

AGE-RELATED VARIATIONS IN DRIVER MENTAL WORKLOAD
DURING MID-BLOCK AND INTERSECTION TRAVEL

By

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Abstract

Population trends continue to show that the number of drivers over the age of 65 is substantially increasing. Because of this, it is imperative to understand how this population surge may impact the driving community. Analysis of crash statistics suggests that older drivers are much more likely to be involved in intersection crashes than any other type of crash. It was hypothesized that this increased likelihood might be related to an overall decrease in availability of information processing resources specific to the task of driving (i.e. visual-spatial resources). To investigate this issue, the current study utilized a subsidiary task paradigm to measure how the availability of spare mental resources fluctuates relative to age during real world driving. Both young and old drivers received secondary task probes [either visual-spatial (i.e. a clock task) or verbal (i.e. a mental arithmetic task)] while traveling through both mid-block locations (low complexity) and turning through intersections (high complexity). As expected, older drivers showed slower response times than younger drivers when performing the visual-spatial task. However the current sample of older drivers did not show any significant slowing in response time when traveling through intersections compared to mid-block sections. Instead, a 3-way interaction involving location, secondary task, and the order of secondary task presentation was observed. The data suggest that by the second half of the experiment, drivers had learned to associate upcoming intersections with potential stimulus probes. In this half of the experiment, independent of driver age, response times were actually faster at intersections than at mid-block probes. These results are important to the workload literature in the sense that they provide information regarding the potential sensitivity of discrete versus continuous subsidiary task probes.

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Introduction

Population trends continue to show that the number of adults over age 65 is increasing dramatically. Researchers predict that this population surge will result in both an increase in the number of licensed drivers and an increase in the number of annual miles driven by this older population. Statistics continue to show that the aging driver is overly represented in crashes which occur while traveling through an intersection. These crash statistics suggest that older drivers are making critical errors while engaging in cross traffic actions, quite possibly due to age-related attention and/or cognitive deficits. Because it is expected that more and more older drivers will be on the road in upcoming years, it would behoove the driving community to understand why certain driving-related problems are occurring.

Crash statistics alone are not enough to fully understand the issue at hand as this is a purely retrospective approach. A more suitable approach would involve developing techniques which provide some indication as to which drivers are more likely to be involved in an automobile crash. The existing research literature dealing with mental workload measurement could potentially offer interesting insight as to the origin of driving-related problems. It is hypothesized that the use of a subsidiary task paradigm might aid in the understanding of how the spare attentional resource capacity of drivers fluctuates during real world traffic navigation. The experiment presented in the following document attempted to measure driver spare capacity using two unique secondary tasks, each specific to different types of mental resources. It was believed that implementation of such a subsidiary task paradigm during real world driving would

provide important information as to how a driver's attentional resource capability changes as a result of the aging process.

Demographics

Population Aging. According to Ahmed & Smith (1992), rising numbers within the aging population is a demographic trend that necessitates considerable thought. Researchers have shown that the one of the fastest growing portions of the population includes adults age 65 years and older while the most rapidly increasing group includes those over 75 years of age (Ostrow, Shaffron, & McPherson, 1992; Waller, 1991). Reports show that from 1992 to 2002, the population growth rate for individuals age 70 and above was 27% higher than the growth rate of the entire population, while currently there are 26 million people age 70 and older (NHTSA, 2002). These numbers suggest that serious consideration must be given to those areas in which this population surge will have considerable impact.

Aging Driver Population. In 2001, there were 19.1 million older licensed drivers in the United States. This is a 32% increase from the values obtained in 1991 (NHTSA, 2002). Waller (1991) predicted that by the year 2025, there will be approximately 50 million people age 65 or older that qualify to drive. Research suggests that not only will the overall rise in population numbers cause an increase in the quantity of older drivers, but with this rise we can expect to see an increased dependency on the automobile as the primary mode of transportation, as well as an increase in the number of miles actually driven (Jette & Branch, 1992; McGwin & Brown, 1999).

Crash Statistics

Rate of Crash Occurrence. When considered in terms of both the number of licensed drivers and the number of miles driven, drivers 65 and older make up the most rapidly growing division of the driving population (Ball & Owsley, 1991; Barr, 1991; & Waller, 1991). However some accident statistics that evaluate older driver risk can be misleading at first glance. When analyzed in terms of the number of accidents relative to the actual number of licensed drivers, the accident rate for drivers over age 65 is no worse than that of any other driving group (Carr, Jackson, Madden, & Cohen, 1992; Waller, 1991). Previous research suggests that older drivers are highly selective of the environments in which they drive. Typically, they tend to reduce their overall speed (Carr et. al., 1992) and avoid high risk situations such as severe weather, dense traffic, complicated roadways, and nighttime driving (Ball & Owsley, 1991; Schieber, Fozard, Gordon-Salant, & Weiffenbach, 1991; Waller, 1991). This reduction in more complex driving environments is viewed by some as a form of self-selection or compensatory behavior in response to age-related perceptual and cognitive deficits (Kosnik, Sekuler, & Kline, 1990).

Despite the fact that older drivers attempt to compensate for their age related deficits by reducing their speed and restricting their driving, researchers continue to find that they have a substantially higher rate of accidents per mile driven (Carr et. al, 1992; Cerrelli, 1989; Waller, 1991; & Massie, Campbell, & Williams, 1995). When driver exposure rates (i.e. crash rates relative to actual miles driven) are considered, we find that drivers over the age of 65 are clearly more likely to be involved in a traffic accident (Gebbers & Peck, 1992 & Waller, 1991). Researchers in the United States and Finland

have repeatedly shown that crash rates for older drivers are as high, if not higher than their younger counterparts (Hakamies-Blomqvist, 1994a; Hakamies-Blomqvist, 1994b; Stamatiadis & Deacon, 1995; & Stamatiadis, 1996). When this older population was broken down into even smaller age groups, Cerrelli (1989) found that drivers over the age of 85 have a crash rate higher than drivers aged 16-19, who have relatively little or no driving experience (see Figure 1).

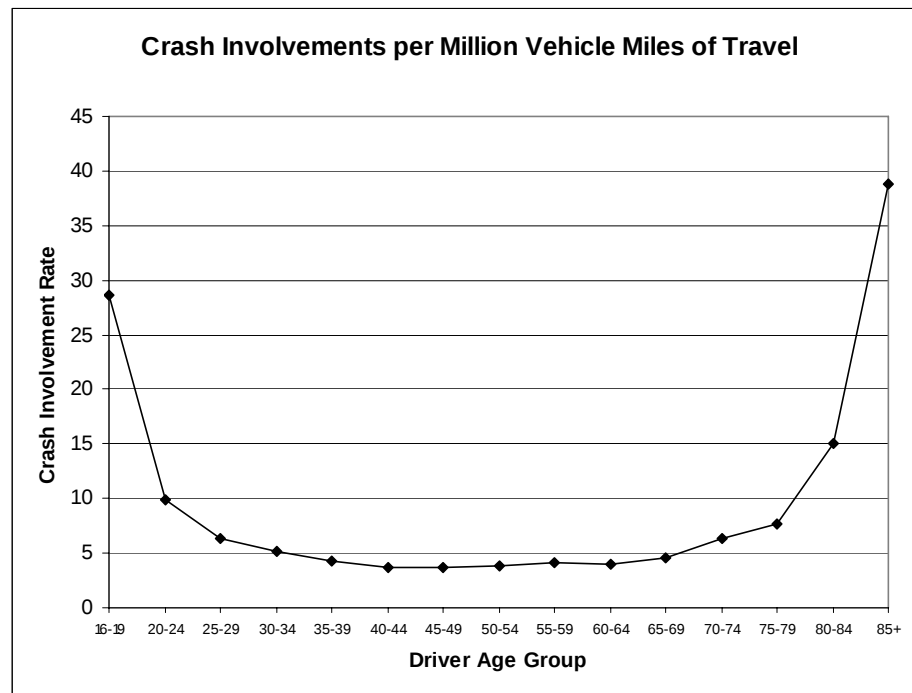


Figure 1. Crash involvement per million miles driven by age groups (Cerrelli, 1989)

Fatality Rate. Coupled with the fact that older drivers are involved in more automobile accidents than any other age group relative to the number of miles driven, they are also more likely to be seriously injured or killed in crashes (see Figure 2) (Cerrelli, 1989; Evans, 1988; & Waller, 1991). In 2002, nearly 154,000 elderly individuals suffered injuries as a result of involvement in traffic accidents. Older drivers also made up 12% of all traffic fatalities in this year (NHTSA, 2002). When compared to

younger drivers, Cerrelli (1997) suggests that those 65 and older are over two and a half times more likely to be in a fatal traffic accident. When the severity of crashes is taken into consideration, older drivers are more likely to suffer from both the immediate and delayed consequences, thus resulting in an increased overall fatality risk (Cerrelli, 1989 & Waller, 1991). As the body ages and becomes more frail, muscles begin to break down and bones become weaker. This overall decrease in the ability to withstand physical trauma results in the increased likelihood of an older individual suffering a fatal outcome in a crash (Waller, 1991). We can expect that as the number of older licensed drivers continues to increase, their total number of miles driven will also increase, thereby leading to an unfortunate rise in older driver fatalities (Barr, 1991; Ball & Owsley, 1991; & Waller, 1991).

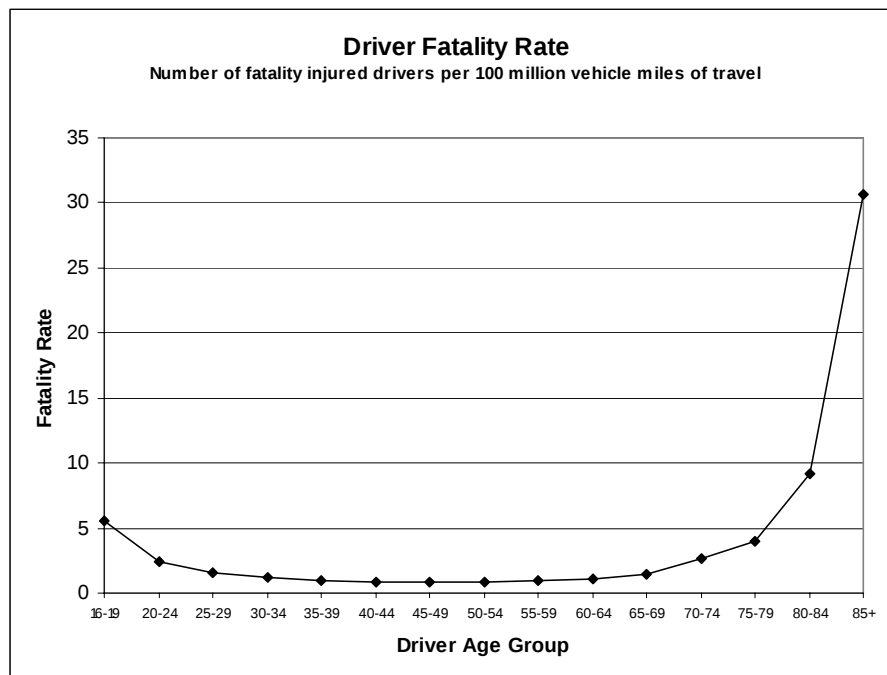


Figure 2. Crash Involvement driver fatality rate by age (Cerrelli, 1989)

Types of Crashes. In recent years, research has shown that older drivers tend to have crashes in certain situations while engaging in specific driving behaviors. NHTSA (2002) published a report indicating that 81% of older driver fatalities occurred during the daytime, 72% took place on weekdays, and most typically involved other vehicles (i.e., multiple vehicle crashes). When involved in accidents with other vehicles, the older driver is more likely to be operating the vehicle that is initially struck (Hakamies-Blomqvist, 1994a) as well as be considered at fault (Hakamies-Blomqvist, 1993, 1994b; Stamatiadis & Deacon, 1995; & Stamatiadis, 1996). When involved in two vehicle fatal accidents, older drivers have been found two times more likely to be operating the vehicle that was struck (NHTSA, 2002). Researchers continue to find that older drivers are disproportionately involved in collisions while turning across traffic, specifically in intersections (see Figure 3) (Cerrelli, 1989, Hakamies-Blomqvist, 1993, 1994b, 1994c; Stamatiadis & Deacon, 1995; & Stamatiadis, 1996).

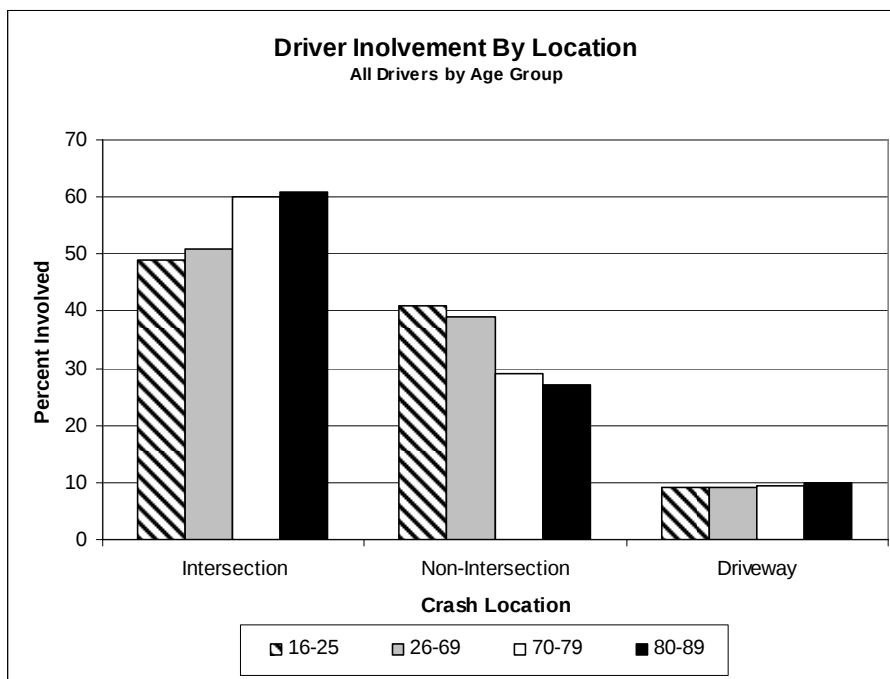


Figure 3. Location of crash involvement (Cerrelli, 1989)

Cerrelli (1989) also analyzed the types of violations for which drivers involved in crashes were cited. Figure 4 (from Cerrelli, 1989) shows that violations involving excessive speed decrease as a function of increasing driver age. For driving situations which demand high levels of visual information processing such as obeying posted traffic signs and yielding the right of way, drivers age 70 and older receive proportionately more citations. Data analyzed by Schieber (2000) revealed interesting findings with regard to the characteristics of intersections in which crashes occur. When older drivers experience an intersection controlled by a traffic signal, they are no more likely to be involved in a crash. However when the intersection is controlled only by a stop sign, the relative percent of involvement increases strikingly as driver age increases (see Figure 5). Schieber (2000) concluded that the presence of a traffic signal minimizes the decision making demands placed on older drivers. The signal bears the brunt of the decision making burden and informs the driver when to proceed. However, when the intersection is controlled by a stop sign, the decision making demands rely solely on the visual information processing resources of the older driver. These findings suggest that older drivers are making critical errors while engaging in cross traffic actions, possibly due to age-related cognitive or perceptual deficits.

