to accurately steer a vehicle. It would appear that further developing techniques which probe the senescent driver's breadth of visual information processing during dynamic real world situations could be highly useful for identifying drivers with an increased likelihood of crash involvement.

Temporal Resolution

The evidence presented thus far suggests that there is definitely a decline in visual capabilities which result from the aging process; however the metrics used to establish such deficits have yet to reveal a reliably predictive relationship with accident involvement. According to Owsley et al. (1991),

> . . . sensory tests, such as visual acuity, contrast sensitivity, and visual field sensitivity, although quite appropriate for the clinical assessment of vision, do not presently reflect the visual complexity of the driving task (visually cluttered array, primary and secondary visual tasks, simultaneous use of central and peripheral vision) (p. 404).

Knowing this, many researchers have attempted to develop more "dynamic" techniques similar to actual real-world driving in hopes of identifying those who are the most likely to be involved in potentially dangerous driving situations.

Dynamic Visual Acuity

This test of visual acuity requires that a person detect the details of a moving target (e.g., a Snellen letter, Landolt ring, or Ortho-Rater checkerboard target) which moves across a horizontal plane directly in-front of the eyes at a fixed angular velocity (Shinar & Schieber, 1991). For example, if the target consisted of a Landolt C, the subject would be required to determine the location of the letter's gap (top, bottom, left, or right) as it moved rapidly from left to right (e.g. 60 deg/sec, 90 deg/sec, 120 deg/sec, 150 deg/sec, etc.). Burg (1966) conducted a large sample study (N = 17,500) investigating dynamic visual acuity (DVA) performance as a function of age. The results of this study show that with increasing age, DVA performance progressively deteriorates with more rapidly moving targets. More importantly, decrements in DVA performance begin much sooner than those of static acuity and increase in severity much faster after the fifth decade of life (Shinar & Schieber, 1991). In an analysis of 3,600 licensed California drivers, Burg (1964) found a significant positive relationship between good driving records (i.e., fewer citations) and good DVA performance. Other researchers have also analyzed similar data and found that poor performance on measures of DVA is a better indicator of accident involvement than are measures of static acuity for the oldest age groups (Burg, 1967; Hills & Burg, 1977), but it should also be mentioned that these relationships are consistently weak accounting for less than five percent of the total variance (Owsley et al. 1991). These results are most likely attributed to very small

effects that reached significance only because of extremely large sample sizes, with the total number of subjects reported as being greater than 17,000. In fact, Hills (1980) discusses the results from Henderson and Burg (1974) and reports that the highest correlations between DVA performance and accident involvement were actually for the youngest subjects, aged 16-24 years. This finding suggests that those with the best DVA, not the worst, were much more likely to be involved in accidents, a somewhat contradictory age-related finding to the previously mentioned Burg data. The increased accident involvement for younger drivers outlined in Hills (1980) is most likely a reflection of the lack of driving experience for younger people who simply have better visual abilities.

The use of dynamic visual acuity as a predictor of driving ability is generally accepted by many as it is the only metric mentioned thus far that even remotely simulates the dynamic information processing demands of driving. The extent to which DVA actually reflects these information processing demands should be questioned however. It is useful to keep in mind the characteristics of the actual task subjects are asked to perform. Typically, subjects have to determine the location of a gap in a high contrast, Landolt C stimulus as it moves horizontally across the field of view at very rapid speeds. If a subject guesses, they have a 1 in 4 chance of choosing the correct answer (top, bottom, left, or right). Also, how often during the task of driving is a person actually required to perform such a task? If a driver is stopped at a highway T-intersection, waiting for a large enough turning gap as the traffic passes at speeds of 60 mph, what critical information are they searching for? Determining a person's DVA would tell us about their abilities to instantaneously extract some piece of high detail information from

such a scenario (the vehicle make, trim package, male or female driver, etc.), but is this really what a driver is interested in? Most would agree the answer to this question is "No." The information immediately critical to the driver has to do more with detecting whether or not a speeding car is present, it's distance, and it's actual speed; all of which can be done without using the highly detailed information necessary for accurately performing tests of DVA. Such considerations, combined with the contradictory age-related findings previously mentioned, suggest that the use of DVA as a metric to identify impaired drivers is still in need of considerable refinement.

Flicker Perception – Critical Flicker Frequency

Determining a person's critical flicker frequency (CFF) is a classical method used to measure the temporal processing abilities of the human visual system. In this paradigm, a high contrast light source constantly oscillates between on and off states at a rapid pace. According to Schieber (2006), "the critical flicker frequency represents the minimum frequency of a pulsating light source at which the light appears to be perceptually fused into a continuous, rather than flickering, stimulus (p. 149)." When the stimulus appears to be continuous, physically it is still flickering on and off, but is doing so at a rate that is beyond the temporal resolving power of the observer. Researchers have empirically determined that the CFF threshold decreases as a person grows older (Brozek & Keys, 1945; McFarland, Warren, & Karris, 1958; Huntington & Simonson, 1965). There is some debate as to the true cause of such a decline. Wolf and Shaffra (1964) reported that the aging persons' weakening CFF thresholds were caused by the reduced illumination of the retina resultant of normal, age-related changes to the structure of the eye (i.e., pupillary miosis). However, other researchers have reported that this

decline in CFF threshold is attributable to changes in the aging person's nervous system (McFarland, et al. 1958; Kline & Schieber, 1981). In terms of the aging driver, it is undocumented how well measures of CFF might account for crash variance and thus, it's usefulness as a tool to identify potentially problematic drivers has yet to be established.

Temporal Contrast Sensitivity Function

Thus far, it has been established that a person's ability to detect a target from its background is a critical function in terms of the ability to safely operate a vehicle. Earlier in this section, it was reported that the aging persons' contrast sensitivity to spatial frequency information changes throughout the lifespan, becoming less sensitive to intermediate and high spatial frequencies during the later years. Once again, keep in mind the visual requirements demanded by the task of driving. Detecting the presence or distance of a nearby vehicle is not determined by the ability of the aging driver to detect the highly detailed, high spatial frequency information to which their sensitivity has weakened, but rather is driven by their retained sensitivity to low spatial frequencies. There is however another critical component in this equation to be considered; the temporal domain. Not only is it important that an approaching vehicle be detected, but it is also imperative that the driver pick-up rate of change information regarding this vehicles pathway. The contrast sensitivity research presented earlier involved stationary targets that only changed in spatial frequency per unit space. It might also be helpful to determine how contrast sensitivity changes as a function of time as well. Luckily, there exists a body of research on what is known as the *temporal contrast sensitivity function (tCSF)*, a metric which determines contrast sensitivity to temporally changing stimuli.

According to Schieber (2006), the tCSF is measured using the following procedure:

> . . . the brightness of a small (2-5^{o}) self-luminous circular target is sinusoidally modulated at a given temporal frequency around a baseline luminance value. Next, the minimum luminance contrast modulation required to detect the presence of flicker is determined for a range of temporal frequencies, which typically extends from 1 to 50 cycles per second (Hz) (p. 149).

A contrast sensitivity curve similar to those mentioned earlier (Figure 11) is used to display the results, except in this instance the x-axis denotes temporal frequency (Hz or cycles/sec) instead of spatial frequency (cycles/deg).

A study conducted by Wright and Drasdo (1985) documented the changes in tCSFs which occur as a function of age. Ten subjects with average visual acuity (20/20) represented each decade of life from 10-79 years of age. The authors reported an overall decline in tCSF for the oldest age groups, the most dramatic of which occurred for high spatial frequency stimuli (i.e., 30 Hz). Wright and Drasdo concluded that this reduced sensitivity could not be attributed to neural, but rather optical factors; such as the increased intraocular scatter and decreased optical transmission due to the increased light absorption of the lens which transpires with age. Tyler (1989) reported similar findings which suggest an ongoing decline in tCSF at higher temporal frequency stimuli which result as a function of normal aging. However, Tyler reported that the decrease in temporal resolving power could be attributed to a reduction in "visual response speed," approximated to be nearly 20% over a life time as opposed to optical factors suggested by Wright and Drasdo (1985). To further understand the source of these age-related declines in tCSFs, Kim and Mayer (1994) controlled for pupil size using a sample of nearly 90 subjects between the ages of 18 to 77. Any differences exposed after carefully

controlling for individual differences in retinal illumination would provide support for a decline in neural processing efficiency as being the source of age-related changes in tCSFs. Kim and Mayer found a significant, albeit small, age-related decrease in temporal contrast sensitivity threshold for higher spatial frequencies (34 - 45Hz) and concluded that such a decline could be attributed to a reduction in neural processing efficiency of visual information, rather than purely to optical factors. Similar results were reported by Mayer, Kim, Svingos, and Glucs (1988).

At its core, the ability of an observer to detect transient targets using the tCSF has potential implications for identifying aging drivers with increased crash likelihood. Establishing the amount of luminance contrast required to detect targets of varying transient signature is, without a doubt, a capability which will influence whether or not a person detects real world targets experienced during the task of driving. Many researchers mention the potential importance of the tCSF in terms of the driver's abilities, however it has yet to be empirically determined how such a metric actually helps explain crash variance, or identifies which drivers will have issues.

Visual Attention

There also exists a body of research which is not interested in the visual abilities of the aging driver *per se*, but rather is concerned with understanding the attentional capabilities of these drivers. The construct of attention is actually a somewhat complicated idea. Everyone knows it exists; but what exactly is it, where is it located, and most important to the experimental psychologist, how can it be measured? We feel attention working as we drive through a torrential downpour and have to turn off the

radio in order to concentrate, or fail to hear the conversation coming from a fellow passenger while merging into rush hour traffic. For many years researchers have invested a great deal of time and effort in an attempt to understand how the construct of human attention behaves. The following section will review a body of literature specifically devoted to examining the attentional demands placed on drivers in a variety of situations.

Divided Attention

Most common theories assume that at any given time the available attentional capacity is of a fixed or finite amount (Wickens, 1984), but this capacity also depends upon both motivation and arousal (Kahneman, 1973). The ability to perform multiple tasks at the same time depends upon one's ability to allocate their limited attentional resources appropriately to each task at hand. When the tasks demand more resources than are available, decrements in performance begin to occur. Typically, the attentional capabilities of a person are determined by having them simultaneously perform both a primary and a secondary task. Subjects are instructed to always maintain 100% performance levels on the primary task, and perform the secondary task to the best of their abilities when capable. The difficulty of the secondary task is then experimentally manipulated and changes in operator performance on this task are used as an indication of spare attentional capacity.

A common finding in the research literature suggests that a person's ability to sustain, divide, and reallocate attention declines in ability as a function of the normal aging process (McDowd & Shaw, 2000). It has been shown that older individuals process information slower and are much more susceptible to distraction from irrelevant stimuli (Madden, 1990). Under dual task situations where both tasks demand visual

resources, older subject performance has been shown to be significantly impaired when compared to that of younger subjects (Korteling, 1991). Many researchers have suggested that such age-related deficits in attentional processing might be informative in terms of better explaining the types of problems elderly drivers typically experience (Ball & Owsley, 1991; Owsley et al., 1991; Parasuraman & Nestor, 1991); especially considering that of the visual techniques mentioned thus far, none have been particularly helpful in furthering our understanding as to the source of such difficulties.

Ponds, Brouwer, and van Wolffelaar (1988) conducted a dual-task driving simulator study which attempted to mimic the dynamic environment experienced during real world driving. The purpose of this study was to identify any age-related differences in the ability to divide attention. Researchers had young, middle-aged, and older drivers perform two continuous performance tasks, a compensatory tracking task and a self-paced visual choice reaction time task. The tracking task required subjects to maintain vehicle position in the right lane of a roadway as unpredictable "wind gusts" pushed the vehicle left and right. The reaction time task demanded that drivers count dots projected within a pre-defined rectangular area on the simulator screen. The drivers' task was to determine whether or not nine dots were present by pressing one of two buttons located on the steering wheel. The dot counting task was self-paced to control for individual differences. Under dual-task situations, no differences were found between the young and middle-aged groups, however the oldest group performed significantly poorer on the simulated driving task. The authors attributed these differences to a decrease in divided attention efficiency for subjects beyond the age of 60 years. It was also pointed out that such age differences might have been due to the integration of multiple motor programs

demanded by both the steering task and the manual response button pushing. To further examine this issue; Brouwer, Waterink, van Wolffelaar, and Rothengatter (1991) conducted a follow-up replication study where the response domain consisted of either manual button presses or vocal responses. Once again, the older subjects showed a decrease in ability to divide attention compared to their younger counterparts, as indicated by performance decrements in lane tracking and visual analysis error scores. However such effects were not significantly different in the vocal response domain, but were for manual responses. According to Korteling (1991), the effects of aging appear to be especially evident when tasks involve the integration of motor skills. It appears that responding manually in an environment with high spatial resource demands (such as real-world and simulated driving) can cause potential interference (Wickens & Liu, 1988). The investigator with aspirations to develop techniques capable of being used during real world driving should carefully consider such consequences; as potential interference could adversely affect the aging driver's abilities to respond to immediate hazards safely.

Other driving related studies have reported similar deficits in performance which appear to occur as a function of increasing driver age. Using a simulator, Baldwin and Schieber (1995) investigated the effects of steering complexity while having subjects perform a secondary task consisting of mental arithmetic problems. As the steering task became more difficult, older drivers took significantly longer to perform the secondary task. In theory, as the primary task of driving demanded more attentional resources, there were fewer residual resources available which could be allocated to the mental arithmetic task. Interestingly, the authors reported that driver steering error did not differ between single and dual task conditions, a finding which supports the use of secondary tasks as an

indication of spare operator capacity. In another simulator study, albeit using a much simpler, rudimentary approach; Crook, West, and Larabee (1993) further explored the differences in attentional capabilities between a group of young and old subjects under dual task conditions. The authors used a touch screen computer monitor to display an accelerator pedal and a brake pedal. When a traffic light turned green, subjects were instructed to press the accelerator pedal as quickly as possible. In turn, when the traffic light turned red, the brake pedal area of the screen was to be pressed. According to the authors, subject "lift time" was attributed to attention whereas "travel time" between the two pedals was associated with psychomotor speed. The second task in this paradigm required subjects to monitor weather reports for a later memory test. After accounting for each groups' single task performance, the authors performed a regression of dual task performance on age and found that aging had a negative impact on lift time, but not travel time. Crook and colleagues interpreted this finding as revealing a dual task cost for the older subjects which could be attributed to the "attention demanding" aspects of the paradigm (i.e., lift time).

An interesting study was conducted by Korteling (1994) to further understand the effects of aging on skill modification for highly practiced tasks involved in driving. Using a driving simulator, subjects were required to perform two tasks, a vehicle steering task and a car-following task. The steering task demanded that subjects maintain their position in the center of the right lane while unpredictable simulated wind gusts forced the use of compensatory steering movements. The car following task required that subjects maintain a following distance of 15m from a lead vehicle whose speed continuously varied. To examine the extent to which a highly practiced skill can be

modified, the polarity of the accelerator pedal was changed. In the normal polarity condition, pressing the gas pedal caused acceleration and releasing it caused deceleration. However in the reversed polarity condition, the pedal functions were switched so that pressing the gas pedal now made the vehicle decelerate and releasing it caused the vehicle to accelerate. Under normal polarity conditions, the two age groups were indistinguishable from one another. In the inverted polarity condition, young subjects were able to modify their responses appropriately whereas the older subjects showed dramatic performance decrements in longitudinal deviation from the lead vehicle. In terms of attentional allocation during multiple task situations, Korteling (1994) suggested that decrements in the aging drivers' performance of well-learned psychomotor tasks only becomes apparent when such a task requires the "active initiation" of higher level processes to account for the demands of all tasks involved. The author goes on to suggest the difficulties experienced by the older driver are not likely to be due to the "invariant components" of driving, but rather are exposed when these drivers are forced to "modify elements of long-existing psychomotor routines which occur during novel situations (removal to another city, changes in regulations, changes in intersection layout, or the purchase of a new car) (p. 41)."

As useful as secondary task paradigms might be, they do have some potential drawbacks that every experimenter should consider. A common criticism of many secondary tasks involves the extent of their resource diagnosticity with the primary task of interest. Secondary task measures are most sensitive when their degree of resource overlap with the primary task is substantial (Wickens & Liu, 1988). In theory, as the driving task becomes increasingly complex and demands more and more of the driver's

mental resources, fewer resources become available in spare capacity to attribute to secondary task performance (de Waard, 1996). Another potential issue has to do with the obtrusiveness of the experimental task. Performing secondary tasks might be difficult to accept by subjects due to their artificial nature relative to the environment under observation (O'Donnell & Eggemeier, 1986). However, careful experimental design and implementation of tasks with high ecological validity can aid in reducing this intrusiveness. Often times in secondary task paradigms, measures are aggregated over a large number of trials which makes it difficult to detect short-lasting peaks in workload. The ability of a metric to detect short lasting peaks in workload is an important quality that many secondary tasks lack, as these momentary spikes in information processing demands during actual driving can be the hazardous, unpredictable events which lead to crashes (Martens & van Winsum, 2000).

Useful Field of View (UFOV)

Another technique which has achieved considerable success in helping to identify potentially problematic drivers is referred to as the "Useful Field of View" (UFOV). The concept of UFOV was derived from research which found that performance decrements on simple discrimination tasks increase as a target's eccentricity moves further into the periphery (Sanders, 1970). Determining a person's UFOV involves measuring the breadth of visual information processing which occurs while engaged in some central task. The size of the UFOV is not equivalent to visual field size as determined by standard clinical techniques (e.g., those outlined in the peripheral visual fields section), and depending upon the complexity of the environmental situation UFOV can actually become quite restricted in size (Ball, Owsley, & Beard, 1990). It is not uncommon for a

person to have a normal sized visual field, but a much smaller UFOV (Ball et al., 1990). One advantage of UFOV metrics is their ability to resemble everyday tasks (i.e., perform multiple tasks with lots of distracters present) to a much greater extent than standard clinical measures of visual function.

Sekuler and Ball (1986) conducted a study on the effects of age in a visual localization task resembling what has come to be known as a UFOV task. Because the components of this experiment provide a good example as to how UFOV is typically measured empirically, the procedural components will be mentioned to further inform the unfamiliar reader. Sekuler & Ball wanted to determine how performance changed when subjects were asked to detect a randomly placed target of varying eccentricity in the presence of irrelevant distracters, and while also performing a central task (Figure 12). The central task always appeared in the center of a fixation box, while the peripheral test stimulus randomly appeared equally often at any of the outer box locations. When distracters were called for, the peripheral test face was presented with all of the box stimuli as well. The central task required that the subject determine the expression of the face presented in the fixation box (happy or sad). The peripheral task simply required that the subject identify the location of the peripherally presented face. All displays were presented for only 125-msec as this exposure forced the subjects to complete both the central and peripheral tasks in a single fixation. Results show that when either the central task or the peripheral task was performed alone, no age differences exist. However, when distracters were included the error rates of the older subject group increased significantly as a function of increased target eccentricity. This finding suggests that the area of the visual field where information can still be acquired and used becomes smaller

for older individuals. Interestingly, the performance of the older group improved dramatically with increased practice, and such improvements were retained over a five day period.

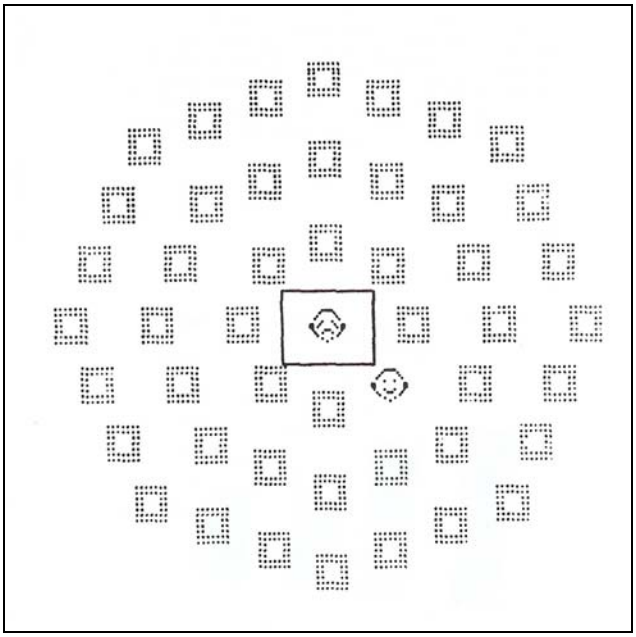


Figure 12. Schematic diagram of the UFOV test stimulus consisting of both a central face identification task and a peripheral localization task for a face target at 10^{o} eccentricity embedded in box distractors (Ball, Roenker, & Bruni, 1990)

Similar results have been reported by other researchers as well. Ball and colleagues (1990) reported that for older adults with decreasing useful fields of view, three factors accounted for 91% of this variance: speed of processing, the ability to divide attention, and susceptibility to distracters. In a follow-up study, Ball, Owsley, and Beard (1990) found that older adults whose performance suggested an increasingly restricted useful field of view also reported having more issues with everyday tasks that required peripheral vision (difficulty walking down stairs, driving, reading a sign in a cluttered environment, etc.), however their visual field sensitivity was measured as being normal using standard techniques. Limitations in the processing capacity of attentional resources

is believed to be a primary influencing factor which leads to a reduction in useful field of view for aging individuals (Ball, Owsley, Sloane, Roenker, & Bruni, 1993).

Based on the assumption that tests of UFOV resemble the visual complexity of driving better than standard tests of visual function (static acuity, contrast sensitivity, visual fields, etc.), many researchers have attempted to use UFOV as a predictor of crash involvement, especially for the aging driver. One study found that when performance on a test of UFOV was combined with a mental status score 20% of the variance for all types of crashes was accounted for, while 29% of the variance for intersection crashes could be explained (Owsley, Ball, Sloane, Roenker, & Bruni, 1991). Owsley and colleagues (1991) also reported that when compared to participants who passed the UFOV test; those who failed were involved in 4.2 more accidents on average, and had 15.6 more accidents at intersections. According to the authors, testing a person's useful field of view is a much better predictor of accident involvement than are simple measures of visual status alone based on the finding that nearly 50% of subjects who were measured as having good visual function failed the UFOV test. Along similar research lines, Ball and colleagues (1993) found that measuring a person's UFOV as a test of visual attention was the best predictor for identifying crash-involved versus crash-free drivers. Those older drivers with a substantial reduction of useful field of view were six times more likely to have been involved in at least one crash in the last five years. Ball and colleagues (1993) suggest that tests of visual attention are better at identifying older drivers with increased crash involvement because such tests examine both visual perceptual and cognitive resources, and thus "provide a more global measure of visual functional status." The authors go on to mention that any policy which restricts driver

licensure strictly on the basis of age is scientifically unfounded, and that tests of visual attention such as UFOV have the potential to offer an objective metric to identify which aging drivers are most likely to experience difficulties.

Given the success of UFOV metrics in the laboratory, several researchers have attempted to implement similar paradigms during actual on-road driving. Miura (1986) presented spots of light on the windshield of a vehicle at different eccentricities while subjects drove through environments of varying complexity. Subjects were required to respond vocally as soon as they detected a target light. The results of this study show that as the situational demands of the immediate driving environment increase, not only do reaction times increase, but the size of the peripheral visual field also decreases. These results suggest that the more demanding or complex the driving scenario becomes, the less likely a driver is able to detect targets or hazards located at more distant peripheral eccentricities. Miura (1986) also points out that decreases in peripheral vision performance were not specific to increases in driving speed, but rather were attributed to the immediate situational demands experienced by the driver. Miura (1990) replicated such findings and explained the narrowing of the driver's useful field of view as a strategy used to cope with the increasing demands of the environment.

In an attempt to understand the effects of driver experience on the size of useful field of view; Crundal, Underwood, & Chapman (1999) had three groups of drivers (experienced, novice, and non-drivers) inspect video clips for hazards while also detecting peripheral target lights. Hit rates for the peripheral targets decreased when hazards occurred, and as target eccentricity increased, however no interactions reached significance. An effect of driver experience was also reported, explained by the authors

as resulting from the development of a more efficient useful field of view that comes with more time spent behind the wheel. Consistent with the Miura studies (1986, 1990), Crundal & colleagues (1999) reported that as the situational demands at the point of fixation intensify, the driver's useful field of view shrinks proportionately at increasing peripheral eccentricity regardless of driver experience. In other words, the decline in performance as a function of increasing eccentricity changed at the same rate for drivers both with and without experience.

In line with the emphasis of the current research project, Gilland (2002) implemented a UFOV paradigm during real world driving which observed both young and old drivers. The central task in this study involved determining whether a plus or minus sign had been presented on the rear of an experimental lead vehicle. Laser diodes were then used to display targets on the test vehicle windshield at eccentricities of 8^{o}, 16^{o}, and 24^{o} into both the left and right periphery. Participants were instructed to verbally indicate which sign was presented on the central task first, and then judge whether or not a peripheral stimulus had been presented. If a peripheral stimulus had been presented, the participants were then to report on which side they detected it (i.e., left or right). The results of this study indicate that the rate of decline in target detection at greater eccentricities were not age-dependent. Instead, a DC-shift in the data was observed. The older adults in this study saw fewer peripheral targets than did the younger adults, but the detection slopes of these groups were practically identical (see Figure 13).

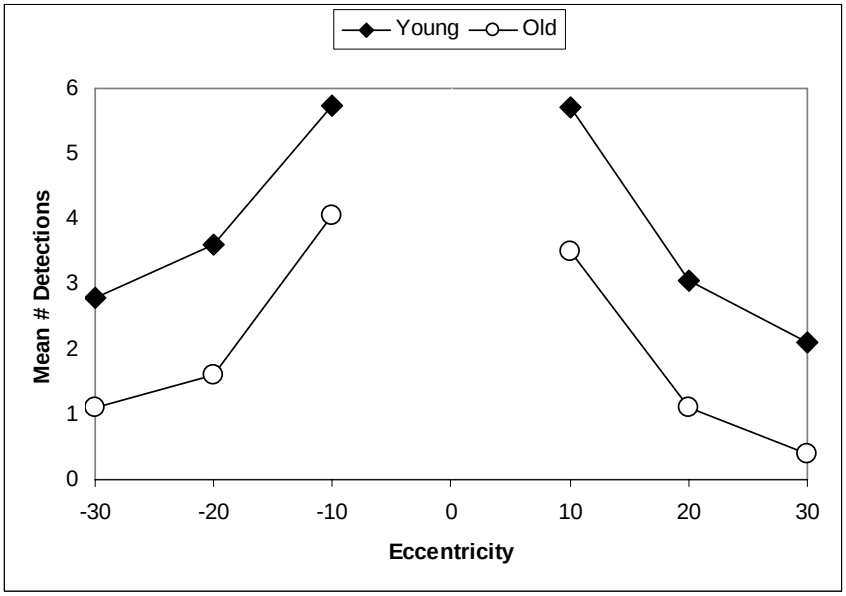


Figure 13. Peripheral detection rates analyzed by age, eccentricity, and side (Gilland, 2002)

The lack of any interactions between eccentricity and age found by Gilland (2002) provide support for what is referred to as the general interference effect. In terms of the aging individual, the general interference effect suggests that losses in performance are attributable to the decline of information processing efficiency which occurs as a result of the normal aging process. The DC-shift in detection rates revealed by Gilland (2002) suggests that age-related decrements are not due to a perceptual narrowing of attentional abilities; otherwise the older subjects should have performed progressively worse than their younger counterparts at increasing eccentricities. As indicated by the slope rates of each age group, deterioration in performance as a function of peripheral eccentricity occurred at the same rate regardless of driver age. Such findings indicate that the younger age group was simply able to process the same information more efficiently. Other age-related UFOV studies have reported similar findings. In a laboratory UFOV paradigm using a low-fidelity driving simulator, Schieber and Benedetto (1998) found

that age differences were most apparent when the presentation rates of target stimuli were limited to brief durations. The results of such findings are consistent with those discussed in the divided attention section mentioned previously. Each body of evidence suggests that while experiencing visually complex situations, the mechanisms which mediate the aging person's information processing abilities become increasingly slower and less efficient. Many researchers explain such issues in terms of attentional resources or attentional processing. Without a doubt, the aging person's ability to distribute attention accordingly is a critical component that receives considerable research interest. However, as mentioned previously, attention is a complicated construct to both define and measure from an empirical standpoint. Knowing this, a slightly alternative approach was taken in an attempt to understand the aging person's information processing abilities. Rather than attempting to measure "attention" in the traditional sense, an approach that explains information processing in terms of two unique, yet non-exclusive visual systems used by all humans throughout their lifespan was used; referred to as the "Ambient & Focal Systems." The following section of this document is dedicated to educating the reader as to the scientific history and evidence for the existence of such visual systems, with the ultimate goal of using such knowledge to develop an experimental paradigm that furthers our understanding as to the information processing abilities of the senescent individual.

Two Visual Systems, History & Evidence

The following section was based on the organization used by Norman (2002). For a thorough review of evidence concerning the existence of two visual systems and their

ensuing relationship with both constructivist and ecological theories of human perception, consult Norman (2002).

For many years, scientific research has consistently suggested the existence of two unique visual systems, each specific to utilizing visual information for different purposes (Held et al., 1967). In hopes of further understanding this dichotomy of the visual system, the use of different investigative approaches has yielded a number of different titles for these two visual systems, although at their core they all essentially refer to the same underlying mechanisms. Schneider's (1969) research with golden hamsters led to the "What" versus "Where" visual system dichotomy, while Trevarthen's (1968) research with split-brain primates coined the "Focal" versus "Ambient" distinction. A few years later, Held (1970) reviewed the literature and reported evidence referring to the visual system as having a "contour-specific mode" and a separate "locus-specific mode." Following this, Ungerleider and Mishkin (1982) described the separation of visual system information via the "Ventral" and "Dorsal" pathways. While the nomenclature changed from study to study, the evidence essentially leads to the same conclusion. The visual system appears to consist of two unique information pathways. Keep in mind that one must be careful not to interpret these systems as being mutually exclusive. Information from each pathway is integrated to create our entire visual experience, thus allowing us to not only see a world rich in detail, but also allow us to interact with this world seamlessly. For the purposes of the current research project, the focal/ambient visual system dichotomy will be used.

History

What versus Where Systems

Different from other researchers of his time, Schneider (1969) was interested in the nature of an animal's response as a result of ablations to different areas of the brain (areas 17, 18, and the superior colliculus). Using golden hamsters, Schneider found that severing areas 17 and 18 impaired the hamsters' abilities to discriminate between patterns, but did not influence their ability to guide themselves toward a reward stimulus (a sunflower seed). In another group of hamsters, the superior colliculus was severed. This brain structure is known to be responsible for producing automatic, reflexive visual orientation behaviors (Carlson, 2004). Interestingly, for this group the exact opposite effect was found. Hamsters with a detached superior colliculus maintained a consistent and accurate ability to discriminate patterns, yet they were unable to guide themselves towards a reward stimulus until their whiskers were actually contacted. In other words, the hamsters were unable to use visual abilities to spatially localize a reward, but were still able to do so using tactile information. When cortical areas 17 and 18 were severed, hamsters were unable to determine "what" a stimulus was in terms of a pattern discrimination task, yet they maintained their abilities to locate "where" in space a reward was. This impairment of abilities under one circumstance, but not another served as evidence which led Schneider to conclude the existence of two visual systems: one at the subcortical level of the superior colliculus, responsible for determining "where" in space a stimulus is present; and yet another system located at a more cortical level, responsible for determining "what" a stimulus actually is.

