Implications for HMI design: Understanding age induced limitations on in-vehicle task complexity

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ABSTRACT

Recent technological advances have enabled a wide variety of information systems to be integrated into a vehicle in order to increase productivity, safety, and comfort. However, improperly deployed technology can degrade safety and annoy drivers. Especially, potential information overload problems may become acute among older drivers who are the fastest growing segment of the driving population.
This paper aims to understand the age-related driving performance decline under a series of increasingly complex in-vehicle auditory tasks (n-backs). Data was drawn from a series of single task exercise and repetitions of the tasks under simulated driving conditions. In the simulation, 63 participants aged 20's and 60's drove through either a complex city or highway paradigm, appropriately counter-balanced. At a specified location in the canter of each of the two contexts, participants were asked to complete a series of auditory tasks of increasing complexity. Before beginning and after completing the simulation, drivers were asked to complete the auditory task in stationary non-driving conditions. Comparisons of younger and older drivers' secondary task performance will be discussed. In addition, differences in driving performance including average speed, speed variability, and lane keeping performance will be used to gauge older adult's capacity to regulate the demands of complex in-vehicle tasks in safe manner.

INTRODUCTION

Driving is a complex psychomotor task often interrupted by secondary activities that divert attention away from the roadway. Diversion of attention to secondary tasks is one of the largest contributors to inattentive driving and, consequently, to accidents (Stutts and Hunter, 2003). Therefore, an understanding of how drivers allocate attention and manage workload is important for informing both vehicle design and driver education. For the vehicle design side, voice recognition is widely used by vehicle manufacturers to reduce secondary workload. Currently voice recognition is considered the safest input user interface and is currently used as input for various infotainment, telematics and other comfort features. However, voice recognition technology also increases cognitive workload. Therefore, it is suggested that the impact on the older driver should be evaluated, since an individual's capacity for managing multiple tasks simultaneously is known to generally decrease with age (McDowd *et al.*, 1991; Rogers and Fisk, 2001). While absolute capacity declines with age, the judgment of typical drivers increases throughout the lifespan. In younger drivers, impaired judgment is often associated with excessive speed and alcohol use (Boyle *et al.*, 1996) while older drivers have been observed to recognize possible limitations and self-regulate their behavior by limiting their exposure to situations in which they may be at higher risk (D'Ambrosio *et al.*, 2008). When workload is high, there is evidence that some drivers engage in compensatory behaviors, such as moderating their driving speed, to manage workload (Harms, 1991; Reimer, 2009; Mehler *et al.*, 2009).
Therefore, when design voice recognition interface, we need to understand the older drivers' behavioral characteristics under dual task conditions.
In this study, we used an auditory cognitive task which is designed for providing increasingly complex in-vehicle auditory tasks (n-backs). The performance of younger and older drivers during single task simulated driving and in response to the added demand of a secondary cognitive task are compared. The overall simulation looked at both urban and highway driving environments.

METHODS

Participants

Participants were: a) required to be between the ages of 20 and 29 or 60 and 69, b) drive on average more than two times per week, c) be in good health and free from a number of major health conditions such as cancer or uncontrolled high blood pressure, d) not taking medications for chronic depression or other psychiatric conditions, e) have a mini mental status score (Folstein *et al.*, 1975) greater than 25 and f) not previously participated in a driving simulation study. Participants were required to sign an informed consent form.

Apparatus

The experiment was conducted on the DGIST fixed-based driving simulator, which incorporated a Mercedes-Benz™ Smart car and STISIM Drive™ software (see Figure 1). Graphical updates to the virtual environment were computed using STISIM Drive™ based upon inputs recorded from the OEM accelerator, brake and steering wheel which were all augmented with tactile force feedback. The virtual roadway was displayed on a large, wall-mounted screen at resolution of 1024 x 768. Feedback to the driver was also provided through auditory and kinetic channels. STISIM Drive provided vehicle sounds that varied with acceleration, braking, and movements off the road. Both urban and highway settings were simulated, using only daylight and dry road conditions. Completed distance, speed, and steering, throttle, and braking inputs were captured at a sampling rate of 20-30 Hz.