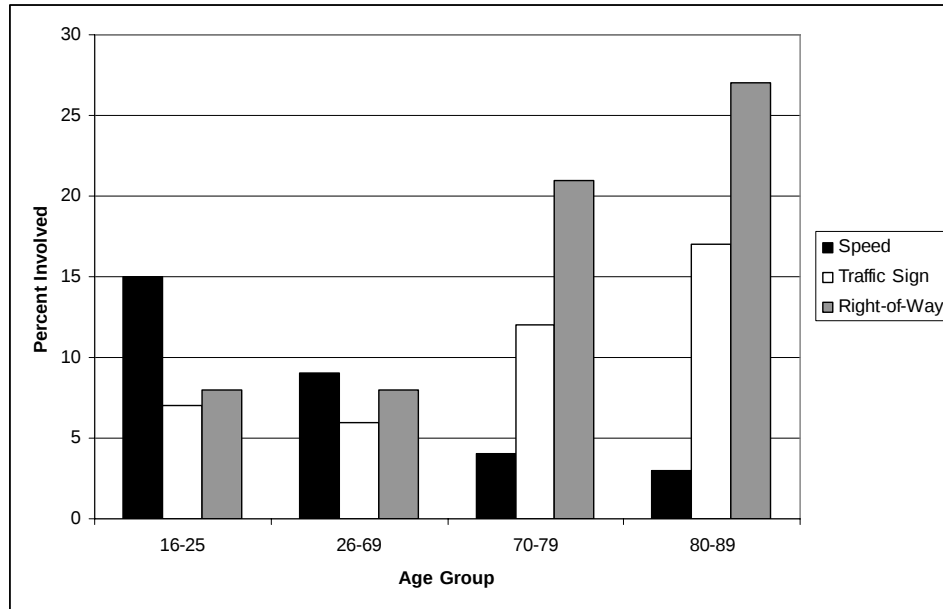


Figure 4. Types of violations for different driver age groups (Cerrelli, 1989)

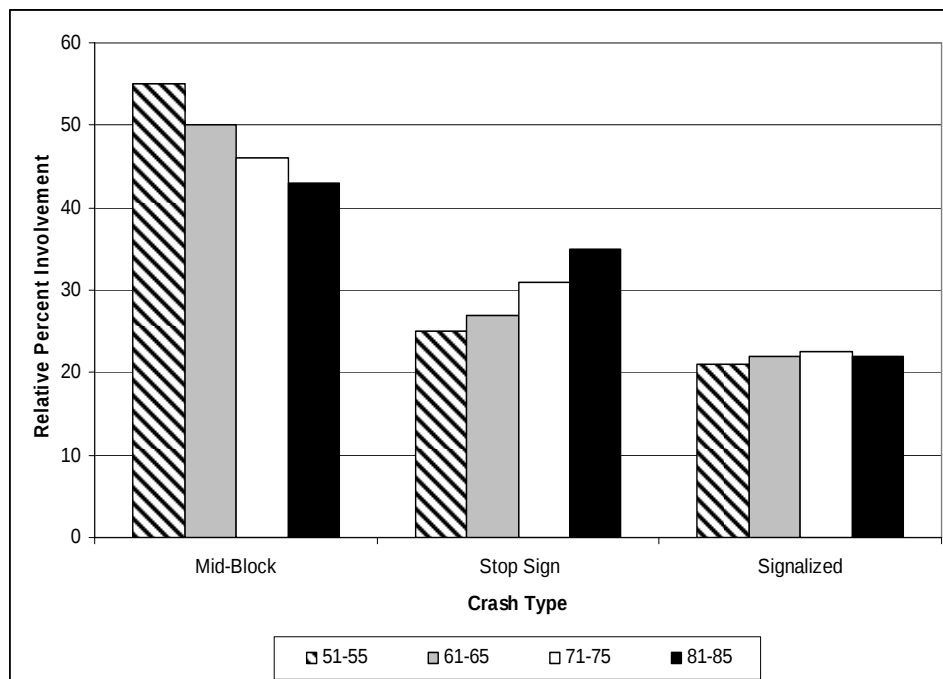


Figure 5. Crash type involvement compared by age (Schieber, 2000)

Capacity Model vs. Multiple Resource Theory of Attention

When examining the attentional demands of complex tasks such as driving, two theories of attention can be considered. Each theory is based on the assumption that attention is a limited resource. Attention is limited in the sense that there is not always a sufficient amount available. Performance on a given task is determined by how well a person is able to distribute attention to the ever-changing situational demands of the environment. Each theory differs with regard to its understanding as to how attentional resources are conceptually structured. One assumes a single pool from which all resources are drawn (Kahneman, 1973, pg 9) while the other assumes the presence of multiple pools of attention each specific to different types of resources (Wickens, 1984).

According to the Capacity Model put forth by Kahneman (1973), attention is drawn from a single pool of resources which is limited in capacity. The overall amount of resources available changes as a function of arousal. This capacity will increase as arousal increases, but in an inverted U-shaped function. Very high levels of arousal actually interfere with overall capacity, and interrupt performance (Kahneman, 1973, pg. 33). A task is performed successfully when the required attentional demands are able to be supplied by the current available capacity. Thus, there is enough overall capacity within this single pool of resources to distribute attention appropriately. However performance decrements occur as the result of: 1) an inadequate supply of overall resources to meet the task demands, or 2) the suboptimal distribution of attention to certain tasks and not others (Kahneman, 1973, pg. 9). A commonly used example involves a person's ability to drive a car and carry on a conversation at the same time. People can easily perform both tasks until the demands of the driving situation become

increasingly complex. In this instance, drivers will cease conversing with other passengers and focus all of their attention on driving. The driving task requires all of the available attentional resources and there is nothing left over to distribute to the conversation. Kahneman (1973, pg. 185) suggests that as more and more effort is attributed to the primary task of interest (i.e. driving), there is less and less spare capacity available for the secondary task (i.e. conversation).

Although Kahneman's capacity model does an excellent job of describing the basic functions of attention, he points out that there are certain phenomena that it cannot thoroughly explain. A study performed by Allport, Antonis, & Reynolds (1972) reported that when subjects were required to shadow an auditory message and remember a simultaneous list of items, their ability to retain the lists was significantly better when the list was presented visually as compared to auditorily. This study also showed that subjects could accurately shadow an auditory message while sight reading piano music. Thus, if attention as a whole is of limited available capacity, why is it that subjects who shadowed a message could not remember lists presented auditorily but could do so if the lists were presented visually? Did the total available capacity change from one manipulation to the next? These findings raise important questions with regard to the effects of how different types of mental resources interfere with attention. Kahneman's capacity model cannot fully differentiate between different mental resources and how they affect attention. For the purposes of the current study, it is necessary that different types of mental resources be distinguishable from one another.

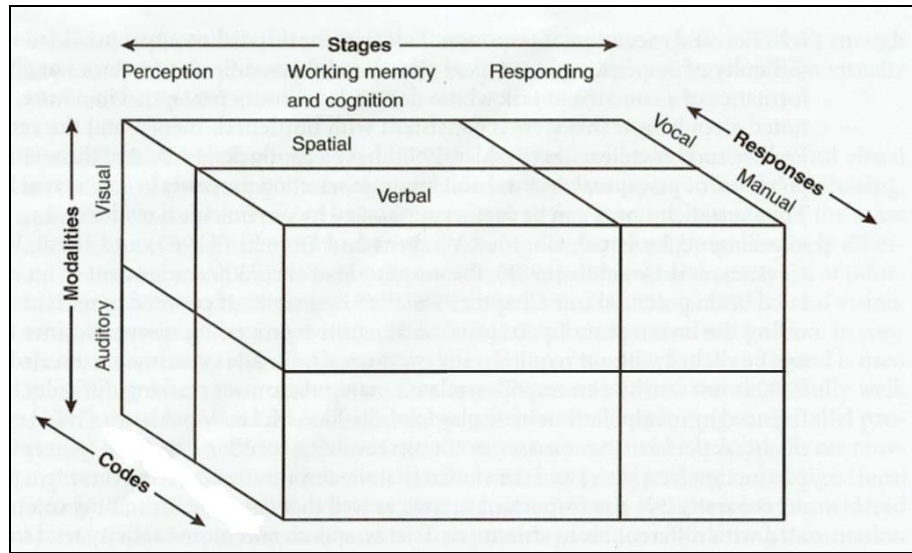


Figure 6. 3-D representation of human information processing resources (Wickens, 1984)

Multiple resource theory suggests that a person's ability to allocate attention relies on three somewhat independent dimensions of cognitive resources (Wickens, 1984; Wickens & Holland, 2000). These dimensions are as follows: stimulus input modality (visual or auditory), encoding modality (verbal/semantic or spatial), and response modality (verbal or manual). Figure 6 provides a graphical depiction of the framework for conceptualizing attentional resources. Each section of the cube represents a somewhat independent pool of mental resources. The mode in which a stimulus is processed determines which resource pools will be required to mediate performance. It is often assumed that each pool of attention has a fixed capacity. Multiple resource theory allows us to explain instances in which two simultaneous tasks can be performed successfully without interfering with one another. Operators can typically perform both a visual and an auditory task simultaneously with minimal errors because these tasks draw resources from separate pools of attention. However when the task involves resources from the same modality (e.g. both visual or both auditory) performance decrements begin

to occur. Multiple resource theory suggests that these tasks are competing for resources from the same pool of attention. Because this resource pool has a limited capacity, there is only so much resource available and as a result, performance on one, or possibly both tasks will suffer as attentional resources are depleted. The current research will examine driver mental workload within a multiple resource theory framework.

Mental Workload

Knowles (1963) provides a simple and concise definition for the concept of mental workload, “How difficult is a task in terms of the perceptual and cognitive demands placed on the operator?” Humans engage in a number of complex tasks in which their ability to perform is based on how well they distribute their attention. The effects of performance are not only endured by the operator, but often by many individuals. Take for example an air traffic controller, a commercial airline pilot, or an automobile operator. In order to minimize the negative consequences for each operator situation, it is imperative that optimal performance be achieved. As a result researchers have acknowledged the importance of identifying and measuring mental workload in complex tasks and have devoted a great deal of resources in an attempt to understand it as a construct (Gopher, 1982; Gopher & Kahneman, 1971; Knowles, 1963; Kraemer, Sirevaag, & Braune, 1987; Ogden, Levine, & Eisner, 1979; and Williges & Wierwille, 1979).

O'Donnell & Eggemeier (1986) classify workload as the amount of required limited capacity that is necessary for an operator to perform a given task. In order to measure workload, researchers need ways of identifying the amount of expended capacity. When selecting a workload assessment technique, researchers must consider

three core criteria: sensitivity, intrusiveness, and diagnosticity. These criteria will determine the overall effectiveness of a technique relative to the experimental environment.

Sensitivity. Workload assessment techniques are considered sensitive based on their ability to detect fluctuations in attentional demands relative to performing a task (O'Donnell & Eggemeier, 1986). De Waard (1996) simply asks, "Is the technique able to reflect changes in workload?" In order to answer this question, a researcher must confine the measurement within a specified region of performance. Workload can basically be broken down into three categories (see Figure 7). Each region is unique based on the relationship between operator performance and workload at a given point. In region A, the operator experiences relatively low levels of task load. Within this region, the operator maintains a high level of performance as the task difficulty gradually increases. According to Wickens' Multiple Resource Theory, the operator is able to maintain optimal performance because he or she has enough spare mental resources to account for the increases in task difficulty. Within region B we begin to see an inverse relationship between performance and task load. As the task becomes increasingly difficult, performance begins to decline. The operator no longer has the mental resources available to maintain a high level of performance. Operator performance will continue to decline as task demand increases. In region C, the operator experiences extremely high levels of mental workload while performance reaches a minimum level. Further increases in task complexity no longer result in diminished performance because resource capacity has been completely exceeded.

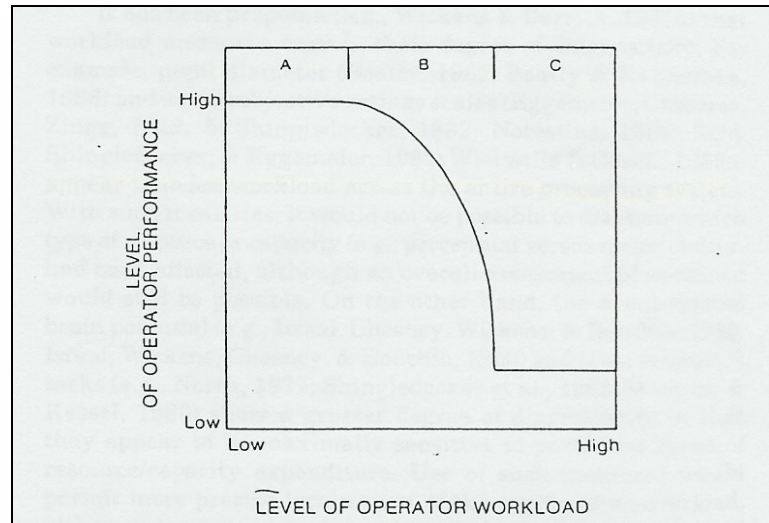


Figure 7. Hypothetical relationship between workload and operator performance (O'Donnell & Eggemeier, 1986)

Once a researcher is able to identify the region in which an operator is able to perform a task, the consequences of degraded performance must be considered. In many real world contexts, decrements in performance may have serious costs for operators. It would be unethical to knowingly degrade driving performance significantly because the operator's safety would be at risk. It is necessary to design techniques that allow us to observe changes in workload before severe decrements in operator performance occur.