Results in line with Schneider (1969) were reported just a few years later in research using frogs (Ingle, 1973). As a result of removing the superior colliculus, Ingle (1973) showed that the frogs' ability to orient towards moving objects became impaired whereas their ability to localize stationary objects remained unaffected. In other words, the frogs were still able to determine what an object was, but declined in their ability to determine precisely where in space this object resided. Held (1970) briefly reviewed a number of research articles at both the retinal and cortical level which provide further support for the existence of two distinct modes of visual information processing. One referred to as the "contour-specific" mode which is utilized to process the rich detail of objects, and the other as the "locus-specific" mode which is utilized for orientation purposes.

Focal versus Ambient Processing

Physiological research with split-brain monkeys by Trevarthen (1968) has also suggested the existence of two distinct visual systems; coined the focal and the ambient systems. Trevarthen's work suggests that the focal system is driven by visual information from the fovea; while ambient vision, whose visual characteristics closely resemble more primitive vertebrates, relies primarily on peripheral vision. Ambient vision, according to Trevarthen (1968), is relatively insensitive with regard to stationary features such as relative position, orientation, and object luminance or hue. It is not until these stimulus characteristics change in some way that the ambient system becomes highly sensitive. Trevarthen hypothesized this to mean that ambient vision is strongly driven by inputs from rod photoreceptors at the retinal level. The focal system, on the other hand, is interested in all of the highly detailed information in the surrounding

environment. Focal vision is capable of discriminating between subtle changes in orientation, hue, position, or luminance. Trevarthen (1968) believed focal vision to be driven exclusively by cone photoreceptors which are concentrated in the fovea of the retina. Because this region only occupies about 2-3 degrees of the entire retina (Levi, Klein, & Aitsebaomo, 1985), focal vision is capable of acquiring highly detailed visual information from a relatively restricted portion of the actual world. In more general terms, this means humans can typically resolve fine spatial detail from an area only about the size of a thumbnail at arms length. To make up for this restricted range, humans continuously scan and sample from the environment using eye and head movements, the result of which is a highly detailed visual experience.

Ventral versus Dorsal Pathways

Further evidence for the existence of two visual systems came about from Ungerleider and Mishkin (1982) and their brain-lesion research with rhesus monkeys. These researchers used the path of visual information at higher-order cortical areas to distinguish between the two visual systems (Figure 14). Ungerleider and Mishkin referred to these systems as the "dorsal" and "ventral" pathways. The dorsal pathway, according to these authors, travels a dorsal route (translated as "towards the back") from the occipital cortex through the posterior parietal region of the cortex, and is primarily responsible for determining where in space an object is located. The ventral pathway, on the other hand, travels a ventral route (translated as "towards the belly") to the temporal lobe of the cortex and is utilized for determining what an object actually is.

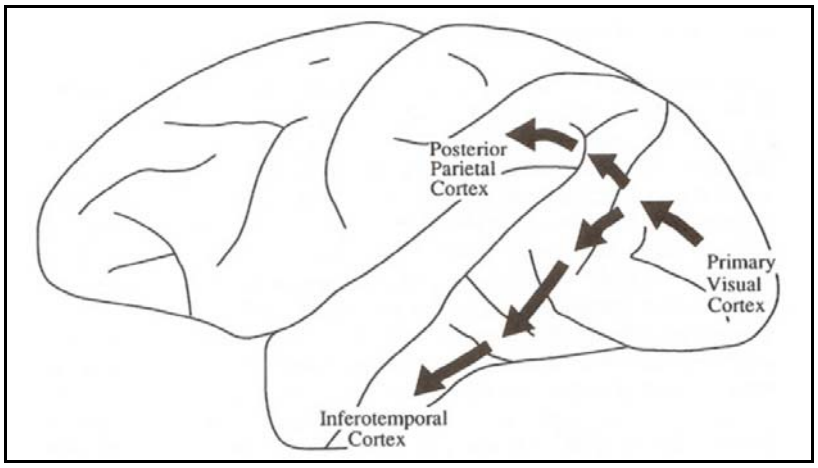


Figure 14. A schematic diagram of Ungerleider & Mishkins (1982) model of the 2 streams of visual processing in the primate cerebral cortex (taken from Milner & Goodale, 1995, pg. 22)

The ventral pathway is the equivalent to what we have referred to thus far as the "focal" or "what" system while the dorsal pathway is synonymous with the "ambient" or "where" visual system. The most significant difference between Ungerleider and Mishkin's dorsal/ventral pathways compared to those mentioned previously by Schneider (1969) and Trevarthen (1968) has to do with the location of visual system separation within the cortex. Whereas previous researchers identified the superior colliculus as the subcortical area primarily responsible for object localization processing, Ungerleider & Mishkin believed the majority of this processing occurred much later in the hierarchy of visual cortical processing, more specifically in the posterior parietal region. The ventral/dorsal nomenclature was also adopted by Goodale and Milner (1992), yet their interpretation has more to do with how the ventral and dorsal pathways both use and transform information to appropriately interact with the surrounding world. More specifically, Goodale and Milner's work with brain damaged patients suggested that the dorsal system is not only involved in the visual localization of objects, but also is responsible for guiding the motor movements necessary to interact within a given

situation (e.g. picking up a pen, clasping the shifter in a manual transmission vehicle, using the steering wheel to control a vehicle, etc…).

Thus far, the existence of two visual systems has been supported by a number of researchers. Although the terminology changes slightly from study to study, the underlying concepts specific to each visual system remain the same. The focal system (i.e. the "what" or "ventral" pathway) is responsible for object identification, where as the ambient system (i.e. the "where" or "dorsal" pathway) is responsible for object localization. At this point, it is necessary to take a closer look at the empirical evidence which distinguishes the functions of each system. To avoid any confusion involved with switching between each of the visual system nomenclatures used thus far, the remainder of this document will use the focal/ambient dichotomy.

Evidence

Neurophysiological

One way to better understand the different functions of both the focal and ambient visual systems is to take a deeper look at where each system receives information from. Evidence from fluorescent tracers injected into the brains of rhesus monkeys found that the ambient system is driven largely by the parietal cortex, an area known to be involved in spatial/motion analysis with origins in the peripheral field of the retina; while the focal system can be traced to the temporal cortex, an area specialized in form and color analysis with links to central vision (see Figure 15) (Baizer, Ungerleider, & Desimone, 1991).

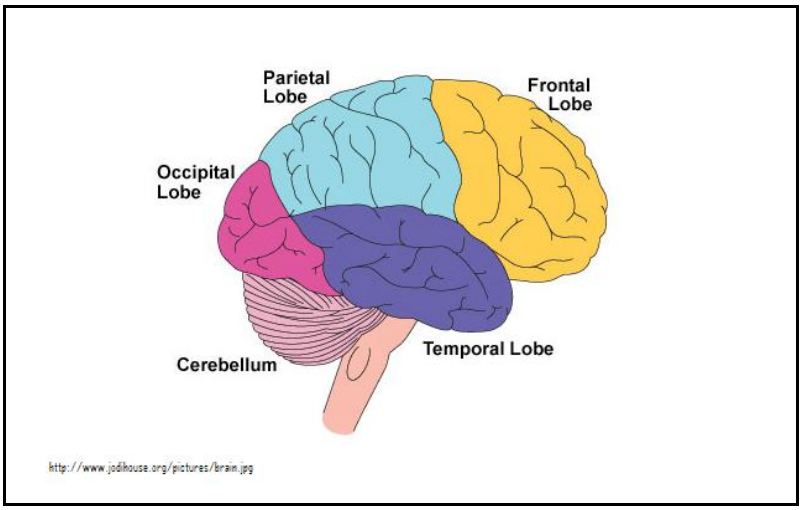


Figure 15. Schematic of the different cortical processing lobes of the human brain (http://www.jodihouse.org/pictures/brain.jpg)

Work by Merigan and Maunsell (1993) suggests that both visual pathways receive information from the subcortical lateral geniculate nucleus (LGN). The LGN itself can be divided into six layers, four parvocellular layers and two magnocellular layers (Livingstone & Hubel, 1988). According to Merigan and Maunsell (1993), the focal system is fed primarily by the parvocellular layers while the ambient system relies on information from the magnocellular layers. The importance of the information coming from each of these LGN layers is dictated by the fact that about 90% of the neuronal axons coming from the retina travel to either the magnocellular or parvocellular layers (Silveira & Perry, 1991).

Research has shown that the magnocellular and parvocellular layers are functionally distinct with regard to certain properties of visual information such as color, motion, image resolution, processing speed, and contrast sensitivity. According to Livingstone and Hubel (1988), roughly 90% of the parvocellular layers are sensitive to wavelength information sent from red, green, and blue cone photoreceptors at the level of

the retina, while the magnocellular layers sum this same photoreceptor information and use it to detect broad changes in illumination, thus rendering these layers colorblind. With regard to the resolution of images, Livingstone and Hubel (1988) contend that each layers' sensitivity is directly related to the size of the retinal ganglion cell receptive fields from which they receive inputs. The size of a cells receptive field is influenced by both the type of photoreceptor to which it is attached, as well as its location on the retina. Cells with very small receptive fields are attached to cones concentrated primarily in the fovea. These cells send detailed information regarding a very small region of space to the parvocellular layers of the LGN, indicating that these layers are heavily involved in the processing of high spatial-resolution information. Those cells with larger receptive fields receive inputs from the more peripherally located photoreceptors and send their low resolution information to the magnocellular layers. Although the magnocellular layers are inferior in terms of visual acuity, they are capable of responding at rates significantly faster than their parvocellular counterpart (Livingstone & Hubel, 1988; Bullier & Nowak, 1995). This ability to process information quickly has led many researchers to conclude that the magnocellular layers of the LGN play a critical role in detecting object motion (Bullier & Nowak, 1995; Logothetis, 1994; Livingstone & Hubel, 1988). In terms of the visual system's ability to detect contrast (i.e., the changes in light over space); the magnocellular layers are capable of detecting extremely low contrast information at threshold levels, while the parvocellular layers need a great deal of contrast to function correctly and are more concerned with wavelength discrimination (Shapely et al., 1981). The magnocellular layers are especially sensitive to low spatial frequency information (Schiller, 1996) and can be thought of as forcing the visual world into black and white

images. The parvocellular layers however, examine the high spatial frequency details of an environment using a “fine-gray scale” which demands a great deal of contrast information in order to function correctly. Lesions in these layers have been shown to severely impair an organisms’ ability to distinguish fine-spatial detail (Schiller, 1996). As Norman (2002) points out, it appears that the magnocellular layers are specific to higher “temporal” frequency visual information (i.e., motion), whereas the parvocellular layers prefer higher “spatial” frequency information (i.e., high frequency visual details). One might think of the magnocellular world as consisting of only the broad brush strokes or outlines of an image, whereas the parvocellular world fills in this same image with all of the detailed information. The combination of information from each of these two worlds produces a virtually seamless visual experience. A summary of the functionally distinct characteristics of both the magnocellular and parvocellular layers are listed in Table 1.

Table 1. Functional distinctions between magnocellular and parvocellular layers of the LGN (adapted from Limrick, 2007)

	Parvocellular	Magnocellular
Photoreceptor Location	Central Retina	Peripheral Retina
Color Sensitivity	90% are sensitive to color	Virtually Colorblind
Image Resolution	High Spatial Resolution	Low Spatial Resolution
Contrast Sensitivity	Needs lots of Contrast	Needs very little Contrast
Spatial Frequency	High Spatial Frequencies	Low Spatial Frequencies
Speed of Processing	Slow	Fast
Sensitivity to Motion	Insensitive	Very Sensitive
Visual System Specificity	Focal Vision	Ambient Vision

Neuropsycholgical

The evidence presented thus far has consisted of primarily neurophysiological research using various monkeys, cats, hamsters, and frogs. The common experimental element has involved the ablation of specific cortical structures to observe how an organisms' behavior changes when certain areas can no longer function. Without a doubt, this research has yielded findings which support the notion of the existence of two unique visual systems. It is at this point one must begin to ask how these findings actually translate to humans. For obvious moral and ethical reasons, it would be inappropriate to intentionally sever various cortical regions of living human beings. To remedy this moralistic obstacle, many researchers have concentrated their efforts using more clinical, case-study approaches. The behavior of patients with known damage to certain areas of the brain is observed to determine how visual perception is adversely

affected. Typically these patients suffer from either optic ataxia or visual form agnosia, each of which has virtually opposite effects on the focal and ambient visual systems.

Patients suffering from optic ataxia typically exhibit difficulties reaching towards or grasping visually displayed objects, but are highly accurate when asked to visually identify these same objects. CT scans of these patients reveal lesions in the posterior parietal regions of the brain (Perenin & Vighetto, 1988), areas known to be crucial for the processing of visual information used by the ambient system. Given the different functional characteristics of the two visual systems outlined thus far, persons with optic ataxia are thought to have a properly working focal system, but a malfunctioning ambient system. To further understand these effects, Milner et al. (1999) examined the pointing accuracy of a patient with parietal lobe damage indicative of optic ataxia. Like most studies of this nature, these authors expected their patient (A.T.) to exhibit significant errors when asked to immediately point towards a target. However, another condition was included where the patient was required to wait a certain amount of time before responding. The authors hypothesized that implementing such a response delay might allow the still intact, yet slower, focal visual system time to process and utilize the necessary spatial information to guide her reaching behavior. The results of reaching accuracy measurements confirmed the authors' predictions. When an immediate reaching response was required, A.T. made significantly larger errors than her three matched control subjects; however, when a 5 second delay was required, A.T.'s reaching behavior was indistinguishable from the controls. According to the authors, these findings suggest the existence of two pathways of visual information, each of which uses spatial representations for different functional purposes. The ambient pathway uses

spatial information immediately to help guide a person's actions, whereas the focal pathway uses this information for higher-order cognitive purposes which take longer to process. In the case of A.T. whose ambient pathway was impeded by cortical lesions, immediately responding to a target resulted in large errors. But during the delay condition when her ambient system was not allowed to respond immediately, the visual information processed by her intact focal system was allowed the opportunity to be utilized.

Visual form agnosia, on the other hand, affects a persons' ability to decipher object qualities. In a study using the famous patient D.F., who suffered irreversible damage to the ventral pathway as a result of carbon monoxide inhalation, Goodale and colleagues (1991) found that D.F. was consistently inaccurate when asked to look directly at an object and determine its form, location, orientation, and size. Interestingly, when asked to reach towards, pick up, or rotate the same objects, D.F. was able to do so with amazing accuracy. For example, when the task involved determining the orientation of a block sitting on a table, D.F. made numerous errors oftentimes reporting a horizontal block as being vertical. But when asked to reach towards and pick-up this same object her reaching movements were accurate and consistent with normal control subjects. D.F.'s orientation perception was also tested by asking her to choose a line orientation from a set of cards that correctly matched a large slot on an upright disc. When the task involved choosing the card with the correct line orientation, D.F. showed significant impairments. However, when asked to actually pick up a card, rotate it to the correct orientation, and then place it in a slot; D.F. could do so with absolutely no errors or delays, in a manner consistent with those of control subjects who had suffered no known

brain damage. Research performed by Carey, Harvey, and Milner (1996) found similar results in that D.F. was able to reach out and grasp different tools effectively, but often displayed problems in grasping the correct part of the tool. These authors concluded that the grasps were guided by visual information affording the tool's axis, orientation, and size; but not by any functional knowledge affording its use. Patla & Goodale (1996) also reported that D.F. could locomote through an environment while negotiating obstacles successfully, but showed difficulty in judging the heights of these same obstacles. Patla and Goodale (1996) explain these findings as "demonstrating dissociation between vision for action and vision for perception." In terms of focal/ambient visual system processing, D.F.'s ability to successfully interact with the world using visuomotor information suggests a properly functioning ambient system. However, her inability to recognize simple objects and their distinct parts, even those same objects she had successfully used in various hand-eye coordination tasks, implies deficits in focal system processing.

There is no doubt that both optic ataxia and visual form agnosia are fairly infrequent neurophysiological disorders. Despite this infrequency, clinical research on patients who suffer from these disorders has proved to be highly valuable as it allows the investigation of human behavior following trauma to specific areas of the brain. These findings, coupled with the neurophysiological animal research discussed earlier can be seen as further evidence for the existence of two separate pathways of visual information; a focal pathway used for object identification purposes and an ambient pathway used for object localization and visuomotor purposes. The fact that patients suffering from either optic ataxia or visual form agnosia exhibit behaviors that are virtually opposite, reaffirms these previous claims, but does so using human subjects. The impact of these disorders

on a person's behavior is determined by the location of trauma within the cortex. In terms of optic ataxia, damage along the ambient pathway severely impairs a persons' ability to localize and interact with objects, yet their focal system continues to function without incidence. On the other hand, patients with visual form agnosia, who suffer from damage to the focal visual pathway, lose their ability to identify object characteristics, yet their ambient visual system operates uninterrupted. Consistent with Norman's (2002) explanation, the true differences between each visual system become evident when we consider the actual purposes for which certain types of visual information are actually used.

Psychophysical

It is at this point that one might begin to ask whether there exists any evidence supporting the focal/ambient pathways of visual information using healthy human subjects. Up until now, the empirical evidence presented has focused on physiological research using a variety of animals and clinical case-study research conducted on brain damaged subjects. As interesting as the existence of the focal/ambient visual systems might be, a theory which cannot be observed in the general population of human subjects is ultimately of limited utility. Luckily, the realm of experimental psychology has also provided evidence for the focal/ambient visual system dichotomy, although this nomenclature has not always been explicitly stated.

Leibowitz and Post (1982) summarized what they believed to be evidence for the focal and ambient modes of visual information processing in terms of human perception and behavior. Their description is as follows:

> The two modes of processing concept can best be described in functional terms. It posits two independent and dissociable modes of processing: (1) a "focal" mode

> that is in general concerned with the question of "what" and subserves object recognition and identification; (2) an "ambient" mode concerned with the question of "where" which mediates spatial orientation, locomotion, and posture (p. 344).

These authors use retinal location, awareness, luminance, refractive error, and spatial frequency to distinguish between the focal and ambient modes of processing, inline with the research discussed earlier. In terms of retinal location, the focal system is subserved by central vision while the ambient system has the capability to draw its information from the entire visual field, but relies primarily on peripheral vision. Focal functions occur on a conscious level (e.g., reading your speed on a speedometer, distinguishing between heating and cooling color indicators for temperature control in a car, etc.), while ambient functions are capable of taking place at an automatic, subconscious level (e.g., automatically detecting a pedestrian walking between two parked vehicles in the periphery, or grabbing a beverage from the cup holder without taking your eyes off the road). Knowing that the focal system relies on foveal cone vision, known to be highly sensitive to photopic light levels, this system is only capable of functioning under high luminance levels. The ambient system, on the other hand relies heavily, although not exclusively, on rod vision which is known to function under scotopic light levels, and thus is capable of working under both high and low luminance conditions. In terms of refractive error, the focal system is the high resolution system (i.e., high spatial frequencies) used for detail-oriented tasks. The ambient system on the other hand, is only interested in the big picture and is capable of processing low spatial resolution visual information (i.e. low spatial frequencies).

Results from a study performed by Leibowitz, Wilcox, and Post (1978) provide additional support for the existence of two visual systems, despite not having used the

focal/ambient nomenclature in their report. In this experiment, refractive error was introduced by blurring objects in the visual field in an attempt to understand how degraded resolution impacted both size constancy and shape constancy judgments. Such a manipulation would also shed light on the specificity of each system to different types of spatial frequency information. These authors found that increasing the level of blur had no impact on size constancy judgments, whereas shape constancy performance consistently deteriorated as the level of blur increased. The shape constancy task was described as demanding high spatial frequency information. Inducing blur systematically removed this information, thus rendering the focal system insensitive. The size constancy task, on the other hand, does not require the use of solely high spatial frequency information, but rather can be performed by utilizing a wide range of spatial frequencies. It appears that these judgments were processed by an alternative system which was still sensitive to the low spatial frequency information left over after the influence of blur.

Leibowitz and Post (1982) also suggested that the information afforded by each system's sensitivity to photoreceptor location on the retina, luminance, and resolution reveals additional information about their resulting sensitivity to spatial frequency information which also helps to explain the findings of Leibowtiz et al. (1978). These authors explained that introducing blur to decrease an images resolution under low luminance levels would impair one's abilities to decipher high spatial frequencies, but not low spatial frequencies. According to Leibowitz and Post (1982), blurring an image under low light levels would rob the focal system of any input coming from cones located in the fovea of the retina as they need ample light to function correctly. This essentially

eliminates the focal system from detecting any high spatial frequency details. The low spatial frequency information however, is still readily available during dimly lit blur conditions and thus is detected. Why is this? This happens because the ambient system is fed by peripherally located rods which are known to be sensitive to low spatial frequency information and capable of functioning under extremely low light levels. It would appear that under such conditions, the requirements for successful ambient system functioning remain sufficient.

Applications of Ambient/Focal Theory to Driving Research

Leibowitz and Owens (1977) used what was known about the characteristics of each visual system to help shed light on a common real world problem, crashes during nighttime driving beyond those attributed to alcohol consumption. It was their belief that increased crash rates at night could be contributed to selective degradation of the focal system, but not the ambient system. Keep in mind what we have learned up to this point about the qualities of each visual system. The focal system is subserved by central vision known to be made up of cone photoreceptors, which in-turn need lots of light in order to function. Under nighttime driving conditions where little light is available, this system obviously becomes impaired. This impairment reduces a persons' ability to detect critical visual stimuli (e.g., pedestrians, wildlife, disabled vehicles, etc) during nighttime driving unless these objects are highly illuminated. The ambient system however, receives its information from rod photoreceptors located in the periphery of the retina which are capable of functioning under extremely low light levels. Research discussed earlier also suggested that the ambient system is responsible for guiding visuomotor

actions and locomotion in a terrestrial environment (Patla & Goodale, 1996). According to Leibowitz and Owens (1977), the characteristics of the ambient system suggest that under nighttime driving conditions the steering ability of a driver should be minimally affected, if at all. The fact that drivers can steer their vehicle just as well under nighttime conditions as during the day, provides a false sense of confidence that all driving abilities are functioning at optimal levels. Unbeknownst to nighttime drivers, their focal system is said to be selectively degraded and in all actuality, is quite incapable of functioning without adequate illumination. Ultimately this causes people to drive too fast at night and renders them unprepared to deal with stimuli that otherwise, under well-illuminated conditions, would be easily processed by the focal system. The purpose of the current research is not to examine driver performance during nighttime conditions. This classic paper was mentioned as it provides an excellent example supporting not only the existence of two visual systems, but also a successful application of the focal/ambient dichotomy to a real world problem which affects people each and every day.

Norman (2002) points out that an important distinction between the two visual systems involves the contribution of peripheral visual field information to ambient system functioning. As suggested in Leibowitz and Owens (1977), the ambient system uses information from the periphery to help sustain some sort of controlled locomotion through the environment; albeit crawling, walking, running, or driving. Further evidence for this claim has been observed within the realm of driving research. Summala and colleagues (1996) were interested in whether or not drivers with more years of experience utilize peripheral vision more efficiently than novice drivers. To do so, drivers were required to perform secondary tasks which involved foveal fixation of visual displays at

different locations within the vehicle. While engaged in these secondary tasks, subjects also had to drive their vehicle along a straight road using only peripheral vision. In terms of focal/ambient processing, the in-vehicle secondary tasks demanded focal vision while controlling the vehicle required ambient vision. Lane-keeping data show that experienced drivers could travel significantly greater distances while performing secondary tasks. This suggests that these drivers were able to utilize ambient vision more efficiently than their novice counterparts who needed both focal and ambient vision to maintain lane position.

Further evidence indicating the unique roles of focal and ambient vision in highly dynamic tasks (i.e., driving) was observed by Higgins, Wood, and Tait (1998). In this experiment, visual acuity was systematically degraded by having subjects wear goggles fixed with blurred lenses. With varying degrees of blurred vision, subjects then drove on a closed driving track and were asked to recognize road signs, avoid hazards, and negotiate gaps outlined by high-contrast orange traffic cones. Given what was learned from the blur manipulation used by Leibowitz et al. (1978) under static conditions, it is understood that blurring an image essentially eliminates all of the high spatial frequency information from reaching the observer, while still allowing low spatial frequencies to pass through. In terms of focal/ambient processing, introducing blur cripples the focal system while the ambient system continues to function relatively uninhibited. The most significant difference between these two studies is that Higgins et al. (1998) wanted to examine how blur impacts a persons' ability to perform within a highly dynamic environment (i.e. while actually driving a vehicle). The results of this study are as follows:

> Acuity degradation produced significant decrements in road sign recognition and road hazard avoidance as well as significant increments in total driving time. Participants' abilities to estimate whether clearances between pairs of traffic cones were sufficiently wide to permit safe passage of the vehicle and to slalom through a series of traffic cones were relatively unaffected by acuity degradation (Higgins et al. 1998, p. 224).

When each of the drivers' tasks is analyzed with respect to focal/ambient processing, these findings are consistent with what would be expected given the unique sensitivities of each visual system outlined thus far. Recognizing both road signs and vehicle hazards are believed to demand focal system processing. Introducing blur essentially removed any high spatial frequency information necessary for this system to function correctly. Interestingly, tasks requiring continuous steering inputs were unaffected by the imposed blur suggesting that the low spatial frequency information still available was sufficient for ambient system processing. These researchers also found that subjects did not reduce their speed while driving under heavily blurred conditions. Similar findings were reported by Brooks, Tyrrell & Frank (2005). Tasks specific to focal system processing (i.e. visual acuity) were highly sensitive to induced blur and reduced luminance levels, whereas ambient processing specific tasks (i.e., visually guided steering performance) were "remarkably robust to these same challenges (p. 695)." Together these observations are consistent with the selective degradation hypothesis for explaining the increase in accident rates during nighttime driving beyond those attributed to alcohol (Leibowitz & Owens, 1977). It appears to be the case that under conditions of reduced focal system abilities such as nighttime driving, drivers are often unaware of their impaired focal abilities because the processing of steering information by the ambient system is preserved. An unfortunate consequence of the selective degradation of the focal system is the driver's failure to reduce vehicle speed to account for such deficits.

The influence of central and peripheral vision on their respective visual systems indicates another important difference that needs to be made apparent. As mentioned earlier, central vision is fueled by cone photoreceptors which are densely packed within 2-3 degrees of the retina's foveal area (Levi et al., 1985), and are responsible for picking up the high resolution details of an image. Visual acuity beyond this region is also known to become increasingly poorer (Rayner & Pollatsek, 1992). In order to detect highly detailed information from a number of locations throughout an image, we have to move our eyes and head at extremely rapid rates, typically between three-to-four times per second (Findlay & Gilchrist, 2003). Eye movements specific to central vision are described as being ballistic, meaning that once they have been planned and launched their path cannot be stopped or altered. Because these ballistic eye movements are occurring so fast, oftentimes reaching peak velocities of 600 degrees per second (Wade & Tatler, 2005), there is no new pick-up of information until the eye actually lands on its intended target. During these movements, central vision is essentially blind. This interruption in information processing during ballistic eye movements can also be thought of as an open-loop process. Peripheral vision on the other hand, is known as the low resolution system. The photoreceptors which drive peripheral vision aren't concerned with the details of an image, but rather are interested in how information changes over time and space. Several researchers have suggested that this information is continuously supplied to an ambient system, which then uses this knowledge to mediate locomotion through the environment without bumping into obstacles. This availability of constant visual feedback to the ambient system can ultimately be thought of as a closed-loop process.

In terms of driving, the open-loop versus closed-loop dichotomy was used by Donges (1978) in his two-level model of driver steering behavior. Consistent with what we know about the characteristics of central and peripheral vision, the Donges model proposed that steering a vehicle could be separated into an open-loop process which serves anticipatory functions, and a closed-loop process which serves vehicle stabilization purposes. At the anticipatory, open-loop level; drivers look down the road to determine upcoming changes in road curvature which might eventually influence steering behavior. According to Donges, this is a "far process" which relies on central vision and is believed to be much more cognitive in nature. The classification of this level as an open-loop process stems from the idea that a driver anticipates the need to alter steering behavior as the roadway deems necessary by looking far down the road, but does not receive any feedback about this prediction until the curve is actually reached. At the vehicle stabilization, closed-loop level; drivers are constantly monitoring their location within the lane for any errors and nulling them from the system as they occur. According to Donges, this is a "near process" which relies on peripheral vision and is considered more perceptual in nature. This level is classified as closed-loop processing given the constant, real-time feedback the driver receives regarding lane position. In terms of the focal/ambient nomenclature, the open-loop component of driver steering behavior would be dictated by the focal visual system; whereas the closed-loop component is said to be driven by the ambient visual system.

Some might wonder why vision uses two systems; why not just use a single system? The answer to this question has to do with the amount of cortical area certain types of information require. Nearly 80% of the human visual cortex can be attributed to

central vision whereas only 20% is connected to peripheral vision (Azzopardi & Cowey, 1993). Keep in mind that central vision only subtends a few degrees of the entire retinal area; yet we also know this same region is responsible for extracting extremely high resolution visual information from a scene. If the entire retina were as sensitive as central vision, we would need a brain the size of a Volkswagen to process all of the information! It would appear that evolution overcame this potential obstacle by utilizing two unique visual systems, each specific to different functions. The focal system examines very small regions of space in great detail and needs a lot of cortex to do so, while the ambient system detects moving stimuli in the periphery using only a small fraction of the cortical area, thus signaling the focal system to examine these stimuli more thoroughly when necessary.

At this point in the document, a wealth of evidence has been provided which supports the existence of two unique systems of visual information processing; a focal system used for object identification and an ambient system used for object localization and visuomotor functions. These systems work in parallel to provide a visual experience rich in both detail and awareness (see Table 2 for summary). We have learned that the focal system is driven by central vision and the parvocellular layers of the LGN; and that this system is primarily interested in the spatial signature of an image (i.e. color, high spatial frequencies, and high contrast information). The ambient system however, is driven by peripheral vision and the magnocellular layers of the LGN; and is concerned primarily with information regarding the temporal signature of a stimulus (i.e. motion, low spatial frequencies, and low contrast information).