Figure 1. The DGIST fixed-based driving simulator

Secondary Task

An auditory prompt and verbal response "n-back" task, which can systematically ramp-up the total task demand on a driver without requiring direct conflict with the manual control or visual processing demands of the primary driving task (Zeitlin, 1993), was employed in this study to develop a baseline of older drivers' dual task capabilities. The form of the n-back employed consisted of a series of 10 single digit numbers (0 – 9) presented aurally to the subject. Each value was presented once per test set and the order of the digits varied with each presentation. The 10 numbers were presented with an inter-stimulus interval of 2.25 seconds, thus requiring fairly rapid response from the subject to keep pace with the task. Consecutive tests appeared every 30 seconds, allowing for only a brief pause between sets.

This secondary task consisted of three levels of difficulty and presented as a block of six trials. The first two trials employed a very mild demand (0-back), the second to two trial a moderate demand (1-back) and finally two trials a high level of task demand (2-back).

In the '0-back' version, the subject was simply to repeat out loud each number immediately after it was presented. In the "1-back" condition, instead of repeating the current number, the subject was required to recall from memory and respond out loud with the number that was presented just prior to the current number (i.e., 1 back from the current number). The '2-back' form of the task required subjects to recall from memory and to verbalize the number that was presented two numbers prior to the current value (i.e. 2 items back). The overall layout of the task was designed to sequentially increase the cognitive load on the subject both in terms of absolute difficulty and sustained load (Mehler *et al.*, 2009)

Procedure

After an introduction to the experiment, training on each level of the n-back task was provided. To facilitate learning, participants were given a written guide to follow along with the research assistant's verbal description and presentation of practice trails. Training on each level continued until satisfactory scores were reached (less than one error on a 0-back task, less than four errors on two consecutive trials of 1-back tasks and less than five errors on two consecutive trials of 2- back tasks). Participants then entered the simulator and began a driving habituation period designed to increase participants' comfort with the simulator. This experience uses a slow "ramp up" approach to reduce the potential for simulator sickness.

Following the habituation period, participants stopped driving and completed a non-driving assessment of the n-back task (six trials) and a questionnaire. The primary simulation protocol followed. To enhance the demands of driving the simulation, a financial incentive was used to encourage people to maintain speed, obey the traffic laws, and devote attention to secondary cognitive task (Mehler *et al.*, 2009; Reimer *et al.*, 2006). During the initial briefing subjects were told that that in addition to the base compensation 25,000KRW, an additional 10,000KRW could be earned during their drive by performing a series of secondary tasks. In order to simulate the conflicting demands of "real" automobile driving subjects were instructed that some of the incentive could be lost for non-safe driving such as a crash and traveling too fast or too slow in relation to the posted limit.

During this period participants engaged in an urban and highway driving experience each lasting approximately 15 minutes. No rest period was provided. The presentation order of the conditions was counterbalanced such that half of the participants drove in urban setting first. During a portion of the urban and highway drive, the n-back task was presented. This procedure provided three equidistant periods of roadway in which to assess driving performance. Following the simulation, a second non-driving assessment on the n-back task was carried out. Figure 2 shows the structure of suggested experimental protocol

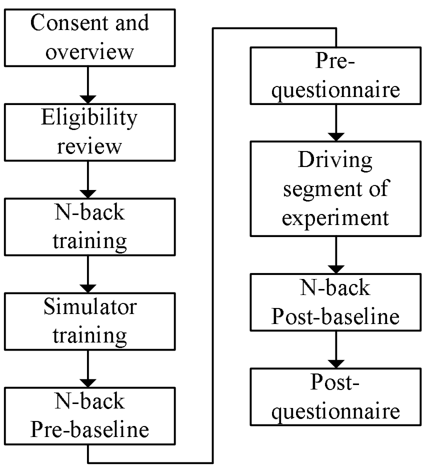

Figure. 2 Structure of experimental protocol

Data Analysis

Data was normalized to reduce the impact of speed on sampling differences in time. The normalization was performed by creating 40 intervals over the 305m(1000ft) that comprised of the average raw (forward velocity and lane position) measure recorded over each consecutive 7.62m (25 ft) road segment. Overall statistical measures were then calculated over the interval data.

Statistical comparisons were computed using SPSS version 14. A level of $p<0.05$ was adopted for all significance statements. Comparisons were made using an ANOVA analysis.

RESULTS

Sample

The sample consisted of 63 participants, 32 in the 20's and 31 in 60's. Gender was balanced by age (one older female participant was not run). Participants averaged 24.6 (S.D. = 2.3) and 63.9 (S.D. = 2.7) years for the two age groups.