Intrusiveness. The second criterion to consider when selecting a mental workload assessment technique is intrusiveness. This is defined as the degree to which a technique influences ordinary task performance (deWaard, 1996). Techniques that are highly intrusive may cause the operator to behave uncharacteristically. The basic application of the technique itself might also cause interruptions in primary task performance. In either case, the operator's performance is no longer a reflection of their mental workload, but rather a result of interference imposed by a particular technique.

Diagnosticity: The third criterion to be considered when selecting a measurement technique is diagnosticity. One must ask the question “Is the technique able to discriminate between the demands placed on specific theoretical resources?” (deWaard, 1996). Measurement techniques that are diagnostic allow workload to be attributed to certain characteristics of the operator’s task and/or operator capacity (Wierwille & Eggemeier, 1993). This ability to reflect workload variations within specific mental resource pools is drawn from the Multiple Resource Theory of Attention (Wickens, 1984). By measuring variation within different pools of attention, resources other than those that are absolutely necessary for successful operator performance can be observed and provide an indication of mental workload. This becomes more difficult when observing complex tasks such as driving because resources from a number of separate pools of attention are often required.

Mental Workload Assessment Techniques

Several techniques have been developed in an attempt to measure mental workload. Techniques typically can be classified into one of the following four categories: (1) subjective measures, (2) physiological measures, (3) primary-task measures, and (4) secondary-task measures. Each method of measurement has its own advantages and disadvantages with regard to sensitivity, intrusiveness, and diagnosticity. Selection of a particular technique depends on how a researcher wishes to identify mental workload, as well as the availability of the necessary equipment. Each category will be discussed in the following sections with respect to these issues.

Subjective Measures. Subjective workload measurement techniques typically require the operator to rate their perceived mental effort for a given task on a pre-

determined scale. Many researchers feel that the operator is an expert with regard to their own capabilities and that simply asking them about their performance results in a sufficient indicator of workload. The Modified Cooper Harper Scale (Wierwille & Casali, 1983), the NASA Task Load Index (Hart & Staveland, 1988), and the Subjective Workload Assessment Technique (Reid & Nygren, 1988) are examples of commonly used methods that have shown sensitivity to resource demands in a number of environments (Wierwille & Eggemeier, 1993). Subjective techniques are usually administered following the completion of a task. As a result they are highly non-intrusive. Asking the operator to reflect on their efforts after the fact does not interfere with their actual performance. However, subjective methods rely on the operator's ability to separate mental and physical workload, which is often difficult to do (O'Donnell & Eggemeier, 1986). Although subjective measures are non-intrusive and can show sensitivity on a global level, they rely on the operators' conscious recollection of events. Subjective measures lack the ability to identify the implicit processes inherent in mental workload of which the subject is not aware.

Physiological Measures. Many researchers have attempted to use physiological techniques to measure mental workload. These techniques measure fluctuations in the physiology of the operator as a result of changes in mental workload with regard to the complexity of a task. The most commonly used methods include: electrophysiological measures of brain function (ERP), cardiovascular activity (heart rate and heart rate variability), eye movements, and pupillary responses (O'Donnell & Eggemeier, 1986). One advantage to using physiological techniques is that they do not require explicit operator response. Instrumentation is simply connected to the preferred body system

which allows data to be collected continuously. In many cases instrumentation is relatively unobtrusive due to improved technology and miniaturized equipment (deWaard, 1996).

A study performed by Lee & Park (1990) showed the ability of heart rate measures to discriminate between physical and mental workload. Increases in physical load caused a reduction in the heart rate variability of subjects with an increase in actual heart rate. However increases in the mental workload resulted in reduced heart rate variability with no effects on heart rate. With respect to pupillary responses, Beatty (1982) found that as the cognitive and perceptual demands of a task increase for operators, their pupillary response amplitude will also increase. Results such as these provide support for the use of physiological techniques as indicators of mental workload.

Physiological techniques have their disadvantages as well. Equipment with the technological capabilities necessary for unobtrusive data collection are often highly specialized and difficult to implement outside of the laboratory. Researchers who have used bio-potential surface electrodes in aviation settings have found that pilots strongly object to the instrumentation (McCloskey, Tripp, Chelette, & Popper, 1992). This leads us to believe that operators in other complex environments, such as driving, might have similar reactions. Physiological techniques can also be very expensive and require high levels of technical expertise (deWaard, 1996).

The diagnosticity of physiological techniques must also be questioned. A person's physiological response is typically the sum of many factors within an environment. Changes in operator physiology may be due to the manipulated task, but they may also be a result of other non-related environmental or biological factors (Hart,

1986). For example, pupil diameter might increase as a function of workload, but pupil diameter also fluctuates relative to the amount of light available. In such a case, the researcher may be unable to decipher whether the change was a result of task complexity or simply to lighting. This suggests that physiological techniques have low diagnosticity because they lack the ability to specify which mental resources are being expended.

Normal physiological changes are also the result of the aging process.

Researchers interested in the differences between young and old individuals must consider this confound. Variations identified in physiological data could quite possibly be due solely to age. In order to use physiological techniques when observing substantially different age groups, researchers must create ways of accounting for these natural physiological differences.

Primary Task Measures. Primary task measures typically measure speed and accuracy of performance for a given task (deWaard, 1996). Workload is assessed by observing the operator's performance as task difficulty increases or decreases. The overall effectiveness of the man-machine interaction is revealed by primary task performance (O'Donnell & Eggemeier, 1986). When a task requires a degree of effort near the limits of the operator's capacity, the operator's performance will begin to decline. Examples of primary task measures within the driving context typically include: vehicle speed, variation in vehicle speed, number of steering reversals, and RMS (root mean square) steering error.

Primary task measures are relatively unobtrusive because they only require measurements of speed and accuracy. These values can be obtained without significantly interfering with the operator while they engage in a task. For example in driving field

studies, speed values and variations can be recorded through the use of computers unbeknownst to the operator. However primary task measures are only able to detect reliably those points at which the operator becomes overloaded (i.e. Region C of Figure 3). Performance declines as the operator struggles to allocate depleted resources appropriately. Therefore primary task measures shed light on the driver's ability to maintain vehicle control, but fail in providing an estimate of moderate increases in operator mental effort (Huddleston & Wilson, 1971; Knowles, 1963, & Ogden et. al., 1979). Manipulating primary task performance in real world environments would put the operator at risk and is therefore not suggested for use in safety-critical domains. DeWaard (1996) suggests that primary task measures must be combined with other workload techniques in order to reveal the true interactions between operator and machine.

Secondary Task Measures. Tasks that an operator performs in addition to a primary task are known as secondary tasks. Research using secondary task measures identifies workload by tapping into the operator's spare resource capacity with the assumption that this mental capacity is fixed (Williges & Wierwille, 1979). Two paradigms exist for implementing task measures: the Loading Task paradigm and the Subsidiary Task paradigm (O'Donnell & Eggemeier, 1986). In the loading task paradigm, the operator is given both a primary and secondary task with the instruction that secondary task performance should be maintained at the exclusion of the primary task. This paradigm then uses performance variations in the primary task as an indication of mental workload. As the secondary task requires more of the operator's available mental resources, it is assumed that there is a decreasing spare resource capacity. The

result is a shift in overall workload from Region A to Region B (see Figure 7) which is revealed by decrements in primary task performance. According to O'Donnell & Eggemeier (1986), those specific locations of secondary task loading which reveal degradations in primary task performance can ultimately be used as an index of primary task workload.

In the subsidiary task paradigm, the operator is instructed to maintain primary task performance at the exclusion of the secondary task. Performance on the secondary task fluctuates with varying task difficulty and provides an indication of the operator's mental workload. O'Donnell & Eggemeier (1986) point out that the purpose of the secondary task within this paradigm is not to load the primary task. The purpose is to provide an indication as to how much spare resource capacity the operator has left while performing at baseline levels of the primary task.

Exclusion of either the primary or secondary task will be determined by the constraints of the experimental environment. Loading task paradigms might be useful in simulator or closed course studies, but degrading primary task performance in complex environments (i.e. driving) could put the operator at risk. Subsidiary task paradigms are capable of being implemented in real world environments as long as the subjects understand the importance of maintaining primary task performance at all times.

In accordance with multiple-resource theory (Wickens, 1984), secondary task measures are most sensitive when their degree of resource overlap with the primary task is substantial. Since both tasks are competing for resources from the same pool of attention, performance will decline for one task because the necessary resources are being used by the other experimental task. Along with being sensitive to workload variations,

secondary tasks can also be diagnostic. If one selects both a primary and secondary task that require similar mental resources, valid conclusions can be made with regard to the specific resources being expended. Although secondary task measures are capable of high levels of sensitivity and diagnosticity, their intrusiveness must be considered carefully. Secondary tasks, of either the loading or subsidiary nature, might be difficult to accept by operators due to their artificial nature relative to the environment under observation. However, careful experimental design and implementation can aid in reducing this intrusiveness. The following section will provide examples of subsidiary tasks implemented in past driving research.

Mental Workload and Driving Research

In order for a subsidiary task to be used, it must not interfere excessively with primary task performance. Within the driving context, a driver must perform as well on the primary task when the secondary task is both present and absent. Brown (1965) had drivers perform two subsidiary attention tasks while driving. The two tasks varied in the amount of attention required, one of which needed a great deal of continuous attention and the other a memory span task which allowed frequent attention switching. No statistical difference was found between driving performance when executing the subsidiary task and when driving alone. Brown concluded that the equivalent performance in these conditions supports the idea that secondary tasks can be non-intrusive within the context of driving research.

A number of researchers have used a mental arithmetic subsidiary task to reveal operator spare resource capacity. A typical mental arithmetic task might typically involve the auditory presentation of a two digit number. The operator's task is to then

subtract the smaller number from the larger (e.g. present “27” and the operator would vocally respond “5” since $7 - 2 = 5$). Brown & Poulton (1961) observed the effects of a mental arithmetic task in both high and low traffic density areas and found this secondary task to be sensitive to the differences in driver workload demands across conditions. Subjects made significantly more arithmetic errors in high density areas than in low density areas.

A simulator study performed by Baldwin (1994) observed the effects of steering complexity and mental arithmetic on old and young drivers. As the steering requirements became more difficult, older drivers took significantly longer to correctly perform the subsidiary task. Baldwin (1994) also found that driver steering error was not different across the single and dual task conditions. This finding supports the use of mental arithmetic tasks as a nonintrusive indicator of driver mental workload. M. Harms (1998) attempted to extend these findings from the simulator to real world driving. The subsidiary task of mental arithmetic was once again found to be sensitive in the laboratory, but in this instance failed to approach significance during actual real world driving. The author cites experimental problems and noisy data for this finding. In fact, other researchers have found this task to be sensitive yet nonintrusive in real world driving situations (L. Harms 1986 & 1991).

A study by L. Harms (1986) observed the effects of different driving environment complexities on a mental arithmetic task. Participants drove in both simple, highway conditions and in more complex, village conditions. Harms found that drivers took significantly longer to perform the arithmetic task when driving through village conditions compared to highway conditions. This study was replicated and extended to

intersections in both rural, highway conditions and village conditions with the same effects of the mental arithmetic task found (L. Harms, 1991). These coupled findings suggest that the driver's allocation of attention was significantly affected by the increasing complexity of the driving environment. In these instances, vocally responding to the mental arithmetic subsidiary task proved sensitive to the presumed changes in driver workload across conditions. Another interesting finding from L. Harms (1986) was the correlation between mental workload fluctuations and the number of reported accidents per road section. The segments of the driving circuit where drivers took longer to perform the mental arithmetic task were also those regions in which more accidents had occurred.

Zeitlan (1995) conducted a long term field study observing driving and mental workload over a four year period. Vanpool members vocally performed two auditory subsidiary tasks, delayed digit recall and random digit generation, in a wide range of traffic situations while driving to and from work. Results suggest that both subsidiary tasks were able to reflect the driver's spare mental capacity. Performance on the subsidiary tasks worsened as driving situations became more complex (e.g. traffic density and speed limit increase). As the vanpool members allocated more of their attentional resources to the increasing demands of the environment, they exhibited a reduction in spare mental capacity as revealed by the subsidiary tasks. Somewhat contradictory to previous findings, the subsidiary tasks used by Zeitlan (1995) were found to be less sensitive in the lab than in the field. This might suggest that the true effectiveness of a subsidiary task's ability to identify operator mental workload may not be completely revealed in a laboratory setting. However simulator and laboratory testing are a

necessary requirement to ensure the nonintrusiveness of a subsidiary task on primary task performance.

Another explanation for this inconsistency in laboratory and field study findings could be due to the overall sensitivity of the secondary task. It appears that mental arithmetic and similar subsidiary tasks are only sensitive when the driving task becomes highly complex. An example of this can be seen in the research performed by M. Harms (1998). When comparing low and high complexity driving environments, statistically significant results were found in the laboratory but not in the real world setting. The author points out that the real world driving conditions may not have been “sufficiently distinct” from one another with regard to complexity. The highly complex condition involved village driving in an area of roughly 10,000 people. This driving environment may not have contained the necessary dynamic requirements to adequately load the attentional capacity of the driver. The result was the inability to successfully differentiate this condition from the simple, rural highway condition. Therefore, the sensitivity of the mental arithmetic task may have been confounded by the operational definitions of both low and high complexity driving conditions. Another possible explanation for these inconsistencies can be drawn from the multiple resource theory of attention.

According to multiple resource theory, performing subsidiary tasks, such as mental arithmetic, would require drawing resources from the semantic/non-spatial domain of stimulus encoding. There is no question that driving does indeed involve semantic processing. Drivers must read gauges and signs for navigation reasons, especially when passing through complex urban and construction areas. However the proportion of semantic/non-spatial processing relative to other attentional resources

required while driving appears to be quite small. Driving primarily involves the processing of visual-spatial information as an operator locomotes through the terrestrial environment. As drivers process this visual-spatial information, they must then make the necessary manual inputs to maneuver their vehicle safely. Therefore a driver's resources are primarily distributed throughout both the spatial encoding and manual response domains. Using a secondary task that requires semantic/non-spatial processing may not adequately reflect true operator workload demands because there is excess spare capacity available within this domain. Wickens (1984) pointed out that in order for a secondary task to be highly sensitive it must engage resources that overlap with the primary task of interest. This suggests that implementing a secondary task that also requires processing within the spatial encoding and manual response domains would result in higher workload sensitivity. A number of driving studies have been mentioned that utilize secondary tasks of semantic/non-spatial nature, all of which require responses from the vocal domain of attentional resources. However, only a few studies have been conducted that require attentional resources similar to those used in actual driving.