Table 2. Functional distinctions between focal & ambient visual systems (adapted from Limrick, 2007)

	Ambient System	**Focal System**
Primary Function(s)	Object Localization / Visuomotor Functions	Object Identification
Retinal Input	Peripheral Vision	Central Vision
LGN Input	Magnocellular	Parvocellular
Processing Speed	Very Fast	Slow
Spatial Resolution	Poor / Low Spatial Frequencies	Excellent / High Spatial Frequencies
Contrast Sensitivity	Needs very little contrast	Needs a lot of contrast
Control Mode Processing	Closed-loop	Open-loop

A majority of this evidence exists in both the realms of physiological animal research and clinical research using brain-damaged humans; however several studies in more applied settings have also shown support for the focal/ambient visual system dichotomy. The domain of driving appears to be of particular usefulness, as several researchers have shown how the behavior of each visual system changes as a function of environmental manipulations such as luminance and road curvature (Leibowitz & Owens, 1977; Donges, 1978). Of particular interest to the current research project is understanding the changes in driving behavior which take place as a result of normal driver aging. Given what has been learned regarding the functional differences in focal/ambient system processing, perhaps it might be advantageous to examine the aging driver using such a perspective. In the opening sections of this document, it was reported that older drivers typically exhibit compensatory behaviors (Kosnick et al., 1990) such as avoiding nighttime conditions, severe weather, dense traffic, and complicated roadways

(Ball & Owsley, 1991; Schieber et al., 1991; Waller, 1991). These same aging drivers are also overly represented in crashes which occur during cross-traffic maneuvers, especially those which occur at intersections (Cerrelli, 1989; Hakamies-Blomqvist, 1993, 1994b, 1994c; Schieber, 2000; Stamatiadis & Deacon, 1995; Stamatiadis, 1996). It might be the case that analyzing these issues using a focal/ambient spotlight might help to shed some new light on the true reasons for their occurrence. Perhaps quickly approaching vehicles in an oncoming lane are not detected because a failing focal system cannot pick-up critical detail information which would help to alert the aging driver of impending danger. At the same time, this scenario might also be the result of a weakened ambient system which fails to detect the necessary motion or rate of change information which would normally afford safe vehicle travel. In order to determine which of these answers is correct, further empirical examination is needed to understand how the aging process potentially impacts both focal and ambient system processing. However, before such an approach is undertaken, it might prove beneficial to see if there already exists any empirical evidence suggesting that senescent individuals suffer from a weakened focal or ambient visual system.

The Aging Visual Information Processing Systems

To further examine the selective degradation hypothesis with respect to age, Owens and Tyrrell (1999) conducted a simulator study where the abilities of both the focal and the ambient visual systems were experimentally manipulated. In this study, subjects were required to navigate a number of curves in a low-fidelity driving simulator. To systematically degrade focal processing, increasing levels of blur and decreasing

illumination levels were imposed upon the drivers. Such manipulations remove any high spatial frequency information and restrict photoreceptor activation at the fovea, both of which are critical components necessary for focal system processing. To degrade ambient system processing, tunnel vision conditions were included to systematically reduce the size of each subjects' visual field. The authors suggested that such a manipulation would impair ambient system processing by restricting optical flow information gathered by the peripheral visual field. In the first experiment, which only looked at a younger group of drivers, steering accuracy was significantly degraded under reduced visual field conditions; while visual acuity measures were significantly poorer under both blurred and reduced luminance conditions. The differential effects of each manipulation provide further support for the role of two parallel modes of visual processing, an ambient system used for visual guidance and a focal system used for visual recognition. In the second experiment, Owens and Tyrrell wanted to understand how the influence of age might impact each visual system's capabilities, more specifically the ambient system's ability to control the vehicle on a designated roadway. Results of this experiment show that under low luminance conditions which resemble nighttime driving, older drivers exhibit significantly less accurate steering behavior than younger drivers. The authors interpret this finding as indicating an age-related weakening of the ambient visual system. Overall, these results provide empirical evidence for the selective degradation hypothesis, as well as provide some insight as to why older drivers continue to exhibit an increasing reluctance to drive at night. However, it should also be pointed out that this study did not control for retinal luminance with regard to each age group. This potential confound might suggest that poorer steering

performance for the older group was simply the result of not receiving as much light at the retina as the younger group. Knowing that the pupil tends to get smaller with increasing age (Pitts, 1982), Owens and Tyrrell go on to state that optical factors, such as pupillary miosis, might very well indeed have had a significant impact on the older groups performance; but a more likely explanation includes some combination of both optical and neural factors. To help further understand the potential weakening ambient system of the aging driver under nighttime conditions, the authors suggest experimentally equating retinal illuminance for each age group in their future work.

There exists another thread in the aging literature which describes the human visual system as consisting of two separate neural channels, a sustained channel and a transient channel. The sustained channel is responsible for object form perception and thus is concerned with the detailed, high spatial frequency information; while the transient channel is sensitive to low spatial frequencies and is particularly interested in how this same information changes over time (i.e., motion detection). The sustained channel is synonymous with what has been described as the focal visual pathway while the transient channel is synonymous with the ambient visual pathway. According to Kline and Schieber (1981), aging persons suffer from the differential aging of the transient channel compared to the sustained channel as evidenced by a decrease in ability to detect stimuli with a rapid temporal signature. Sekuler and Hutman (1980) reported evidence supporting such an age-related decline in neural transient channel mechanisms. These authors compared contrast sensitivity functions for a group of young adults to those of older adults with good visual acuity. At low spatial frequencies (to which the transient channel is most sensitive), the older observers needed significantly more

contrast to reach threshold levels than did their younger counterparts. Interestingly, both of the age groups had virtually identical contrast thresholds for high spatial frequencies (to which the sustained channel is most sensitive). According to Sekuler and Hutman, these differences could not be attributed to ocular factors because none of the older individuals suffered from significant ocular pathology. A more likely explanation is one suggesting that the aging persons decline in abilities to detect low spatial frequencies is the result of a weakening visual system whose primary objective is to detect temporally transient stimuli.

Additional evidence supporting this claim was reported by Schieber and Kline (1982), who found that compared to a younger group, older subjects needed significantly longer stimulus asynchrony times to determine order of offset discriminations. Kline et al. (1990) also found that when asked to determine the point at which two consecutively presented sine wave gratings appeared "just continuous," older subjects required significantly longer interstimulus intervals than did a group of younger subjects, but only at the lowest spatial frequencies. This suggests that the aging transient visual channel was no longer capable of processing information as quickly as it could during its younger years. Interestingly, the two age groups were indistinguishable at higher spatial frequencies indicating a properly functioning sustained channel.

The processing of temporally transient stimuli (i.e., motion) is undoubtedly of significant importance as our ability to adequately do so determines the extent to which we can pick up the necessary information which affords successful locomotion through an environment. To further test the claim that the transient channel's ability to detect motion decreases as a function of age (Kline & Schieber, 1981); Owsley and colleagues

(1983) conducted a study of contrast sensitivity using a number of different age groups, all of whom did not suffer from any ocular pathology. These researchers were particularly concerned with understanding how the human contrast sensitivity function changes throughout adulthood, especially with regard to moving stimuli. Interestingly, the contrast threshold for younger adults improved by a factor of 4-5 for a low spatial frequency grating which was set into motion compared to a purely static grating, a phenomenon known as the *motion enhancement effect*. No such improvement in contrast sensitivity occurred for low spatial frequency gratings for individuals over 60 years of age. The lack of a motion enhancement effect suggests that the transient mechanisms which process motion information decline in ability as a result of the normal aging process. Control measurements taken by the authors also found that these results could not be attributed to the reduced retinal illuminance of the aged eye, an issue pointed out in a previously mentioned study as a potential problem (Owens & Tyrrell, 1999). When younger subjects viewed stimuli through neutral density filters to equate their retinal illuminance to that of the older subjects, their resulting contrast sensitivity to low spatial frequency moving sine wave gratings remained the same. Similar deficits were reported by Sloane et al. (1988) who found that across a range of decreasing luminance levels, older individuals needed significantly more contrast to detect low spatial frequency stimuli with a rapid temporal signature (i.e., flicker rate) than did younger individuals. In addition, Wright and Drasdo (1985) reported that with increasing age, subjects need substantially more contrast to detect flickering stimuli with increasingly rapid temporal frequencies. The findings of these contrast sensitivity studies suggest that as a result of the normal aging process, individuals appear to become less sensitive to large targets (i.e.

low spatial frequencies) that are moving quickly (i.e. those having a rapid temporal signature), especially when these stimuli are viewed under low light levels. In terms of real-world application, targets with such qualities are often encountered during the act of driving. The basic outline of any vehicle on the road could be described using low spatial frequency sine waves; whereas high spatial frequency information would define the more intricate details which are not immediately critical for avoiding crashes (i.e., a vehicle's make, model, accessories, etc…). In terms of safe vehicle operation, the critical information drivers' need clearly lies with the low spatial frequency information and how it changes over both time and space, as this knowledge helps the driver detect potentially hazardous components within traffic situations. Returning to the focal/ambient visual system nomenclature, it is understood that the ambient system is responsible for detecting both low spatial frequencies and motion information. However, given what was reported via the contrast sensitivity research just mentioned, it appears that the ambient system of the aging person is becoming progressively weaker throughout adulthood, a phenomenon recently referred to as the *ambient insufficiency hypothesis* (Schieber, Schlorholtz, & McCall, in press). Consistent with this hypothesis, Owens and Tyrrell (1999) reported a "progressive degradation" in steering performance as a function of reduced luminance levels for older subjects, but not younger subjects. In addition, Woods (2002) reported that the strongest indicators of age-related decrements during closed-course driving performance included tests of global motion sensitivity, the ability to quickly detect and localize targets in the visual periphery (i.e., UFOV), and contrast sensitivity. From a traffic safety perspective, it might be a weakening or malfunctioning ambient system that is responsible for the overrepresentation of elderly drivers in certain types of crashes.

One objective of the current research is to develop and test techniques which are designed to expose the unique abilities of both the focal and ambient visual systems. It is believed that doing so might help to further our understanding as to how potential deficits might negatively influence the senescent persons' ability to drive safely.

The Peripheral Detection Task (PDT)

PDT, what is it?

In more recent years, with the increasing availability and use of in-vehicle technologies (i.e. cell phones, navigation systems, internet-in-the-car, etc…); a great deal of research has been dedicated to understanding the effects of such devices on driver performance. As more information is made available to the driver, whether it via the driving environment itself or from in-vehicle technologies, drivers will be faced with the task of appropriately dividing their attention in such a way that safe vehicle travel is maintained at all times. As the use of such devices has become increasingly more widespread, the scientific community has accordingly invested a great deal of resources into examining the extent to which in-vehicle technologies potentially distract a driver's attention away from critical elements on the road ahead. The secondary task paradigm is a commonly used approach for measuring the impact of in-vehicle information systems on driver workload (Harms & Patten, 2003). More recently, one particular technique which has shown relatively impressive sensitivity to fluctuations in driver workload is known as the peripheral detection task or PDT (Martens & van Winsum, 2000; Olsson & Burns, 2000; Harms & Patten, 2003). The development of the PDT is based on the findings of studies such as Miura (1986, discussed in the visual capabilities section) who

found that the size of the driver's field of view decreases in response to the increasing demands within the immediate driving environment.

Typically in the PDT paradigm, red light emitting diodes (LED's) are reflected off of the vehicle windshield at random eccentricities between 11^{o} and 23^{o} to the left of the driver's normal line of sight (see Figure 16). The LED stimuli are presented for durations of approximately two seconds at random intervals between three and five seconds. Subjects are instructed to detect as many stimuli as possible, as quickly as they are able, but to do so without ever completely withdrawing attention from the driving scene (Harms & Patten, 2003). In most PDT experiments subjects respond by pressing a micro-switch attached to their index finger, while reaction time and hit rate are used as the dependent measures. Following the onset of a target, subjects are typically allowed a two second time gap to detect it; otherwise a missed target is registered.

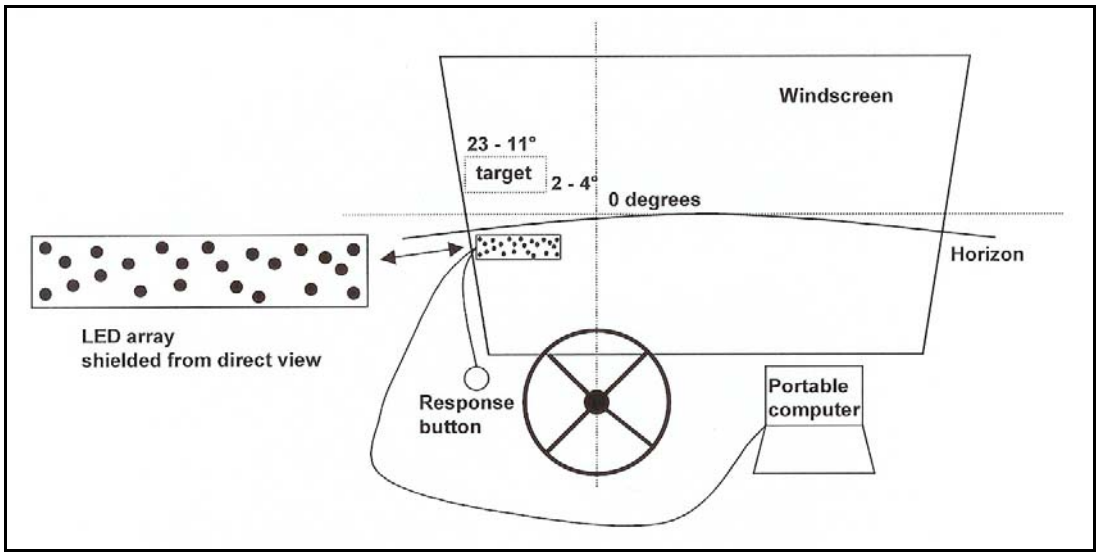


Figure 16. Typical PDT instrumentation (Olsson & Burns, 2000). LED targets are presented as reflections off of the windscreen. The instrumented LED array is not directly visible to subjects. The reflection of 1 of the 23 possible LEDs is presented within a horizontal angle between 11-23^{o} in the left-hand visual field approximately 2-4^{o} above the horizon. The response button, typically in the form of a microswitch attached to the index finger, is pressed anytime a peripheral LED target is detected by subjects.

One of the first documented uses of the PDT took place in a simulator study which investigated variations in driver workload induced by in-vehicle support systems (Martens & van Winsum, 2000). As the subjects operated a simulator, they experienced both normal driving scenarios (straight roads, wide curves, etc…) and critical driving scenarios (sharp curves, braking lead vehicle, overtaking a lead vehicle, etc…). Using PDT performance on straight road driving as a baseline measure, this study found a remarkable sensitivity of the metric to both critical driving situations and instances when subjects were actively engaged with messages from the driver support systems. As the task demands increased, whether it related to the driving environment or the message system, substantially more PDT targets were missed and reaction times increased. According to the authors, "situations that require immediate actions and that are characterized by a sudden and unexpected change in criticality result in deteriorated performance on the PDT." Similar results were reported in a field study conducted by Olsson and Burns (2000). In this small sample study, subjects drove on both motorways and country roads while engaged in one of the following three tasks: (1) a radio task where subjects were asked to adjust the radio to a certain frequency, (2) a CD player task which required the CD player to be turned on and a specific track be played, or (3) a backwards counting task believed to be more cognitive in nature which demanded that subjects continuously subtract "7" from a given three digit number (e.g., 897, 890, 883, 876, etc.). Consistent with the simulator study just mentioned, Olsson and Burns (2000) reported that compared to baseline straight road driving, PDT performance was significantly impaired in terms of longer reaction times and decreased hit rates. Subject reaction times were significantly slower on country roads when performing the

backwards counting task, while hit rates were significantly poorer when performing the CD task (45%) compared to backwards counting (54%) and the radio task (65.5%). According to the authors from each of the PDT studies mentioned thus far, the sensitivity of the PDT to variations in workload are indicative of driver distraction caused by the allocation of attention to information sources other than the immediate roadway environment. Both Martens and van Winsum (2000) and Olsson and Burns (2000) suggest that the locations of the PDT stimuli directly correspond to the location of critical roadway elements such as pedestrians, bicyclists, road signs, and nearby vehicles that when missed could prove potentially hazardous. These findings suggest that impaired performance on the PDT might be useful as a tool to both indicate and quantify the extent of driver distraction created by in-vehicle information systems, quite possibly for regulatory purposes.

The PDT has also been used to examine the effects of cell phone use while driving in a few recent studies. Research to date suggests that PDT reaction times increase significantly when driver's become engaged in increasingly complex cell phone conversations during real world driving (by as much as 45% compared to a baseline), however subject performance has typically been reported as being indistinguishable between hands-free and hand-held cell phones (Patten, Kircher, Ostlund, & Nilsson, 2004; Tornros & Bolling, 2005; Tornros & Bolling, 2006). In another field study, it was reported that PDT reaction times were significantly longer when subjects dialed phone numbers using a hand-held device, especially while driving through higher complexity urban environments compared to motorway and rural road situations (Engstrom, Aberg, Johansson, & Hammarback, 2005). Implementation of the PDT suggests that the critical

contributing factor to driver distraction is not related to the type of cellular telephone, but rather is a function of the overall complexity of the immediate environment in terms of both driving difficulty and conversation complexity.

According to Patten and colleagues (2006), the impressive sensitivity of the PDT to cognitive workload variations in simulated and real-world driving studies is the result of overlapping visual resource demands required by both the PDT and the driving task. To further understand the effectiveness of the PDT, these researchers examined the effects of driver experience (low mileage, non-professional vs. high mileage, professional) while navigating road sections classified as being of low, medium, or high complexity depending upon both the information processing and vehicle handling demands. Overall, drivers with less experience had PDT reaction times nearly 250 ms longer than high-mileage drivers. When moving from low to medium to high complexity driving environments, high-mileage driver performance did not decline until the most difficult driving conditions, whereas low-mileage driver performance revealed performance decrements with the slightest increases of environmental complexity in terms of both PDT reaction time and hit rate. Overall, the more experienced drivers had consistently faster responses and more accurate hit rates. According to Patten and colleagues (2006), this finding suggests that drivers with more thorough training and experience were able to free-up information processing resources by more efficiently automating the driving task than did their low-mileage counterparts. This added availability of resources could then be successfully allocated to the peripheral targets, in essence indicating a broader functional field of view for the more experienced drivers.

The increasing popularity of the PDT in both laboratory and field studies is the result of several experimental advantages. The PDT does not appear to be as resource demanding as many other commonly used secondary tasks (i.e., mental arithmetic, visual-spatial tasks, etc.), the result of which is a minimal level of interference or obtrusiveness with respect to the primary task of driving. Responses to the PDT are considered simple and relatively easy to perform in a range of driving environments of varying complexity (Jahn, Oehme, Krems, & Gelau, 2005). The PDT is also a continuous task which allows the opportunity to present a large number of trials so that a wealth of data can be collected; including baseline measures (Patten et al., 2006). PDT targets which occur during critical driving situations can also be used to indicate short-lasting peaks in driver workload (Jahn et al., 2005). From an instrumentation standpoint the equipment needed is both simple and inexpensive; while typically the targets and responses are automated so that data acquisition and analysis can be completed in a timely fashion (Jahn et al, 2005). One of the most attractive qualities of the PDT is its high level of face validity with regard to the primary task of driving (Martens & van Winsum, 2000; Olsson & Burns, 2000; Jahn et al., 2005). Detecting a PDT target in the visual periphery is analogous to quickly detecting critical real-world objects or events such as brake lights, stop lights, pedestrians, bicyclists, approaching traffic, and so on. Any tool which allows researchers to predict instances where drivers will miss critical targets in their immediate field of view has the potential to be extremely helpful in understanding the information processing demands placed on drivers.

PDT, why it works, the current argument.

The impressive sensitivity of the PDT to fluctuations in resource demands is commonly explained as being indicative of rising workload levels, typically attributed to difficult driving situations and/or driver distraction imposed by in-vehicle systems. It is quite common to see the terms "workload" and "distraction" used interchangeably in PDT studies. In theory, as the information provided by an in-vehicle message system becomes more complex it has the potential to distract the driver and demand that more attention is paid to it. As more attentional resources are allocated to the device, the driver's ability to concurrently pay full attention to the immediate driving environment becomes potentially impaired. This appears to be especially true during highly complex driving maneuvers which demand a great deal of information processing resources. Keep in mind what has been discussed regarding attention up to this point. Attention is not of infinite availability, but rather is of limited quantity (Kahneman, 1973, Wickens, 1984). As drivers experience situations of varying information processing demands, they are forced to continuously update their attentional allocation strategy so that safe vehicle navigation is afforded. The driver is caught in an ever-changing balancing act where attention has to be appropriately distributed between the primary task of driving and any other in-vehicle secondary tasks. By measuring PDT hit rate and reaction time, experimenters have been able to successfully identify instances where this attentional resource balancing act has become potentially suspect.

As mentioned earlier, the PDT paradigm was created based on the findings of studies such as Miura (1986) who found that as the driving environment became more complex, subjects took significantly longer to respond to peripherally presented stimuli.

The increasing complexity of the driving environment is believed to reduce the overall size of the driver's functional field of view, ultimately making it more difficult to detect targets that aren't located near central, foveal vision (Martens & van Winsum, 2000). Many of the PDT studies explain this finding using the terminology outlined in Dirkin and Hancock (1985) who referred to such a phenomenon as "cognitive tunneling." The term "cognitive tunneling" is used instead of "visual tunneling" based on the idea that the decreasing breadth of the driver's functional field of view can be attributed to attentional mechanisms rather than purely to visual/perceptual mechanisms (Olsson & Burns, 2000). According to Dirkin and Hancock (1985), an operator in a highly stressful environment exhibits "increasingly selective patterns of attending" which negatively impacts the likelihood of peripheral target detection.

PDT, why it works, an alternative argument.

Despite the recent success of the PDT in both laboratory and field settings, it remains unclear as to what resources this tool is tapping. The impressive sensitivity of the PDT in terms of reaction time and hit rate has been extremely helpful in identifying critical points where the breadth of driver information processing has become constrained. Most studies which have used the PDT are based on the assumption that the construct under investigation is one involving mental workload and attentional resource allocation. However, the theoretical underpinnings which help to explain why the PDT is in fact such a sensitive tool have yet to be sufficiently understood or outlined. It is quite common in the PDT literature to allude to concepts such as Dirkin & Hancock's (1985) cognitive tunneling, or Miura's (1986) functional field of view, or even Wicken's (1984)

multiple resource theory of attention. It might very well be the case that one of these theories is able to sufficiently explain the results of PDT research, but to date a justifiable favorite has yet to be empirically determined. This claim is not to be interpreted as a failure to acknowledge a clear theoretical foundation by authors who have implemented the PDT secondary task paradigm. Martens and van Winsum (2000) clearly state that the mechanisms which mediate changes in PDT performance as a function of environmental demands are not entirely understood, but despite this it still has the potential to be a highly useful tool for identifying critical changes in driver workload. Martens and van Winsum (2000) go on to explain the potential benefits as follows:

> An added advantage of this approach (PDT) is that mere peripheral detection without the need for a complex decision is a low-level easy-to-automate process that requires little conscious attention. By this, the disadvantages of secondary tasks, that need to be loading to some extent in order to show effects, can be avoided (p. 2).

Such reasoning is both understandable and justifiable to a certain extent, but it is also imperative that steps be taken to further develop the underlying theory which drives the PDT's sensitivity to environmental demands. If it continues to remain unclear as to why the PDT is such a sensitive metric, how can any conclusions drawn from its use be interpreted convincingly?

The current research project has elected to take a slightly different approach to interpreting the results of PDT studies. A large section of the current document was dedicated to presenting evidence suggesting that humans pick-up visual information via two unique, yet non-exclusive visual systems; known as the focal and ambient visual systems. Each is responsible for processing different types of information, yet the two work in parallel to provide a visual experience both rich in detail and situation awareness

(see Table 2). The focal system is concerned with object identification, relying on central vision and the slower parvocellular system to detect the high-detail, spatial qualities of an image (i.e., color, high spatial frequencies, and high contrast information). The ambient system is geared towards object localization in space, relying on peripheral vision and the faster magnocellular system to quickly process the low-detail, temporal qualities of surroundings (i.e., motion, low spatial frequencies, and low contrast information). As an observer inspects the immediate environmental surroundings, the ambient system's role is to quickly identify "where" in space potentially relevant information is located, while it remains the focal system's responsibility to analyze "what" exactly has been located. In terms of attention, the ambient system is driven by automatic, bottom-up mechanisms that occur preemptively with little or no conscious awareness; while the focal system can be thought of as guided by top-down attentional mechanisms which operate based on an observer's knowledge and goals. Some interesting inferences can be drawn when the focal/ambient dichotomy is applied to understanding why the PDT has shown itself to be such a sensitive metric.

Given what has been reported concerning the unique responsibilities of the two visual systems, each task that a driver carries out in the typical PDT paradigm could be defined as either a focal or an ambient task. Those tasks which require central vision are thought of as being responsibilities of the focal visual system. Such tasks would include fixating a lead vehicle or oncoming traffic, reading roadway signs, inspecting an in-vehicle navigation system for route information, preparing for an upcoming curve in the roadway, finding a specific radio station, and so on. Tasks which rely heavily on peripheral vision, such as detecting PDT stimuli, might be a responsibility of the ambient

visual system. In order for an event to be classified as requiring ambient visual system processing, it's important that its qualities automatically attract attention in a bottom-up, preemptive fashion without the driver's conscious awareness. There do appear to be some visual events which are capable of capturing a person's attention regardless of any other concurrent tasks at hand. The immediate capture of visual attention has shown to be afforded by luminance-based transients such as rapid changes in brightness (Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001), as well as by motion transients (Abrams & Christ, 2003; Franconeri & Simons, 2003) and abrupt stimulus onset (Yantis & Jonides, 1990). According to Franconeri, Hollingworth, & Simon (2005), "such changes may capture attention because they strongly activate transient channels in the visual system, which are maximally sensitive to abrupt onset, luminance flicker, and rapid motion." For the purposes of the current project, these "transient channels" can be considered synonymous with the "ambient visual system." At first glance, it would appear that the PDT satisfies some of the aforementioned bottom-up, attention capturing stimulus qualities by randomly presenting brief LED flashes on the windshield in the driver's peripheral field of view. However, there are a few issues with regard to the PDT methodology as it currently stands. Such issues call into question the extent to which the peripheral LED stimulus qualities actually satisfy the necessary requirements for preemptive detection by the ambient visual system. Before the PDT can be considered indicative of ambient processing, it is necessary to systematically manipulate specific components of the paradigm in order to empirically address the methodological issues outlined in the following paragraphs.

Testing the Alternative Argument

Using both the focal and ambient visual system's respective sensitivity to either top-down or bottom-up attentional mechanisms allows for two potential explanations regarding the PDT's impressive sensitivity to situational driving demands:

Explanation 1 – The peripheral LED stimuli preemptively grab driver attention. As focal processing demands increase at central vision, it becomes more difficult to preemptively attract ambient system processing in the visual periphery. In essence, the focal visual system's top-down mechanisms momentarily block ambient access in accordance with moment-to-moment increases in situational demands. This explanation suggests that PDT performance is truly sensitive to the depth of focal system processing, a conclusion consistent with the current PDT literature (i.e., the PDT is most sensitive when workload demands are high).

In order to determine if such an interpretation is accurate, it is necessary to examine the extent to which the PDT truly reflects top-down search strategies implemented by the focal visual system. It might very well be the case that the impressive sensitivity of the PDT to date can be attributed to the driver's ability to efficiently time share between different focal tasks which require central vision, such as inspecting the immediate driving environment for potential hazards and/or interpreting messages from various in-vehicle devices. As the PDT paradigm currently stands, the spatial location of the LED stimuli are confined to the same region of space throughout the entire testing period (i.e., the LED's are reflected off of the windshield at random eccentricities between 11^{o} and 23^{o} left of the driver's normal line of sight and presented for two second durations at random intervals between three and five seconds). This

approach introduces little, if any, spatial uncertainty which suggests that subjects always know the general area in the left-hand field of view where to find a PDT target. Always knowing the location of a potential target might minimize any need for ambient system processing. It might very well be the case that subjects frequently fixate this area using a top-down focal vision scanning strategy to determine whether or not a target has been presented, especially considering that there is ample inspection time available to do so given that each stimulus is typically presented for two second durations.

If indeed the PDT is significantly dependent upon such a top-down search strategy, disrupting this strategy should yield a drop in PDT sensitivity. One potential approach for doing so involves introducing spatial uncertainty with regard to LED stimulus location so that driver's do not know exactly where in space a potential stimulus will be. To increase the spatial uncertainty of target location, the current paradigm will display LED targets within pre-defined regions of space on both the left and right-hand sides of the driver field of view. In addition to this manipulation, stimulus presentation times will also be reduced to only single second durations. The introduction of stimulus spatial uncertainty, combined with shorter stimulus presentation times should limit the number of spatial locations a driver can inspect using top-down strategies in a given period of time. On any given trial a single LED will be presented in either the left or right-hand field of view as subjects are engaged in one of two simulated driving conditions. While performing the PDT, subjects will be required to complete a low workload, straight road driving task as well as a high workload, lane changing task. If indeed the PDT is truly sensitive to a top-down focal vision scanning strategy, disrupting this strategy should result in the decline of PDT sensitivity across changes in driving

workload demands. More specifically, it is hypothesized that as the spatial location of potential targets becomes more uncertain, the ability of the PDT to reliably differentiate between the different levels of driving task difficulty will become unlikely (Hypothesis 1 – Positional Uncertainty X Workload). This expected drop in PDT sensitivity as a function of stimulus spatial uncertainty and increasing driving task demands is depicted in Figure 17 below.

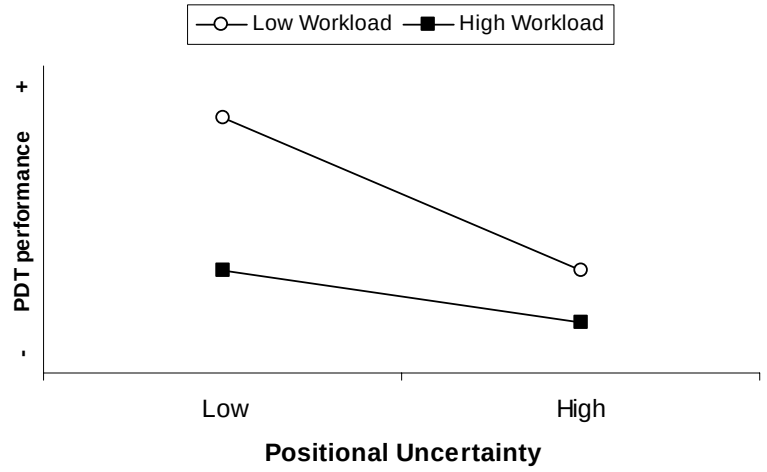


Figure 17. Hypothesis 1 – Positional Uncertainty X Driving Workload 2-way Interaction

Explanation 2 – The peripheral LED stimuli might simply be too weak to satisfy the requirements for preemptive ambient system processing. Preemptively inefficient stimuli force drivers to rely on top-down strategies driven by central vision of the focal system whereby the area of PDT stimuli are repeatedly sampled via direct fixations in conjunction with the demands of the primary driving task and any other in-vehicle secondary tasks. This explanation suggests that PDT performance is sensitive to top-down focal processing not solely because of increasing primary or secondary task demands, but rather because the stimulus qualities of the peripheral LED failed to meet the necessary requirements for bottom-up preemptive ambient system processing.

