# Assessment of Age Differences in Mental Workload while Driving using Verbal versus Visual-Spatial Subsidiary Tasks

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Age differences in mental workload demands imposed by driving were investigated using a dual-task paradigm. Two subsidiary tasks, thought to tax separate attentional resource pools (verbal versus visual-spatial), were compared. Dual-task cost ratios [$RT_{dual\text{-}task}/RT_{single\text{-}task}$] using each subsidiary task were collected from young (mean age = 20.6) and older (mean age = 72.4) drivers at midblock locations (low driving task load) and while approaching intersections (high driving task load). Consistent with expectations, age differences were exacerbated on the visual-spatial subsidiary task. However, the expected workload increase at intersections (relative to midblock locations) was not observed. Instead, a more complex 3-way interaction of roadway location with subsidiary task and task order was obtained. This pattern of results has important implications with regard to the following two issues: 1) the use of discrete versus continuous subsidiary task probes during real world driving, and 2) the sensitivity and specificity of subsidiary task approaches in the assessment of age-related cognitive deficits and their potential impact upon driving performance.

## Introduction

Older drivers, as a group, demonstrate a higher crash rate per mile of exposure than young and middle-aged drivers (Cerrelli, 1989). Evidence has progressively accrued which suggests that much of this increased crash risk can be attributed to age-related reductions in the efficiency of visual information processing (Owsley, et al., 1998; Schieber, 2000).

Several studies conducted in our labs have used secondary task techniques in an attempt to quantify the age-related increase in the mental workload demands of driving that would be expected to accompany a general decline in information processing efficiency. Baldwin and Schieber (1995) demonstrated age-related increases in response time on a mental arithmetic secondary task in a low-fidelity driving simulation study. However, Schieber and Harms (1998) were unable to replicate a robust age-difference using the same secondary task in a real-world follow-up study of driving performance. Retrospective analysis suggests several factors that may have reduced the sensitivity of the protocol used in this field study. First, the arithmetic task employed as the index of mental workload can be classified as a *verbal* task; and, hence, may not have drawn resources from the *visual-spatial* domain previously implicated as the primary source of age-related increases in driver crash risk (e.g., Owsley et al., 1998). Second, the manipulation of driving task load may not have been effective considering the relatively low demands imposed across experimental conditions (i.e., rural highway versus rural village driving – representing, low and high demand, respectively).

The current investigation was designed in an attempt to remedy some of the shortcomings of our previous field study of age differences in the mental workload demands of real-world driving. In addition to using the *verbal* subsidiary task (i.e., mental arithmetic), we also implemented an alternative secondary task condition which required the participants to perform discrete *visual-spatial* judgments while driving. Next, we used a highly accurate differential GPS system to deliver our secondary task probe stimuli either at midblock locations (low driving demand) or at approaches to intersections where a turn was required (high driving demand). It was hypothesized that: (1) age differences in dual-task cost ratio measures of mental workload would be significantly greater when using the new *visual-spatial task* relative to the previously employed *verbal task*; and, (2) that dual-task cost ratio measures of workload would be significantly greater for secondary task probes delivered while approaching an intersection (relative to the midblock condition).

## Method

### Participants

16 young drivers (mean=20.6 years; range: 18-26 years) and 16 older drivers (mean=72.4; range: 65-85) participated in the current study. All participants were required to provide a current driver's license and proof of medical insurance, as well as have a far visual acuity of 20/40 or better, complete an auditory screening, and pass a test for gross cognitive impairment.

### Secondary Tasks

The *verbal secondary task* consisted of arithmetic computations performed on a series of pre-recorded 2-digit numbers, ranging from 12-98. These number stimuli were presented auditorally. The driver's task was to subtract the smaller numeral from the larger numeral as quickly as possible (i.e. "68" would be 8–6 = "2"). The *visual-spatial secondary task* (or, "clock" task) consisted of a series of pre-recorded clock times (adapted from Paivio, 1978). Upon

hearing a clock time (e.g., "10:30), the driver's task was to visualize the location of this time's hour and minute hands on the face of an imaginary analog clock and ask themselves the following yes/no question: "Is any angle formed by the hour and minute hands less than 90 degrees" (The correct answer for the 10:30 example is "No"). Participants were instructed to provide accurate answers to these tasks as quickly as possible. Only correct responses were used for data analysis.

**Apparatus and Stimuli**

All participants drove an instrumented research vehicle (a 1998 Toyota Avalon) around two pre-determined routes through Vermillion, SD. The order of secondary task and route were counterbalanced. Within each route, there were 22 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 continuously monitored differential GPS in real-time (10Hz). As participants 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 participants to hear stimuli at essentially the same location on each route. In the rare event that GPS information was not available, no stimulus was presented.