Secondary Task Performance

Cognitive task performance was assessed as an error rate computed as the percentage of incorrect or non-responses to the total number of stimuli. Error rates are reported in Table 1. Error rate increased under dual-task conditions, $F(1,118) = 4.18$, $p = 0.043$. Older participants committed an error 28.79% more often than the younger group, $F(1,118) = 77.56$, $p < 0.001$.

Table 1.
Composite accuracy scores on the secondary task

		Non-driving	Dual-task
20's	Male	3.90(6.59)	6.69(7.36)
	Female	4.96(7.12)	10.12(9.75)
Total		4.43(6.77)	8.41(8.68)
60's	Male	26.92(20.60)	35.14(17.20)
	Female	30.83(27.94)	39.39(24.82)
Total		28.81(24.09)	37.20(20.98)

* Note: table entries are mean percentages with the standard deviation in parentheses

Using the error rate for all tests undertaken by the participants as an index, performance was essentially perfect (1.66%) across subjects for the 0-back (see Figure 3). As the level of cognitive challenge increased, error rates of 16.7% appeared for the 1-back and 41.7% for the 2-back. The effect of task difficulty on error rate was significant across all 3 levels of the n-back task ($F(2,189) = 42.1$, $p<0.001$). The observed error rates support the assertion that workload increased across the task periods.

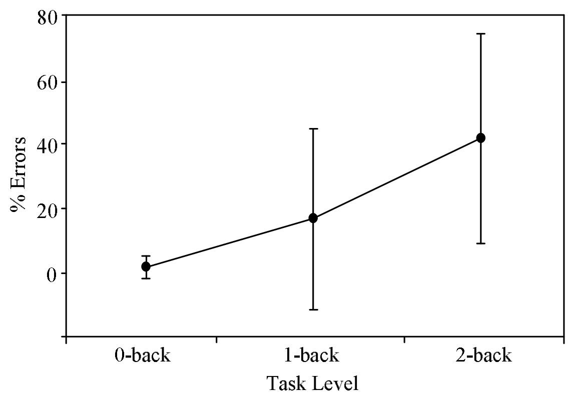

Figure. 3 N-Back Errors as a Function of Task Difficulty

Driving Performance

Forward velocity - Forward velocity is presented in Figure 4. Consistent with Mehler et al. (2008), forward velocity is significantly affected by the secondary task, $F(2, 177) = 7.641$, $p=0.001$. Across age and gender, velocity decreased by 1.21 m/s during the secondary task and recovered by 1.43 m/s afterwards.
Age interact significantly with the secondary task on forward velocity, ($F(2, 177) = 3.812$, $p = 0.024$), but the difference between age groups, $F(2, 177) = 0.056$, $p=0.813$, and between genders, ($F(2, 177) = 2.863$, $p=0.092$), were not statistically significant.
As shown in Figure 2, participants drove slower during the dual-task and resumed near the pre-task speed following the secondary task. Especially, the older drivers were more affected by the secondary task.
During the task, younger drivers slowed 2.7% and older drivers were 10.1%. It suggested that the secondary task impacted on primary driving task and the older drivers were more significant than younger drivers.

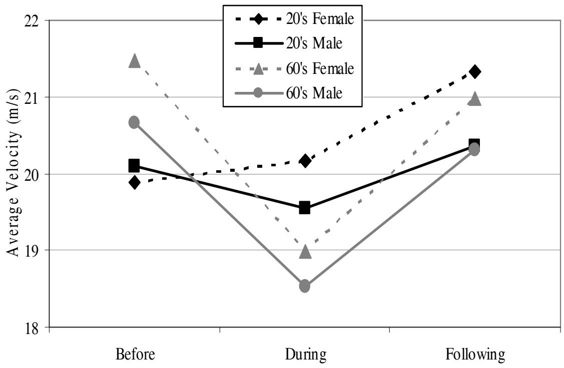

Figure 4. Forward velocity by age and gender

Speed control - Figure 5, displays speed control expressed as the percent coefficient of variation on velocity. The difference between age groups was statistically significant, $F(1,177) = 12.614$, $P<0.001$, but gender, $F(1,177) = 0.509$, $p=0.477$, and the secondary task, $F(2,177) = 1.864$, $p=0.158$, were not statistically significant.
According to Figure 3, the coefficient of the older drivers was increased during the secondary task and decreased after the task, while the younger drivers' coefficient was barely changed during secondary task but increased following the task.
During the task, the coefficient of younger drivers decreased 3.9% and older drivers increased 22.9%. This results suggested that the secondary task impacted on primary driving task, and the older and younger drivers had an opposite characteristics. The older drivers have more difficulty controlling speed during the secondary task.