To determine if such an explanation is plausible, it is necessary to evaluate the LED signal strength used in the typical PDT paradigm. It was mentioned earlier that the ambient system is tuned to detect certain stimulus qualities which occur in the visual periphery such as abrupt onset, luminance flicker, and motion transients. However, a stimulus which appears to have some of these qualities is not guaranteed to trigger ambient system processing. These characteristics must fall within the ambient system's range of sensitivity in order to be detected. To determine the effectiveness of a stimulus, it is imperative to consider the extent to which the stimulus' qualities are actually able to trigger ambient system processing given the unique sensitivities of this system outlined previously. Out of all of the successful PDT studies discussed, only a single study mentioned the actual stimulus qualities of the LED stimuli as having a light intensity of 8.2 candelas and a wavelength of 660nm at a projection angle of +/- 3 degrees (Patten et al., 2006). Although not explicitly stated, it is likely that these qualities are specifications outlined by the LED manufacturer, not truly indicative of the actual luminance values under highly variable real-world lighting conditions. In fact many of the PDT studies, especially those carried out in the field, report degraded visibility of the LED reflection during testing days with bright sunlight (Jahn et al., 2005; Olsson & Burns, 2000; Engstrom, Aberg, Johansson, & Hammarback, 2005). Given this complication, there may have been many instances where the LED stimuli might have been too weak to adequately trigger ambient system processing. In other words, the luminance qualities of the LED stimuli might have been insufficiently transient, thus rendering the ambient system ineffective. The only way for the driver to detect a peripherally located LED target at this point would be to fixate it using central vision; a process carried out by the

focal visual system. If this were indeed the case, the PDT's impressive sensitivity to workload demands might be related more to a top-down strategic sampling process used by drivers, as opposed to a deficient ambient system or shrinking field of view which is commonly reported in the PDT literature (Martens & van Winsum, 2000; Olsson & Burns, 2000).

To determine whether or not the LED stimulus qualities failed to satisfy the requirements for bottom-up ambient system processing, it was necessary to manipulate the signal strength of the PDT targets. In essence, when a weak peripheral stimulus is used; as the tasks related to the driving situation (both primary and secondary) demand more and more focal processing via central vision, a stronger peripheral signal is necessary to trigger the preemptive, bottom-up mechanisms maintained by the ambient visual system. To further explore this issue, the current project attempted to operationalize the ambient system by temporally modulating the signal strength of the peripherally located LED targets. This temporal modulation was based on a series of investigations which modeled the psychophysical response to temporal stimulus properties at different eccentricities (Mandler & Makous, 1984; Witus, 1996; Snowden & Hess, 1992, see the Methods section as to how this process was carried out). Using this method allows the systematic manipulation of LED signal strength in such a way that each target can be made more or less likely to trigger preemptive ambient system processing. Based on the visual system's actual response to a given stimulus outlined by the aforementioned model, the current project will implement LED targets whose ability to stimulate processing by the ambient system fluctuates between one of three possible preemptive levels: 1) targets with low-preemption; believed to represent the ambient

processing (or potential lack thereof) used in previous PDT research, 2) moderately preemptive targets, and 3) highly preemptive targets predicted to represent absolute, preemptive ambient processing regardless of focal task demands. It is hypothesized that if the LED targets used in previous PDT studies were too weak to sufficiently trigger ambient processing, subjects will be forced to acquire such targets using direct fixations via the focal system; therefore increasing the preemptive ability of the targets should result in a decline in PDT diagnosticity across changes in driving task difficulty (Hypothesis 2 – Ambient Level X Workload 2-way Interaction). PDT performance should improve as the preemptive ability of the targets increasingly satisfies the bottom-up requirements of the ambient visual system. Such an effect is depicted in Figure 18 below.

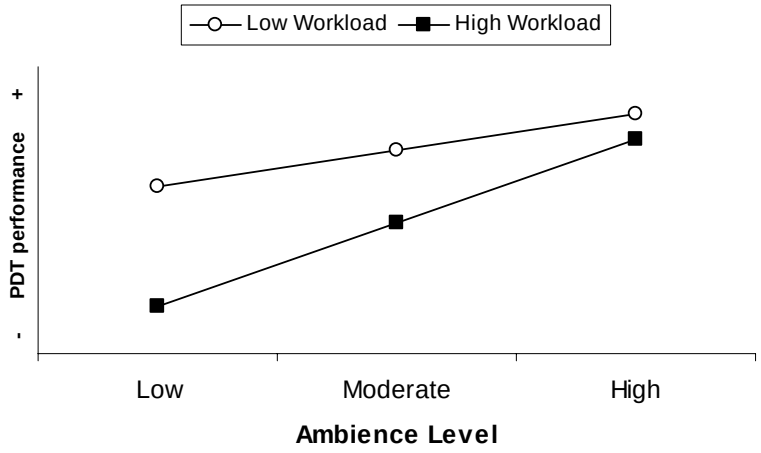


Figure 18. Hypothesis 2 - Ambience Level X Driving Workload 2-way Interaction

Focal/Ambient Theory with Implications for Aging Research

Of considerable interest to the current research project is examining the role of age with regard to the ability to process information efficiently during complex driving situations. A body of evidence was presented suggesting that many older individuals

exhibit driving behaviors which suggest the onset of visual information processing difficulties. Given the impressive sensitivity of previous PDT studies to both the visual and cognitive resource demands associated with complex driving environments and in-vehicle secondary tasks, it seems logical that this paradigm might provide further insight into the information processing abilities of the senescent driver. A thorough review of the PDT literature failed to identify any studies which explicitly investigated any changes in performance as a function of age differences. Despite this lack of age specific research, the PDT paradigm still affords an opportunity to make some general predictions as to how performance might change as a result of the normal aging process. Useful-field-of-view research in both the laboratory and field indicates that while experiencing visually complex situations, the mechanisms which mediate the aging person's information processing abilities become increasingly slow and less efficient (Gilland, 2002; Owsley et al., 1991;, Ball et al., 1993). Such a claim suggests that the PDT paradigm might reveal similar findings. Using the PDT paradigm in the traditional sense (i.e. the targets have little to no spatial uncertainty and low preemptive ability), the current investigation attempted to establish how performance changes as a function of both driver age and primary task driving demands. It was hypothesized that compared to younger drivers, PDT performance of the older group should become more sensitive to workload demands imposed during the complex lane changing task (Hypothesis 3 – Age X Workload 2-way Interaction, see Figure 19)

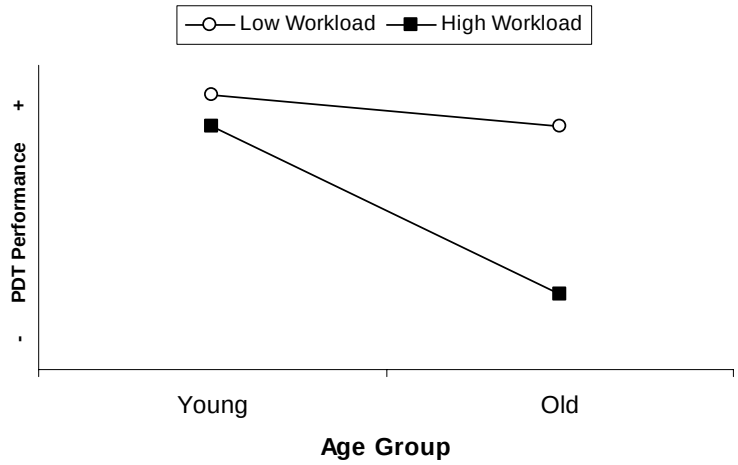


Figure 19. Hypothesis 3 - Age X Driving Workload 2-way Interaction

At this point however, it remains unclear whether or not such a result is truly indicative of the aging person's weakening ambient system, as the same result might also be explained in terms of a focal-task time sharing strategy. All subjects, regardless of age, may rely on top-down periodic scanning of the target area by focal vision to detect peripheral targets in cases where the stimuli were insufficient in their ability to automatically trigger an ambient system response. The less likely a target is to attract ambient system processing, the more PDT performance is expected to rely on focal abilities. By making the peripheral stimuli used in the paradigm progressively more ambient, observations can be made as to those points at which subjects begin to rely primarily on ambient system processing as opposed to focal system processing. If PDT performance fails to improve when the paradigm's characteristics are optimally ambient, such a finding can be interpreted as an age-related weakening of the ambient visual system, previously referred to as the *ambient insufficiency hypothesis* (Schieber et al., in press).

Evidence was presented in each major section of this report supporting the *ambient insufficiency hypothesis*. Analyses of driving patterns revealed that a large portion of the aging population restricts their driving to situations of minimal complexity. Crash records also indicate an over-involvement of collisions which occur during cross-traffic maneuvers. The results from several UFOV studies, performed in both the laboratory and field, have suggested a decline in information processing efficiency as a result of the normal aging process (Gilland, 2002; Owsley et al., 1991; Ball et al., 1993). A line of research was discussed in the visual system's section of the current document suggesting that this decline in ability can be attributed to the differential aging of the ambient visual system compared to the focal system (Kline & Schieber, 1981; Sekuler & Hutman, 1980; Schieber & Kline, 1982; Owsley et al., 1983). Many of the information processing responsibilities of the ambient system, such as detecting temporally transient stimuli in the periphery, are believed to become less effective as a person progresses into the later years of life. From the perspective of traffic safety, it might be a weakening or malfunctioning ambient system that is responsible for the overrepresentation of elderly drivers in certain types of collisions.

Temporally modulating the ambience level or preemptive ability of the LED targets provides an opportunity to diagnose the extent to which the PDT actually relies on ambient system processing. Given what has been discussed regarding ambient sensitivity to temporally changing targets, as the preemptive ability of a target increases, this target becomes much more likely to effectively stimulate the automatic, bottom-up mechanisms driven by the ambient system regardless of any immediate demands required by the driving task. Such an effect is expected to occur for the younger group of subjects in the

current study (Hypothesis 4 – Age X Workload X Ambient Level 3-way Interaction, see Figure 20). As the preemptive ability of peripheral targets is increased to optimal levels, PDT performance for these younger subjects is predicted to reliably improve. Such an effect is expected to occur at both levels of driving task workload, with the PDT being more diagnostic to ambient system abilities during the difficult lane changing scenario compared to easy straight road driving. The older group of subjects, however, is expected to exhibit a much different pattern of results. PDT performance is expected to be sensitive to changes in driving task demands as revealed by significantly poorer performance during the high workload condition. But because this group's ambient system abilities have grown progressively less sensitive as a result of the normal aging process, their ability to reliably take advantage of the increasingly preemptive targets at both the moderate and high ambience levels should be significantly compounded. As a result, the ability of the PDT to reliably diagnose the older group's ambient system abilities is expected to be limited across any changes in driving task difficulty. Although PDT performance does improve for the older group when driving workload demands are low, they still remain unable to capitalize on the increasingly preemptive targets due to their impaired ambient system, a finding consistent with the *ambient insufficiency hypothesis.*

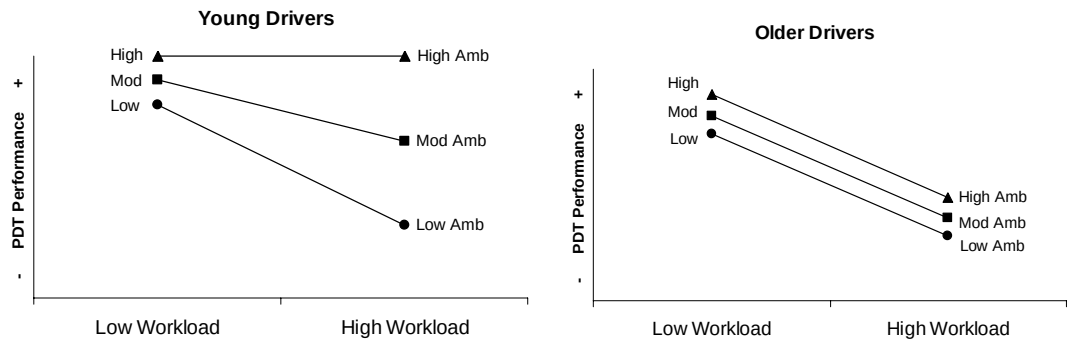


Figure 20. Hypothesis 4 – Age X Driving Workload X Ambient Level

A final analysis will help further the understanding as to which visual system PDT performance is truly sensitive to. Previously in Hypothesis 4, temporally modulating the signal strength of peripheral targets allowed the assessment of PDT diagnosticity with respect to ambient visual system abilities. It was also discussed in Hypothesis 1 that by introducing spatial uncertainty with regard to peripheral target location, inferences can be made as to whether or not subjects rely primarily on top-down focal vision scanning strategies to perform the PDT. When combined, these two manipulations essentially force subjects to utilize their ambient system abilities in order to detect targets in the visual periphery. It is hypothesized that when forced to rely solely on the ambient system, PDT performance for the younger subjects will improve significantly as the preemptive ability of the targets rises (Hypothesis 5 – Age X Positional Uncertainty X Ambient Level 3-way interaction, see Figure 21). More specifically, when spatial uncertainty with respect to target location is high, subjects are essentially unaware if a target will be presented in either the left or right visual periphery. As a result, PDT performance for the younger subjects is expected to be significantly degraded when the preemptive ability of the targets is at its lowest levels. The younger

subjects however, having heightened overall ambient system sensitivity, are then expected to take advantage of the increasing preemptive abilities of the peripheral targets and improve PDT performance accordingly. The older group of subjects is predicted to exhibit PDT performance levels similar to those predicted earlier. Because the ambient system declines in sensitivity as a result of the normal aging process, the older group cannot reliably capitalize on any increases in the preemptive strength of the targets, and therefore PDT performance remains at a relatively constant low rate across all ambience levels.

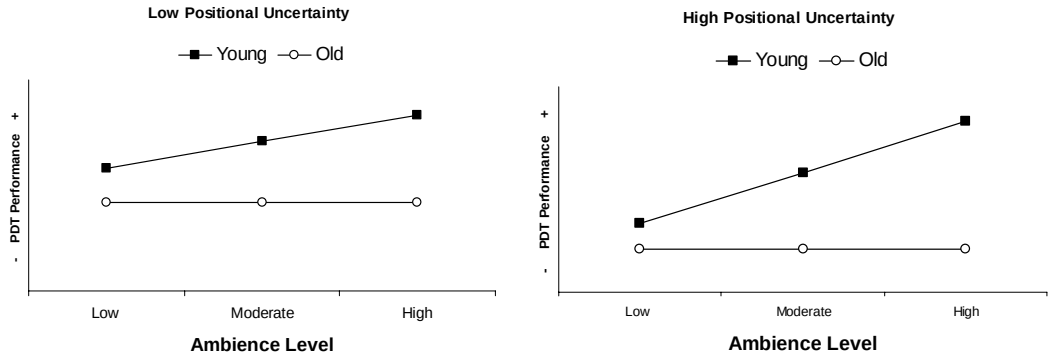


Figure 21. Hypothesis 5 - Age X Positional Uncertainty X Ambient Level 3-way Interaction

Method

Participants (a-priori power analysis)

A-priori analysis using G-Power version 3 (Faul, Erdfelder, Lang, & Buchner, 2007) was conducted based upon previous PDT study results in order to determine effect size (as defined by Cohen, 1988), appropriate sample size, and expected power values. According to Cohen, $f = 0.10$, $f = 0.25$, and $f = 0.40$ are defined as being small, medium, and large effects, respectively. Cohen's f was approximated using the reported F-ratios,

sample sizes, and levels of the independent variables as reported in the previous PDT studies. Using response time as the dependent variable, estimated effect sizes for the main effect of driving task were calculated as being large (f = .96) for Martens & van Winsum (2000) and large (f = .83) for Olsson & Burns (2000) as well. A large effect size (f = .84) was also reported for the main effect of driver experience in Patten et al (2006). Estimations of statistical power were at least equal to .94 for each of these main effects. With regard to estimating interaction effect sizes, the significant 2-way interaction from Olsson & Burns (2000) resulted in a medium effect size (f = .27) and a lower power value (*power* = .48), however it should also be mentioned that data from only 11 subjects were used in this study. The significant 2-way interaction reported in Patten & colleagues (2006) yielded a smaller effect size (f = .18), but a substantially larger power value (*power* = .94). Given the relative consistency in effect sizes across these PDT studies, the current study also expected medium effect sizes with regard to 2-way interaction effects. According to G-Power results, the necessary total sample size was 32 subjects given the following parameters of a 2 (between-subjects) by 3 (within-subjects) experimental design: f = .25, $\alpha = 0.05$, and *power* = .85.

Thirty-four subjects were enlisted from the Vermillion, SD area. A total of sixteen younger subjects (M=23 years, 9 males) ranging in age from 18-30 years were recruited from the University of South Dakota. Eighteen older subjects (M=72 years, 12 males) ranging in age from 65-85 were also recruited from various local community service organizations. All subjects were required to have a current driver's license and recent driving experience.

Independent Variables

Four experimental variables were examined in the current laboratory study. Subject age was the lone between-subjects variable; while driving task difficulty, positional uncertainty of targets, and peripheral stimulus ambience level were all within-subjects variables. The two levels of driver age consisted of young drivers between the ages of 18-30 years and older drivers between the ages of 65-85 years. All subjects were required to operate the driving simulator during two levels of workload; a low workload, straight road baseline condition and a high workload, continuous lane changing condition referred to as the lane changing task (LCT). While operating the simulator, subjects were asked to detect light emitting diode (LED) targets presented in their periphery whose location was considered to be of low positional uncertainty (i.e. displayed only in the left-hand field of view) or high positional uncertainty (i.e. displayed in either the left or right-hand field of view). The ambience level of the peripheral targets consisted of three levels of ambient system preemptive ability; low-ambience, moderate ambience, and high ambience.

Dependent Variables

The dependent measure in the primary analysis consisted of peripheral detection task hit rate (the fraction of detected signals divided by the total number of signals). This measure was chosen because it has successfully identified points of elevated workload in previous PDT studies (Martens & van Winsum, 2000; Olsson & Burns, 2000; Patten et al., 2006). Following the onset of a peripheral target, subjects were allowed a response window ranging from 200 msec after the target onset up to 2000 msec. Introducing a

delay of 200 msec before recording a response helped to reduce the occurrence of false alarms. If no response was provided within this response window, a missed target was recorded. An additional exploratory analysis also used peripheral detection task response time (in milliseconds) as a dependent measure.

Temporal Modulation of Peripheral Stimuli (Ambience Level)

The model chosen to simulate the visual system's response to temporal stimuli was first derived by Mandler & Makous (1984) and later implemented by Witus (1996). The psychophysical results of this model are depicted below in Figure 22. This curve shows that the human visual system is less sensitive to very low and very high temporal frequencies, and maximally sensitive to mid-range frequencies between 10-12 Hz. The x-axis scale used in the following figures is represented in log-space (i.e. 10^{0}=1, $10^{.5}$=3.16, and 10^{1}=10).

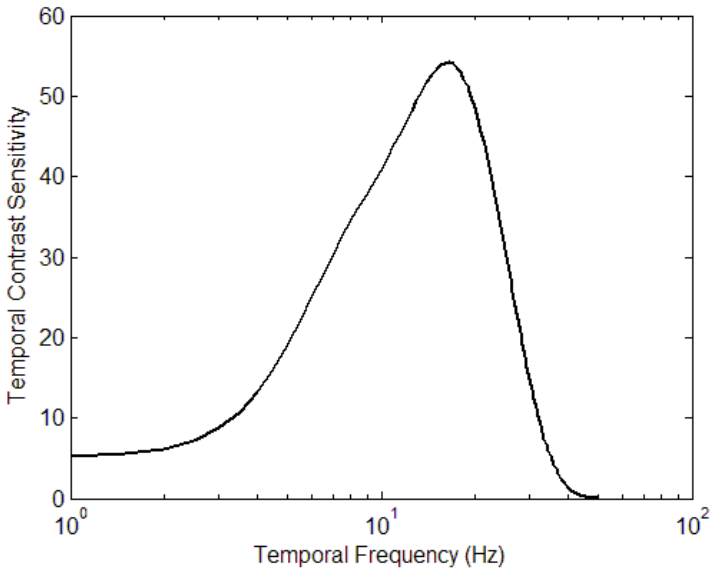


Figure 22. Temporal contrast sensitivity model of human vision (Witus, 1996)

Mandler and Makous (1984) used an analytical approach constrained by theory and knowledge of the visual temporal response to develop a 3-channel model which describes the mechanisms which dictate visual system sensitivity to temporally modulated stimuli, the summation of which produces the curve in Figure 22 just mentioned. These three mechanisms are interpreted as follows; (1) a low-pass channel maximally sensitive to temporal frequencies below 10 Hz, (2) a mid-range bandpass channel with peak sensitivity near 5.5 Hz, and (3) a higher-range bandpass channel whose peak sensitivity is near 12 Hz (see Figure 23 below). The low-pass channel is consistent with what has been described up to this point as the focal system; whereas the two bandpass channels, when combined, are thought to represent the temporal sensitivity of the ambient system.

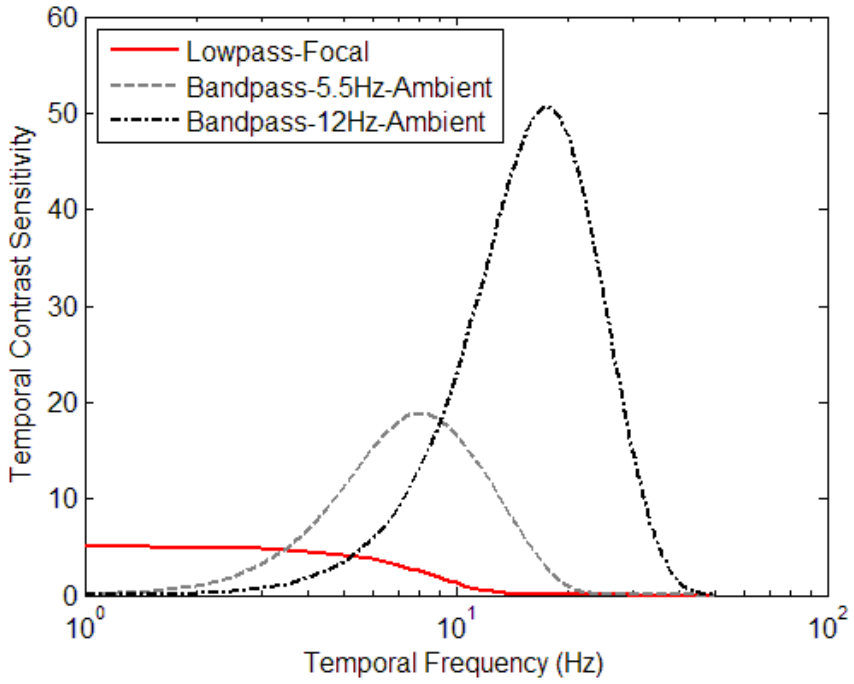


Figure 23. Three channel temporal contrast sensitivity model of human vision (Witus, 1996)

Below are the equations used by Witus (1996) to create each of the three mechanisms needed to describe the temporal response profile of the visual system. It should be noted that although the mechanisms initially described in Mandler and Makous (1984) were based on stimuli presented in central vision, their results are consistent with Snowden and Hess (1992) who reported similar functions for data collected in the near visual periphery.

$$Temporal\_Lowpass(f) = \exp\left[\ln\left(\frac{1}{2}\right)\left(\frac{f}{f_{50}}\right)^3\right] \quad \text{(Eq. 1)}$$

$$Temporal\_Bandpass_1(f) = \exp\left[\ln\left(\frac{1}{2}\right)\left(\frac{f}{f\_high_1}\right)^3\right] - \exp\left[\ln\left(\frac{1}{2}\right)\left(\frac{f}{f\_low_1}\right)^3\right] \quad \text{(Eq. 2)}$$

$$Temporal\_Bandpass_2(f) = \exp\left[\ln\left(\frac{1}{2}\right)\left(\frac{f}{f\_high_2}\right)^3\right] - \exp\left[\ln\left(\frac{1}{2}\right)\left(\frac{f}{f\_low_2}\right)^3\right] \quad \text{(Eq. 3)}$$

Given that the current research project had a goal of examining ambient system abilities, it ignored the focal function and used the summation of the two bandpass mechanisms implemented by Witus (1996) to create a mathematical function which describes ambient channel sensitivity to temporal stimuli (see Figure 24). The current study then used this model of ambient system sensitivity to filter various temporal profiles of stimuli in order to select those that have different degrees of effectiveness in actually stimulating ambient system processing.

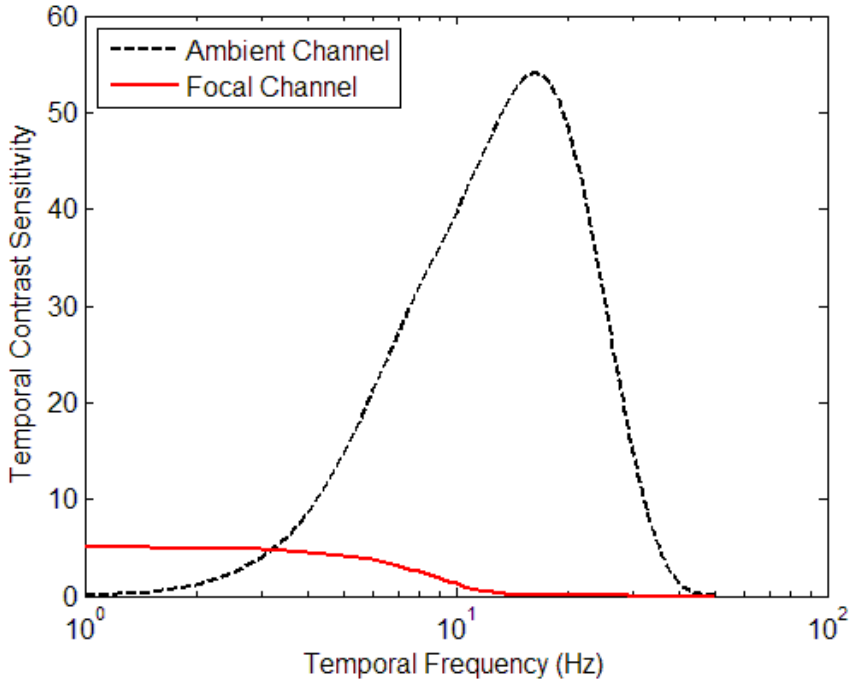


Figure 24. Ambient versus Focal channel temporal contrast sensitivity

Generally speaking, a 2 Hz stimulus located in the far left tail of the ambient channel model would be much less effective in triggering ambient system processing when compared to a 10 or 12 Hz stimulus located near the peak of the ambient sensitivity curve. By running a number of stimuli of various temporal profiles through the ambient model, the extent to which each stimulus actually meets the requirements for ambient processing can be quantified. As the stimulus qualities more effectively satisfy the conditions for ambient system processing, less of its energy is attenuated by the model. The more energy that passes through the model, the more likely a stimulus is to be automatically detected by the ambient system. In turn, the less effective a stimulus is in meeting the requirements for ambient processing the more the model is forced to attenuate the signal, thus limiting the likelihood of triggering any automatic ambient system processing.

Table 3. Stimulus properties after filtering by the ambient sensitivity model

Stimulus	Preemptive Ability	Percent residual energy after ambient model filtering	Log Value
10 Hz sine wave	High	0.75692	-0.12
3 Hz sine wave	Moderate	0.16279	-0.79
1 sec Gaussian (mu=0.5, sigma=0.15)	Low	0.10193	-0.99

Table 3 describes three stimuli of varying temporal signature after being filtered through the current model. It should be noted that the respective height of each stimulus was normalized to assure that equal amounts of integrated light energy was delivered over the same 1 second stimulus presentation epoch. This table shows that a 10 Hz sine wave is attenuated only slightly by the model and as a result, is classified as being highly preemptive with respect to automatic ambient processing. The 3 Hz sine wave is filtered by the model to a greater extent and classified as being moderately preemptive. A one second Gaussian on the other hand, is a highly ineffective stimulus whose energy is almost entirely attenuated by the model. It is unlikely that this stimulus would trigger any automatic ambient processing essentially forcing subjects to utilize the focal visual system for detection. For further clarification consult Appendix A to view graphs of each temporal stimulus. The MATLAB scripts used to create the model of ambient system sensitivity can be found in Appendix B.

Apparatus

The driving simulation software was developed by DaimlerChrysler AG, Research and Technology. The simulated roadway consisted of a three-lane road (lane width = 3.85 m) with both straight and curved sections (Figure 25). Initially a Lane-Change-Task (LCT) was developed as a simple, cost effective approach for measuring the extent of driver distraction imposed by in-vehicle information systems. To perform the LCT, subjects are required to change their lane position as instructed by signs which they encounter throughout each straight road section of the track (Figure 26). The mean distance from sign to sign is 150 m and 18 signs are encountered during each straightaway (Mattes, 2003). The distance at which the information on the sign first becomes visible to the subjects was set at 40 m. The subject's actual driving trajectory is then compared to a normative model which represents the optimal driving path. The extent of deviation from the normative model while performing a variety of secondary tasks is then typically used as an indicator of driver distraction. It should be noted that the information on these signs can be turned off at the experimenter's discretion. During the low workload, straight driving conditions used in the current study, all signs experienced by subjects remained blank.

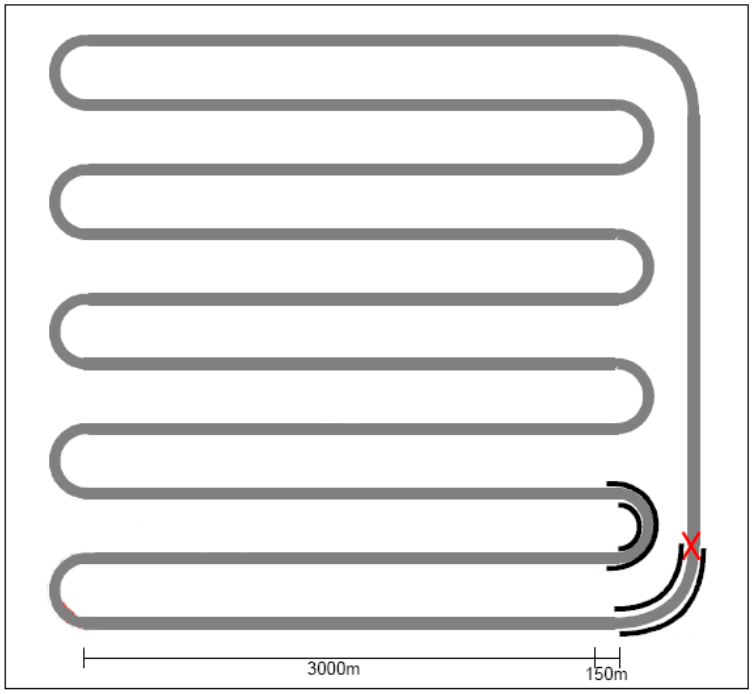


Figure 25. Track layout used in PC based DaimlerChrysler driving simulator

Figure 26. Simulated road with 3 lanes. According to the sign, the driver has to change from the center to the right lane (taken from Mattes, 2003)

According to Mattes (2003), the LCT was able to successfully differentiate between twelve in-vehicle distraction tasks which ranged from unwrapping a candy to interacting with an in-vehicle navigation system. Perhaps most importantly, as Mattes (2003) notes, results correlated highly with those obtained using a high-end moving base driving simulator (correlations ranged from $r = 0.540$ to $r = 0.835$). Ultimately these results suggest that the LCT used in the PC based DaimlerChrysler driving simulation software is a useful, cost-effective research tool which is sensitive to both visual and cognitive distraction (Mattes, 2003). Although the LCT data were not used as the primary dependent measure in the current research proposal, having subjects perform the LCT while detecting peripheral targets is believed to be sufficiently resource demanding. Subjects were also required to maintain a constant speed of 50 mph to ensure that the simulated driving task adequately loaded driver information processing demands.