A driving simulator study performed by Ponds et al. (1988) implemented a dual task methodology which required attentional resources similar to those used in actual driving. This study attempted to identify age differences involved in the ability to divide attention. Researchers had young, middle age, and older drivers perform two continuous performance tasks, a compensatory tracking task and a self-paced visual choice reaction time task. The tracking task consisted of maintaining vehicle position in the right lane of a roadway as unpredictable "wind gusts" pushed the vehicle left and right. The reaction time task involved drivers counting dots projected within a pre-defined rectangular area

on the simulator screen. Drivers were required to determine whether or not nine dots were present by manually pressing one of two buttons located on the steering wheel. The dot counting task was self-paced to control for individual differences. In other words, drivers were not given a new dot configuration until they responded to the current presentation. Under dual task conditions, tracking task performance of the elderly adults declined significantly when compared to both young and middle age adults. The authors suggest that this decline is the result of an overall reduction in attentional capacity suffered by older individuals.

Some might argue that the impairment of dividing attention for older people in Ponds et al. (1988) was due to the integration of the manual secondary task response and the manual inputs required by steering. Brouwer et al. (1991) replicated this experiment to explore this argument. In this experiment, drivers participated in two response conditions; manual response and verbal response. Older adults again showed a decrease in ability to divide attention compared to their younger counterparts, as revealed by performance decrements in lane tracking and accuracy in visual analysis. When elderly individuals responded verbally to visual stimuli, these effects were less apparent. The effects of aging appear to be especially evident when tasks involve the integration of motor skills (Korteling, 1991).

When examined from the perspective of multiple resource theory, these findings yield interesting conclusions. Responding manually in the dual task conditions appears to severely impair older driver performance. Multiple resource theory would suggest that for older individuals, the manual response resources required for driving are already near operator capacity. Therefore, within this domain there are no spare resources left to

allow older drivers to also respond manually to the visual task. The fact that all of the research presented up to this point found an effect when drivers were required to respond verbally to stimuli suggests that the verbal response domain did still possess spare resources. As a result, the drivers were able to respond verbally without interfering with the manual steering responses. Wickens and Liu (1988) point out that responding manually in an environment with high spatial resource demands can cause interference. These findings have important implications for field study driving research. Having drivers, especially those that are older, respond manually to a secondary task might dramatically affect their ability to react to the ever-changing driving environment. In order to maintain the safety of the experimental driver, response resources from the verbal domain should be employed instead of those from the manual response domain.

Although the research performed by Ponds et al. (1988) and Brouwer et al. (1991) was successful in exposing age effects while manually responding to a spatial task, the resources required to execute the dot counting task need further consideration. This task does not require resources from the semantic domain as seen in the previously mentioned mental workload studies. The necessary resources appear to be drawn from the spatial domain of attention. However, the extent to which these resources overlap with the visual spatial demands of the driving environment is not clear. The spatial demands of the dot counting task are relatively simple, especially when compared to the complex spatial requirements of driving. According to Wickens (1984), in order for a secondary task to be highly sensitive it must engage resources that have some degree of overlap with the primary task. This suggests that a secondary task should be utilized which requires visual spatial resources similar to those used in actual driving. Developing such

a task may yield important findings regarding the visual spatial information processing capabilities of older drivers.

One study which successfully implemented both verbal and spatial domain specific tasks was conducted by Recarte and Nunes (2000). In the verbal condition drivers had to produce and recite words beginning with a certain letter of the alphabet for 30 seconds (i.e. a word fluency test). In the spatial-imagery condition, drivers were required to mentally generate letters of the alphabet and determine the following conditions: (a) did the letter remain unchanged after vertical rotation, (b) did the letter remain unchanged after horizontal rotation, and (c) was the letter closed (e.g. B and O) or open (e.g. Y and J). Operators drove in two different highway and two different road conditions while their visual search patterns were recorded by an eye-tracker. Recarte and Nunes used pupillary dilations as an indicator of task effort which revealed similar effort levels for both the verbal and visual-imagery tasks. However for those spatial-imagery tasks, driver functional-field size decreased both horizontally and vertically. When compared to normal driving with no secondary task, fixations during the spatial-imagery tasks were much longer. Overall, spatial-imagery tasks resulted in significantly different results for nearly all observed variables when compared to the verbal tasks. Because the effort required for both tasks was similar, the researchers concluded from visual inspection patterns that spatial-imagery tasks required more attentional resources similar to those necessary for driving when compared to verbal tasks. This study suggests that the use of spatial-imagery tasks as indicators of mental workload can be diagnostic, sensitive, and nonintrusive in real world settings.

Of significant importance from the Recarte and Nunes (2000) study is the identification of a secondary task that is highly diagnostic. Driver inspection patterns differed significantly while performing the visual-spatial task compared to the verbal task. This suggests that the spatial-imagery tasks were able to utilize resources similar to those used during actual driving. Because visual functional-field size decreased significantly while performing the spatial imagery task, we are able to conclude that this secondary task and the primary task of driving were in competition for similar visual spatial resources.

In accordance with multiple resource theory, having drivers construct spatial images would require attention from the spatial domain of attention. This domain is also the primary location of resources necessary for driving (with the exception of manual steering outputs derived from the manual response domain). Recarte and Nunes (2000) demonstrated that visual spatial tasks can be implemented during real world driving situations without putting subjects and other drivers at risk. For the purposes of the current research, it is necessary to observe the behavior of age-related attentional resources in a diagnostic manner. Driver crash statistics suggest that older drivers are disproportionately involved in crashes which occur during cross traffic actions (Cerrelli, 1989; Schieber, 2000). The fact that older drivers are overly represented in crashes which take place at intersections requires further investigation. Navigating through an intersection places high visual information processing demands on the driver. Driver crash literature suggests that this is even more so for older drivers. An information processing bottleneck appears to be taking place, quite possibly due to age-related cognitive and perceptual deficits. The purpose of the current research was to examine the

visual spatial resource capabilities of older drivers in an attempt to gain a further understanding of their over-involvement in intersection crashes.

Selecting a Spatial Imagery Subsidiary Task

In order to achieve the goals of the current study, it was necessary to employ a subsidiary task that provides an index of the driver's available visual-spatial resources. Identifying an appropriate visual spatial task which can be safely used within the context of real world driving must account for two experimental constraints. First, the secondary task must load the driver's visual spatial attention. However, due to the high information processing demands of the driving environment, this cannot easily be done using visually presented stimuli. Using a task that is presented visually could potentially distract the driver's attention from the roadway. An alternative method would involve presenting the stimulus auditorily. According to multiple resource theory, an auditory presentation would require processing resources from a separate domain of attention (see Figure 6). This would allow the driver's visual attention to be allocated appropriately throughout the driving environment, yet still allow a spatial-imagery task to be presented. The second constraint involves the overall difficulty of the secondary task itself. In order to compare the information processing resources of both young and old drivers, each group must be able to perform the task on comparable levels. Identifying a task with which all subjects have considerable experience will aid in overcoming this constraint.

Such a task might involve the mental manipulation of analog clock faces. Previous research conducted by Paivio (1978) presented subjects with pairs of digital clock times and asked that they select the time in which the hour and minute hand formed the smaller angle. In order to complete this task successfully, subjects were required to

mentally transform each of the digitally presented times into an analog clock face equivalent, and base their decisions on these mental transformations. Results showed that subjects consistently reported using visual imagery to make their decisions. Paivio coined the term “clock task” to describe his visual imagery technique. The importance of this study to the current project is the fact that it successfully identified a technique that remedies both the experimental secondary task constraints outlined in the previous paragraph. Not only does Paivio’s clock task require subjects to use visual spatial resources, but it also involves the concept of telling time on a clock face. Telling time using an analog clock face is a task in which people of all ages are believed to have considerable experience.

Slight manipulation of the clock task developed by Paivio (1978) resulted in the development of a secondary task with two necessary and sufficient characteristics: (1) stimulus targets can be presented via the auditory channel of attention, and (2) drivers must use visual spatial imagery to successfully complete the task. In the current study, this task is referred to as the *visual-spatial secondary task* and involves the auditory presentation of individual clock times. Following presentation, the driver’s task was to visualize the location of the hour and minute hand on an imaginary clock face and ask themselves the following yes/no question: “Is any angle formed by the hour and minute hand less than 90 degrees?” See Figure 10 in the Methods section for examples.

Summary and Research Hypotheses

Population trends continue to show that the number of adults age 65 and older is rapidly increasing. Researchers predict that the result of this population growth will be a substantial increase in the number of licensed drivers, as well as the number of miles

driven by the older population. Driving research continues to find that older drivers are overly represented in crashes which occur while passing through an intersection. These crash statistics suggest that older drivers are making critical errors while engaging in cross traffic actions, quite possibly due to age-related attention and/or cognitive deficits. However, a better understanding of the behavior and structure of these deficits is needed. Crash statistics and previous research suggest that an information processing bottleneck is occurring in older drivers. The current investigation attempted to identify whether or not this bottleneck takes place within the visual-spatial resource domain of the aging driver.

The purpose of the proposed study is to investigate the amount of mental workload placed on drivers of various age while locomoting through real-world traffic intersections. The workload of both young and old drivers will be probed while driving through straight, mid-block road sections and while turning through intersections. Two workload techniques, each requiring unique mental resources (one *verbal* and the other *visual-spatial*), will be implemented in order to tap into separate pools of attentional resources (see Figure 6). According to multiple resource theory, having drivers perform a verbal secondary task would require allocation of attention from the semantic/non-spatial domain. Previous driving research has shown mental arithmetic, a *verbal* task, to be sensitive to fluctuations in driver mental workload (L. Harms, 1986; M. Harms, 1998; & Baldwin, 1994). The *visual-spatial* task (“clock”), on the other hand, is believed to draw mental resources from the visual-spatial domain of attention. This also happens to be the primary domain of mental resources used during driving. Tapping into this

domain may provide valuable information regarding the performance of visual-spatial resources of older drivers.

Traffic intersections are highly complex situations that significantly engage the visual information processing resources of drivers. From the perspective of multiple resource theory, the increased complexity associated with intersections would result in a higher demand on visual-spatial attentional resources, especially when compared to mid-block road sections. As a result of this increased demand, it is hypothesized that drivers will take longer to perform the workload tasks when driving through intersections as compared to mid-block road sections (Hypothesis 1 - Location effect). This effect is consistent with the results found by L. Harms (1986) who compared simple, highway driving to complex, village driving. It is also hypothesized that young drivers will perform the secondary tasks faster than older drivers due to performance degradations resulting from the natural aging process (Hypothesis 2 - Age effect). Multiple resource theory would suggest that there is less spare resource capacity available for older drivers because they are allocating more attention to the primary task of driving. Because each of the secondary tasks is believed to require unique mental resources, performance on each task should differ depending on the resource demands of the environment. The fact that the attentional resources used for the *visual-spatial task* overlap more with those necessitated by the primary task of driving, suggests that there will be less spare capacity available to allocate to this task. For the *verbal task* however, the resources required are believed to come from a resource pool independent of those needed for the primary task of driving. Therefore there will be minimal resource overlap between the primary and secondary tasks. This concept supports the prediction that drivers will take longer to

perform the *visual-spatial task* while driving than the *verbal task* (Hypothesis 3 – Secondary Task effect).

Driving simulator studies have shown that as the complexity of the environment increases, older driver performance is much more degraded than that of younger drivers (Baldwin, 1994; M. Harms, 1998; Ponds et al., 1988; & Brouwer et al., 1991). It is predicted that when older drivers experience intersections (high complexity), their performance will decline more so than that of the younger drivers (Hypothesis 4 - Age x Location effect). More specifically, it is hypothesized that as the visual spatial resource demands of the environment increase during intersection travel, older driver performance will degrade significantly more when executing the *visual-spatial task* compared to the *verbal task* (Hypothesis 5 - Task x Age x Location). In accordance with MRT, this prediction is based on the idea that the *visual-spatial task* requires the same resources necessary for driving (i.e., visual spatial resources). Both the primary task of driving and the *visual-spatial task* will attempt to recruit available mental resources from the same visual spatial domain of attention, thus creating resource competition between the tasks. Because driving is always the top priority during any field-study experiment, it will always require a sufficient amount of visual-spatial resources. This will be heightened during intersection travel. Because the driving task requires such a large percentage of the available visual spatial resources, there will be an insufficient amount left over to allocate to the *visual-spatial task*. This is expected to be especially apparent in older drivers.

Method

Participants

Thirty-four participants were recruited from the Vermillion, SD area. A total of seventeen younger subjects (mean=20.6 years) ranging in age from 18-26 years were used. Younger subjects signed up to participate using the University of South Dakota's Experimatrix Online subject recruitment system. A total of seventeen older subjects (mean=72.4 years) ranging in age from 65-85 years were also used. Older subjects were recruited from various area community service organizations. All subjects had a current driver's license and recent driving experience.

Independent Variables

Four experimental variables were examined in the current field study: driver age, roadway location, secondary task, and task order. The two levels of age consisted of young drivers (18-26 years) and old drivers (65-85 years). Drivers performed a secondary task while driving through each of the following roadway locations: (1) while driving through straight mid-block sections (low complexity) and (2) while turning through intersections (high complexity). The secondary tasks included the *verbal task* (mental arithmetic) and the *visual-spatial task* (clock task). Drivers performed each of the two secondary tasks during separate experimental blocks. Half of the subjects performed the *visual-spatial task* first (task order 1) while the other half performed the *verbal task* first (task order 2).

Dependent Variable

To determine driver spare attentional capacity, reaction time measures were recorded for each of the secondary tasks. Participant reaction times (in milliseconds)

were computed by subtracting the offset time of the stimulus presentation from the onset time of the subject's vocal stimulus response (i.e. $\text{RESPONSE}_{\text{beginning}} - \text{STIMULUS}_{\text{end}} = \text{RT}_{\text{raw}}$) (Figure 8). The current research chose to use a verbal response protocol to reduce the possibility of secondary task interference with the manual steering responses demanded by driving. Previous research suggests that when measuring age differences in information processing capacity, verbal responses are a more informative indicator than manual responses (Brouwer et al. 1991). Only correct responses were used for reaction time computation.