In order to present each stimulus auditorily as well as record verbal responses, each driver was fitted with a small monaural headphone and microphone set. This setup allowed both the stimulus presentation and the driver's verbal responses to be recorded on separate audio channels via a stereo VCR. These audio tapes were then digitized offline using the Goldwave digital audio editing software in order to calculate secondary task reaction time.

**Procedure**

Following completion of the informed consent process and the screening tests, participants were escorted to the research vehicle and allowed to adjust the seat and mirrors to comfortable positions. Participants were then fitted with the monaural headphones and required to adjust the volume to a comfortable level. The experimenter then introduced the first of the two secondary tasks. Following this introduction, each participant was required to complete at least one block of 20 practice trials whose stimulus presentation rates varied randomly between 5-10 seconds. Before any data were recorded, each participant was required to reach a criterion of no more than 2 errors in a series of 20 successive stimulus presentations. Next the participant 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 via directions provided by the experimenter in the back seat. Throughout this dual task portion of the experiment, each participant drove 2 laps around the route and received approximately 44 secondary task probes, half occurring in mid-block road sections and half occurring during intersections. Participants 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, participants were allowed a short break and then an identical procedure was followed for the remaining secondary task and route.

## Results

The ratio of the time needed to perform a given cognitive task under dual-task conditions relative to single-task conditions (i.e., $RT_{ratio} = RT_{dual\text{-}task} / RT_{single\text{-}task}$) served as a surrogate measure of relative mental workload expenditure for performing the secondary tasks while driving. This surrogate index shall be referred to as the *dual-task cost ratio* throughout the remainder of this report. A ratio metric was determined to be an appropriate index of mental workload based on the fact that the visual-spatial task was expected to take slightly longer than the verbal task. Simply computing a difference score, which is the typical metric seen in the driving and mental workload literature, would create an inflated cost of dual tasking for the visual-spatial task compared to the verbal task. Use of the $RT_{ratio}$ metric not only allowed each task to be compared relative to its own performance under single task conditions, but also allowed each subject to serve as their own control.

To verify the necessity of the $RT_{ratio}$ metric, one-way ANOVAs were conducted on single task scores (averaged across blocks 1 and 2) to determine if the driver age groups were different under single task conditions. Results showed that for the visual-spatial task, young drivers (1.67 sec) were significantly faster than old drivers (2.41 sec) [$F(1,30)=7.845$, $MSE=.561$, $p<.009$] which can be interpreted as support for the $RT_{ratio}$ metric. For the verbal task, no significant differences were found between driver age groups (Young=.818 sec vs. Old=.900 sec)

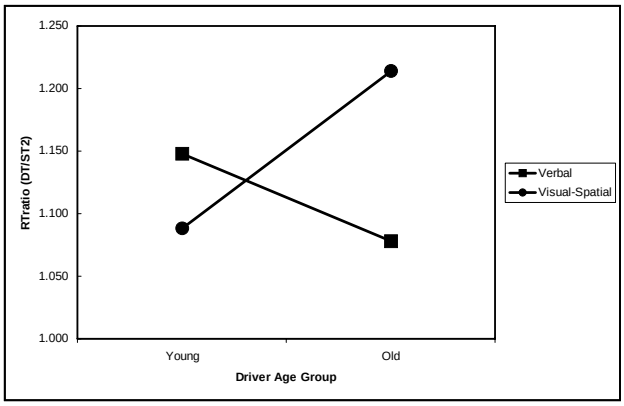


Figure 1. Age by Secondary Task interaction.

Analysis of performance on the first and second blocks of single task probes showed that both young [$F(1,15)=7.138$, $MSE=.041$, $p<.017$] and old drivers [$F(1,15)=4.010$,

*MSE*=.164, $p<.064$] were significantly faster during the second block compared to the first block of visual-spatial task probes. Because of this, only the second block of single task scores was used as the denominator of the $RT_{ratio}$ metric.

A (2) Age by (2) Task Order by (2) Secondary Task by (2) Roadway Location ANOVA was performed upon the dual-task cost ratio data ($RT_{ratio} = RT_{DT}/RT_{ST2}$). The results of this analysis revealed that two sources of effect yielded statistical significance: (1) the Age by Secondary Task interaction and (2) the Secondary Task by Roadway Location by Task Order interaction.