Each participant's visual acuity was measured using a Bausch & Lomb Orthorater (using the binocular, far vision plates). A Gateway E-Series PC running Windows XP Professional OS using a Pentium® 4 CPU at 2.80 GHz, 1.00 GB RAM, DirectX 9.0, and an ATI Radeon Graphics Processor (Internal DAC 400MHz, 256MB) was used to power the PC based DaimlerChrysler driving simulator. A Logitech Wingman Formula Force GP USB consisting of a steering wheel, brake pedal, and accelerator pedal was used by participants to control the simulated vehicle. To ensure that the angular distance subtended by objects during the driving simulation was comparable to that actually experienced in the real world, it was necessary to back project the simulation (Sharp model XG-NV2U) to a screen width of approximately 66 inches at a viewing distance of 36 inches. A large sheet of plexi-glass was then positioned between the projected

simulation image and the steering wheel device to imitate a vehicle windshield. The simulation computer was attached via a crossover cable to a neighboring data logging computer so that these machines could communicate through a static TCP/IP address. Such a connection was selected because it allows the ability to record the exact location of each stimulus as it occurred on the simulated roadway environment. This information was time stamped with simulator performance data (speed, lane position, steering wheel position, track location), data concerning levels of the independent variables (driving task difficulty, positional uncertainty of targets, and peripheral stimulus ambience level), and data specific to the dependent variables (PDT response time and hit rate). This data logging computer consisted of a Dell PC running Windows 2000 OS using a Celeron 900 CPU and 256 MB RAM. A third computer was then used to generate the different ambient levels of the LED targets using pulse width modulation. This system ran in MS-DOS in order to achieve real-time process administration with millisecond precision. None of the machines were connected to the internet.

Two identical external circuit boxes were then built to house and drive the LED stimuli so that when illuminated the LED target itself was shielded from the direct view of subjects (see Appendix C for apparatus photos). To eliminate any extraneous light scatter which might inadvertently capture the subject's attention, each LED was hidden within a plastic enclosure whose surface was then covered by a diffuser. The use of a diffuser created a Lambertian surface with reflective qualities that remained constant across changes in subject viewing angle. In-house pilot testing determined that distracter LEDs were necessary in order to eliminate potential ceiling effects for the younger group of subjects. Two distracter LEDs were mounted 1 ¼" to each side of the two test LED's

within each external circuit box. These distracter LEDs remained illuminated throughout the entire experimental session. Each LED circuit box was fixed to the table which housed the steering controls in such a manner that when illuminated, the actual visual stimulus target consisted of an LED reflection off of the plexiglass windshield in the area 2-4^{o} above the simulator horizon located at a horizontal angle 18^{o} in both the left and right-hand peripheral fields of view. Each temporally modulated peripheral target LED was illuminated for 1000 msec durations while the presentation rate varied randomly between 5000-9000 msec. To record target detection, subjects were required to press one of two buttons mounted to the simulator steering wheel. Subjects were allowed to press either button regardless of the LED target's location (i.e., left or right visual field), but were instructed to press the button which afforded the quickest target detection rates.

Photometric measurements of the apparatus were taken using a Minolta CS-100A Photometer on May 2, 2008. The LED target reflection plus overhead ambient illumination was measured as being 4.2 cd/m^2. The blue sky background of the projected driving simulation image plus overhead ambient illumination was determined to be 10.0 cd/m^2. This provided an LED target luminance constrast of 0.70 (background/ (target + background) = 10/(4.2 + 10)). The overall ambient laboratory illumination was measured as being 50 lux (nominal). Illumination measurement employed an Avian Technologies Model FWT99 Reflectance Standard. According to manufacturer specifications, the LEDs used for targets were rated at 9,000-13,000 mcd at a wavelength of 625 nm.

Procedure

Approval for use of human subjects was obtained from the University of South Dakota's Institutional Review Board. Upon arrival, all subjects were given a description of the study and informed as to what would be expected of them. All participants were then required to read and sign an informed consent sheet (see Appendix D). Following the signed consent, subject visual acuity was determined. All subjects were required to have a minimum binocular far visual acuity of 20/40. This value was chosen because it is the cutoff for driver licensing in many states, including South Dakota.

Following completion of the informed consent process and visual acuity evaluation, subjects were introduced to the Daimler-Chrysler driving simulator. Each participant was required to complete a 5 minute practice session to become familiar with the controls of the simulator and the target response instrumentation. For the first minute of practice, subjects were allowed to drive on a straight road section and maneuver the vehicle at their discretion. Anytime subjects were instructed to simply drive straight, blank signs with no lane changing information were provided. The following two minutes were spent practicing the LCT, while the final two minutes of the practice session involved simultaneously performing both the LCT concurrently with the PDT. If necessary this practice session was repeated until the participant felt comfortable with both the simulated driving and the target response protocol. All participants were instructed to obey standard driving laws and to maintain a speed limit of 50 mph whenever possible throughout the driving scenarios.

Each subject was then assigned to one of eight possible experimental blocks in order to randomly distribute any extraneous variation which might be attributed to

procedural or practice effects (see Appendix E for list of potential task order sequences). Each of these blocks were separated into two distinct halves, whereby subjects experienced a single level of the positional uncertainty of targets variable (either low or high) in the first portion of the experiment, and the remaining level of this variable in the latter half of the experiment. Within each of these halves, both levels of the driving task difficulty variable were performed. Presentation sequences for the ambience level manipulation were varied randomly within each experimental block.

After being assigned to the appropriate experimental sequence block, subjects were reminded once again to maintain a constant speed of 50 mph whenever possible throughout the entire session. In addition, without ever withdrawing their full attention from the simulated driving task, subjects were instructed to respond as quickly as possible whenever a peripheral LED target had been detected by pressing one of the buttons attached to the steering wheel. Participants were also instructed to refrain from any extraneous conversation with the experimenter during testing periods. In between each of the four experimental blocks participants were allowed the opportunity to take a short break and ask any questions if necessary.

In its entirety, subjects received 192 peripheral detection targets of varying ambience level throughout the experiment. More specifically, 16 targets were randomly presented at each of the three ambience levels (16 x 3 = 48 targets) during each of the two driving task workload manipulations. In other words, 48 targets were presented in the low positional uncertainty stimulus location condition (only the left hand field of view) while driving straight and while performing the lane changing task (48 x 2 = 96 targets). Another 48 targets were then presented in the high positional uncertainty stimulus

location condition (either the left or right hand field of view) during both straight road driving and while completing the lane changing task (48 x 2 = 96 targets). Each block of 48 targets was expected to last approximately 6 minutes. Presentation rates for peripheral targets varied randomly between 5000 – 9000 msec; while the actual location of each peripheral target presentation within the simulated driving environment varied across all subjects. The decision to randomly vary target location was based on previous in-house research which found that when targets are confined to precise locations, subjects are able utilize this information and eventually develop the ability to reliably predict upcoming stimuli (Schlorholtz & Schieber, 2006).

Considering the time taken to inform subjects as to what was expected of them, practice driving the simulator, practice performing the PDT task, in addition to completing each of the four experimental blocks; the entire experiment took no longer than one hour to complete (see Appendix F).

Results

A-priori Hypotheses

In order to maintain a sense of consistency with *a-priori* hypotheses discussed in the introduction section of this document (see pages 91-98), the statistical analyses of Hypotheses 1, 2, and 3 are briefly mentioned below. Further decomposition and discussion of these results will be provided in later analyses where all variables of interest are considered. SPSS version 12.0 was used for all statistical analyses. All η^2 values reported in the results section were calculated by hand.

Hypothesis 1 predicted that as the spatial location of peripheral targets became more uncertain, the ability of the PDT to reliably differentiate between low and high workload conditions would become less likely. This hypothesis was examined using a 2 (Workload) by 2 (Positional Uncertainty) repeated measures ANOVA with PDT target hit rate as the dependent variable. Because this hypothesis served as a basic replication of the typical PDT paradigm, only those targets with the weakest preemptive/ambient ability were analyzed. The predicted 2-way interaction failed to achieve statistical significance (p=.054, η^2=.017). However, both the main effect of Workload [F(1,33)=23.343, MSE=.019, p<.001, η^2=.11] and Positional Uncertainty [F(1,33)=74.710, MSE=.021, p<.001, η^2=.40] were found to be statistically significant. As expected, PDT hit rates declined significantly as the demands of the driving task increased from low workload (M=0.766) to high workload conditions (M=0.651), as well as when the location of potential PDT targets had a low positional uncertainty (M=0.816) compared to high positional uncertainty (M=0.601).

Hypothesis 2 predicted that the LED targets used in previous PDT studies were insufficiently transient in their ability to trigger ambient processing and thus relied on direct fixations via the focal system for detection. In addition, increasing the preemptive ability of peripheral targets was also expected to produce a decline in PDT Diagnosticity across changes in simulated driving workload. This hypothesis was examined using a 2 (Workload) by 3 (Ambience) repeated measures ANOVA with PDT target hit rate as the dependent variable. Because this hypothesis served as a basic replication of the typical PDT paradigm, only those targets with low positional uncertainty (i.e., those presented in the left-hand field of view) were analyzed. This analysis failed to produce a significant

2-way interaction (p=.605, η^2=.002), but did yield statistically significant main effects of Workload [F(1,33)=25.432, MSE=.007, p<.001, η^2=.06] and Ambience [F(1.324, 43.693$_{\text{Greenhouse-Geisser Adj.}}$)=25.556, MSE=.025, p<.001, η^2=.29]. With respect to the demands of the driving task, subjects had significantly higher hit rates during low workload simulated driving conditions (M=0.935) compared to high workload conditions (M=0.877). In turn, subject hit rates were substantially degraded when target ambience was lowest (M=0.816), while hit rates were indistinguishable at the moderate (M=0.944) and highest ambience levels (M=0.958).

The third hypothesis predicted that compared to younger drivers, PDT performance of the older group would become significantly degraded as simulated driving demands increased from low to high conditions. This hypothesis was examined using a 2 (Age) by 2 (Workload) split-plot ANOVA with PDT target hit rate as the dependent variable. Because this hypothesis served as a basic replication of the typical PDT paradigm, only those targets with low positional uncertainty and low preemptive/ambient ability were analyzed. This analysis failed to produce both a significant interaction (p=.904, η^2=.00) and a main effect of Age (p=.098, η^2=.06), but did reveal a significant main effect of driving task Workload [F(1,32)=5.087, MSE=.017, p<.031, η^2=.036, $power$=.590] where subjects detected fewer PDT targets under high workload conditions (M=0.781) compared to low workload conditions (M=0.851).

The remaining hypotheses predicted that due to an age-related failure of the ambient visual system, older subjects would not be able to reliably capitalize on increasingly preemptive targets across changes in simulated driving workload (Hypothesis 4) and the positional uncertainty of PDT target location (Hypothesis 5).

These hypotheses were answered using 2 (Age) by 2 (Workload) by 2 (Positional Uncertainty) by 3 (Ambience) split-plot ANOVA with PDT target hit rate as the dependent variable. The following age-specific 2-way interactions were identified: Age by Workload [$F(1,32)=5.207$, $MSE=.017$, $p<.029$, $\eta^2=.01$, $power=.60$] and Age by Positional Uncertainty [$F(1,32)=8.096$, $MSE=.018$, $p<.008$, $\eta^2=.01$, $power=.788$]. Additional significant 2-way interactions were also revealed for Positional Uncertainty by Ambience [$F(2,64)=22.228$, $MSE=.009$, $p<.001$, $\eta^2=.03$, $power>.999$] and Workload by Ambience [$F(2,64)=4.670$, $MSE=.009$, $p<.013$, $\eta^2=.01$, $power=.766$]. Each interaction will be decomposed into its simple effects in the following paragraphs. Significant main effects were also identified for each of the four variables of interest: Age [$F(1,32) = 12.059$, $MSE=.079$, $p<.001$, $\eta^2=.06$, $power=.920$], Workload [$F(1,32)=33.164$, $MSE=.017$, $p<.001$, $\eta^2=.04$, $power>.999$], Positional Uncertainty [$F(1,32)=85.922$, $MSE=.018$, $p<.001$, $\eta^2=.11$, $power>.999$], and Ambience [$F(1.4, 44.801_{\text{Greenhouse-Geisser Adj.}})=75.439$, $MSE=.035$, $p<.001$, $\eta^2=.24$, $power>.999$]. For a complete table of age group means at each level of the independent variables see Appendix H.

To better understand the 2-way Age by Workload interaction, analyses of simple effects were performed using a Bonferroni adjusted $\alpha=.05/4=.0125$. Results of this statistical decomposition are presented in Figure 27 and show a significant decrease in PDT target hit rate during high workload simulated driving conditions compared to low workload conditions for both the young subjects [$F(1,15)=11.191$, $MSE=.001$, $p<.004$] as well as the old subjects [$F(1,17)=23.981$, $MSE=.004$, $p<.001$]. With respect to age differences, the older subjects had significantly lower PDT hit rates ($M=0.745$) when compared to their younger counterparts ($M=0.871$), but only under the highest workload

conditions [$F(1,32)=15.936$, $MSE=.008$, $p<.001$]. During low workload simulated driving conditions the age groups were statistically indistinguishable from each other (0.849 vs. 0.916). These results suggest that all subjects, regardless of age detected fewer overall PDT targets as the demands of the driving task were increased, but it was only at the highest workload levels where age differences became apparent.

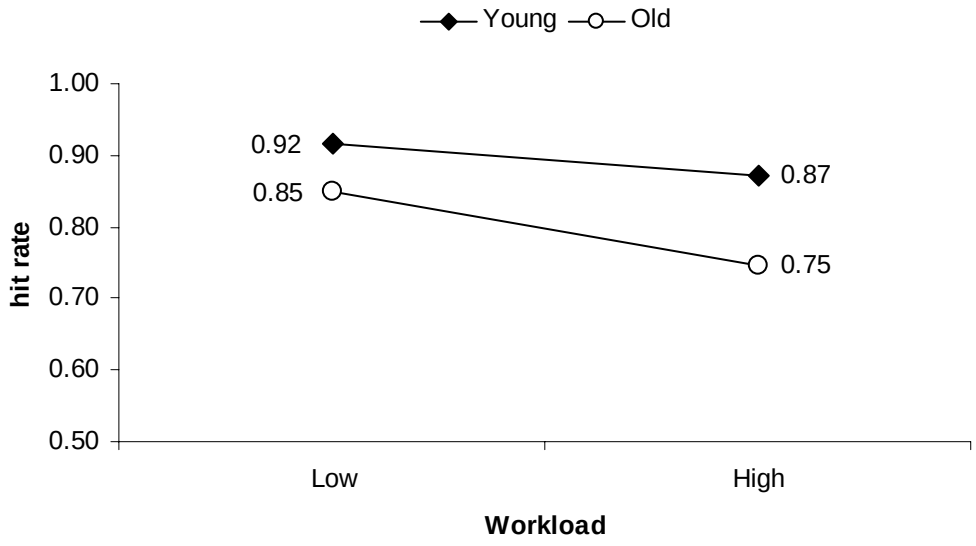


Figure 27. Significant 2-way Age by Workload Interaction

A decomposition of simple effects was also performed for the 2-way Age by Positional Uncertainty interaction using a Bonferroni adjusted $\alpha = .05/4 = .0125$ (see Figure 28). Significantly fewer PDT targets were detected when positional uncertainty was high compared to when uncertainty was low, and such an effect held true for both the young group of subjects [$F(1,15)=19.866$, $MSE=.003$, $p<.001$] as well as for the older group of subjects [$F(1,17)=76.681$, $MSE=.003$, $p<.001$]. With respect to age differences, older subjects detected significantly fewer targets ($M=0.715$) than did younger subjects ($M=0.851$) when positional uncertainty was high [$F(1,32)=14.013$, $MSE=.011$, $p<.001$].

No such age differences were found when the location of PDT targets was highly predictable (i.e. those of low positional uncertainty always appeared in the left-hand field of view). At first glance, such a result could be interpreted as an indication of a weakening ambient system for the older group of subjects, but the lack of any additional age specific interactions with the ambience level manipulation limits the evidence supporting such an interpretation.

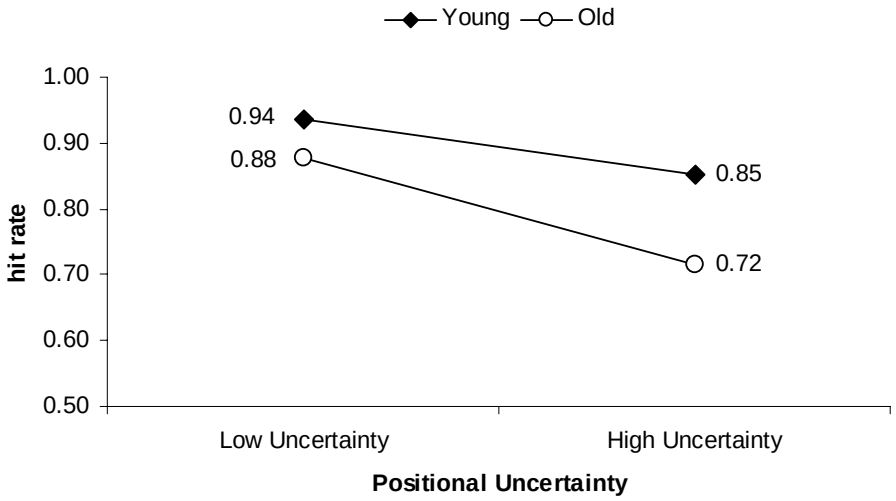


Figure 28. Significant 2-way Age by Positional Uncertainty Interaction

With respect to the significant 2-way Workload by Ambience interaction (see Figure 29), simple effects were analyzed using an adjusted α =.01. Significantly fewer PDT targets were detected under high workload demands compared to low workload demands when the target ambience levels were lowest [$F(1,33)=23.343$, $MSE=.010$, $p<.001$], when target ambience levels were moderate [$F(1,33)=11.425$, $MSE=.006$, $p<.002$], and when targets were of the highest ambience levels [$F(1,33)=12.671$, $MSE=.004$, $p<.001$]. To further understand the effect of target ambience a repeated measures ANOVA was performed at each level of driving task workload. During low

workload simulated driving the effect of target ambience was statistically significant [$F(2,66)=33.786$, $MSE=.010$, $p<.001$]. Pairwise comparisons of the three ambience levels using Fisher's LSD during low workload simulated driving also revealed significantly lower hit rates for low vs. moderate ambience targets ($p<.001$), low vs. high ambience targets ($p<.001$), but not between moderate vs. high ambience targets ($p=.129$). During high workload simulated driving conditions the effect of target ambience was once again found to be significant [$F(2,66)=92.223$, $MSE=.007$, $p<.001$]. Pairwise comparisons of the three target ambience levels revealed similarly lower hit rates for low vs. moderate ambience targets ($p<.001$), low vs. high ambience targets ($p<.001$), but once again failed to produce significance between moderate vs. high ambience targets ($p=.059$). To better understand this interaction a "differences among differences" *t*-test analysis was performed. The difference in hit rates between low vs. high workload for low ambience targets (weight = -2) was compared to those differences for both moderate (weight = 1) and high ambience targets (weight = 1). With $t_{critical}(30)=2.750$, a highly significant effect was identified ($t(34)=-69.3$). These results suggest that when workload demands are greatest, targets which are the least likely to stimulate preemptive processing by the ambient system were detected at significantly lower rates than targets more specifically tuned to automatically trigger attentional processing.

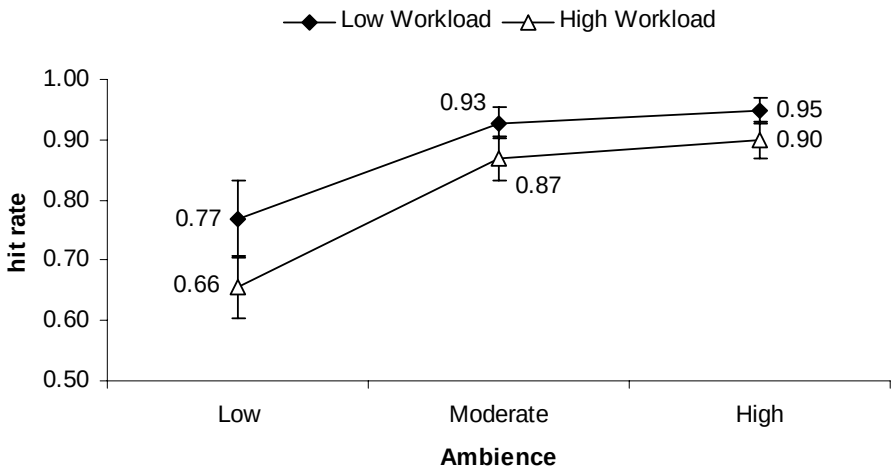


Figure 29. Significant 2-way Workload by Ambience Interaction (error bars indicate 95% Confidence Interval)

The 2-way Positional Uncertainty by Ambience interaction was also decomposed into its simple effects using an adjusted α =.01 (see Figure 30). PDT hit rates were significantly lower when the target's location was highly uncertain compared to when there was little to no stimulus uncertainty during conditions where target ambience levels were lowest [F(1,33)=74.710, MSE=.011, p<.001], where target ambience levels were moderate [F(1,33)=29.224, MSE=.005, p<.001], and where targets were of the highest ambience levels [F(1,33)=19.183, MSE=.005, p<.001]. To further understand the effect of target ambience a repeated measures ANOVA was performed at each level of positional uncertainty. When there was little to no uncertainty with respect to potential target location the effect of target ambience was statistically significant [F(2,66)=25.556, MSE=.008, p<.001]. Pairwise comparisons of the three ambience levels using Fisher's LSD for low positional uncertainty targets also identified significantly lower hit rates for low vs. moderate ambience targets (p<.001), low vs. high ambience targets (p<.001), but not between moderate vs. high ambience targets (p=.246). Similarly, when the location

of a potential target was highly uncertain the effect of target ambience was again statistically significant [$F(2,66)=97.963$, $MSE=.008$, $p<.001$]. Pairwise comparisons of the three ambience levels using Fisher's LSD for high positional uncertainty targets also revealed significantly lower hit rates for low vs. moderate ambience targets ($p<.001$), low vs. high ambience targets ($p<.001$), but not between moderate vs. high ambience targets ($p=.054$). To further decompose this interaction a "differences among differences" *t*-test analysis was performed. The difference in hit rates between low vs. high positional uncertainty for low ambience targets (weight = -2) was compared to those differences for both moderate (weight = 1) and high ambience targets (weight = 1). With $t_{critical}(30)=2.750$, a highly significant effect was identified [$t(34)=-157.4$]. These results show that when an upcoming targets location is unpredictable, subjects exhibited substantially lower detection rates for targets which were the least likely to capture preemptive, ambient system processing.

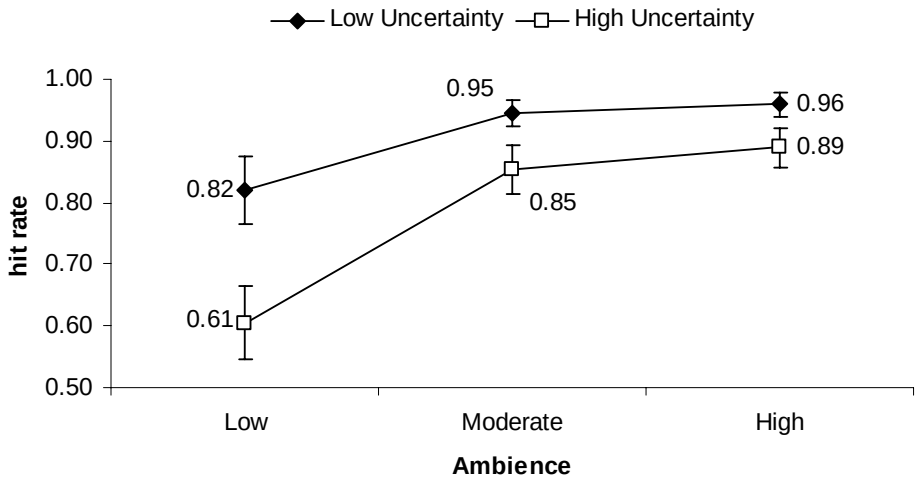


Figure 30. Significant 2-way Positional Uncertainty by Ambience Interaction (error bars indicate 95% Confidence Interval)

A follow-up analysis also investigated whether or not the role of gender might influence peripheral target detection rates. A 2 (Gender) by 2 (Age) by 2 (Workload) by 2 (Positional Uncertainty) by 3 (Ambience) split-plot ANOVA with PDT target hit rate as the dependent variable was conducted. The main effect of gender, nor its interactions were found to be statistically significant.

Post-hoc Analyses

PDT Hit Rate

The failure of the current PDT paradigm to produce any age-specific interactions with respect to the target ambience variable merits further consideration. It is suggested in the transportation literature that relying purely on the chronological aspect of driver age is not sufficient when attempting to identify potentially problematic senescent drivers (Ball, et al., 1993). All analyses to this point have relied solely upon chronological subject age to designate group membership as being either Young (18-30 years) or Old (65-85 years). Based on the notion that there could be extensive individual performance differences in the current older group of subjects, a median-split analysis was performed on PDT target hit rate. Hit rate was collapsed across all levels of Workload, Positional Uncertainty, and Target Ambience. After determining that the median hit rate = 0.79, those older subjects with an average hit rate greater than 0.79 were assigned to the Old-High Performance group (N=9, M=70.67 years, 7 males), while those subjects with an average hit rate less than 0.79 were assigned to the Old-Low Performance group (N=9, M=74.44 years, 5 males). A one-way ANOVA determined that these two age groups were not statistically different in terms of chronological subject age (p=.191).

The first *post hoc* analysis attempted to determine if any differences existed between the Old-High Performance group and the Old-Low Performance group. See Appendix H for a complete table of age group hit rates across all other independent variables. A 2 (Old-Low vs. Old-High) by 2 (Workload) by 2 (Positional Uncertainty) by 3 (Ambience) split-plot ANOVA was performed using PDT target hit rate as the dependent variable. Two significant interactions were identified: a 2-way Positional Uncertainty by Ambience interaction [$F(2,32)=7.365$, $MSE=.012$, $p<..002$, $\eta^2=.02$, $power=.916$] and a 3-way Old-Low vs. Old-High by Workload by Ambience interaction [$F(2,32)=5.086$, $MSE=.007$, $p<.012$, $\eta^2=.01$, $power=.783$]. Significant main effects were also identified for each of the four variables of interest: Old-Low vs. Old-High [$F(1,16)=28.091$, $MSE=.034$, $p<.001$, $\eta^2=.10$, $power > 0.999$], Workload [$F(1,16)=22.685$, $MSE=.025$, $p<.001$, $\eta^2=.06$, $power=0.994$], Positional Uncertainty [$F(1,16)=74.062$, $MSE=.019$, $p<.001$, $\eta^2=.16$, $power > 0.999$], and Target Ambience [$F(2,32)=42.605$, $MSE=.027$, $p<.001$, $\eta^2=.25$, $power > 0.999$].

Further decomposition of the 3-way Old-Low vs. Old-High by Workload by Target Ambience interaction yielded simple effects similar to previously discussed interactions (see Figures 31 & 32 below). Both sets of figures show that each of the two *post hoc* older age groups exhibited significantly lower PDT hit rates for the lowest ambience targets compared to both moderate and high ambience targets (*p*-values ranged from .001 to .004), while hit rates between the moderate and high ambience targets were statistically indistinguishable for the two older groups. These effects were identified for both low and high workload simulated driving conditions.

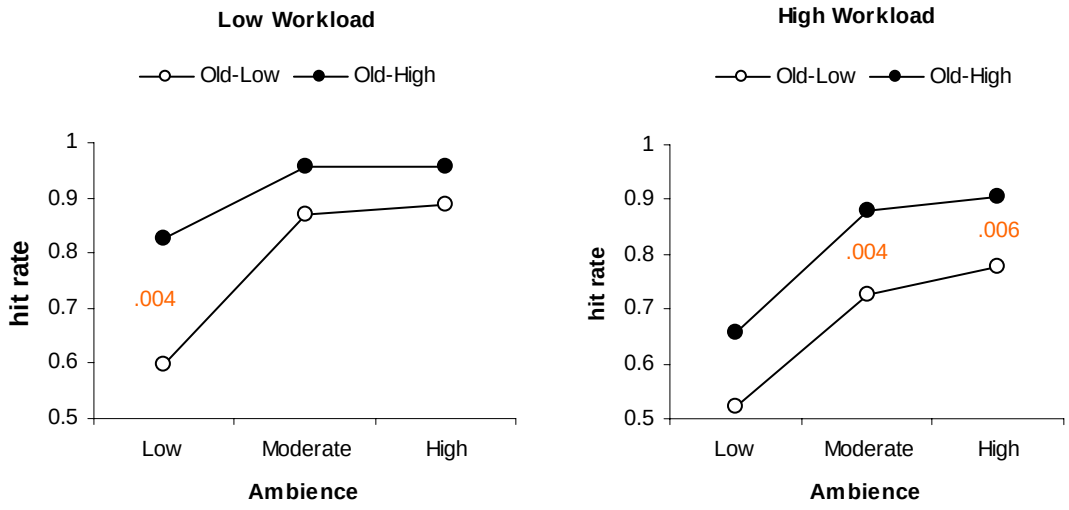


Figure 31. 3-way Old-Low vs. Old-High by Workload by Ambience interaction using median split older age group (sig. simple effects *p*-values presented in orange)

The nature of this 3-way interaction becomes better understood when the effects of subject age are analyzed at each level of ambience (Figure 31). During low workload simulated driving conditions, the Old-Low Performance group (*M*=0.59) had significantly poorer PDT hit rates for the low ambience targets ($p<.004$) compared to the Old-High group (*M*=0.82), but were no different from their High Performance counterpart when considering moderate (0.86 vs. 0.95, $p=.04$) and high ambience targets (0.88 vs. 0.95, $p=.07$). In turn, during high workload simulated driving conditions, PDT hit rates for the Old-High Performance group declined for the lowest ambience targets (*M*=0.65) to a level that was statistically no different to those of the Old-Low Performance group (*M*=0.52, $p=.03$). However, while these groups remained indistinguishable for the least ambient of targets under high workload conditions, PDT hit rates for the Old-Low Performance group dropped to significantly lower levels for both targets of moderate ambient ability (0.72 vs. 0.88, $p<.004$) and high ambient ability (0.77

vs. 0.99, $p<.006$). These results suggest that even during the least demanding of simulated driving scenarios, PDT hit rate performance for the low performance subgroup was already substantially lower for stimuli which are the least likely to trigger ambient processing. As workload demands increased, the finding that this groups PDT performance also declined for targets designed to more efficiently trigger automatic processing suggests that the preemptive nature of the ambient visual system is deteriorating in ability for some, but not all senescent individuals.