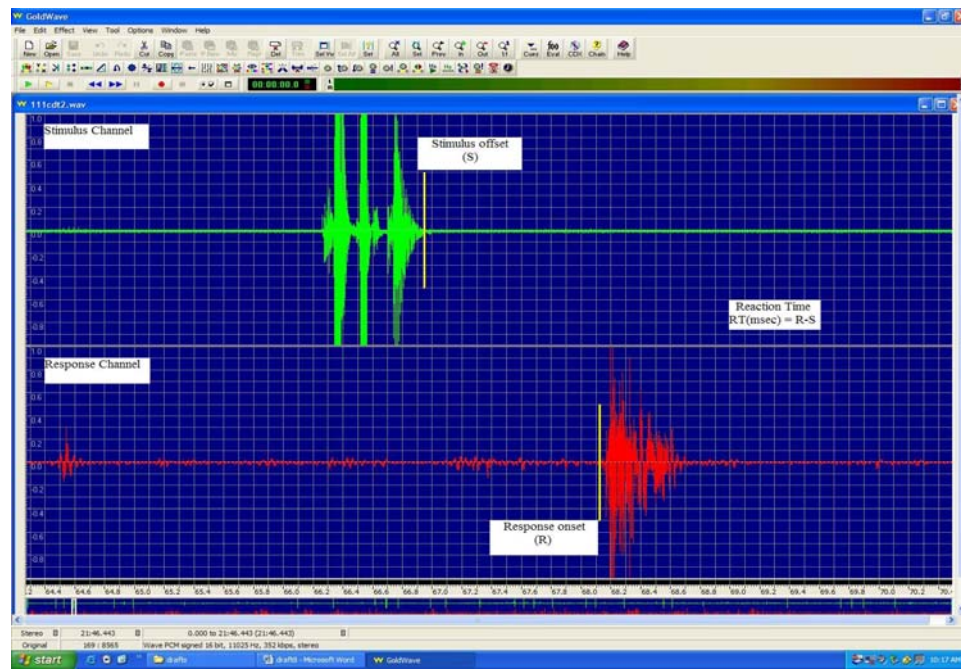


Figure 8. Screenshot of Goldwave digital audio editing software used to analyze response latency

To evaluate single vs. dual task performance, drivers performed each secondary task while actually driving (dual-task) and while remaining stationary in a parked vehicle (single-task). The primary performance measure consisted of the ratio between dual-task to single-task reaction times (i.e. $\text{RT}_{\text{DT}}/\text{RT}_{\text{ST}} = \text{RT}_{\text{ratio}}$). By forming a ratio reaction time measure, the current study was able to identify costs in performance when moving from

dual to single-task conditions. Computing ratio reaction times not only allows each subject to serve as their own control, but it also allows each of the secondary tasks to be compared on the same level. Solving mental arithmetic problems is believed to be a well-practiced task that can be performed very quickly. However, the visual imagery skills required to answer questions involving clock times was expected to initially be more foreign to subjects, and anticipated to take slightly longer. The reaction time metric commonly seen in similar driving related workload research involves computing a difference score (i.e. $RT_{DT} - RT_{ST} = RT_{\text{difference}}$) (Baldwin, 1994; M. Harms, 1998; L. Harms, 1986 & 1991). However, because there was no dispute in the current study that the visual-spatial task would take slightly longer to perform than the verbal task, simply comparing difference reaction time scores for the two tasks would be like comparing “apples to oranges” (Figure 9). Because of this the decision was made to implement a reaction time metric which consisted of the ratio between dual task performance compared to single task performance.

$RT_{\text{ratio}} = RT_{DT} / RT_{ST}$	
<u>Verbal</u> (920ms / 800ms) = 15% DT cost	<u>Visual-Spatial</u> (2070ms / 1800ms) = 15% DT cost
But, the same RTs using a difference metric inflate the effects of the Visual-Spatial task.	
$RT_{\text{difference}} = RT_{DT} - RT_{ST}$	
<u>Verbal</u> 920ms – 800ms = 120ms	<u>Visual-Spatial</u> 2070 - 1800 = 270ms

Figure 9. Comparison of reaction time metrics, RTratio vs. RTdifference

By using the ratio of dual/single task performance, both the verbal and visual-spatial tasks are able to be compared on the same level. For example, there are three

possibilities of ratio reaction time results; (1) a ratio equal to 1 would suggest no cost of dual-task loading, (2) a ratio greater than 1 would suggest a cost attributed to performing the secondary task under dual-task conditions, and (3) a ratio less than 1 would suggest faster secondary task reaction times under dual-task conditions than for single-task.

Secondary Tasks: Verbal versus Visual-Spatial

Verbal Task. This task was similar to the mental arithmetic used by L. Harms (1986 & 1991). Stimuli consisted of a series of prerecorded 2-digit numbers, ranging from 12 to 98, presented to the driver via monaural headphones. The driver's task was to subtract the smaller digit from the larger and then verbally report their computation as quickly as possible (e.g. the correct response for "68" would be "2" i.e., $8-6=2$). The probe numbers used were presented in random order. No two numbers were presented twice in a row and numbers which resulted in an answer of zero were excluded (33, 44, 55, etc...).

Visual-Spatial Task. This task was derived from the clock task used by Paivio (1978). The visual-spatial task consisted of a series of pre-recorded clock times presented to the driver via monaural headphones. Upon hearing a clock time, the driver's task was to visualize the location of this time's hour and minute hand on an imaginary analog clock face and ask themselves the following yes/no question: "Is any angle formed by the hour and minute hand less than 90 degrees" (e.g. the correct response for 10:30 would be "no" while the correct response for 9:54 would be "yes," see Figure 10). The probe times used were presented in random order with equal numbers of hour/minute hand angles which were considered less than or greater than 90 degrees. No two times

were presented twice in a row and no times were used in which the angle formed was equal to 90 degrees.

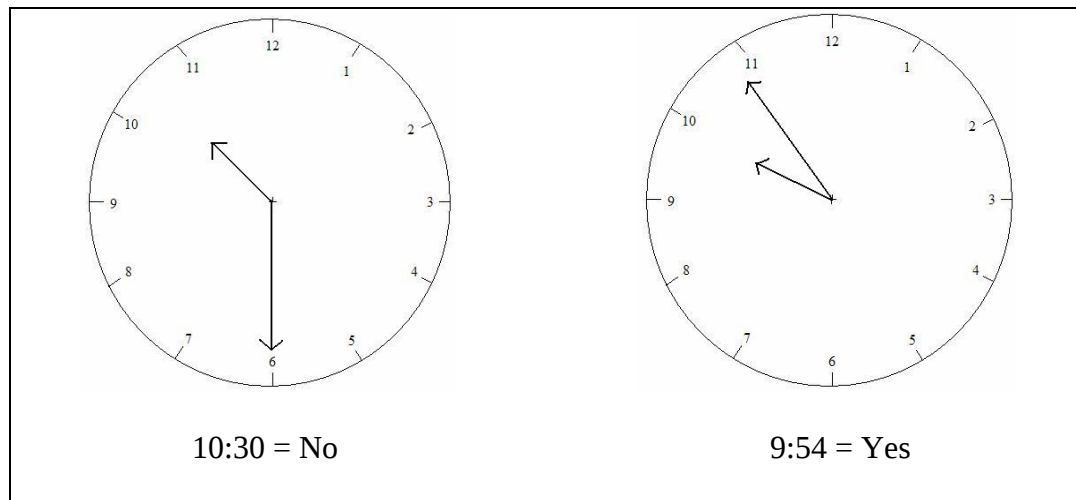


Figure 10. Examples of visual-spatial task (i.e. clock) stimuli

Apparatus and Stimuli

All participants drove USD's instrumented research vehicle (a 1998 Toyota Avalon) through two pre-determined routes around Vermillion, SD deemed similar in traffic characteristics. The order of secondary task and route were counterbalanced across subject age groups. Within each route, there were 22-24 predefined differential GPS locations per lap which were used as secondary task stimulus trigger points, half of which occurred at mid-block road sections and half which occurred at intersections (equal numbers of left and right turns). A computer in the trunk of the research vehicle continuously monitored differential GPS information at 10Hz. As a subject navigated around each route, a stimulus presentation would occur when the research vehicle entered an invisible 10m radius surrounding each predefined stimulus trigger point. The use of differential GPS information allowed all subjects to hear stimuli at essentially the same

location on each route. In the event that GPS information was not available, no stimulus was presented.

In order to present the auditory stimulus and record the verbal response, each driver was fitted with a small monaural headphone and microphone set (Figure 11). This setup allowed the audio stimulus presentation to be recorded on one audio channel and the driver's verbal response to be recorded on a separate audio channel. Both channels were recorded simultaneously using an onboard stereo VCR. These audio tracks were then digitized off-line using the Goldwave digital audio editing software (Figure 8).

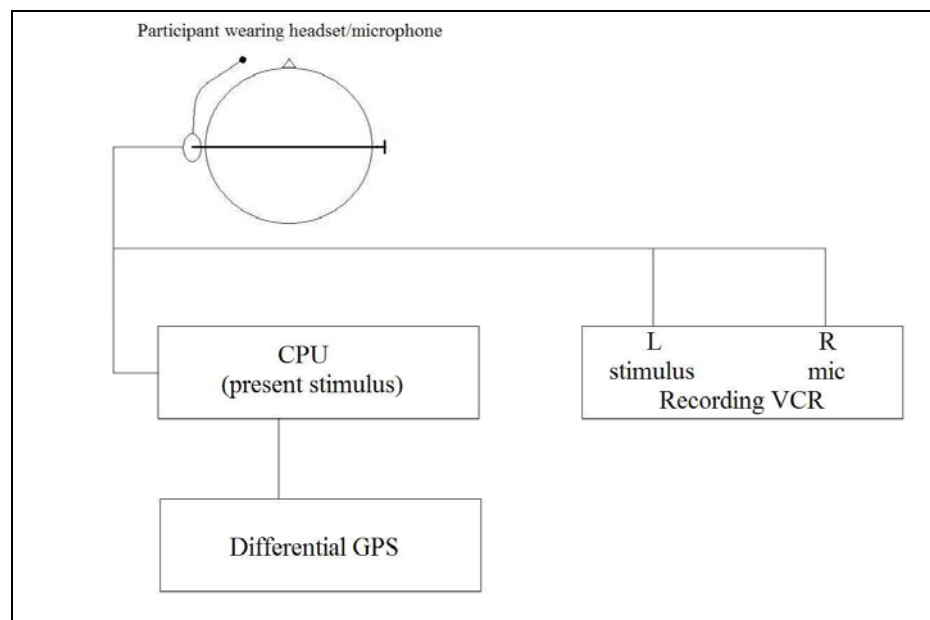


Figure 11. In-vehicle apparatus schematic

Driving Route

In order to accurately and consistently trigger the auditory secondary task stimuli at identical locations for each participant, GPS technology was used to map out two driving routes throughout Vermillion, SD. To determine this route, GPS information was

recorded a-priori by the primary investigator. This helped to ensure that all potential stimulus presentation points did not occur at GPS signal dead spots due to reasons such as excessive foliage cover. The same routes were used for all participants that took part in the study (Figure 12). Two laps around each individual route constituted successful completion of one dual-task portion of the experiment.

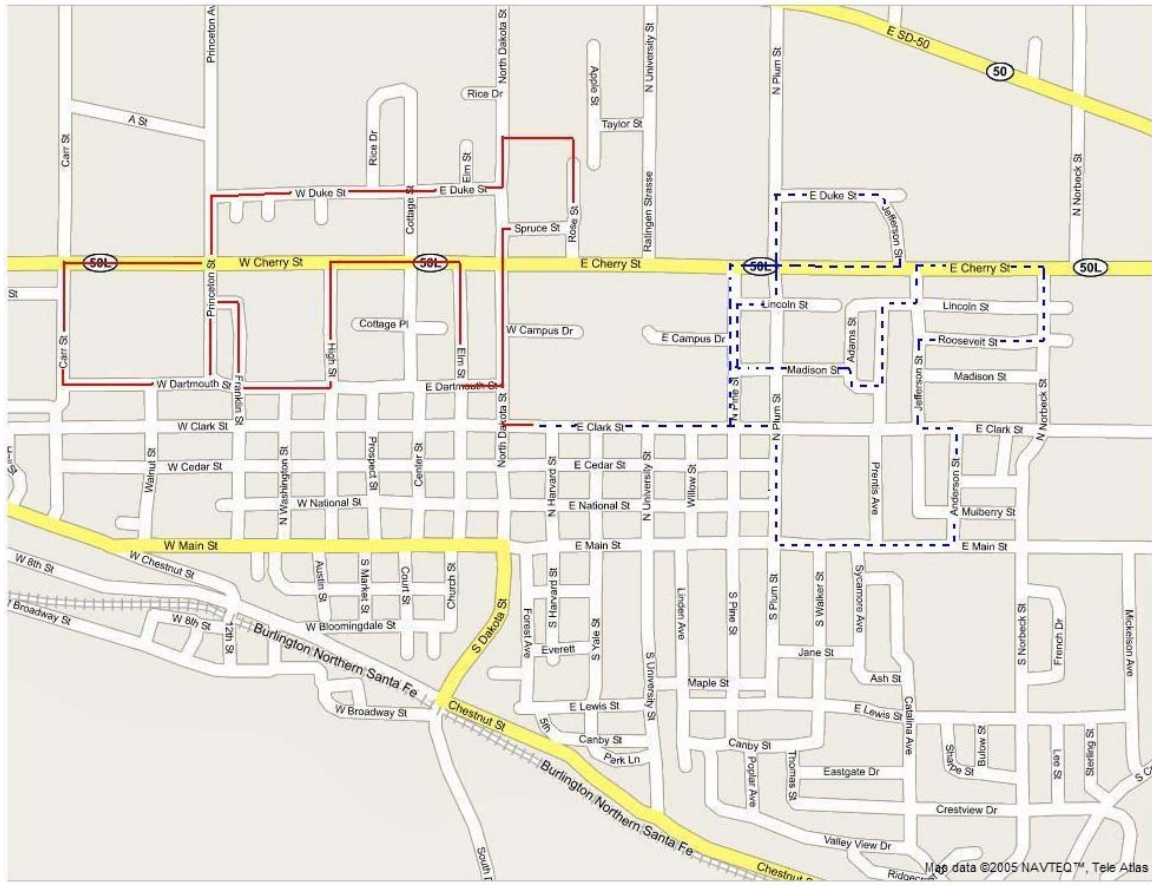


Figure 12. Experimental driving routes 1 (straight) & 2 (dashed) through Vermillion, SD; taken from <http://maps.google.com/>

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. Following the signed consent, subject visual acuity and auditory sensitivity were determined. Acuity was measured using a Bausch & Lomb orthorater. 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. Auditory sensitivity was measured using a Beltone Audio Scout portable screening audiometer. This was done to ensure that the subjects could hear the auditory stimulus presentations. Next the WAIS Information subtest was completed to evaluate gross cognitive impairment. Subjects were then asked to fill out a short form which queried their basic driving information (i.e. current driving status, length of driving experience, number of accidents in the last ten years, known driving impairments, etc...).