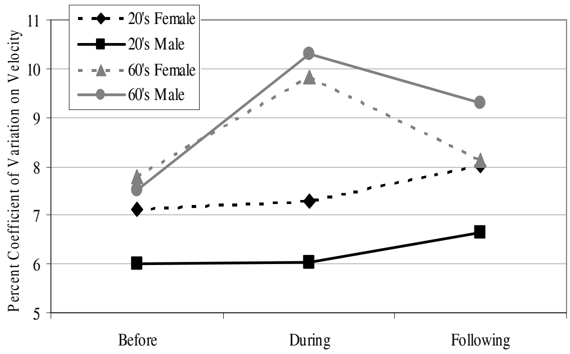

Figure 5. Percent coefficient of variation on velocity by age and gender

Lateral control - Lateral control expressed as the standard deviation of lane position is shown in Figure 6. Consistent with earlier field studies on younger participants using n-back tasks (Reimer, 2009), drivers across gender ($F(1,177) = 4.874$, $p = 0.029$) and the secondary task ($F(2,177)= 3.269$, $p = 0.040$) showed a significant reduction in lateral variation, , while no significant age effect exist, $F(1,177) = 3.137$, $p = 0.078$.
As shown in Figure 4, the standard deviation of lane control of all participants except younger male drivers was decreased during the secondary task and increased after the task. Regarding the younger drivers' behavior, we need additional subject for better understand.
During the task, the standard deviation of lane position of younger and older drivers decreased 19.1% and 18.7%, respectively. There was no significant difference across age.

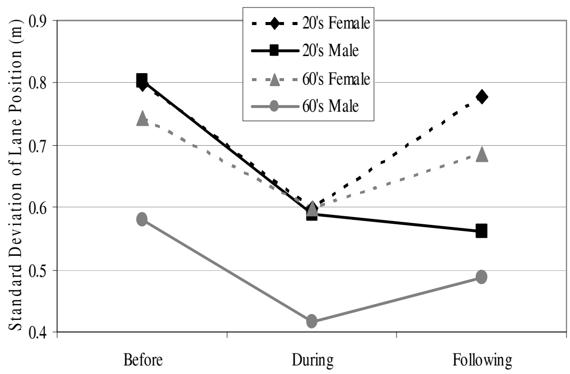

Figure 6. Standard deviation of lane position by age and gender

CONCLUSION

This study aims to understand the age-related driving performance decline under a series of increasingly complex auditory cognitive tasks (n-backs). 63 participants aged 20's and 60's drove and completed the auditory cognitive tasks. From the younger and older drivers' secondary task and driving performance including average speed, speed variability, and lane keeping performance, we drew a characteristics of older drivers' dual task capabilities. Each of the age and gender subgroups showed a parallel decrement in performance on the n-back task during simulated driving relative to their performance under non-driving conditions. This may be interpreted as evidence that each group invested a comparable amount of their available cognitive resources in the n-back task during the driving phase relative to their overall capability to perform the task under single task conditions. Considering the sample as a whole, the introduction of the secondary task during driving resulted in a compensatory slowing of forward velocity during the heightened workload and an increase in driving speed following, extending previous findings (Mehler et al., 2008; Reimer, Mehler et al., 2006). Similarly there is the suggestion of a tunneling effect in which the standard deviation of lane position decreases, most likely due to a rigidification of control so that attention can be divided between the tasks (Reimer, 2009).
In summary, age appears to impact both driving performance and, consequently, compensatory behavior during dual load conditions. This suggests that the capacity declines with age should be considered when designing a in-vehicle interface system.

LIMITATION

There are several limitations of this study. Connections between cognitive distractions such as voice recognition and cellular telephone use, and the surrogate n-back task are not well established. The use of monitored experimentation likely impacts drivers' performance versus that of truly naturalistic driving conditions. Results based upon the measure of lane performance do not include data from approximately half of the sample. Finally, the presentation of the n-back task was not randomized (always 0-back followed by 1-back and then 2-back task). Future research will attempt to address these limitations.

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