Additional simple effects analyses were also performed for this 3-way interaction to determine any effects of simulated driving workload at each level of ambience for the two *post hoc* older sub groups (see Figure 32). With respect to the Old-Low Performance group, PDT performance during low workload conditions ($M=0.59$) was no different from high workload conditions ($M=0.52$) for the least ambient targets ($p=.193$). However for the Old-High Performance group, PDT hit rates dropped significantly for low ambience targets when task demands increased from low workload ($M=0.82$) to high workload conditions ($M=0.65$, $p<.001$). For targets of more moderate ambient ability, both the Old-Low Performance (0.72 vs. 0.86, $p<.012$) and the Old-High Performance groups (0.88 vs. 0.95, $p<.017$) exhibited PDT hit rates that declined significantly during high workload conditions compared to low workload conditions. Finally, when targets were of the highest ambient ability, only the Old-Low Performance group had worse PDT hit rates during high workload conditions ($M=0.77$) compared to those with lower demands ($M=0.88$, $p<.017$). Inline with previously discussed results, PDT hit rates for the Old-Low Performance group declined significantly for targets with the greatest theoretical likelihood of stimulating ambient processing as a function of increasing

workload demands (i.e., those of moderate and high ambience). Once more, the simple effects specific to the Old-High Performance group help to shed additional light on our understanding regarding age-related changes in ambient system ability. The finding that this high performing group showed significant declines in PDT hit rates during the greatest workload conditions for less-than-optimal ambient stimuli (i.e., low and moderate ambience), but not for those considered the most likely to trigger ambient processing suggests a potential age-related change in visual system sensitivity for targets of varying temporal signature. Such findings may indicate a weakening of ambient system sensitivity at variable rates for different aging individuals.

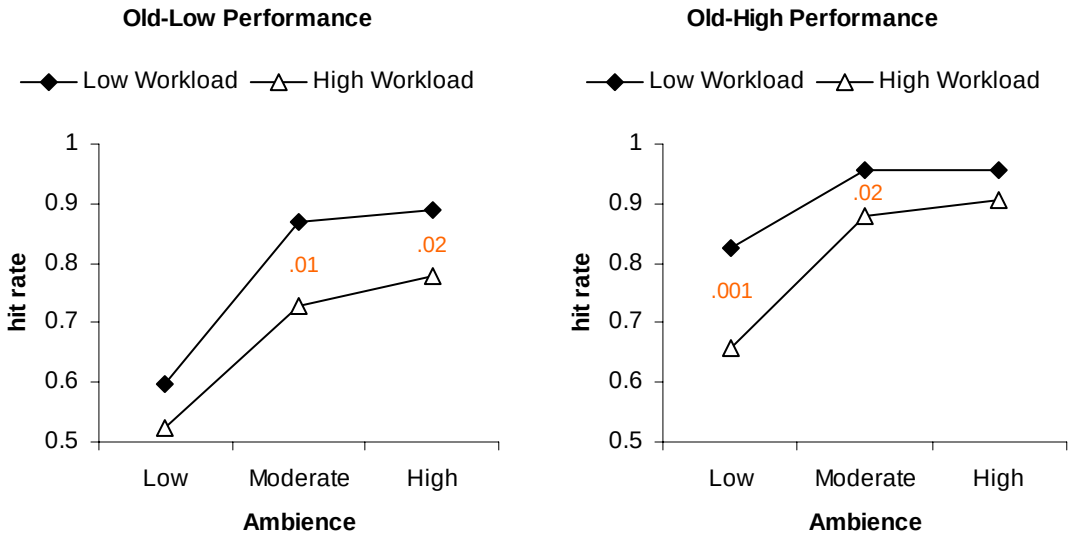


Figure 32. 3-way Old-Low vs. Old-High by Workload by Ambience interaction using median split older age group (sig. simple effects *p*-values presented in orange)

At this point it was also necessary to determine whether any age differences might also exist between the Old-High Performance group and the Young group. A 2 (Young vs. Old-High) by 2 (Workload) by 2 (Positional Uncertainty) by 3 (Ambience) split-plot ANOVA was performed once again using PDT hit rate as the dependent variable. Two

significant interactions were observed after controlling for Type I error rate (α=.01): a 2-way Workload by Ambience interaction [$F(2,46)=10.352$, $MSE=.007$, $p<.001$, $\eta^2=.02$, $power=0.982$] and a 2-way Positional Uncertainty by Ambience interaction [$F(2,46)=28.063$, $MSE=.007$, $p<.001$, $\eta^2=.05$, $power > 0.999$]. No age specific interactions were identified between the Old-High Performance and Young groups. The main effect of Young vs. Old-High also failed to produce significance (p=.280). Similar to prior analyses, significant main effects were revealed for Workload [$F(1,23)=31.562$, $MSE=.011$, $p<.001$, $\eta^2=.04$, $power > 0.999$], Positional Uncertainty [$F(1,23)=55.290$, $MSE=.018$, $p<.001$, $\eta^2=.12$, $power > 0.999$], and Target Ambience [$F(1.305,30.009_{Greenhouse\text{-}Geisser\ Adj.}) = 56.918$, $MSE=.027$, $p<.001$, $\eta^2=.25$, $power > 0.999$].

For the sake of being thorough, a median-split analysis was also performed for the younger group of subjects. After determining that the median hit rate = 0.91, those younger subjects with an average hit rate greater than 0.91 were assigned to the Young-High Performance group (N=8), while those subjects with an average hit rate less than 0.91 were assigned to the Young-Low Performance group (N=8). A 2 (Young-Low vs. Young-High) by 2 (Workload) by 2 (Positional Uncertainty) by 3 (Ambience) split-plot ANOVA was performed using PDT target hit rate as the dependent variable. After adjusting α=.015, only the main effect of Young-High vs. Young-Low was determined to be significant [F(1,14)=18.6, MSE=.031, p<.001], however this difference was not systematically related to any other variables of interest.

PDT Reaction Time

In addition to hit rate data, PDT reaction time data was also recorded. Knowing that the hit rates of the two older age groups differed significantly, it might also prove beneficial to determine whether or not these groups also differed with respect to reaction time. However, due to the fact that each of the three levels of target ambience have rather unique temporal signatures which restrict any direct comparisons of reaction time, it was necessary to look at each of the target ambience levels independently. It should be noted that a single subject from both the original Young and Old groups had a single piece of missing reaction time data for low ambience targets in the high positional uncertainty/high workload condition. These missing cells were filled using each subject's respective group mean for this single condition. A follow-up analysis was conducted which excluded these two subjects with missing data and identical effects were identified. All effects reported in the following paragraphs include data from all subjects.

Table 4. Reaction times (msec) for the three *post hoc* age groups

Age	Workload	Positional Uncertainty	Low Ambience	Std dev.	Moderate Ambience	Std dev.	High Ambience	Std dev.
Old-Low	Low	Low	795.914	140.47	634.398	123.76	587.410	98.80
		High	875.607	138.89	794.570	126.74	752.362	96.48
	High	Low	953.096	104.41	842.022	115.90	791.769	155.90
		High	965.767	180.71	961.750	122.34	917.837	125.13
Old-High	Low	Low	661.040	84.80	450.722	61.18	467.807	61.54
		High	784.546	96.17	676.456	69.46	631.744	89.92
	High	Low	793.483	114.81	609.647	83.28	566.927	71.73
		High	839.494	89.73	791.201	130.05	734.979	81.05
Young	Low	Low	635.074	94.21	484.303	117.35	429.903	110.06
		High	780.605	81.71	644.358	135.71	554.965	116.94
	High	Low	741.232	119.26	573.323	125.41	543.425	113.12
		High	832.575	119.15	735.423	142.41	644.902	128.27

After setting α=.01 to control for Type I error rates, using the *post hoc* performance based older age groups a 2 (Old-Low vs. Old-High) by 2 (Workload) by 2 (Positional Uncertainty) split-plot ANOVA was performed at each of the three target ambience levels. Reaction times are listed in Table 4 above. For the lowest ambience targets, significant main effects were identified for Workload [$F(1,16)=16.594$, $MSE=12812.768$, $p<.001$, $power=0.968$], Positional Uncertainty [$F(1,16)=10.659$, $MSE=7238.298$, $p<.005$, $power=0.865$], and Old-Low vs. Old-High [$F(1,16)=11.212$, $MSE=26284.69$, $p<.004$, $power=0.881$], while no significant interactions were found between the Old-High Performance and Old-Low Performance groups. For targets of moderate ambience, main effects were identified for Workload [$F(1,16)=57.245$, $MSE=8264.258$, $p<.001$, $power>0.999$], Positional Uncertainty [$F(1,16)=73.416$, $MSE=7236.294$, $p<.001$, $power>0.999$], and Old-Low vs. Old-High [$F(1,16)=29.801$, $MSE=18747.531$, $p<.001$, $power=0.999$], while no interactions reached significance. For the highest ambience targets, significant main effects were identified for Workload [$F(1,16)=32.462$, $MSE=11346.339$, $p<.001$, $power>0.999$], Positional Uncertainty [$F(1,16)=57.547$, $MSE=7587.798$, $p<.000$, $power>0.999$], and Old-Low vs. Old-High [$F(1,16)=29.583$, $MSE=15964.374$, $p<.001$, $power=0.999$], but once again no interactions approached significance. Overall these results suggest that the Old-Low Performance group had significantly slower reaction times than did their Old-High Performance counterparts, but these differences remained relatively constant across all other variables of interest.

A similar analysis was performed to determine if the Old-High Performance group differed from the original Young group of subjects. After controlling for Type I

error rates (α=.01), a 2 (Young vs. Old-High) by 2 (Workload) by 2 (Positional Uncertainty) split-plot ANOVA was once again performed at each of the three target ambience levels. Reaction times are listed in Table 4. For the lowest ambience targets, significant main effects of Workload [$F(1,23)=31.185$, $MSE=5512.644$, $p<.001$, $power>0.999$] and Positional Uncertainty were identified [$F(1,23)=77.382$, $MSE=3073.334$, $p<.001$, $power>0.999$], however none of the interactions nor the main effect of Young vs. Old-High achieved significance. For targets of moderate ambience, significant main effects of Workload [$F(1,23)=40.339$, $MSE=7349.790$, $p<.001$, $power>0.999$] and Positional Uncertainty were identified [$F(1,23)=86.873$, $MSE=8819.798$, $p<.001$, $power>0.999$], but once again none of the interactions and the main effect of Young vs. Old-High were not significant. Likewise for targets of high ambience, significant main effects of Workload [$F(1,23)=67.686$, $MSE=3503.6$, $p<.001$, $power>0.999$] and Positional Uncertainty were revealed [$F(1,23)=111.955$, $MSE=4012.468$, $p<.001$, $power>0.999$], but none of the interactions nor the main effect of Young vs. Old-High approached significance. These results suggest that the Old-High Performance group had reaction times equal to those of the Young group.

Discussion

General PDT Findings

One goal of the current study was to gain a better understanding as to the true nature of the PDTs diagnosticity by systematically manipulating its different components. Finding that hit rate performance declined significantly as a function of increasing simulation workload demands and increasing positional uncertainty of target location

supports the initial claim that PDT findings to date are truly diagnostic to top-down focal vision scanning strategies. The focal processing demands associated with fixating upcoming signs for lane changing instructions, carrying out such instructions via manual steering inputs, continuously updating and maintaining lane position, and monitoring the speedometer for speed maintenance purposes were such that a subjects' ability to concurrently inspect peripheral regions for brief flashes of light was impaired. We know this because drivers exhibited lower peripheral target detection rates for the least ambient targets as the focal processing demands of central vision increased during the continuously involved lane changing task. Also in line with *a priori* expectations, disrupting this top-down focal strategy by limiting the extent to which an upcoming target's location could be predicted also significantly reduced PDT hit rates. The introduction of high positional uncertainty with respect to potential target location, coupled with brief stimulus presentation durations (1 sec) restricted the number of spatial locations a subject could inspect using focal, top-down strategies in a given period of time.

In general these results are consistent with PDT literature to date which typically reports the greatest task sensitivity during the most demanding of workload situations. It is quite common to see the PDT paradigm implemented in both high-fidelity driving simulation studies as well as real world field studies. It should be noted that the current PDT paradigm proved sensitive to changes in workload demands and target location using a very simplistic driving simulator. There were no other vehicles, no oncoming traffic, no complex intersections, no traffic lights or construction zones. Subjects were not required to perform other potentially distracting in-vehicle tasks such as answer a cell

phone, change a CD, or adjust climate controls. The fact that the current PDT study proved sensitive using a highly simplistic simulator only adds to the list of experimental advantages commonly attributed to the PDT paradigm.

The current study also set out to establish whether or not the targets used in previous PDT studies were insufficient in their ability to trigger automatic, preemptive ambient processing used in peripheral vision. Knowing that the ambient system is tuned to detect certain stimulus qualities better than others (i.e., abrupt onset, luminance flicker), the current study developed a model of ambient system sensitivity to implement a variety of targets that differed in their ability to effectively trigger preemptive processing by ambient vision. The results of this manipulation support the notion that targets used in previous PDT studies were indeed too weak to adequately stimulate automatic processing in the visual periphery. During both workload conditions but even more pronounced when workload demands were highest, PDT hit rates were significantly lower for the least ambient of targets whose characteristics were designed to replicate those used in past PDT research. In addition, those targets that were better equipped theoretically to satisfy the requirements for ambient system processing (i.e., moderate and high ambience targets) had substantially higher PDT hit rates compared to low ambience targets. Similar findings were revealed with respect to positional uncertainty as well. Finding that changes in both workload demands and target positional uncertainty interacted with the ambience manipulation suggest that for the current study, the PDT was potentially diagnostic to ambient system processing. With respect to the PDT paradigm in general however, a more appropriate interpretation would be that the use of preemptively inefficient stimuli essentially forced drivers to repeatedly sample the area of

PDT stimuli via direct fixations guided by the focal system. Such an interpretation suggests that the PDT to date is perhaps more diagnostic to top-down scanning strategy efficiency as opposed to a "shrinking field of view" which is commonly reported in the PDT literature (Martens & van Winsum, 2000; Olsson & Burns, 2000). For validation purposes, future PDT research should consider using eye tracking technology or video-based gaze analysis (Schieber, Harms, Berkhout & Spangler, 1997) to objectively confirm whether or not subjects were periodically scanning peripheral target areas using direct fixations guided by the focal system, or were relying on ambient mechanisms to detect peripheral targets while concurrently limiting scanning behavior to the primary task of driving.

The decline in PDT hit rates for the least ambient of targets across the different experimental manipulations suggests it was very difficult to detect such targets without the use of direct fixations guided by focal vision. Future studies which desire a target that is detected via central vision might find it particularly beneficial to use a Gaussian pulse stimulus such as that used for the least ambient of targets in the current study. These targets have a slow developing temporal signature that lacks the necessary transient characteristics which trigger preemptive processing in peripheral vision. For future studies interested specifically in top-down scanning behavior, the use of similar Gaussian pulse stimuli over longer time epochs (e.g., 2 seconds, MTF = 0.001 using current model of ambient sensitivity) might prove useful as such stimuli might be even more focally demanding than the one-second epoch used currently. On the flip side of this coin, studies which desire target detection to rely primarily on preemptive mechanisms which reside in peripheral vision might benefit from using stimuli similar to

the 3 Hz or 10 Hz sine waves used to create the more efficient ambient targets in the current study.

Age-specific differences in Ambient/Focal processing

The second goal of the current study was to use the PDT paradigm to examine the role of age with respect to information processing abilities during simulated driving. To date, this experimental paradigm had yet to be explicitly used to investigate any such age differences. Consistent with expectations, significant age effects were identified as a function of simulated driving workload demands and positional uncertainty with respect to target location. While both age groups exhibited significant declines in PDT hit rate performance when comparing low versus high workload conditions, it was only during the highest of workload conditions where older group performance became noticeably less than that of the younger group. Similar results were identified with respect to the positional uncertainty of potential target locations. Both age groups detected fewer targets when positional uncertainty was high compared to when it was low, but significant age differences were only apparent when subjects could not reliably predict on which side an upcoming stimulus might occur. These results suggest that as the information processing demands of both workload and positional uncertainty increased, older subjects were simply not able to concurrently process the demands of the PDT with those of the driving simulator as efficiently as younger subjects.

The additional lack of any age-specific interactions with the ambience manipulation supports previous interpretations suggesting that all subjects, regardless of age, were relying on top-down periodic scanning of the target area using focal vision.

These results do not support the *a priori* claims suggesting an age-related weakening of the ambient visual system referred to as the *ambient insufficiency hypothesis* (Schieber et al., in press). If indeed the ambient system declines in ability as a function of the normal aging process, then PDT performance patterns across target ambience should be unique to each age group. Consistent with the current ambient model of sensitivity for targets of varying temporal signature, PDT hit rate performance improved as the paradigm's characteristics became increasingly more ambient; but contrary to *a priori* predictions these improvements took place at essentially the same rate for both age groups. Despite having lower overall hit rates compared to the younger subjects, the older group was still able to reliably take advantage of the increasingly preemptive targets of moderate and high ambient ability.

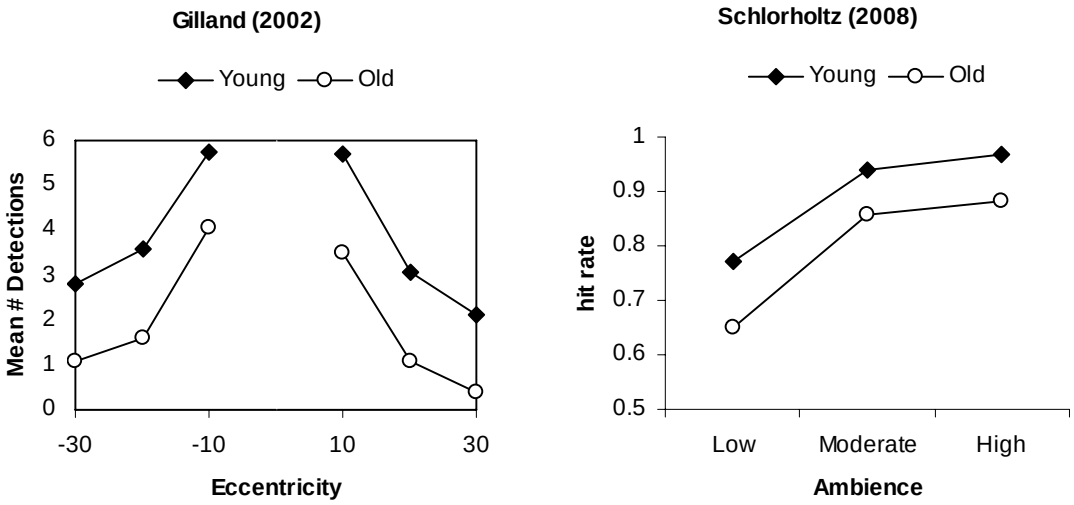


Figure 33. DC-shift in performance commonly observed in Aging & Driving research

The lack of any age-specific interaction with the current target ambience manipulation is consistent with conclusions drawn from previous UFOV studies, performed in both the laboratory and the field, which reported an overall decline in

higher-order information processing efficiency as a result of the normal aging process (Gilland, 2002; Owsley et al., 1991; Ball et al., 1993). Finding significant main effects of subject age and target ambience in the absence of any interactions is quite similar to results from a previous in-house field study (Gilland, 2002). Figure 33 above depicts the results from both Gilland (2002) and the current project to show the DC-shifts in performance which suggest age-related decrements cannot be attributed to perceptual narrowing (as predicted by the *ambient insufficiency hypothesis*). Otherwise older subjects should have performed progressively worse compared to their younger counterparts at increasing eccentricity and decreasing ambience level. In both studies, the trends for each age group were virtually identical. Perhaps this general slowing in ability is not related to changes of the ambient and focal visual systems *per se*, but rather is attributable to the failure of some higher-order cognitive process responsible for integrating information from the two visual streams. Further testing is required to determine if there is any validity to such speculation.

The current primary analysis findings suggest that the *ambient insufficiency hypothesis* proposed by Schieber, Schlorholtz, and McCall (in press) is too simplistic with respect to its predictions regarding age-related changes in ambient visual system sensitivity. Keep in mind however, the application of the ambient/focal dichotomy as a theoretical framework for better understanding the domains of aging and driving is an approach in its relative infancy. The predictions made were very general in nature and were developed using a "worst case scenario" which assumed a catastrophic failure of the senescent person's ambient system. Despite this initial lack of support, additional evidence for the *ambient insufficiency hypothesis* is provided by Owens and Tyrrell

(1999) who report a "progressive degradation" of steering performance as a function of decreasing luminance conditions for older, but not younger individuals. Along similar lines, Woods (2002) reported that the strongest predictors of age-related decrements during closed-course driving performance included tests which rely primarily on ambient system functioning (i.e., tests of global motion sensitivity and the ability to quickly detect/localize targets in the visual periphery). More specifically, the proposed ambient/focal theoretical framework for understanding the visual requirements of driving presented by Schieber and colleagues is dedicated solely to measures of vehicular guidance. Perhaps the current projects inability to provide support for the *ambient insufficiency hypothesis* was the product of using an approach that lacks sufficient between systems diagnosticity. It might very well be the case that the PDT, as implemented within the traditional secondary task paradigm, lacks the necessary components to sufficiently diagnose age-related changes of the ambient visual stream. However, *post hoc* analyses discussed in the following section suggest that abandoning the current PDT paradigm altogether may be premature.

Performance-based age differences in Ambient/Focal processing

Figure 34 below graphically depicts the relationship between the three *post hoc* subject age groups, workload, and target ambience. The lack of any age specific interactions between the Young and Old-High Performance groups supports the notion that examinations of age differences solely based on chronological age are insufficient when attempting to understand the true nature of any disparities in ambient system ability. While the Young and Old-High Performance groups were statistically

indistinguishable during varying conditions of simulated driving workload, significant decrements in PDT hit rate performance for the Old-Low Performance group were apparent for targets theoretically designed to maximally stimulate ambient system processing. It was only after the older subjects were assigned to specific PDT performance based groups that results were revealed which might help to shed light on possible age-related changes in ambient system sensitivity.

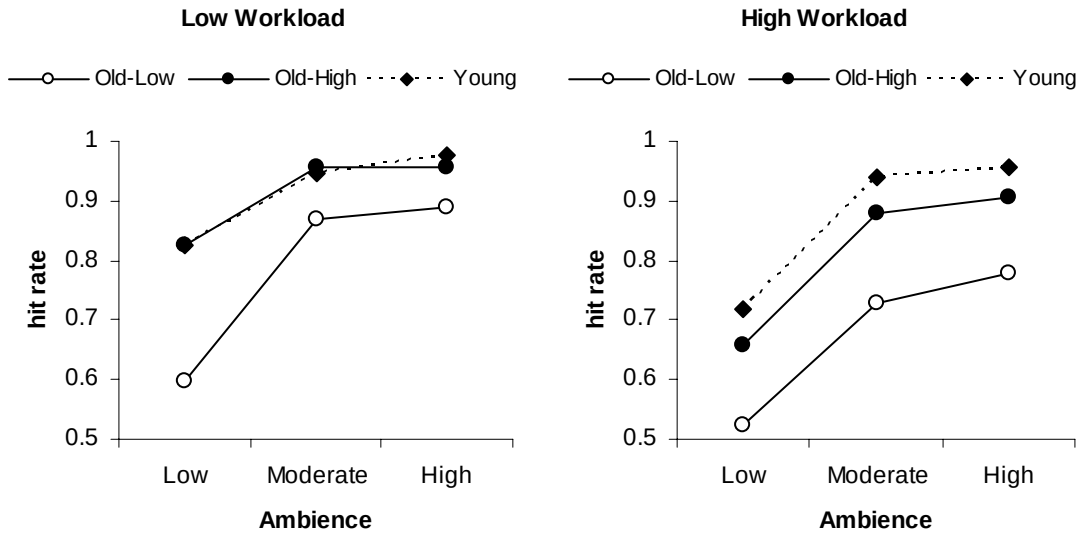


Figure 34. PDT hit rates for the 3 *post hoc* age groups

Under the simplest of workload conditions, the Old-Low Performance group had PDT hit rates significantly less than that of the Old-High Performance group for the least ambient PDT targets. This initial difference in target detection performance, which was apparent even when the simulated driving task involved nothing more than maintaining vehicular position in the center lane of a straightaway while maintaining 50mph, suggests that some older individuals were simply not able to scan peripheral areas for targets as efficiently as other cohorts. Such a finding is consistent with the explanation that PDT

results to date are indicative of top-down focal scanning strategy efficiency. However, as central task workload demands were increased and required subjects to continuously change lanes while also maintaining 50mph, PDT hit rates for the Old-Low Performance group declined remarkably for targets with a much greater likelihood of triggering preemptive, ambient system processing; while hit rates of the Old-High Performance group remained indistinguishable from those of the Young group. This suggests that a select group of senescent individuals in the current sample were no longer able to reliably capitalize on targets specifically designed to trigger preemptive, ambient processing. Such findings indicate a change in ambient system sensitivity for some, but perhaps not all aging persons.

Post hoc evidence for age-related reductions in ambient system sensitivity was also provided by the analysis of PDT data collected from the High Performance subgroup of older participants. Increasing central task workload was accompanied by a large and statistically significant reduction in PDT detection rates for Gaussian (low ambient) stimuli. The size of this effect was reduced – but not statistically eliminated – for the moderate ambient (3 Hz) stimulus. Yet, the deleterious effects of increased central task workload were eliminated given the same moderate ambient stimulus modulation for the young participants in this study ($F(1,15)=0.2$, $p < 0.66$). The High Performance subgroup of older participants required the greatest level of ambient stimulus modulation (10 Hz) in order to statistically eliminate PDT decrements due to increased central task workload (see Figure 32, p.122). This pattern of evidence, although not compelling, suggests that the development of more sensitive laboratory procedures may hold the

potential for generating evidence to support the *ambient insufficiency hypothesis* of visual aging.

Contrary to results from the primary analysis where group designation relied solely on chronological subject age, those of the *post hoc* performance based age groups provide support for the *ambient insufficiency hypothesis*. When senescent individuals are compared based on some performance metric, in this instance PDT hit rate, the age-specific DC-shift identified commonly in aging and driving research becomes less absolute. Indeed, differences between the Young and Old-High Performance groups adhere to a similar shift in behavior, but the change in trend specific to older subjects with poorer overall hit rates introduces the opportunity for alternative explanations beyond those which typically attribute normal age-related performance reductions purely to the slowing of information processing efficiency. It is premature to speculate that the current study's observed changes in ambient system ability identified for a select group of older individuals contribute to the aging drivers' overrepresentation in crashes which occur during cross-traffic maneuvers. However the observed change in the likelihood of peripheral target detection for some, but not all senescent drivers suggests that varying the temporal components of targets using the PDT paradigm is a useful approach for understanding age-related changes in ambient system ability.

Given the consistent nature of detection patterns for each of the three ambient targets used, it appears that the ambient system has some detection threshold necessary for triggering immediate, preemptive processing. As used in the current PDT paradigm, ambient system sensitivity was initially hypothesized as being more continuous in nature. For example, *a priori* predictions expected high ambience targets to have the highest hit

rates, moderate ambience targets to have significantly lower hit rates, while low ambience targets were expected to have the lowest overall hit rates. These predictions were based on the percentage of residual target energy after being filtered by the current continuous model of ambient system sensitivity (see Table 3 in the Methods section, p. 102). Contrary to these predictions, targets of both moderate and high ambient ability typically had far superior detection rates which were very similar in nature, while those of low ambience were always detected at substantially lesser rates. Such consistent patterns indicate that once a stimulus's transient characteristics crossed a certain threshold of ambient sensitivity (most likely somewhere between the low and moderate ambience targets), target detection was just as likely for any and all targets above this threshold. This finding suggests that future studies which intend to use the current PDT paradigm might benefit from determining each subject's detection threshold prior to experimental testing, and then running each subject at some level just beyond this value (e.g., 0.1 log units above threshold). Such a psychophysical approach would ensure that subjects of all ages were initially just as likely to detect peripheral targets, and any additional changes in hit rate as a function of varying environmental demands would afford potentially interesting observations regarding age-related information processing ability.

Some mention should also be given to the results of the PDT reaction time data. When referring to the ambient system, it is assumed that certain types of stimuli are capable of automatically triggering processing via bottom-up attentional mechanisms. In essence, such stimuli "preempt" any other concurrent information processing demands. Such preemption is thought of as being absolute. However, qualitative inspection of the

current reaction time data (see Table 4) calls into question the absolute nature of this preemptive ability. If preemptive processing by the ambient visual stream is absolute, and thus capable of overriding all other immediate situational demands; why is it that response times for optimally ambient targets get progressively slower as conditions change from low to high workload or low to high positional uncertainty? Isn't preemption, preemption? The reliable slowing of response times as a function of increasing situational demands suggests that the true nature of this preemptive ability might not be as absolute as once thought. Perhaps there are different degrees of preemptive ability which change in response to the immediate environment that should be considered in future studies.

There also exists the possibility that the ambient visual stream's preemptive ability remains uninhibited as a function of changing environmental demands or increasing subject age, and that the true source of interference resides at a failing higher-order level of cognition. Such an interpretation is consistent with what has been coined the *central-bottleneck hypothesis* (Welford, 1952, Pashler & Johnston, 1998). According to Levy, Pashler, and Boer (2006) this hypothesis states the following:

> . . . certain central mental operations cannot be performed in parallel. These operations are termed "central" because, at least in many laboratory tasks, they occur after ("early") perceptual processing but before ("late") response production. . . . The clearest experimental evidence for this processing bottleneck is found in experiments in which people are instructed to perform two speeded tasks requiring them to respond to two stimuli presented in close temporal proximity, separated by a stimulus onset asynchrony (SOA) that varies from very brief to very long (e.g., 50-800ms). The CB model entails that when central processing is under way for one task, central processing for the other task must be postponed. The model predicts that if subjects carry out tasks in the same order as the stimuli are presented, then as the SOA decreases, the reaction time to the second task should increase. This slowing has become known as the psychological refractory period (PRP) effect (p. 228).

Evidence for the psychological refractory period effect is typically limited to highly controlled laboratory settings which typically use simplistic tasks with low external validity. Recently however, Levy and colleagues (2006) reported the existence of such an effect during a driving simulation study. In this experiment, the psychological refractory period was observed for the highly practiced "simple" task of vehicle braking. This suggests that even automatized tasks are capable of suffering from the effects of serial processing constraints which result from a central processing bottleneck.

In terms of ambient/focal processing, the *central bottleneck hypothesis* would suggest that while a subject was involved in some focal processing task, such as inspecting roadway signs for lane changing instructions, peripheral targets detected via the ambient system had to wait to be serviced until initial focal processing had successfully passed through the bottleneck. The closer these events occurred in time (i.e., the shorter the SOA), the longer the response times to peripheral targets. As the focal processing demands of the current paradigm continued to increase as a function of either workload or target location demands, central processing of ambient information appears to have been postponed to an even greater degree. Given the increasing reaction times observed for the current sample of older individuals, such an interpretation suggests an age-related narrowing of the central processing bottleneck. In this instance, a narrower bottleneck would reflect additional slowing of focal processing, thus further delaying the servicing of any ambient information for aging persons. Such an interpretation is purely speculative at this point, but considering the recent observations reported by Levy and colleagues (2006) as well as those of the current study, it would appear that future age-

specific studies might benefit substantially from implementing and extending similar hypotheses and paradigms.

References

Abrams, R.A. & Christ, S.E. (2003). Motion onset captures attention. *Psychological Science, 14(5),* 427-432.

Ahmed, B. & Smith, S. (1992). How changes in components of growth affect the population aging of states. *Journal of Gerontology: Social Sciences, 47*(1), S27-37.

Azzopardi, P. & Cowey, A. (1993). Preferential representation of the fovea in the primary visual cortex. *Nature, 361,* 719-721.