The nature of the significant Age by Secondary Task interaction [$F(1,28)=5.2$, *MSE*=.059, $p<0.03$] is depicted in Figure 1. It should be noted that none of the simple effects for this interaction produced significance. Dual-task costs (i.e., relative mental workload demands) for performing the visual-spatial secondary task were greater for older drivers compared to younger drivers [$F(1,52_{\text{Satterthwaite adj}})=1.55$, $MSE_{pooled}=.0813$, $\eta^2=.02$], while no such age-related decrement emerged for the verbal secondary task. Older drivers also took longer to perform the visual-spatial task compared to the verbal task [$F(1,28)=2.508$, *MSE*=.041, $\eta^2=.02$].

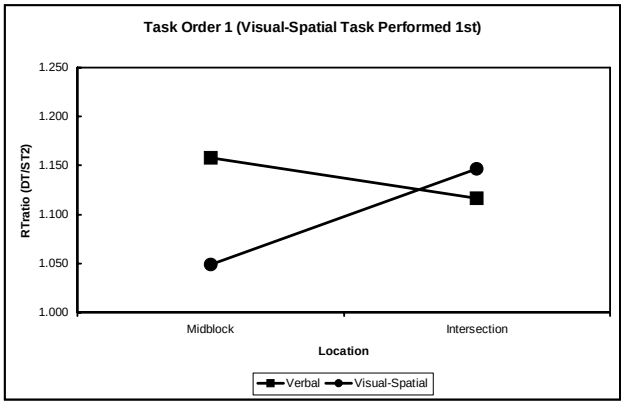


Figure 2. 3-way interaction for Task Order 1

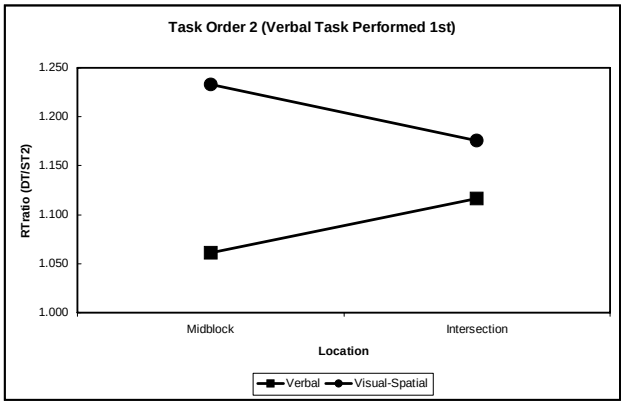


Figure 3. 3-way interaction for Task Order 2

The Secondary Task by Roadway Location by Task Order interaction [$F(1,28)=10.8$, *MSE*=.012, $p<0.012$] is depicted in Figures 2 and 3. This complex interaction yielded two significant simple effects. Drivers who performed the visual-spatial task first (Task Order 1) exhibited more of a dual task cost when traveling through intersections (high complexity) compared to mid-block road sections (low complexity) [$F(1,55_{\text{Satterthwaite adj}})=6.875$, $MSE_{pooled}=.0112$, $\eta^2=.01$] (Figure 2). The same trend was seen for those drivers who performed the verbal task first (Task Order 2), however this effect failed to produce significance [$F(1,55_{\text{Satterthwaite adj}})=2.23$, $MSE_{pooled}=.0112$, $\eta^2=.004$] (Figure 3). However the opposite trends were found for the subsidiary task performed second in the protocol for both task order groups. Regardless of task order presentation, drivers now exhibited less of a dual task cost at intersections compared to mid-block road sections. These findings suggest that drivers of both age groups might have been using their increasing knowledge of the experimental paradigm to improve intersection probe performance. Also for drivers in the Task Order 2 group, response times were significantly faster at mid-block probes when performing the verbal task compared to response times at mid-block probes when performing the visual-spatial task [$F(1,38_{\text{Satterthwaite adj}})=6.69$, $MSE_{pooled}=.035$, $\eta^2=.04$]. The fact that this effect was significant for the Task Order 2 group, but not the Task Order 1 group suggests that fatigue might have also played a role in shaping driver response times.

## Discussion

The performance of older drivers was consistent with what would be predicted from previous age-related driving research. Older drivers exhibited an increased cost of dual tasking for the visual-spatial task compared to the verbal task due to competition for visual-spatial attentional resources between the primary task of driving and the secondary visual-spatial task. Because attention is of limited capacity, there are simply fewer resources available for the visual-spatial task, the result of which was an increase in response times. Theoretically, there was no dual task cost for the verbal secondary task because the necessary attentional resources overlap minimally with the primary task of driving.