Following completion of the informed consent process, visual and auditory evaluation, and gross cognitive impairment screening; subjects were escorted to the research vehicle and allowed to adjust the seat and mirrors to comfortable positions. Subjects were then fitted with the monaural headphones and required to adjust the volume to a comfortable level. At this point, the experimenter introduced the first of the two secondary tasks. Following introduction, each subject was required to complete at least one block of 20 practice trials. Before any data was recorded, each subject was required to reach a criterion of no more than 2 errors in a series of 20 successive stimulus presentations. All errors were recorded by the experimenter in the back seat. Next the subject was required to complete 20 single task probes while the research vehicle was parked. Then the first dual-task (i.e. secondary tasks while driving) segment of the experiment began. At this point, the driver navigated a predetermined route throughout

Vermillion, SD via directions provided by the experimenter in the back seat. Throughout this dual-task portion of the experiment, each subject drove 2 laps around the route and received approximately 44-48 secondary task probes (44 total on route 1 and 48 total on route 2), half occurring in mid-block road sections and half occurring during intersections. Subjects then returned to the vehicle's original parking spot and were required to complete 20 more secondary task probes while the vehicle was parked. This constituted the completion of the first secondary task. At this point, subjects were allowed a short break and then an identical procedure was followed for the remaining secondary task and route.

Results

Before a proper analysis could be completed, it was necessary to verify the use of the RT_{ratio} metric. One-way ANOVAs were conducted on single task scores (averaged across single task block 1 & block 2) to determine if there were any differences between the age groups. Results revealed that for the visual-spatial task, young subjects (1.67sec) were significantly faster than older subjects (2.41sec) [$F(1,30)=7.845$, $MSE=.561$, $p<.009$]. This can be interpreted as evidence for the necessity of a RT_{ratio} metric. No such age differences were found for the verbal task (Young = .818sec vs. Old = .900sec) [$F(1,30)=.470$, $MSE=.053$, $p<.498$]. See Table 1 for single task descriptive statistics.

Table 1. Single task RT means (in seconds)

	<u>Visual-Spatial</u>			<u>Verbal</u>		
	ST block1	ST block2	ST Avg	ST block1	ST block2	ST Avg
<u>Young</u>	1.769	1.578	1.673	.834	.802	.818
<u>Old</u>	2.559	2.272	2.415	.915	.884	.900

To examine driver performance, a 2 (Age) by 2 (Task Order) by 2 (Location) by 2 (Secondary Task) split-plot design was implemented. The between-subjects variables were driver age and task order while the within-subjects variables were roadway location and secondary task. Ratio reaction time measures (RT_{DT}/RT_{STavg}) were used as the dependent variable. An $\alpha=.05$ was used for the evaluation of all planned statistical tests. Of the total 34 subjects, only the data from 32 (Young=16 & Old=16) were used in the statistical analyses. Data from one older subject was eliminated due to self-reported fatigue unrelated to the experimental protocol. To maintain equal sample sizes for each counterbalanced route/task order combination, the data from one younger subject was also eliminated. It should be noted that this subject's data had yet to be scored prior to elimination. Analysis of the data indicated the following statistically significant effects: a 2-way Age by Secondary Task effect [$F(1,28)=6.216$, $MSE=.040$, $p<.019$, $\eta^2=.06$, $power=.38$] and a 3-way Secondary Task by Location by Task Order effect [$F(1,28)=9.606$, $MSE=.011$, $p<.004$, $\eta^2=.03$, $power=.28$]. None of the main effects approached significance.

Further analysis of the significant 2-way Age x Secondary Task interaction simple effects failed to produce significance (see Table 2 for descriptives). For the visual-spatial

task, the ratio reaction time trend was in the direction predicted by hypothesis 2; in that older drivers showed slower response times than did younger drivers [$F(1,51_{\text{Satterthwaite adj}}) = 1.66$, ns , $MSE_{\text{pooled}} = .0571$, $\eta^2 = .022$] (Figure 13). Of particular surprise was the dual task performance for each age group on the verbal task [$F(1,51_{\text{Satterthwaite adj}}) = .613$, ns , $MSE_{\text{pooled}} = .0571$, $\eta^2 = .008$]. Older drivers were faster on this task than for the visual-spatial task [$F(1,28) = .825$, ns , $MSE = .040$, $\eta^2 = .008$], however the opposite trend was found for the younger drivers [$F(1,28) = 2.475$, ns , $MSE = .040$, $\eta^2 = .023$]. For these younger drivers there was practically no cost of dual-tasking for the visual-spatial task, but an unexpected dual-task cost for the verbal task. In fact, the data suggest that the younger driver response times for the verbal task ($M = 1.125\text{sec}$) were practically equivalent to the response times on the visual-spatial task for older drivers ($M = 1.123$).

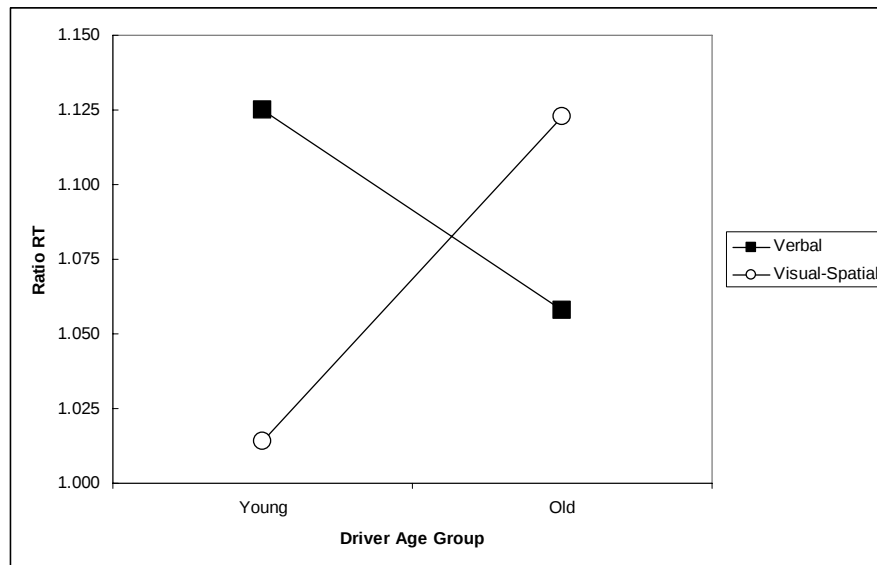


Figure 13. Significant 2-way Age x Secondary Task Interaction

Table 2. RTratio descriptive statistics for 2-way Age x Secondary Task

<u>Age Group</u>	<u>Secondary Task</u>	<u>Mean</u>	<u>SD</u>
<u>Young</u>	<u>verbal</u>	1.125	.168
	<u>visual-spatial</u>	1.014	.164
<u>Old</u>	<u>verbal</u>	1.058	.150
	<u>visual-spatial</u>	1.123	.176

Further analysis of the 3-way Task x Location x Task Order interaction yielded a single significant simple effect. Consistent with hypothesis 5, drivers who performed the visual-spatial task first in the experiment (i.e. Task Order 1) had significantly longer response times when navigating through intersections as compared to mid-block road sections (see Figure 14) [$F(1,55_{\text{Satterthwaite adj}})=5.73$, $MSE_{\text{pooled}}=.011$, $\eta^2=.015$]. However in the second half of the experiment for these same drivers, there was no significant effect of location for the verbal task [$F(1,55_{\text{Satterthwaite adj}})=1.0$, ns , $MSE_{\text{pooled}}=.011$, $\eta^2=.003$]. For those drivers who performed the verbal task first in the experiment (i.e. Task Order 2), response times were once again slower when performing the verbal task while traveling through intersections compared to mid-block road sections, however this effect was not significant [$F(1,55_{\text{Satterthwaite}})=2.36$, ns , $MSE_{\text{pooled}}=.011$, $\eta^2=.006$].

**Table 3. RTratio descriptive statistics for 3-way Task x Location x Task Order
(1st tasks completed are in bold)**

<u>Secondary Task</u>	<u>Location</u>	<u>Task Order 1</u>		<u>Task Order 2</u>	
		(VS task 1 st)		(V task 1 st)	
		<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>
<u>Verbal</u>	<u>Mid-block</u>	1.124	.213	1.050	.078
	<u>Intersection</u>	1.086	.238	1.107	.151
<u>Visual-Spatial</u>	<u>Mid-block</u>	1.014	.214	1.104	.183
	<u>Intersection</u>	1.102	.186	1.053	.184

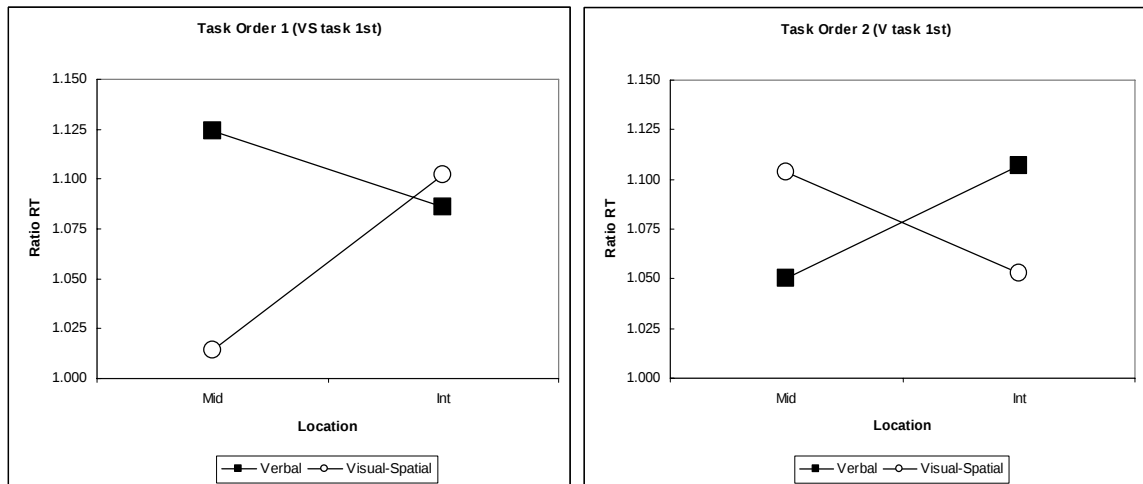


Figure 14. Significant 3-way Task x Location x Task Order

Post Hoc Analyses. With regard to the significant 2-way Age by Task interaction, no logical conclusion can be provided to explain why younger drivers exhibited slower response times for the verbal task compared to the visual-spatial task (Figure 13). Review of the workload and driving literature predicts that younger drivers should show little to no cost when concurrently driving and performing the verbal task. In an attempt

to gain an understanding as to why these results were obtained, post hoc analyses were conducted.

A priori it was decided that a combined single task score (i.e. average across single task blocks 1 & 2) would be used as the baseline measure to which all dual task performance would be compared. However, inspection of each driver age group's single task performance revealed faster performance in the second block of single task probes compared to the first block (Table 1). This suggests that the use of an average single task value in the RT_{ratio} metric might not have been providing a stable baseline measure of performance. Without a stable baseline, the ratio metric used to evaluate reaction times would not truly reflect the spare attentional resource capacity of drivers.

To evaluate the stability of this metric, one-way repeated-measures ANOVAs were conducted on single task performance for each age group. For the Young subjects, performance on the visual-spatial task was significantly faster during the second block of single task probes (1.57sec) than during the first block (1.76sec) [$F(1,15)=7.138$, $MSE=.041$, $p<.017$]; whereas no significant differences were found for the verbal task [$F(1,15)=1.968$, $MSE=.004$, $p<.181$]. For the Older subjects, performance on the visual-spatial task was also faster during the second block of single task probes (2.27sec) compared to the first block (2.55sec), however this effect was only marginally significant [$F(1,15)=4.010$, $MSE=.164$, $p<.064$]. Older subjects did not show any performance differences for the verbal task [$F(1,15)=1.034$, $MSE=.007$, $p<.325$]. These findings suggest that there is merit in reanalyzing the data using a different ratio metric than the proposed "pooled" single task denominator. Because both age groups exhibited faster reaction times during the second block of single task probes, the decision was made that

for both secondary tasks the denominator of the RT_{ratio} would consist of only the second block of single task reaction times (i.e., RT_{DT}/RT_{ST2}).

To examine driver performance, a 2 (Age) by 2 (Task Order) by 2 (Location) by 2 (Secondary Task) split-plot design was conducted. The between-subjects variables were driver age and task order while the within-subjects variables were roadway location and secondary task. In this analysis, the dependent variable was now comprised of the metric $RT_{ratio}=RT_{DT}/RT_{ST2}$. As in the initial analysis, only the data from 32 subjects (Young=16 & Old=16) were analyzed. Results once again supported the existence of both a 2-way Age by Secondary Task effect [$F(1,28)=5.199$, $MSE=.059$, $p<.030$, $\alpha=.035$ using a Bonferroni correction] and a 3-way Secondary Task by Location by Task Order effect [$F(1,28)=10.802$, $MSE=.012$, $p<.012$, $\alpha=.015$ using Bonferroni correction]. The fact that the same effects were found using two different ratio metrics as the dependent variable lends evidence to the claim that these results are not simply a chance occurrence. However, the figures provided by this analysis offer a more clear explanation of the data and as a result, all interpretations and discussions from this point will refer to this post hoc analysis.

Further analysis of the 2-way Age by Secondary Task interaction once again failed to produce any significant simple effects. Consistent with hypothesis 2, Figure 15 shows that the older drivers took longer to perform the visual-spatial task while driving than did younger drivers [$F(1,52_{Satterthwaite\ adj})=1.55$, ns , $MSE_{pooled}=.0813$, $\eta^2=.02$]. As predicted, older drivers took longer to perform the visual-spatial task while driving compared to the verbal task [$F(1,28)=2.508$, ns , $MSE=.041$, $\eta^2=.02$]. Once again, the younger drivers unexpectedly took slightly longer to perform the verbal task while

driving compared to the visual-spatial task [$F(1,28)=.491$, ns , $MSE=.021$, $\eta^2=.005$], however this difference is substantially reduced from that shown using the *a priori* RT_{ratio} metric (RT_{DT}/RT_{STavg}) in the initial analysis (see Figure 12). Figure 15 shows that the effects of this 2-way interaction are housed primarily within the differences between young and old drivers on the visual-spatial task, as well as in the differences between older driver performance on each of the tasks. It appears that using a more stable baseline in the RT_{ratio} metric affords a more logically interpretable analysis.