Baldwin, C.L. & Schieber, F. (1995). Dual task assessment of age differences in mental workload with implications for driving. *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting,* 167-171.

Ball, K. & Owsley, C. (1991). Identifying correlates of accident involvement for the older driver. *Human Factors, 33*(5), 583-595.

Ball, K., Owsley, C. & Beard, B. (1990). Clinical visual perimetry underestimates peripheral field problems in older adults. *Clinical Vision Science, 5(2),* 113-125.

Ball, K., Owsley, C., Sloane, M.E., Roenker, D.L. & Bruni, J.R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Investigative Ophthalmology & Visual Science, 34(11),* 3110-3123.

Ball, K.K., Roenker, D.L. & Bruni, J.R. (1990). Developmental changes in attention and visual search throughout adulthood. In J.T. Enns (Ed.), *The Development of Attention: Research and Theory* (pp. 489-508). North-Holland: Elsevier Science Publishers.

Barr, R. A. (1991). Recent changes in driving among older adults. *Human Factors 33*(5), 597-600.

Bell, B. (1972). Retinal field shrinkage, age, pulmonary function, and biochemistry. *Aging & Human Development, 3,* 103-109.

Bergman, B. & Sjostrand, J. (2002). A longitudinal study of visual acuity and visual rehabilitation needs in an urban Swedish population followed from the ages of 70 to 97 years of age. *Acta Ophthalmologica Scandinavica, 80(6),* 598-607.

Birren, J.E., Casperson, R.C. & Botwinick, J. (1950). Age changes in pupil size. *Journal of Gerontology, 5,* 267-271.

Brooks, J.O., Tyrrell, R.A. & Frank, T.A. (2005). The effects of severe visual challenges on steering performance in visual healthy young drivers. *Optometry and Vision Science, 82(8),* 689-697.

Brouwer, W.H., Waterink, W., van Wolffelaar, P.C. & Rothengatter, T. (1991). Divided attention in experienced young and older drivers: lane tracking and visual analysis in a dynamic driving simulator. *Human Factors, 33(5),* 573-582.

Brozek, J. & Keys, A. (1945). Changes in flicker-fusion frequency with age. *Journal of Consulting Psychology, 9,* 87-90.

Bullier, J. & Nowak, L.G. (1995). Parallel versus serial processing: New vistas on the distributed organization of the visual system. *Current Opinion in Neurobiology, 5,* 497-503.

Burg, A. (1964). An investigation of some relationships between dynamic visual acuity, static visual acuity, and driving record (Report 64-18). Los Angeles: University of California, Los Angeles, Department of Engineering.

Burg, A. (1966). Visual acuity as measured by dynamic and static tests: a comparative evaluation. *Journal of Applied Psychology, 50(6),* 460-466.

Burg, A. (1967). The relationship between vision test scores and driving record: general findings. Report 67-24, Department of Engineering, University of California, Los Angeles.

Carey, D.P., Harvey, M. & Milner, A.D. (1996). Visuomotor sensitivity for shape and orientation in a patient with visual form agnosia. *Neuropsychologia, 34(5),* 329-337.

Carlson, N.R. (2004). Structure of the nervous system. In *Physiology of Behavior 8th Edition* (pp. 66-99). Boston, MA: Allyn & Bacon.

Carr, D., Jackson, T. W., Madden, D. J., & Cohen, H. J. (1992). The effect of age on driving skills. *Journal of the American Geriatric Society, 40*(6), 567-573.

Cerrelli, E. (1989). Older drivers: the age factor in traffic safety (DOT-HS-807 402). Washington, DC: National Highway Safety Administration.

Cerrelli, E. (1997). *Fatal crash involvements-what are the odds?* Research Note. National Center for Statistics and Analysis. National Highway Traffic Safety Administration. Washington, DC. www-nrd.nhtsa.dot.gov/pdf/nrd-30/ncsa/RNotes/1997/fatalodd.pdf.

Coeckelbergh, T.R.M., Cornelissen, F.W., Brouwer, W.H. & Kooijman, A.C. (2002). The effect of visual field defects on eye movements and practical fitness to drive. *Vision Research, 42,* 669-677.

Cohen, J. (1988). The Analysis of Variance. In: *Statistical Power Analysis for the Behavioral Sciences, Second Edition* (pp. 273-406). Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Crook, T.H., West, R.L. & Larabee, G.J. (1993). The driving-reaction time test: assessing age declines in dual-task performance. *Developmental Neuropsychology, 9(1),* 31-39.

Crundal, D., Underwood, G. & Chapman, P. (1999). Driving experience and the functional field of view. *Perception, 28,* 1075-1087.

Decina, L.E. & Staplin, L. (1993). Retrospective evaluation of alternative vision screening criteria for older and younger drivers. *Accident Analysis & Prevention, 25(3),* 267-275.

deWaard, D. (1996). *The measurement of drivers' mental workload*. PhD thesis, University of Groningen. Haren, The Netherlands: University of Groningen, Traffic Research Centre.

Dirkin, G.R. & Hancock, P.A. (1985). An attentional view of narrowing: The effect of noise and signal bias on discrimination in the peripheral visual field. In I.D. Brown, R. Goldsmith, K. Coombes & M.A. Sinclair (Eds.) *Proceedings of the Ninth Congress of the International Ergonomics Association,* London: Taylor and Francis.

Donges, E. (1978). A two-level model of driver steering behavior. *Human Factors, 20(6),* 691-707.

Elliott, D.B. (1987). Contrast sensitivity decline with aging: A neural or optical phenomenon? *Ophthalmic and Physiological Optics, 7,* 415-419.

Elliott, D.B. & Whitaker, D. (1992). Clinical contrast sensitivity chart evaluation. *Ophthalmic and Physiological Optics, 12,* 275-280.

Engstrom, J., Aberg, N., Johansson, E., & Hammarback, J. (2005). Comparison between visual and tactile signal detection tasks applied to the safety assessment of in-vehicle information systems. *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*. Retrieved from http://ppc.uiowa.edu/driving-assessment/2005/final/papers/34_Engstr%C3%B6m%C3%85bergformat.pdf

Enns, J.T., Austen, E.L., Di Lollo, V., Rauschenberger, R. & Yantis, S. (2001). New objects dominate luminance transients in setting attentional priority. *Journal of Experimental Psychology: Human Perception and Performance, 27(6),* 1287-1302.

Evans, L. (1988). Older driver involvement in fatal and severe traffic crashes. *Journal of Gerontology: SOCIAL SCIENCES, 43(6),* S186-193.

Evans, D.W. & Ginsburg, A.P. (1985). Contrast sensitivity predicts age differences in highway sign discriminability. *Human Factors, 27,* 637-642.

Faul, F., Erdfelder, E., Lang, A.G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39,* 175-191.

Findlay, J.M. & Gilchrist, I.D. (2003). *Active Vision: The psychology of looking.* New York: Oxford University Press.

Franconeri, S.L., Hollingworth, A. & Simons, D.J. (2005). Do new objects capture attention? *Psychological Science, 16(4),* 275-281.

Franconeri, S.L. & Simons, D.J. (2003). Moving and looming stimuli capture attention. *Perception & Psychophysics, 65(7),* 999-1010.

Gebers, M. A. & Peck, R. C. (1992). The identification of high-risk older drivers through age-mediated point systems. *Journal of Safety Research, 23,* 81-93.

Gilland, J. (2002). Evaluation of driver useful field of view (UFOV): Effects of age and eccentricity. Unpublished Master's Thesis. The University of South Dakota.

Ginsburg, A.P. (1978). Visual information processing based on spatial filters constrained by biological data. *AMRL-TR-78-129*. Springfield, VA: National Technical Information Service.

Goodale, M.A. & Milner, A.D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15(1),* 20-25.

Haegerstrom-Portnoy, G., Schneck, M.E. & Brabyn, J.A. (1999). Seeing into old age: Vision Function beyond acuity. *Optometry and Vision Science, 76(3),* 141-158.

Hakamies-Blomqvist, L. (1993). Fatal accidents of older drivers. *Accident Analysis & Prevention, 25(1), 19-27.*

Hakamies-Blomqvist, L. (1994a). Compensation in older drivers as reflected in their fatal accidents. *Accident Analysis & Prevention, 26*(1), 107-112.

Hakamies-Blomqvist, L. (1994b). Aging and fatal accidents in male and female drivers. *Journal of Gerontology, 49*(6), S286-S290.

Hakamies-Blomqvist, L. (1994c). Accident characteristics of older drivers: can findings based on fatal accidents be generalized? *Journal of Traffic Medicine, 22*(1). 19-25.

Harms, L. & Patten, C. (2003). Peripheral detection as a measure of driver distraction. A study of memory-based versus system-based navigation in a built-up area. *Transportation Research Part F, 6,* 23-36.

Held, R. (1970). Two modes of processing spatially distributed visual stimulation. In: F.O. Schmitt (Ed.), *The Neurosciences* (pp. 317-323). New York: Rockefeller University Press.

Held, R., Ingle, D., Schneider, G. & Trevarthen, C. (1967). Locating and Identifying: Two modes of visual processing. *Psychologische Forschung, 31,* 42-43.

Henderson, R.L. & Burg, A. (1974). "Vision and audition in driving" report TM (L)-5297/000/000, System Development Corporation, Santa Monica, CA.

Higgins, K.E., Wood, J. & Tait, A. (1998). Vision and driving: selective effect of optical blur on different driving tasks. *Human Factors, 41(2),* 224-232.

Hills, B.L. (1980). Vision, visibility, and perception in driving. *Perception, 9,* 183-216.

Hills, B.L. & Burg, A. (1977). A reanalysis of California driver vision data: general findings. Report LR768, Department of the Environment/Department of Transport, TRRL, Crowthorne, Berks.

Huntington, J.M. & Simonson, E. (1965). Critical flicker fusion frequency as a function of exposure time in two different age groups. *Journal of Gerontology, 20,* 527-529.

Jahn, G., Oehme, A., Krems, J.F. & Gelau, C. (2005). Peripheral detection as a workload measure in driving: Effects of traffic complexity and route guidance system use in a driving study. *Transportation Research Part F, 8,* 255-275.

Jette, A. M. & Branch, L. G. (1992). A ten-year follow-up of driving patterns among the community dwelling elderly. *Human Factors, 34*(1), 25-32.

Johnson, C.A. & Keltner, J.L. (1983). Incidence of visual field loss in 20,000 eyes and its relationship to driving performance. *Archives of Ophthalmology, 101*, 371-375.

Kahneman, D. (1973). *Attention and Effort.* Englewood Cliffs, NJ: Prentice-Hall Inc.

Kim, C.B.Y. & Mayer, M.J. (1994). Flicker sensitivity in healthy aging eyes. II. Cross sectional aging trends from 18 through 77 years of age. *Journal of the Optical Society of America A, 11*, 1958-1969.

Kline, D.W., Kline, T.J.B., Fozard, J.L., Kosnick, W., Schieber, F. & Sekuler, R. (1992). Vision, aging, and driving: The problems of older drivers. *Journal of Gerontology: PSYCHOLOGICAL SCIENCES, 47(1),* P27-34.

Kline, D.W. & Schieber, F. (1981). Visual aging: A transient/sustained shift? *Perception & Psychophysics, 29(2),* 181-182.

Kline, D.W., Scialfa, C.T., Lyman, B.J. & Schieber, F. (1990). Age differences in the temporal continuity of gratings as a function of their spatial frequency. *Experimental Aging Research, 16(2),* 61-65.

Kolb, H., Fernandez, E. & Nelson, R. (2007). Visual Acuity. *Webvision: The Organization of the Retina and Visual System* (Part IX Section 2). Retrieved May 24th, 2007, from http://webvision.med.utah.edu/KallSpatial.html .

Korteling, J.E. (1991). Effects of skill integration and perceptual competition on age-related differences in dual-task performance. *Human Factors, 33(1),* 35-44.

Korteling, J.E. (1994). Effects of aging, skill modification, and demand alternation on multiple task performance. *Human Factors, 36(1),* 27-43.

Kosnik, W., Sekuler, R., & Kline, D. (1990). Self-reported visual problems of older drivers. *Human Factors, 32*, 597-608.

Kuwabara, T. (1979). Age-related changes in the eye. In S.S. Hain & D.H. Coons (Eds.), *Special Senses in Aging* (pp. 46-78). Ann Arbor, MI: Institute of Gerontology, University of Michigan.

Leibowitz, H.W. & Owens, D.A. (1977). Nighttime driving accidents and selective visual degradation. *Science, 197*, 422-423.

Leibowitz, H.W. & Post, R.B. (1982). The two modes of processing concept and some implications. In: J. Beck (Ed.), *Organization and representation in perception* (pp. 343-363). Hillsdale, NJ: Erlbaum Associates.

Leibowitz, H.W., Wilcox, S.B. & Post, R.B. (1978). The effect of refractive error on size constancy and shape constancy. *Perception, 7(5)*, 557-562.

Levi, D.M., Klein, S.A. & Aitsebaomo, A.P. (1985). Vernier acuity, crowding, and cortical magnification. *Perceptual and Motor Skills, 91*, 546-552.

Levy, J., Pashler, H. & Boer, E. (2006). Central interference in driving: is there any stopping the psychological refractory period? *Psychological Science, 17(3)*, 228-235.

Limrick, K. (2007). Eye movement signatures of ambient vs. focal visual processing while viewing dynamic simulated driving scenarios. Unpublished Masters Thesis, The University of South Dakota.

Livingstone, M. & Hubel, D. (1988). Segregation of form, color, movement, and depth: anatomy, physiology, and perception. *Science, 240*, 740-749.

Logothetis, N.K. (1994). Physiological studies of motion inputs. In: A.T. Smith & R.J. Snowden (Eds.), *Visual Detection of Motion* (pp. 177-216). San Diego, CA: Academic Press Ltd.

Madden, J. (1990). Adult differences in the time course of visual attention. *Journal of Gerontology: PSYCHOLOGICAL SCIENCES, 45*, P9-16.

Maffei, L. (1978). Spatial frequency channels: Neural mechanisms. In R. Held, H.W. Leibowitz, & H. Teuber (Eds.), *Perception* (pp. 39-66). Berlin, Springer-Verlag.

Mandler, M.B. & Makous, W. (1984). A three channel model of temporal frequency perception. *Vision Research, 24(12),* 1881-1887.

Martens, M.H. & van Winsum, W. (2000). Measuring distraction: the peripheral detection task. *Driver Distraction Internet Forum.* Soesterberg, Netherlands: TNO Human Factors. Retrieved from www-nrd.nhtsa.gov/departments/nrd-13/driver-distraction/PDF/34.PDF

Massie, D. L., Campbell, K. L., & Williams, A. F. (1995). Traffic accident involvement rates by driver age and gender. *Accident Analysis & Prevention, 27*(1), 73-87.

Mattes, S. (2003). The lane-change-task as a tool for driver distraction evaluation. *Annual Spring Conference of the GfA/17th Annual Conference of the International-Society-for-Occupational-Ergonomics-and-Safety (ISOES).* QUALITY OF WORK AND PRODUCTS IN ENTERPRISES OF THE FUTURE, 57-60.

Mayer, M.J., Kim, C.B.Y., Svingos, A. & Glucs, A. (1988). Foveal flicker sensitivity in healthy aging eyes. I. Compensating fir pupil variation. *Journal of the Optical Society of America A, 5(12),* 2201-2209.

McDowd, J.M. & Shaw, R.J. (2000). Attention and aging: a functional perspective. In F.I.M. Craik & T.A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp. 221-292). Mahwah, N.J., Lawrence Erlbaum Associates.

McFarland, R.A., Warren, B. & Karris, C. (1958). Alterations in critical flicker frequency as a function of age and light:dark ratio. *Journal of Experimental Psychology, 56,* 529-538.

McGwin, G. J. & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accident Analysis & Prevention, 31*, 181-198.

Merigan, W.H. & Maunsell, J.H.R. (1993). How parallel are the primate visual pathways? *Annual Review of Neuroscience, 16*, 369-402.

Milner, A.D. & Goodale, M.A. (1995). *The Visual Brain in Action*. Oxford: Oxford University Press.

Milner, A.D., Paulignan, Y., Dijkerman, H.C., Michel, F. & Jeannerod, M. (1999). A paradoxical improvement of misreaching in optic ataxia: new evidence for two separate neural systems for visual localization. *Proceedings of the Royal Society of London B, 266*, 2225-2229.

Miura, T. (1986). Coping with situational demands: A study of eye movements and peripheral vision performance. In A.G. Gale et al (Eds.) *Vision in Vehicles* (pp. 205-216). North-Holland: Elsevier Science Publishers.

Miura, T. (1990). Active function of eye movement and useful field of view in a realistic setting. In R. Groner, G. d'Ydewalle, & R. Parham (Eds.) *From Eye to Mind: Information Acquisition in Perception, Search and Reading* (pp. 119-127). North-Holland: Elsevier Science Publishers.

NHTSA (2002). Traffic safety facts 2002: older population. Washington, DC: USDOT, NHTSA.

NHTSA (2005). Traffic safety facts 2005: older population. Washington, DC: USDOT, NHTSA.

Nomura, H., Ando, F., Niino, N., Shimokata, H. & Miyake, Y. (2003). Age-related change in contrast sensitivity among Japanese adults. *Japanese Journal of Ophthalmology, 47,* 299-303.

Norman, J. (2002). Two visual systems and two theories of perception: An attempt to reconcile the constructivist and ecological approaches. *Behavioral And Brain Sciences, 25,* 73-144.

O'Donnell, Col. R. D. & Eggemeier, F. T. (1986). Workload assessment methodology. In K.R. Boff, L. Kaufman, & J. P. Thomas, (Eds.), *Handbook of Perception and Human Performance, Vol. II*, New York: John Wiley and Sons.

Olsson, S. & Burns, P.C. (2000). Measuing driver visual distraction with a peripheral detection task. *Driver Distraction Internet Forum.* Soesterberg, Netherlands: TNO Human Factors. Retrieved from www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/PDF/6.PDF

Ostrow, A. C., Shaffron, P., & McPherson, K. (1992). The effects of a joint range-of-motion physical fitness training program on the automobile driving skills of older adults. *The Journal of Safety Research, 23*, 207-219.

Owsley, C. & Sloane, M.E. (1990) Vision and Aging. In F. Boller and J. Grafman (Eds.) *Handbook of Neuropsychology (Vol 4)* Amsterdam: Elsevier (pp.229-249).

Owsley, C., Sekuler, R. & Siemsen, D. (1983). Contrast sensitivity throughout adulthood. *Vision Research, 23,* 689-699.

Owsley, C., Ball, K., Sloane, M.E., Roenker, D.L. & Bruni, J.R. (1991). Visual/cognitive correlates of vehicle accidents in older drivers. *Psychology and Aging, 6(3),* 403-415.

Parsonson, B.S., Isler, R.B. & Hansson, G.J. (1999). Ageing and driver behaviour at rural T-intersections. *New Zealand Journal of Psychology, 28(1),* 51-54.

Pashler, H. & Johnston, J.C. (1998). Attentional limitations in dual-task performance. In H. Pashler (Ed.), *Attention* (pp. 155-189). Hove, England: Psychology Press.

Patla, A.E. & Goodale, M.A. (1996). Obstacle avoidance during locomotion is unaffected in a patient with visual form agnosia. *Neuroreport, 8(1),* 165-168.

Patten, C.J.D., Kircher, A., Ostlund, J., & Nilsson, L. (2004). Using mobile telephones: cognitive workload and attention resource allocation. *Accident Analysis & Prevention, 36,* 341-350.

Patten, C.J.D., Kircher, A., Ostlund, J., Nilsson, L., & Svenson, O. (2006). Driver experience and cognitive workload in different traffic environments. *Accident Analysis & Prevention, 38,* 887-894.

Perenin, M.T. & Vighetto, A. (1988). Optic ataxia: a specific disruption in visuomotor mechanisms. *Brain, 111,* 643-674.

Pitts, D.G. (1982). The effects of aging on selected visual functions: Dark adaptation, visual acuity, stereopsis, and brightness contrast. In: *Aging and Human Visual Function* (pp. 131-159). New York, NY: Alan R. Liss Inc.

Ponds, R.W.H.M., Brouwer, W.H. & van Wolffelaar, P.C. (1988). Age differences in divided attention in a simulated driving task. *Journal of Gerontology: PSYCHOLOGICAL SCIENCES, 43(6),* P151-156.

Rayner, K. & Pollatsek, A. (1992). Eye movements and scene perception. *Canadian Journal of Psychology, 46,* 342-376.

Sample, P.A., Esterson, F.D., Weinreb, R.N. & Boynton, R.M. (1988). The aging lens: *In vivo* assessment of light absorption in 84 human eyes. *Investigative Ophthalmology and Visual Science, 29,* 1306-1311.

Sanders, A.F. (1970). Some aspects of the selective process in the functional visual field. *Ergonomics, 13(1),* 101-117.

Schieber, F. (1991). Aging & the senses. In: J.E. Birren, R.B. Sloan & G. Cohen (Eds.), *Handbook of Mental Health and Aging* (pp. 251-306). New York, NY: Academic Press.

Schieber, F. (2000). What do driving accident patterns reveal about age-related changes in visual information processing? In: K. Warner Schaie & M. Pietrucha. (Eds.), *Mobility and Transportation in the Elderly* (pp. 207-211), New York: Springer.

Schieber, F. (2006). Vision and Aging. In: J.E. Birren & K. Warner Schaie (Eds.), *Handbook of the Psychology of Aging 6th Edition* (pp. 129-161). San Diego, CA: Elsevier Inc.

Schieber, F., Fozard, J.L., Gordon-Salant, S. & Weiffenbach, J.M. (1991). Optimizing sensation and perception in older adults. *International Journal of Industrial Ergonomics, 7,* 133-162.

Schieber, F., Harms, M.L., Berkhout, J. & Spangler, D.S. (1997). Precision and accuracy of video-based measurements of driver's gaze location. Annual Meeting of the Human Factors and Ergonomics Society, Santa Monica, CA: Human Factors and Ergnomics Society. (pp. 929-933).

Schieber, F. & Kline, D.W. (1982). Age and the discrimination of visual successiveness. *Experimental Aging Research, 8(3),* 159-161.

Schieber, F., Kline, D.W., Kline, T.J.B. & Fozard, J.L. (1992). The relationship between contrast sensitivity and the visual problems of older drivers. Warrendale, PA: Society of Automotive Engineers [SAE Technical Paper No. 920613].

Schieber, F., Schlorholtz, B, & McCall, R. (in press). Visual requirements of vehicular guidance. In C. Castro & R. Fuller (Eds.), *Human Factors of Visual and Cognitive Performance in Driving*. Boca Raton, FL: CRC Press.

Schiller, P.H. (1996). On the specificity of neurons and visual areas. *Behavioural Brain Research, 76,* 21-35.

Schlorholtz, B. & Schieber, F. (2006). Assessment of age differences in mental workload while driving using verbal versus visual-spatial subsidiary tasks. *In the Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting.* San Francisco, CA: Human Factors and Ergnomics Society.

Schneider, G.E. (1969). Two visual systems. *Science, 163*(3870), 895-902.

Sekuler, R. & Ball, K. (1986). Visual localization: age and practice. *Journal of the Optical Society of America A, 3(6),* 864-867.

Sekuler, R. & Hutman, L.P. (1980). Spatial vision and aging. I: Contrast sensitivity. *Journal of Gerontology, 35(5),* 692-699.

Shapley, R., Kaplan, E. & Soodak, R. (1981). Spatial summation and contrast sensitivity of X and Y cells in the lateral geniculate nucleus of the macaque. *Nature, 292*, 543-545.

Shinar, D., McDonald, S.T. & Treat, J.R. (1978). The interaction between driver mental work and physical conditions and errors causing traffic accidents: An analytical approach. *Journal of Safety Research, 10(1),* 16-23.

Shinar, D. & Schieber, F. (1991). Visual requirements for safety and mobility of older drivers. *Human Factors, 33(5),* 507-519.

Sloane, M.E., Owsley, C. & Alvarez, S.L. (1988). Aging, senile miosis and spatial contrast sensitivity at low luminance. *Vision Research, 28(11),* 1235-1246.

Silveira, L.C.L. & Perry, V.H. (1991). The topography of magnocellular projecting ganglion cells (M ganglion cells) in the primate retina. *Neuroscience, 40,* 217-237.

Sloane, M.E., Owsley, C. & Jackson, C.A. (1988). Aging and luminance-adaptation effects on spatial contrast sensitivity. *Journal of the Optical Society of America A, 5(12),* 2181-2190.

Snowden, R.J. & Hess, R.F. (1992). Temporal frequency filters in the human peripheral visual field. *Vision Research, 32(1),* 61-72.

Stamatiadis, N. (1996). Gender effect on the accident patterns of elderly drivers. *The Journal of Applied Gerontology, 15*(1), 8-22.

Stamatiadis, N. & Deacon, J. A. (1995). Trends in highway safety: effects of an aging population on accident propensity. *Accident Analysis & Prevention, 27*(4). 443-459.

Staplin, L. (1995). Simulator and field measures of driver age differences in left-turn gap judgements. *Transportation Research Record, 1485*, 49-55.

Summala, H., Nieminen, T. & Punto, M. (1996). Maintaining lane position with peripheral vision during in-vehicle tasks. *Human Factors, 38(3)*, 442-451.

Tornros, J.E.B. & Bolling, A.K. (2005). Mobile phone use – Effects of handheld and handsfree phones on driving performance. *Accident Analysis & Prevention, 37,* 902-909.

Tornros, J. & Bolling, A. (2006). Mobile phone use – effects of conversation on mental workload and driving speed in rural and urban environments. *Transportation Research Part F, 9,* 298-306.

Trevarthen, C.B. (1968). Two mechanisms of vision in primates. *Psychologische Forschung, 31(4),* 299-337.

Ungerleider, L.G. & Mishkin, M. (1982). Two cortical visual systems. In: D.J. Ingle, M.A. Goodale, & R.J.W. Mansfield (Eds.), *Analysts of Visual Behavior* (pp. 549-586). Cambridge, MA: MIT Press.

Waller, P. F. (1991). The older driver. *Human Factors 33*(5), 499-505.

Weale, R.A. (1975). Senile changes in visual acuity. *Transactions of the Ophthalmological Society (U.K.), 95,* 36-38.

Weale, R.A. (1982). Senile ocular changes, cell death, and vision. In R. Sekuler, D.W. Kline, & K. Dismukes (Eds.), *Aging and Human Visual Function* (pp.161-172). New York, NY: Alan R. Liss Inc.

Welford, A.T. (1952). The “psychological refractory period” and the timing of high speed performance — a review and a theory. *The British Journal of Psychology, 43*, 2-19.

West, C.G., Gildengorin, G., Haegerstrom-Portnoy, G., Lott, L.A., Schneck, M.E. & Brabyn, J.A. (2003). Vision and driving self-restriction in older adults. *Journal of the American Geriatrics Society, 51,* 1348-1355.

Weymouth, F.W. (1960). Effect of age on visual acuity. In M.J. Hirsch & R.E. Wick (Eds.), *Vision of the aging patient: An optometric symposium.* (pp. 37-62). Philadelphia: Chilton.

Wickens, C.D. & Liu, Y. (1988). Codes and modalities in multiple resources: A success and qualification. *Human Factors, 30,* 599-616.

Witus, G. (1996). *TARDEC National Automotive Center Visual Performance Model (NAC-VPM): Analyst’s manual (*Final Report: U.S. Army contract no. DAAE07-94-CR11). Ann Arbor, MI: OptiMetrics Corporation. (Technical Report No. OMI-577).

Wolf, E. & Shaffra, A.M. (1964). Relationship between critical flicker frequency and age in flicker perimetry. *Archives of Ophthalmology, 72,* 832-843.

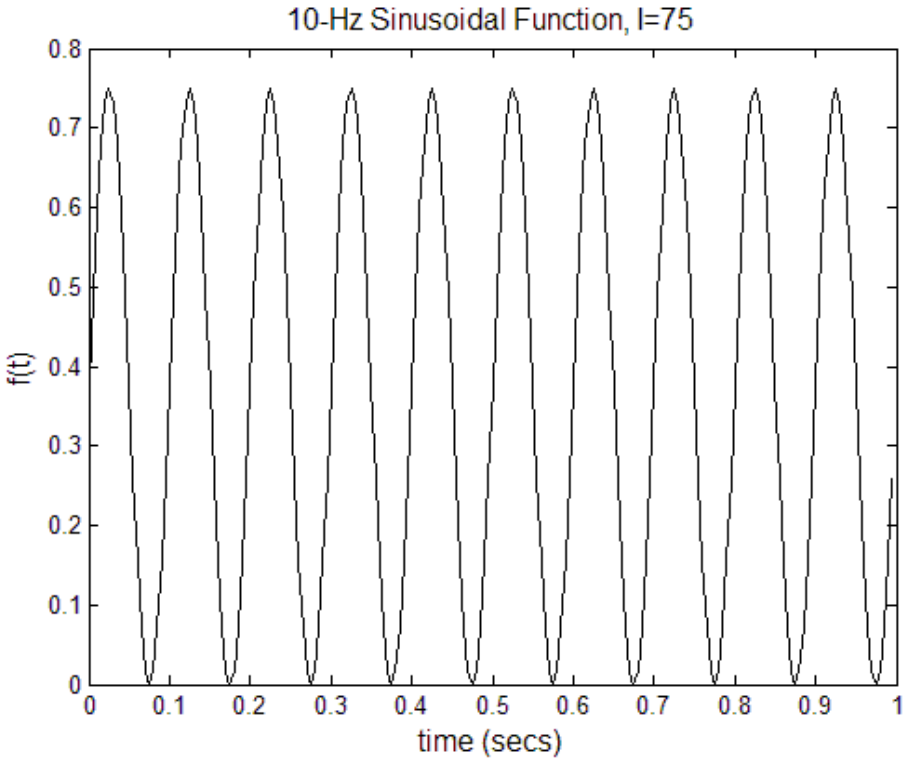
Wolf, E. (1967). Studies on the shrinkage of the visual field with age. *Highway Research Record, 167,* 1-7.

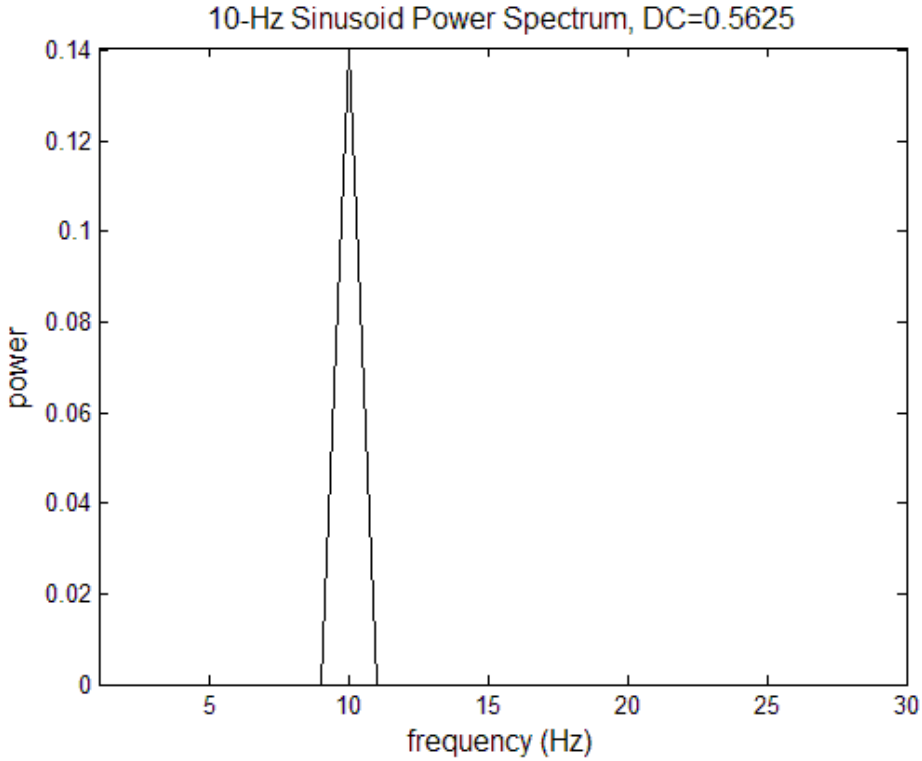
Wood, J.M. (2002). Age and visual impairment decrease driving performance as measured on a closed-circuit road. *Human Factors, 44(3),* 482-494.