However, the fact that there were no significant age differences with respect to location is interesting. Previous in-house attempts cited difficulties in differentiating between low versus high complexity situations in a real world driving environment (Schieber & Harms, 1998). It was believed that this obstacle had been overcome in the current study by incorporating the highly dynamic act of intersection travel. This was based on the idea that intersection navigation involves a rapid change in the drivers visual orientation, the calculation of appropriate manual steering and acceleration inputs, and a critical decision regarding whether or not it is safe to proceed. Given these characteristics, intersections were believed to be sufficiently more complex than mid-block travel (i.e. driving straight at a consistent speed). The fact that older drivers were indistinguishable from younger drivers relative to roadway location complexity suggests that the use of subsidiary tasks as an indicator of workload might not be a useful tool in real world driving research. Subsidiary task paradigms have shown promise in the driving simulator (Schieber & Baldwin, 1995; Schieber & Harms, 1998), but have yet to show reliable sensitivity to age-differences under

real world driving conditions (Schieber & Harms, 1998). Perhaps it is not an issue of sensitivity to age differences, but rather specificity with regard to identifying cognitively impaired drivers. It might be the case that the healthy older driver's ability to efficiently process visual-spatial information is not as impaired as many crash statistics lead us to believe. It could be the case that decrements in information processing are not readily apparent until the onset of certain age-related cognitive diseases, such as dementia. Perhaps future research could compare the subsidiary task performance of healthy older drivers with that of individuals believed to be in the early stages of cognitive disease.

The results of the significant 3-way interaction suggest that independent of age differences, the subsidiary task performed first in the experimental protocol showed longer response times at the higher complexity intersection probes compared to mid-block probes. That is, dual-task costs increased as drivers approached an intersection (relative to midblock driving), but this was only the case during the first-half of the experiment. Hence, one can observe an increase in dual-task cost across the midblock-to-intersection locations for the visual-spatial task when the visual-spatial secondary task was administered first (Task Order 1); and, observe a similar trend for the verbal secondary task when it, too, was administered during the first-half of the experiment (Task Order 2). However, when the same secondary tasks were administered during the second-half of the experimental protocol just the opposite trend can be observed (i.e., there is a reduction in relative workload at intersections compared to the midblock locations).

One possible explanation for this complex pattern of results might proceed as follows: During the first-half of the experimental protocol, while participants were getting accustomed to driving an unfamiliar vehicle and learning to efficiently juggle the demands of the secondary task, drivers may have needed to tax their spare attentional capacity in order to perform according to expectations. This consequent reduction in the availability of spare attentional capacity during the initial phase of the study might be expected to have become more noticeable upon approaching intersections (where attentional demands are assumed to be elevated). However, by the second-half of the experimental protocol (when drivers also switched to the other secondary task), participants appear to have learned to associate the approach to an intersection with the delivery of a secondary task probe. As a result of this ability to accurately predict the delivery of a stimulus as one approached an intersection, drivers appear to have learned how to switch between primary and secondary task demands in a highly efficient manner. At the same time at which drivers may have developed this capacity to precisely predict the spatial location of stimulus probes at intersections, they were unable to predict the spatial location of secondary task probes delivered at midblock locations (as their placement was not associated with any readily discriminable roadway cues) (Figure 4). Hence, the predictability associated with discrete stimulus probes at intersections may have reduced task loading at intersections but not at the midblock locations. Consequently, dual-task cost ratios were reduced across midblock-to-intersection locations for secondary tasks performed during the second-half of the study. It is interesting to note that the nature of these effects was the same for both young and older drivers. The data suggest that the use of discrete stimulus probes (via differential GPS) which were initially intended to increase experimental control under real world conditions may have actually reduced the attentional demands placed on driver spare resource capacity during intersection travel, but not during mid-block travel.