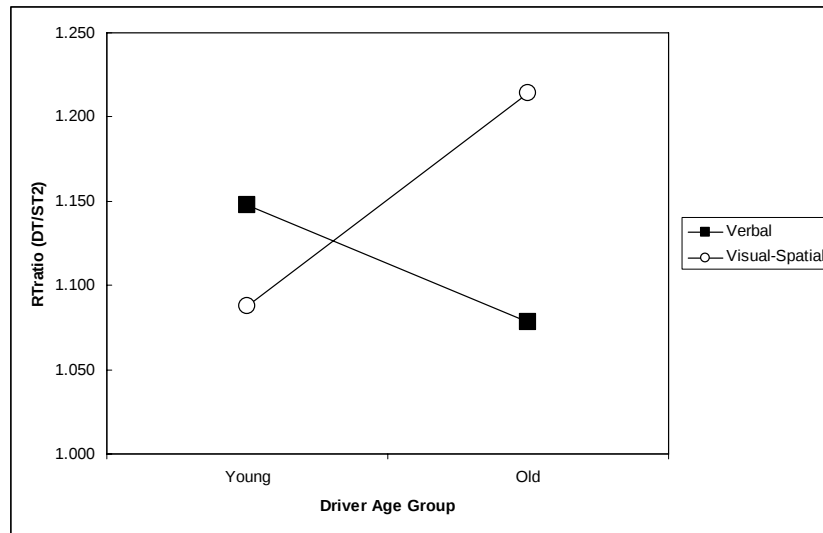


Figure 15. 2-way interaction using RTratio (DT/ST2)

Table 4. 2-way descriptive statistics using RTratio(DT/ST2)

<u>Age Group</u>	<u>Secondary Task</u>	<u>Mean</u>	<u>SD</u>
<u>Young</u>	<u>verbal</u>	1.148	.176
	<u>visual-spatial</u>	1.088	.205
<u>Old</u>	<u>verbal</u>	1.078	.194
	<u>visual-spatial</u>	1.214	.222

Further analysis of the 3-way Task by Location by Task Order interaction yielded two significant simple effects (Figure 16). Consistent with hypothesis 5, drivers who performed the visual spatial task first in the experiment (i.e. Task Order 1) took significantly longer to respond when driving through intersections compared to mid-block road sections [$F(1,55_{\text{Satterthwaite adj}})=6.875$, $MSE_{\text{pooled}}=.0112$, $\eta^2=.01$]. The same trend was seen for those subjects who performed the verbal task first, however this effect was not significant [$F(1,55_{\text{Satterthwaite adj}})=2.23$, *ns*, $MSE_{\text{pooled}}=.0112$, $\eta^2=.004$]. The fact that drivers took longer to perform each task when probed during intersection travel compared to mid-block travel, but only for that task which was performed first in the protocol is interesting. This suggests that subjects might have been using their increasing familiarity with the experimental protocol to their advantage. Also for those drivers who performed the verbal task first (i.e. Task Order 2), response times were significantly faster during mid-block travel compared to response times for the visual-spatial task during mid-block travel [$F(1,38_{\text{Satterthwaite adj}})=6.69$, $MSE_{\text{pooled}}=.035$, $\eta^2=.04$]. The fact this difference was significant for the Task Order 2 group but not for the Task Order 1 group could be interpreted as evidence that fatigue was influencing driver response times. These ideas are elaborated upon further in the discussion section.

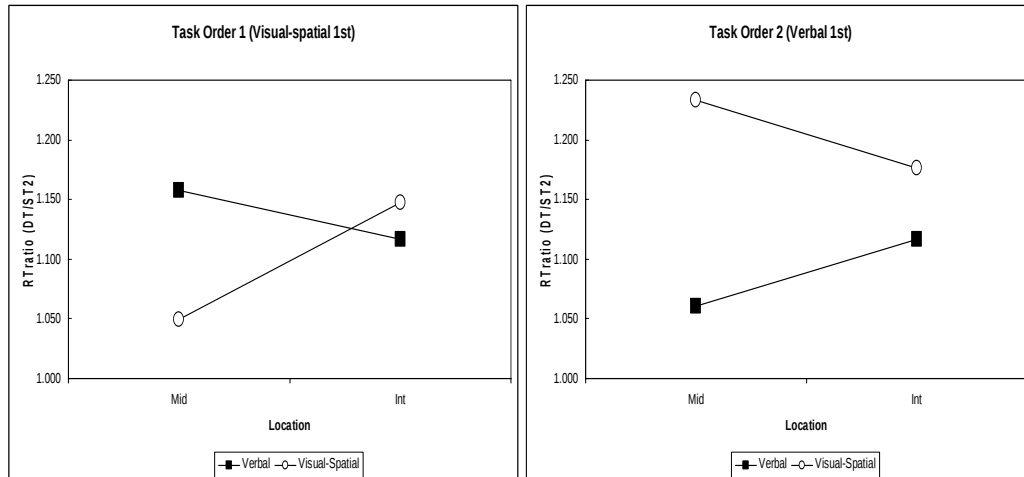


Figure 16. 3-way interaction using RRatio (DT/ST2)

Discussion

Overall these results were somewhat inconsistent with previous driving and age-related workload research. Previous laboratory experiments which utilized a mental arithmetic secondary task found a cost of dual-tasking for older drivers in high vs. low complexity scenarios while no such effect was found for young drivers (Baldwin, 1994 & M. Harms, 1998). The same mental arithmetic subsidiary task was also found to be sensitive, yet non-intrusive during real world driving conditions (L. Harms, 1986 & 1991); however these studies did not investigate age differences. Inconsistent with previous research was the finding that young drivers showed more of a cost of dual-tasking for the verbal task (i.e. mental arithmetic), but practically no cost for the visual-spatial task. This result was completely unexpected given that each age-related workload study reviewed prior to experimentation which used a verbal task consistently showed little to no dual task cost for young drivers, even across varying levels of driving complexity (Baldwin, 1994; M. Harms, 1998; Ponds et al., 1988; Brouwer et al., 1991).

At this point, no logical conclusion can be reached as to why young drivers had slower response times when responding to the verbal task compared to the visual-spatial task. Further research is needed to validate the sensitivity of verbal secondary tasks under real world driving conditions.

For the older driver age group, dual task performance was in line with what would be predicted from previous age-related workload research (Baldwin, 1994; M. Harms, 1998; Ponds et al., 1988; Brouwer et al. 1991), as well as from the perspective of Multiple Resource Theory. Older drivers showed a greater cost of dual-tasking for the visual-spatial task (i.e. clock) than for the verbal task (i.e. mental arithmetic). This suggests that there was more resource competition among the primary task of driving and the visual-spatial task compared to the verbal task. Because both the visual-spatial task and the driving task require resources from the same limited capacity visual-spatial resource pool, these attentional resources have to be allocated appropriately. Theoretically, costs of dual-tasking for the verbal task were not as noticeable because this task is drawing mental resources from an attentional pool independent of those required by the driving task.

Surprisingly, there were no significant interaction effects involving both age and stimulus location [mid-block (low complexity) vs. intersection (high complexity)]. Previous in-house research (M. Harms, 1998) cited difficulties in operationally defining low and high complexity driving scenarios under real-world conditions (M. Harms' study compared rural highways vs. in-town roadways). However for the current study, it was believed that these difficulties had been remedied by presenting stimuli during the highly dynamic act of intersection navigation. While navigating intersections, not only does the

driver's visual field quickly change orientation by at least 90°, but this action also involves the integration of both manual steering and acceleration control movements for successful completion. Most would argue that the attentional demands required during this portion of driving are much more complex than those demanded during mid-block travel (i.e. while driving straight on a roadway at a relatively consistent speed). The data however did not support this claim. It should be noted that the older drivers who participated can be considered a "cream of the crop" type sample. All were Emeritus faculty with not only extensive educational experience, but also many years of driving experience within the community of Vermillion, SD. A plausible, yet unlikely, conclusion for the current study's inability to establish a sensitive secondary task relative to varying degrees of stimulus location complexity might simply be explained by the extent of familiarity with the experimental driving routes used. However a more logical, data driven explanation is simply that the current secondary tasks were not sensitive to establishing age differences under real world driving conditions.

The fact that older drivers were not different from younger drivers with respect to mid-block versus intersection travel might also have potential implications. The use of subsidiary task probes has yet to prove reliable sensitivity to age differences under real world conditions. Perhaps it isn't an issue of sensitivity, but rather specificity. In the driving simulator, significant age differences are only found when drivers are pushed to their absolute limits of driving ability (Baldwin, 1994 & M. Harms, 1998). In these instances, practically all of an older drivers attentional resources are focused on the difficult driving task and little are left over for the subsidiary task. But when the research moves out into the field, no such age differences are apparent. It might be the case that

everyday driving around a town of 10,000 residents is not sufficiently complex to require a substantial portion of a driver's attention. In this situation, ample spare resources are still available to be appropriately allocated to tasks other than driving. It could also be the case for a large number of older drivers their ability to quickly and accurately process visual-spatial information is not as handicapped as crash statistics lead us to believe.

With regard to these healthy older drivers, the use of subsidiary tasks as an indicator of spare resource capacity may simply not be an informative tool. However it might very well be the case that we do not begin to see any impairment until the onset of certain age-related cognitive diseases, such as dementia. Using subsidiary tasks might be most informative when applied specifically to certain cognitive impairments directly related to the aging process, as opposed to simply an indicator of differences between driver age groups. It may prove useful for future research to investigate how the performance of healthy older individuals on subsidiary tasks compares to those who are suspected to be developing some form of gross cognitive impairment, and even those who have been diagnosed with more fully developed cognitive impairments, although not necessarily under real world driving conditions. From this perspective, implementation of secondary task methodology would focus on identifying which drivers have insufficient attentional resources available, regardless of age.

The results of the significant 3-way Task x Location x Task Order interaction yield somewhat interesting results when approached from the perspective of the current study's secondary task implementation. To maximize experimental control under real-world driving conditions, differential GPS information was used to trigger stimulus probes at exact, discrete locations on each driving route. According to the data, the

secondary task performed first in the experimental protocol (either verbal or visual-spatial, but only significant for the visual-spatial task) exhibited slower response times during intersection travel compared to mid-block travel (see Figure 15). The most logical explanation for this is as follows: During the first half of the experiment, regardless of driver age, subjects were in the process of familiarizing themselves with the experiment as a whole. Drivers were getting used to driving an unfamiliar vehicle, wearing a headset while driving, driving with an experimenter in the back seat, as well as becoming more familiar with navigational instructions provided by the experimenter. The primary task of driving, coupled with the unfamiliar experimental situation demanded a sufficient amount of available mental resources leaving little spare capacity to be attributed to the secondary tasks. At this point in the experiment, the data suggest that the secondary tasks were successful in differentiating between low and high complexity driving situations, independent of driver age. However, by the second half of the experiment it appears that subjects were able to anticipate and utilize the discrete stimulus probe locations to efficiently switch between the primary and secondary tasks. In each task order condition regardless of secondary task, subjects now exhibited faster response times during the more complex act of intersection travel compared to mid-block travel. This suggests that the drivers were using the approaching intersection as a cue for an upcoming stimulus probe. This predicative quality afforded by intersections allowed drivers, both young and old, to utilize a highly efficient switching strategy between the primary task of driving and secondary task demands (see Figure 17). This was not the case for mid-block travel most likely because the time and location of potential stimulus probes was almost completely unpredictable; hence, task priority could not be switched until a stimulus

actually occurred. For drivers in the second half of the experiment it appears that using discrete probes which were intended to increase experimental control may have actually reduced the effects of task loading during intersection travel, but not during mid-block travel.

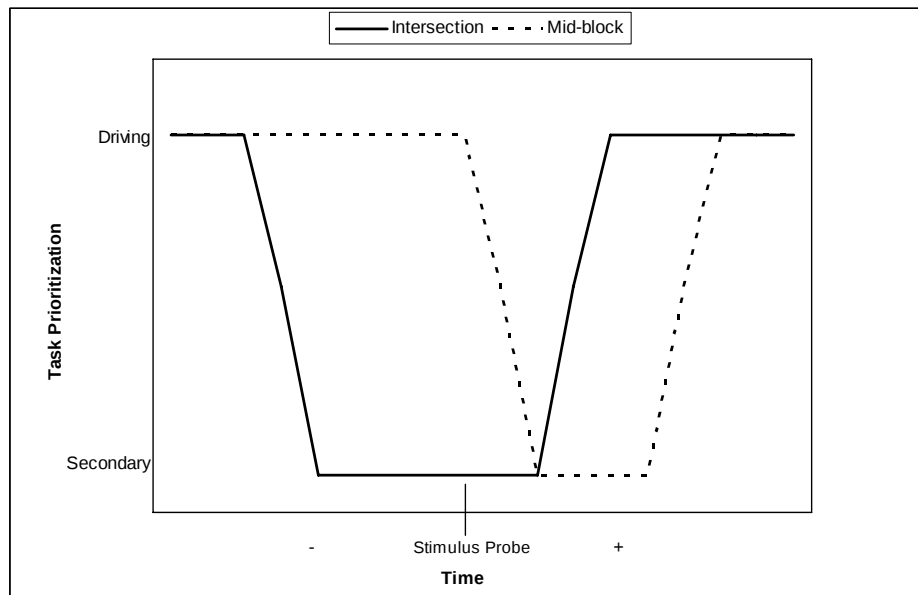


Figure 17. Use of intersections as cue for secondary task preparation

The fact that this effect was independent of driver of age suggests that both young and old drivers were continuously adjusting their behavior as they gained more experience with the experimental protocol. Secondary task performance during the first and second half of the experiment shows that drivers were always learning something about their environment. Both driver age groups were able to use the information afforded by the discrete stimulus probes at intersections. This finding could be interpreted as support for an “adaptive organism” argument. The data suggests that the information processing capabilities for the current sample of healthy older drivers adapted to the environmental demands in a manner indistinguishable from younger

drivers. Future research might benefit from establishing if and when this ability to adapt to a continuously changing environment fluctuates as a result of the aging process.