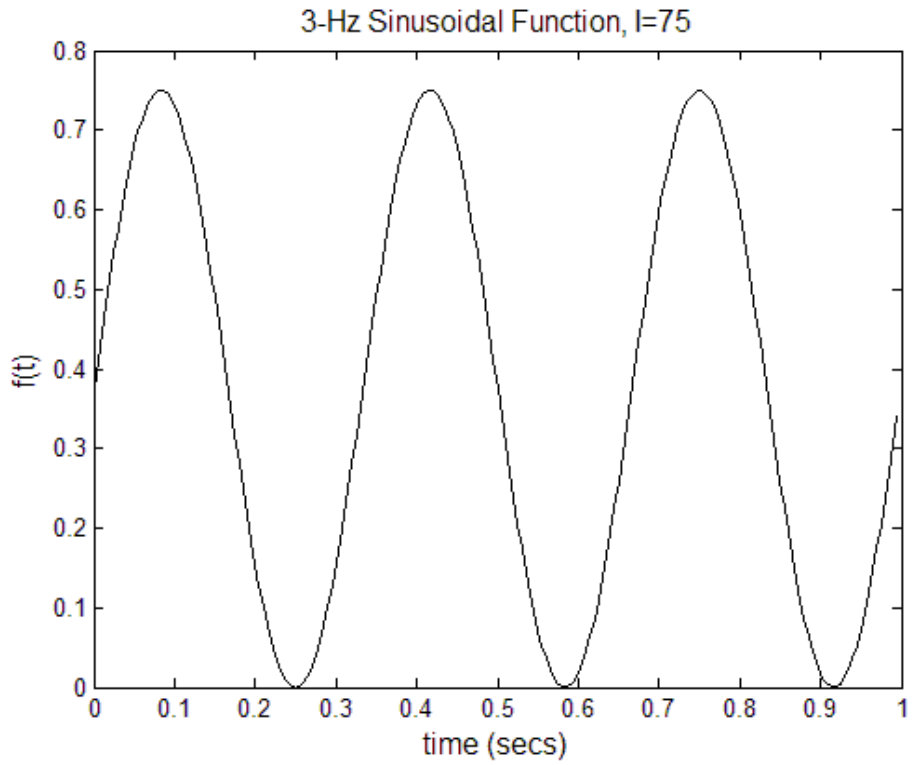
Wright, C.E. & Drasdo, N. (1985). The influence of age on the spatial and temporal contrast sensitivity function. *Documenta Ophthalmologica, 59,* 385-395.

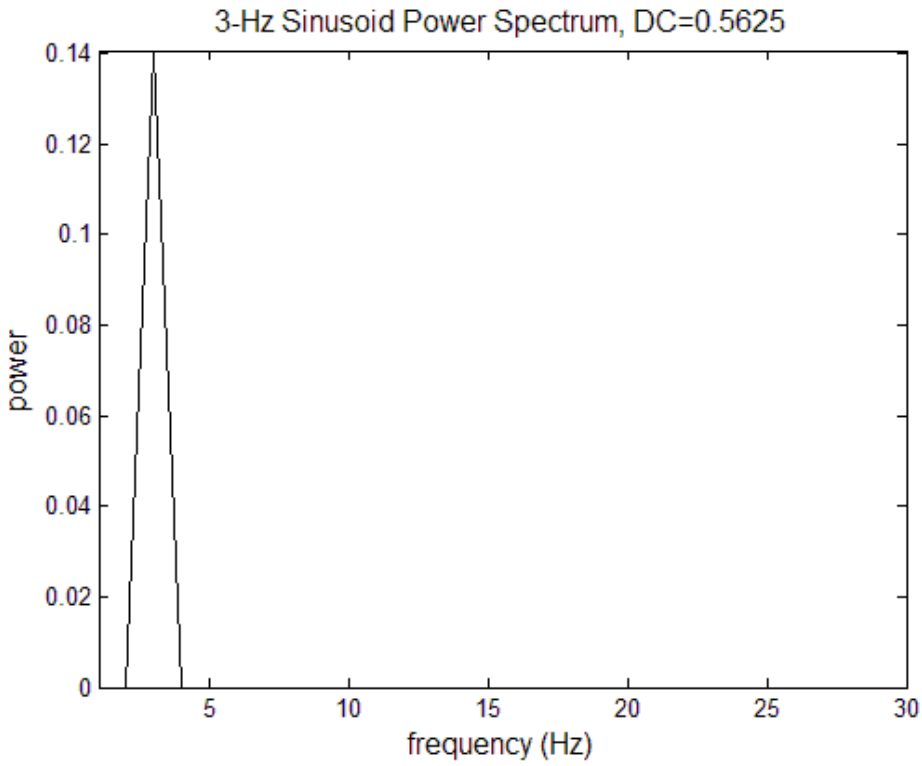
Yantis, S. & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance, 16(1),* 121-134.

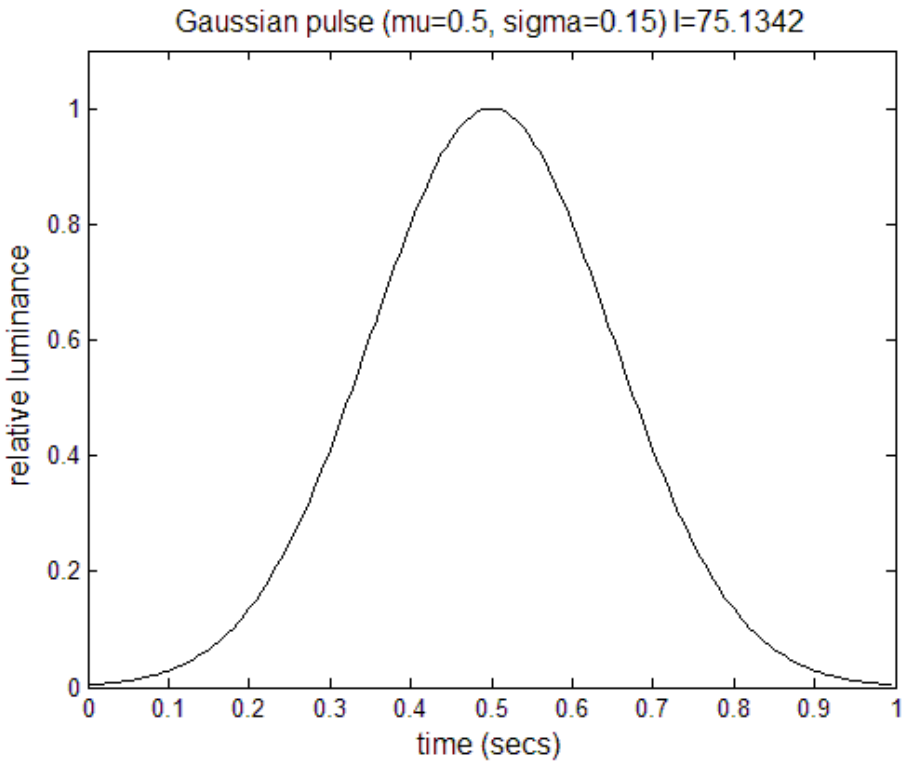
Appendix A - Figures of each temporal stimulus

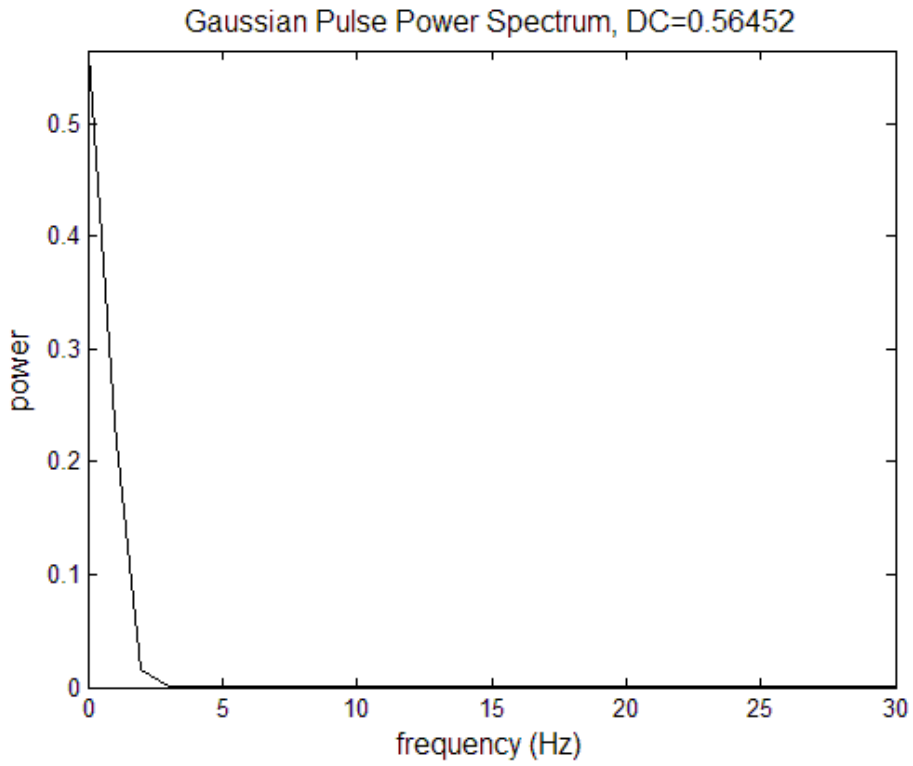





3-Hz Sinusoidal Function, I=75
f(t)
time (secs)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


3-Hz Sinusoid Power Spectrum, DC=0.5625
power
frequency (Hz)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
5
10
15
20
25
30


Gaussian pulse (mu=0.5, sigma=0.15) I=75.1342
relative luminance
time (secs)
0
0.2
0.4
0.6
0.8
1
0.1
0.3
0.5
0.7
0.9


Gaussian Pulse Power Spectrum, DC=0.56452
power
frequency (Hz)
0
0.1
0.2
0.3
0.4
0.5
5
10
15
20
25
30

Appendix B - MATLAB scripts for modeling ambient channel sensitivity

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% ambient_modeling.m                                                    %
%                                                                       %
% TARDEC VPM Model of Visual Temporal Sensitivity                       %
% after Witus (1996), Optimetrics Tech Report OMI-577                   %
% (see pp. 10-14)       fs 2-Feb-2008                                   %
%                                                                       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
clear all;
%
%generate row-vector of freq values from 1-100 Hz (in 1-Hz steps)
f=linspace(1,100,100);
%
%build lowpass (FOCAL) filter
%3-dB cutoff = 8 Hz; gain = 5
cf=8;
gain=5;
for n=1:100
    focal(n)=exp(log(0.5) * ((f(n)/cf)^3)) * gain;
end
%plot low-pass filter
figure(1); clf;
semilogx(f,focal,'r:');
axis([1 100 0 60]);
hold on;
%
%generate mid-freq bandpass filter
%f-low = 5 Hz, f-high = 12 Hz, gain = 25
%
flow=5;
fhigh=12;
gain=25;
for n=1:100
    tbm(n)=exp(log(0.5)*(f(n)/fhigh)^3)-exp(log(0.5)*(f(n)/flow)^3);
    tbm(n) = tbm(n) * gain;
end
%plot mid-freq bandpass filter
semilogx(f,tbm,'b:');

%
%generate high-freq bandpass filter
%f-low = 12 Hz, f-high = 22 Hz, gain = 86
%
flow=12;
fhigh=22;
gain=86;
for n=1:100
    tbh(n)=exp(log(0.5)*(f(n)/fhigh)^3)-exp(log(0.5)*(f(n)/flow)^3);
    tbh(n) = tbh(n) * gain;
end
%plot high-freq bandpass filter
semilogx(f,tbh,'g:');
```

```
%
%combine three sub-filters into one TCSF (photopic deLange function)
%
for n=1:100
    tcsf(n)=focal(n)+tbm(n)+tbh(n);
end
semilogx(f,tcsf,'k:');
%
%label plot
legend('Lowpass','Bandpass-5.5Hz','Bandpass-12Hz','Overall TCSF',2);
xlabel('Temporal Frequency (Hz)');
ylabel('Temporal Contrast Sensitivity');
title('VPM Three-Channel Model of Temporal Sensitivity');
hold off;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                                           %
% combine the two bandpass filters to model AMBIENT response %
%                                                                           %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for n=1:100
    ambient(n)=tbm(n)+tbh(n);
end
figure(2); clf;
%plot ambient TCSF
semilogx(f,ambient,'k:');
hold on;
%plot focal TCSF
semilogx(f,focal,'r:');
axis([1 100 0 60]);
%label plot
legend('Ambient Channel','Focal Channel',2);
xlabel('Temporal Frequency (Hz)');
ylabel('Temporal Contrast Sensitivity');
title('Ambient versus Focal Channel Temporal Sensitivity');
hold off;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                                           %
% Add DC-component to AMBIENT and FOCAL system filters %
% Normalize filters to max(ambient)                                         %
%    index   freq(Hz)                                                       %
%      1      0.0                                                          %
%      2      1.0                                                          %
%      3      2.0                                                          %
%      4      3.0                                                          %
%      .       .                                                           %
%    101    100.0                                                          %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%normalize filters
amax=max(ambient);
ambient=ambient/amax;
focal=focal/amax;
tcsf=tcsf/amax;
%append DC-component
ambient = [0,ambient];
```

```
focal = [0,focal];
tcsf = [0,tcsf];


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                            %
% Compute and analyze various experimental temporal stimuli %
%                                                            %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
% compute power spectrum of 10Hz sine wave sampled at 200 Hz
%
% epoch = 1.0 sec, Nyquist freq=(200/2)-1=99 Hz, Lpeak = 0.75, Int=75.0
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
N=200;                  %number of samples
Lpeak=0.75;             %luminance scaling factor
T=1.0;                  %length of sample epoch
t = [0:(N-1)]'/N;       %define time line
t = t*T;                %convert timeline to secs
y = sin(2*pi*10*t);     %generate 10Hz sine wave
y = y * (Lpeak/2);      %scale stimulus
y = y + (Lpeak/2);      %DC luminance restoration
iy=sum(y);              %integrate signal
F = fft(y);             %xform data
a = abs(F/(N/2));       %compute amplitude spectrum
p = a(1:(N/2)).^2;      %compute power spectrum of positive frequencies
%plot sine wave
figure(3), clf
plot(t,y);
hold on;
xlabel('time (secs)');
ylabel('f(t)');
title(['10-Hz Sinusoidal Function, I=',num2str(iy)]);
hold off;
%plot power spectrum
freq = [0:(N/2)-1]'/T; %convert sample times (sec) to freq (Hz)
figure(4), clf
%semilogy(freq,p);      %linear freq axis, log power axis
plot(freq,p);
hold on;
axis([1 30 0 max(p(2:30))]);      %show only 1-30 Hz on freq axis
xlabel('frequency (Hz)');
ylabel('power');
title(['10-Hz Sinusoid Power Spectrum, DC=',num2str(p(1))]);
hold off;
%
%calculate ambient filter MTF index (skip DC component)
%
ein=sum(a(2:100));
eout=0.0;
for n=2:100
    eout=eout+(a(n)*tcsf(n)); %integrate filtered power spectrum
```

```
end
mtf=eout./ein;
disp(' ')
disp(['10 Hz: Eout=',num2str(eout),' Ein=',num2str(ein),' MTF =
',num2str(mtf)])


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%
%generate a Gaussian Pulse stimulus
%
%duration=1 sec, mu=0.5 sec, sigma=0.15 sec, Lpeak = 1.0, Int=75.13
%
%sampling rate = 200 Hz, Nyquist Freq = 99 Hz
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%
N=200;                  %number of stimulus samples
Lpeak = 1.0;            %peak relative luminance
T=1.0;                  %stimulus epocch = 1 sec
t=[0:N-1]'/N;           %1000 equally spaced samples (0-1000)
t=t*T;                  %convert sampling line to timeline (0-2 secs)
mu=0.5;                 %Gaussian mean
sigma=0.15;             %Gaussian standard deviation
y=normpdf(t,mu,sigma); %generate Gaussian stimulus
y=(y/max(y)) * Lpeak;  %scale stimulus
iy=sum(y);              %integrate stimulus
figure(5), clf
plot(t,y);
hold on;
set(gca,'XLim',[0 1]);
set(gca,'YLim',[0 Lpeak+0.1]);
xlabel('time (secs)');
ylabel('relative luminance');
title(['Gaussian pulse (mu=0.5, sigma=0.15) I=',num2str(iy)]);
hold off;
%
%generate and plot power spectrum for Gaussian pulse
%
F = fft(y);           %xform data
a = abs(F/(N/2));     %compute amplitude spectrum
p = a(1:(N/2)).^2;    %compute power spectrum of positive frequencies
freq = [0:(N/2)-1]'/T; %convert sample times (sec) to freq (Hz)
figure(6), clf
%semilogy(freq,p);     %linear freq axis, log power axis
plot(freq,p);
hold on;
axis([0 30 0 max(p)]);     %show only DC-30 Hz on freq axis
xlabel('frequency (Hz)');
ylabel('power');
title(['Gaussian Pulse Power Spectrum, DC=',num2str(p(1))]);
hold off;
%
%calculate ambient filter MTF index
%
ein=sum(a(2:100));
```

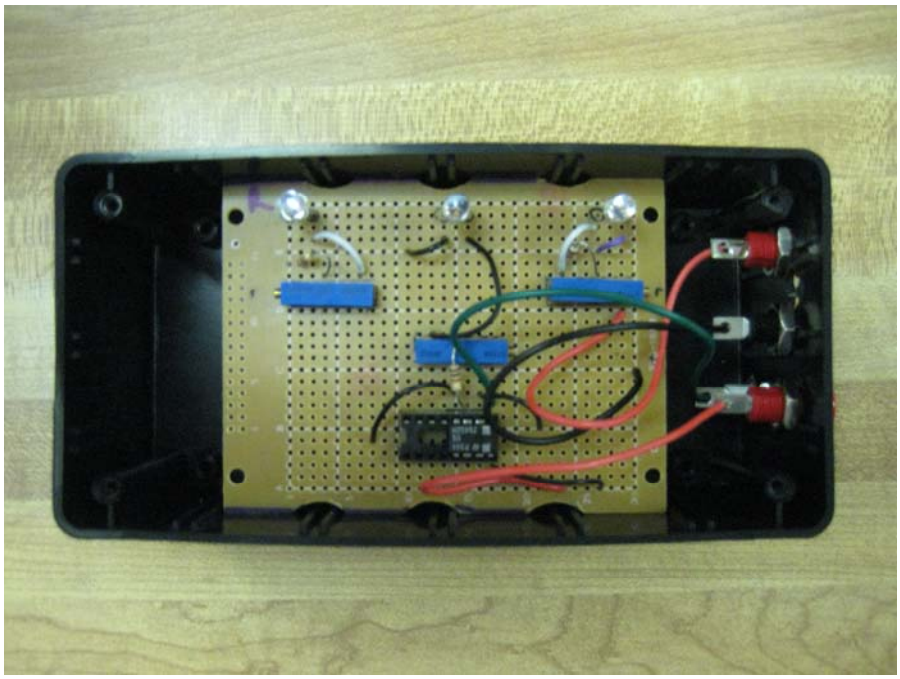
```
eout=0.0;
for n=2:100
    eout=eout+(a(n)*tcsf(n)); %integrate filtered power spectrum
end
mtf=eout./ein;
disp(' ')
disp(['Gaussian: Eout=',num2str(eout),' Ein=',num2str(ein), ' MTF =
',num2str(mtf)])



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
% compute power spectrum of 3-Hz sine wave sampled at 200 Hz
%
% epoch = 1.0 sec, Nyquist freq=(200/2)-1=99 Hz, Lpeak = 0.75, Int=75.0
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
N=200;                %number of samples
Lpeak=0.75;           %luminance scaling factor
T=1.0;                %length of sample epoch
t = [0:(N-1)]'/N;     %define time line
t = t*T;              %convert timeline to secs
y = sin(2*pi*3*t);  %generate 3-Hz sine wave
y = y * (Lpeak/2);    %scale stimulus
y = y + (Lpeak/2);    %DC luminance restoration
iy=sum(y);            %integrate signal
F = fft(y);           %xform data
a = abs(F/(N/2));     %compute amplitude spectrum
p = a(1:(N/2)).^2;    %compute power spectrum of positive frequencies
%plot sine wave
figure(7), clf
plot(t,y);
hold on;
xlabel('time (secs)');
ylabel('f(t)');
title(['3-Hz Sinusoidal Function, I=',num2str(iy)]);
hold off;
%plot power spectrum
freq = [0:(N/2)-1]'/T; %convert sample times (sec) to freq (Hz)
figure(8), clf
%semilogy(freq,p);     %linear freq axis, log power axis
plot(freq,p);
hold on;
axis([1 30 0 max(p(2:30))]);     %show only 1-30 Hz on freq axis
xlabel('frequency (Hz)');
ylabel('power');
title(['3-Hz Sinusoid Power Spectrum, DC=',num2str(p(1))]);
hold off;
%
%calculate ambient filter MTF index (skip DC component)
%
ein=sum(a(2:100));
eout=0.0;
for n=2:100
```

```
    eout=eout+(a(n)*tcsf(n)); %integrate filtered power spectrum
end
mtf=eout./ein;
disp(' ')
disp(['3 Hz: Eout=',num2str(eout),' Ein=',num2str(ein),' MTF =
',num2str(mtf)])
```

Appendix C – Apparatus photos

Experimental set-up with 2 distracter reflections visible

Experimental set-up with distracter and target reflections visible



PDT enclosure box circuitry

Illuminated PDT enclosure box covered with diffusers

Appendix D – Informed Consent Form

UNIVERSITY OF SOUTH DAKOTA
Institutional Review Board
Informed Consent Statement

TITLE OF PROJECT: Examining the differential aging of the ambient and focal visual systems: An approach using the peripheral detection task

PRINCIPLE INVESTIGATORS: Ben Schlorholtz, SDU 208, Vermillion, SD 57069
605-677-5295 Ben.Schlorholtz@usd.edu
Dr. Frank Schieber, SDU 303, Vermillion, SD 57069
605-677-5295

1. **PURPOSE OF THE STUDY:**
   You are invited to be in a research study whose purpose is to further understand the characteristics of how visual attention is distributed while driving. You were selected as a possible participant because you satisfy the following requirements: you (1) currently hold a valid driver's license, (2) have a minimum visual acuity of 20/40 as determined using a Bausch & Lomb Orthorater by the experimenter, and (3) have met certain age-related eligibility criteria (subjects must be between the ages of 18-30 or 65-85). You will also be asked about the number of driving accidents, if any, you have been involved in within the last two years.

2. **PROCEDURES TO BE FOLLOWED**:
   You will be asked to operate a driving simulator during different situations while concurrently performing a secondary task. The secondary task will involve detecting brief flashes of light in your visual periphery as quickly as possible and as accurately as possible.

3. **RISKS:**
   There are no risks in participating in this research beyond those experienced in everyday life.

4. **BENEFITS:**
   You will not benefit personally from being in this study. However, we hope that in the future, other people might benefit from this study because it will contribute to our understanding about how attention is distributed while driving.

5. **DURATION:**
   It will take about 1 hour to complete this study.

6. STATEMENT OF CONFIDENTIALITY:

The research data does not give the researchers any information that would identify you. Your results will be coded so that we do not know whose responses are whose. However, since the students participating in this project will receive extra credit in a psychology class, there will be a coded link that will allow the researchers to assign that extra credit.

7. RIGHT TO ASK QUESTIONS:

The researchers conducting this study are ***[Dr. Frank Schieber, Ben Schlorholtz, & Kevin Limrick]***. You may ask any questions you have now. If you later have questions, concerns, or complaints about the research please contact ***Ben Schlorholtz or Frank Schieber*** at 605-677-5295**.**

If you have questions regarding your rights as a research subject, you may contact The University of South Dakota - Institutional Review Board at (605) 677-6184. You may also call this number to tell us about any problems, complaints, or concerns about the research. Please call this number if you cannot reach research staff, or you wish to talk with someone who is an informed individual who is independent of the research team.

General information about being a research subject can be found on the IRB website "Information for Research Participants"
http://www.usd.edu/oorsch/compliance/participants.cfm

8. COMPENSATION:

Students will receive 1 hour of extra credit for their specified course.

9. VOLUNTARY PARTICIPATION:

You do not have to participate in this research. You can stop your participation at any time. You may refuse to participate or choose to discontinue participation at any time without losing any benefits to which you are otherwise entitled. You do not have to answer any questions you do not want to answer.

10. ALTERNATIVES TO PARTICIPATING:

The alternative is NOT to participate

For this study you must be 18 years of age older to consent to participate in this research study.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. Please keep this form for your records or future reference.

_____

Subject's Name

_____ _____

Subject's Signature **Date**

I have discussed the above points with the subject or, where appropriate, with the subject's legally authorized representative. It is my opinion that the subject adequately understands the risks, benefits, and procedures involved with participation in this study.

_____ _____

Experimenter's Signature **Date**

Appendix E - Potential Task Order Sequences

Random Block				
1	1 Low Load Low Uncertainty	2 High Load Low Uncertainty	3 Low Load High Uncertainty	4 High Load High Uncertainty
2	1 Low Load Low Uncertainty	2 High Load Low Uncertainty	4 High Load High Uncertainty	3 Low Load High Uncertainty
3	2 High Load Low Uncertainty	1 Low Load Low Uncertainty	3 Low Load High Uncertainty	4 High Load High Uncertainty
4	2 High Load Low Uncertainty	1 Low Load Low Uncertainty	4 High Load High Uncertainty	3 Low Load High Uncertainty
5	3 Low Load High Uncertainty	4 High Load High Uncertainty	1 Low Load Low Uncertainty	2 High Load Low Uncertainty
6	3 Low Load High Uncertainty	4 High Load High Uncertainty	2 High Load Low Uncertainty	1 Low Load Low Uncertainty
7	4 High Load High Uncertainty	3 Low Load High Uncertainty	1 Low Load Low Uncertainty	2 High Load Low Uncertainty
8	4 High Load High Uncertainty	3 Low Load High Uncertainty	2 High Load Low Uncertainty	1 Low Load Low Uncertainty

Appendix F- Total Time and Number of Experimental Trials

Informed Consent	2 minutes
Measure Visual Acuity	2 minutes
Task Introduction/Explanation	2 minutes
Practice Straight Driving	1 minute
Practice LCT	2 minutes
Practice LCT & PDT	2 minutes

Experimental Blocks

Stimulus Location = Certain (Left)

- -Straight Road Driving
  - -Low Ambience – 16 targets
  - -Med Ambience – 16 targets
  - -High Ambience – 16 targets 6 minutes
  - -Rest
- -Lane Changing Task
  - -Low Ambience – 16 targets
  - -Med Ambience – 16 targets
  - -High Ambience – 16 targets 6 minutes
  - -Rest

Stimulus Location = Uncertain (Left or Right)

- -Straight Road Driving
  - -Low Ambience – 16 targets
  - -Med Ambience – 16 targets
  - -High Ambience – 16 targets 6 minutes
  - -Rest
- -Lane Changing Task
  - -Low Ambience – 16 targets
  - -Med Ambience – 16 targets
  - -High Ambience – 16 targets 6 minutes
  - -Rest

Appendix G - Pre-experiment Screening Form

Pre-experiment Screening Procedure Date: _____

Name: _____ Time: _____

Subject Number: _____

Age: _____ Sex: _____

Do you have a driver's license?_____

Have you been in any accidents in the last 2 years?_____ If so, how many? _____

Informed Consent _____

Orthorater Acuity

Binocular Far-3

Number	Response	Acuity
1	R	20/200
2	L	20/100
3	T	20/67
4	L	20/50
5	B	20/40
6	L	20/33
7	T	20/29
8	B	20/25
9	T	20/22
10	R	20/20
11	B	20/18
12	R	20/17

Task Introduction/Explanation: _____

Set-up LED reflections: _____

Practice Low Load/Straight Driving: _____

Practice High Load/LCT Driving: _____

Practice High Load & PDT: _____

Experimental Block Order: _____

Number	Condition	Condition	Condition	Condition

Notes:

Appendix H - *A priori* and *post hoc* Age group PDT hit rate means

Age Group	Workload	Positional Uncertainty	Ambience	Mean	Std. Deviation
Young	Low	Low	Low	0.902	.159
			Moderate	0.973	.039
			High	0.996	.015
		High	Low	0.750	.211
			Moderate	0.918	.084
			High	0.957	.081
	High	Low	Low	0.828	.148
			Moderate	0.949	.065
			High	0.973	.039
		High	Low	0.611	.228
			Moderate	0.926	.105
			High	0.941	.080
Old	Low	Low	Low	0.806	.232
			Moderate	0.976	.043
			High	0.965	.053
		High	Low	0.619	.186
			Moderate	0.847	.148
			High	0.878	.136
	High	Low	Low	0.739	.173
			Moderate	0.881	.103
			High	0.903	.117
		High	Low	0.441	.165
			Moderate	0.726	.171
			High	0.781	.145

Age Group	Workload	Positional Uncertainty	Ambience	Mean	Std. Deviation
Young	Low	Low	Low	0.902	.159
			Moderate	0.973	.039
			High	0.996	.015
		High	Low	0.750	.211
			Moderate	0.918	.084
			High	0.957	.081
	High	Low	Low	0.828	.148
			Moderate	0.949	.065
			High	0.973	.039
		High	Low	0.611	.228
			Moderate	0.926	.105
			High	0.941	.080
Old-Low Performance	Low	Low	Low	0.653	.242
			Moderate	0.952	.052
			High	0.945	.065
		High	Low	0.543	.164
			Moderate	0.785	.177
			High	0.833	.139
	High	Low	Low	0.686	.181
			Moderate	0.825	.070
			High	0.847	.136
		High	Low	0.358	.164
			Moderate	0.629	.143
			High	0.708	.708
Old-High Performance	Low	Low	Low	0.959	.062
			Moderate	1.000	.000
			High	0.986	.027
		High	Low	0.694	.183
			Moderate	0.910	.083
			High	0.924	.124
	High	Low	Low	0.792	.156
			Moderate	0.938	.103
			High	0.959	.062
		High	Low	0.525	.124
			Moderate	0.822	.143
			High	0.854	.082