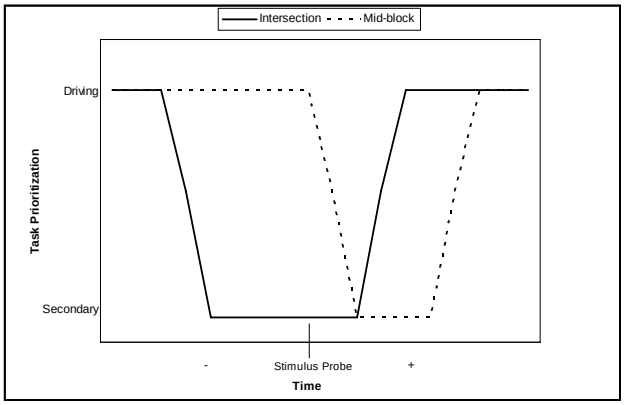

Figure 4. Intersections as a cue for subsidiary task prediction

The results of this experiment contribute to the driving and mental workload literature because they shed some light on the potential sensitivity of discrete versus continuous subsidiary task probes under real world driving conditions. As stated previously, the use of discrete stimulus probes at intersections appears to have allowed drivers to switch between the primary task of driving and the secondary task in a highly efficient manner. Once this strategy was learned, the subsidiary tasks were no longer providing an accurate indication of spare resource capacity. Previous research which was able to reliably differentiate between varying degrees of driving complexity using a verbal subsidiary task (i.e. mental arithmetic) did so using a presentation method more continuous in nature (L. Harms, 1986 & 1991; M. Harms, 1998; Baldwin, 1994). In these studies, stimulus probes were presented repeatedly every few seconds; whereas in the current study, probes were presented at specific points so that all subjects received stimuli at essentially the same locations. However it appears that employing a stimulus presentation method more continuous in nature would restrict a driver's ability to develop a highly efficient task switching strategy. A continuous stimulus presentation rate would require a constant division of attentional resources between the primary and secondary task, thus providing a more accurate depiction of available spare resource capacity relative to the ever-changing driving environment.

Figure 5 shows how a continuous stimulus presentation rate could be used given the roadway location manipulation observed in the current study. A continuous stream of stimulus probes would be delivered every two seconds and a driver would be required to respond as quickly as possible. One might expect the amount of workload experienced by the driver to increase steadily as a function of distance from the

intersection. Figure 6 illustrates a single potential relationship between the amount of driver workload relative to distance from an intersection (it should be noted that there are potentially a vast number of curves that might explain this relationship and this figure provides only a single relationship).

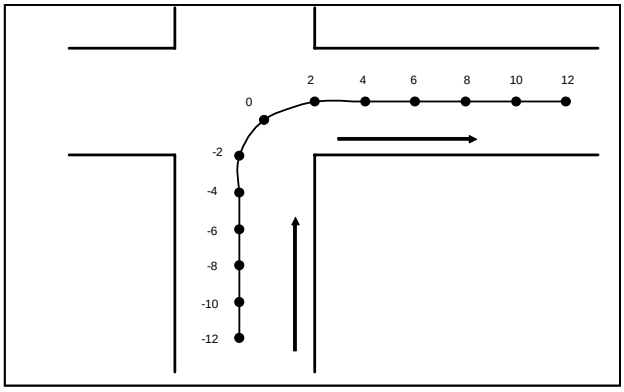

Figure 5. Example of continuous probes during an intersection

Given the relationship outlined in Figure 6, workload is thought to remain at low levels until the driver begins to approach the intersection. As the driver moves closer to the apex of the turn, workload would be expected to increase in response to the necessary allocation of attentional resources to an increasing number of environmental demands (i.e. planning the turn, committing to the turn, incorporating steering and acceleration control inputs, checking for other vehicles and pedestrians, etc…). After navigating through the intersection apex, the driver's workload would then be expected to once again decrease as environmental complexity decreases. Through the use of a subsidiary task whose probes are continuous in nature, response times could provide a useful indication as to the availability of spare attentional resources. As the highly complex act of intersection navigation demands more attentional resources, theoretically there should be fewer left over to allocate to the subsidiary task. The implementation of a continuous probe paradigm would provide an indication of the overall workload amplitude relative to an intersection, as well as response latencies as a function of distance from the intersection apex. It might also be interesting to see how the

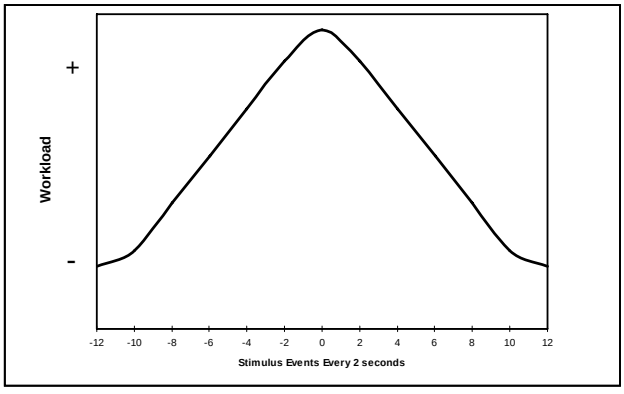

Figure 6. Hypothetical workload relationship

shape of the curve shown in Figure 6 changes relative to different types of intersections and turning maneuvers (i.e. right vs. left, uncontrolled vs. stoplight controlled, etc…).

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