For the Task Order 2 group, the significant difference between secondary tasks at mid-block probes suggests that fatigue might have also been influencing response times. For these drivers the first half of the experiment involved performing the verbal task, which unarguably is the less effortful of the two secondary tasks. By the second half of the experiment, these drivers might have begun to experience some slight effects of fatigue. Coupled with the fact that they then had to perform the more difficult visual-spatial task appears to have exacerbated this fatigue, the result of which was slower response times at only mid-block probes (see Figure 15). It should also be noted that these drivers still had faster response times at intersection probes. This is interpreted as evidence for the previous claim that intersections were utilized as a tool for stimulus prediction, but only in the second half of the experiment. Fatigue might also have been a factor for drivers in the Task Order 1 group. For these drivers, response times were slower for the second task completed (i.e. verbal task) compared to the first task completed (i.e. visual-spatial task) at mid-block probes. However this difference was not as apparent most likely due to the fact that the more effortful visual-spatial task had already been completed. Although these drivers had less attentional resources available for the second task completed, because this task was considered less effortful it was not as influenced by fatigue as was the visual-spatial task for drivers in the Task Order 2 group. From the perspective of Multiple Resource Theory, it appears that for drivers in both task order groups, there was less overall attention available to recruit during the second half of the experiment.

The results of this study are important to the workload literature in the sense that they provide information regarding the potential sensitivity of discrete versus continuous subsidiary task probes under real world conditions. The fact that the current results were not able to identify age differences under varying degrees of driving complexity for each of the subsidiary tasks may have been due to the use of discrete stimulus probes. Use of discrete probes may have allowed subjects to potentially predict both when and where a stimulus would occur. It appears that in the current study, once drivers became highly familiar with the experimental protocol the use of discrete stimulus probes afforded a highly efficient task switching strategy when approaching intersections; and after a point did not provide a true indication of the availability of different types of spare mental resources. Previous research which found a verbal, mental arithmetic task to be sensitive to low vs. high driving complexity conditions did so using relatively continuous task probes (L. Harms, 1986 & 1991; M. Harms, 1998; Baldwin, 1994). Stimulus probes were presented every few seconds instead of at specific points in the driving environment. Future research which intends to utilize a subsidiary task as an indicator of spare mental capacity should employ a methodology which is continuous in nature. Doing so would require subjects to constantly divide attentional resources between the primary and subsidiary task. Theoretically, as the primary task requires more and more resources there would be less spare attentional resources to allocate to the subsidiary task.

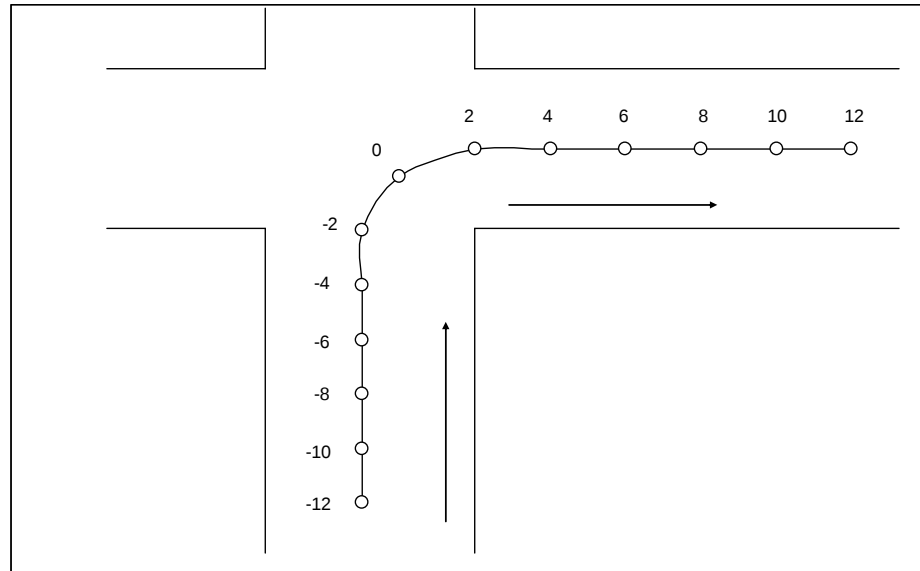


Figure 18. Possible use of continuous stimulus probes during intersection travel (probes every 2 seconds with 0 representing the apex of the turn)

Given the task complexity manipulation of the current study (intersections vs. mid-blocks), Figure 18 portrays how such a continuous stream of stimulus probes could be implemented. For example, every two seconds drivers would be given a stimulus to which they must respond as quickly as possible. In this scenario, drivers would be required to constantly divide their attention appropriately between the primary task of driving and the secondary task. Based on the reaction time measures obtained for both tasks used in the current study it does not appear that they would be appropriate for the proposed continuous probe paradigm. However a task commonly used in the focal attention literature might have potential implications for real world driving research. This task is known as the *N-back task* (McElree, 2001). Typically, digits are presented sequentially on a computer monitor and subjects are instructed to indicate whether or not the current digit being displayed is the same as the digit recently shown *N* positions prior. Examples of a few variations of the N-back task are shown in Table 5. This task not only

loads attentional resources, but is also able to be completed quickly. It appears that such a task might be appropriate for a continuous probe paradigm similar to that depicted in Figure 18. However because driving is primarily a visual-spatial task, it would be necessary to alter this task so that stimuli were not presented visually. The most logical remedy would involve presenting the stimuli auditorily, similar to the presentation method outlined in the procedure section of the current study. Future research which intends to use fluctuations in spare resource capacity as an indicator of driver mental workload might benefit substantially from using the *N-back task*, or similar continuous tasks.

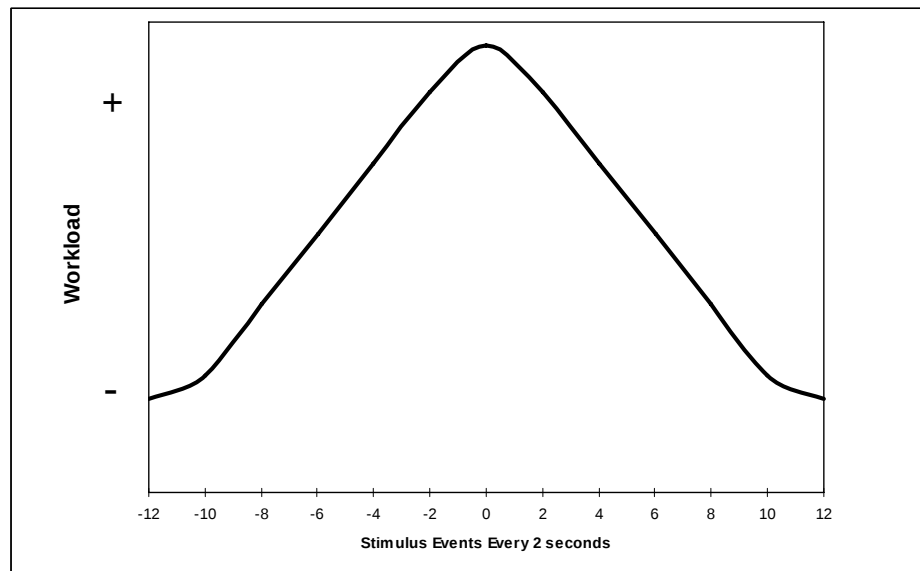
Table 5. Examples of the N-back task with correct responses

Stimuli	3	4	4	2	4	6	6	4	6
N-1	...	No	Yes	No	No	No	Yes	No	No
N-2	...	...	No	No	Yes	No	No	No	Yes
N-3	...	...	...	No	Yes	No	No	Yes	Yes

Given the sheer complexity of intersection navigation, one could envision that driver workload would fluctuate as a function of distance from an intersection (see Figure 19). There are a vast number of curves that could successfully explain these changes in workload and it must be pointed out that this figure only depicts a single potential explanation.

In this figure, workload levels are relatively low until the driver begins to move closer to the apex of a turn. Workload is thought to increase as a result of the necessary allocation of attentional resources to an increasing number of tasks (i.e. planning the turn, checking for pedestrians, checking for other vehicles, etc...). It is at the intersection apex

where drivers would be expected to experience maximum workload. At this point, attention must not only be distributed to each of those tasks just mentioned, but these tasks must then be integrated with the necessary manual inputs required to safely control the vehicle. Then, as drivers travel through the intersection workload would begin to once again decrease. Given this description of the relationship between workload and intersection travel, the use of continuous stimulus probes might help in determining if such a relationship actually exists. This would allow us to establish where the peak loading of workload actually occurs during the act of intersection navigation. Such use of continuous probes would provide us with not only response latencies as a function of location relative to the intersection, but also with an indication of workload amplitude relative to this intersection.



**Figure 19. Mythical relationship between intersections and workload
(0 represents the apex of the intersection)**

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Appendix A. Informed Consent Form

Informed Consent
The University of South Dakota
Vermillion, SD 57069

TITLE: Age-related variations in driver information processing capacity
PROJECT DIRECTOR: Ben J. Schlorholtz
Contact Info: 605-677-5295 or bschlorh@usd.edu
Department: Department of Psychology, Human Factors

STATEMENT OF RESEARCH

It is a basic ethical principle that a person who is to participate in research must give his or her informed consent to such participation. This consent must be based on the understanding of the nature and risks of the research. This document provides information important for this understanding. Research projects include only participants who choose to take part. Please take your time to make this decision. If at any time you have questions please ask.

WHAT IS THE PURPOSE OF THIS STUDY?

You are invited to be in a research study whose purpose is to further understand the characteristics of how 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 successfully passed a brief Vocabulary subtest of the Wechsler Adult Intelligence Scale, (3) have a minimum visual acuity of 20/40, (4) have not been involved in more than 1 vehicular accident in the past two years, (5) are covered by personal medical insurance or Medicare, and (6) have met certain age-related eligibility criteria.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately forty (40) people will take part in this study.

HOW LONG WILL I BE IN THIS STUDY?

Your participation in the study will last approximately 2 hours. The experiment will begin within Heimstra Human Factors Laboratory at the University of South Dakota, and then follow-up with driving the University's research vehicle around the city of Vermillion.

WHAT WILL HAPPEN DURING THIS STUDY?

You will first be given a brief description of the project and complete the informed consent procedure if they agree to participate. Visual and auditory health will then be checked using standard visual acuity and auditory sensitivity procedures. Mental awareness will be assessed via administration of a brief vocabulary sub-test. Next, you will be seated in the USD instrumented research vehicle (a 1998 Toyota Avalon) and allowed to adjust the seat and mirrors to ensure comfortable operation. You will then be

introduced to a simple reasoning task which you will be asked to perform while both sitting in a parked car and while driving. Once comfortable with the task, you will then begin driving around Vermillion via directions provided by the experimenter in the back seat. Following the completion of approximately 80 trials, you will return to the original parking lot and will then be introduced to a second reasoning task. Once comfortable with this task, you will once again begin driving around Vermillion via directions provided by the experimenter. Following the completion of approximately 80 more trials, you will return to the original parking lot and be debriefed regarding the experimental hypotheses of the study. If at any time you wish to quit the study for any reason whatsoever, the experiment will be stopped and you will be allowed to leave. Be aware that the experimental session will be recorded to a VHS tape. This tape will contain possible identifiable information in the form of the vocal responses made for each task. It should be noted that this information will only be accessed by the Primary Investigator and his Academic Advisor. Once the necessary information is extracted from these tapes, their audio and video data will be erased so that participant confidentiality is upheld.

WHAT ARE THE RISKS OF THIS STUDY?

As is the case whenever one drives an automobile in traffic, there is a risk that personal injury or death could result from an automobile crash while participating in this study. However, previous research and the past experience of the experimenters indicate that the chance you will be involved in a crash is no greater than that you would encounter during normal, everyday driving.

In the event of a vehicular accident, expenses related to the damage of the research vehicle, other property and the medical expenses of other involved drivers, their passengers or pedestrians will be covered under the State of South Dakota's self-insurance program. However, this liability coverage should not be considered as a replacement for personal medical insurance to cover potential injuries to yourself. If you are not covered by personal medical insurance and/or Medicare you should not participate in this study.

If you are injured or become ill from taking part in this study, 24-hour emergency medical treatment is available at Sioux Valley Vermillion Medical Center. The University of South Dakota will provide compensation for research related injury if it is proven to be the direct result of negligence by a University of South Dakota employee. No other funds have been set aside to compensate you in the event of an injury.

WHAT ARE THE BENEFITS OF THIS STUDY?

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 increase our understanding regarding the limits of how attention is processed and distributed while driving. Such information may be useful for improving the design of highways, vehicles, and driver screening tests.

ALTERNATIVES TO PARTICIPATING IN THIS STUDY

The participant's alternative is simply to not participate.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will not incur any costs for being in this research study.

WILL I BE PAID FOR PARTICIPATING?

You will not be paid for being in this research study. There will however be class credit points awarded for those recruited from psychology classes at USD. Students expecting class credit in exchange for their participation should be sure to identify the specific class to which they want the credit to apply using Experimetrix Online.

WHO IS FUNDING THE STUDY?

The University of South Dakota and the research team are receiving no payments from other agencies, organizations, or companies to conduct this research study.

CONFIDENTIALITY

The records of this study will be kept private to the extent permitted by law. In any report about this study that might be published, you will not be identified. Your study record may be reviewed by the USD Compliance Office and the University of South Dakota Human Subjects Committee.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by storing all results of visual acuity screening and performance data electronically. This data will also be coded by anonymous sequence number and gender only. Informed consent documents will be the only project documents containing identifying information and will be stored in a locked file cabinet in the office of the principle investigator.

If we write a report or article about this study, we will describe the study results in a summarized manner so that you cannot be identified. Any presentation or publication data will be in the form of anonymous group statistics only.

IS THIS STUDY VOLUNTARY?

Your participation is voluntary. You may choose not to participate or you may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Your decision whether or not to participate will not affect your current or future relations with the University of South Dakota.

CONTACTS AND QUESTIONS?

The researchers conducting this study are Project Director: **Ben Schlorholtz** and Advisor: **Professor Frank Schieber**. You may ask any questions you have now. If you have questions later, you may contact **Ben Schlorholtz** at (605) 677-5295 or **bschlorh@usd.edu** during the day. You may also contact **Professor Frank Schieber** at (605) 677-5295 or **schieber@usd.edu** during regular business hours.

If you have questions regarding your rights as a research participant, or research related injury you may contact the **University of South Dakota Institutional Review Board** at **(605) - 677-6184**.

General information about being a research participant can be found by clicking “Information for Research Participants” on the Research Compliance web site <http://www.usd.edu/oorsch/compliance/>.

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. You will receive a copy of this form.

Participant's Name: _____

Signature of Participant

Date

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

Signature of Person Who Obtained Consent

Date