Safety Implication of Auditory and Visual In-Vehicle Interfaces for Older Drivers: The effect of surrogate in-vehicle information systems

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Abstract

This paper presents the findings of a simulator study that explain potential risks induced by visual and auditory interaction while driving. Differences in subjective distraction and driving performance of younger and older drivers were compared while interacting with two different types of surrogate user interface in a driving simulator. To assess the differences, 30 drivers, divided into younger (25–35) and older (60–69) age groups were participated. Each driving takes about 20 minutes, and participants perform a secondary task, i.e. n-back task or arrow task at a specified segment. Comparisons of younger and older drivers' subjective ratings of difficulty and perceived distraction and driving performance were conducted. As a result, it was found that the effect of interaction types, i.e. visual and auditory, on younger and older drivers' performance was significantly different.

Keywords: Older Driver, Human-Vehicle Interface, Visual Distraction, Cognitive Distraction, Interface Modality

Introduction

The driver's distraction is a specific type of inattention that occurs when drivers divert their attention away from the driving task to focus on another activity instead [1]. These distractions can be from electronic distractions, such as navigation systems and cell phones, or more conventional distractions such as interacting with passengers and eating. Although mobile phone use has been spotlighted as a major source of driver's distraction, other in-vehicle electronic devices also have the potential to increase perceptual and cognitive demand when driving [2]. Stutts et al. [3] also reported that diversion of attention to in-vehicle secondary tasks is one of the largest contributors to inattentive driving and, consequently, to accidents.

Therefore, car manufacturers are widely adopting in-vehicle voice interface to reduce secondary task induced workload. In the multiple resource theory, individuals are viewed as having several different capacities of resources and different types of resources are used for different modalities, e.g. auditory and visual, during performing a task [4]. According to the theory, auditory in-vehicle interface such as voice interaction is safer method than visual interface, because driver's eyes, i.e. visual input, obtain about 90% of driving information [5] although the percentage of visual input while driving has been subject to debate [6]. However, when considering the fact that auditory interaction usually requires longer time to complete an interactive in-vehicle task than visual one, and a person's cognitive and physical capability to drive is diminished with advancing age [7], it is questionable if auditory in-vehicle interface would be still safer for older drivers.

In this study, therefore, the effect of in-vehicle interaction types, e.g. auditory and visual, on the older driver was investigated using delayed digit recall task (n-back) as a surrogate auditory task and arrow detection task (arrow) for visual-manual interaction.

Method

Participants

For this study, 30 younger and older drivers participated and they met the following criteria: age between 25-35 or between 60-69, drive on average more than twice a week, be in self-reported good health and free from major medical conditions, not take medications for psychiatric disorders, score 27 or greater on the mini mental status to screening cognitive impairment. The sample consisted of 15 younger males in the 25-35 age range (M=27.9, SD=3.13) and 15 older males in the 60-69 age range (M=63.2, SD=1.74).

Apparatus

The experiment was conducted in a fixed-based driving simulator, which incorporated STISIM Drive™ software and a fixed car cab. 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. Distance, speed, steering, throttle, and braking inputs were captured at a nominal sampling rate of 30 Hz. Physiological data such as ECG and Skin conductance level, and eye behavior data were collected.

Secondary Task

In order to investigate an impact of in-vehicle interaction types, e.g. auditory and visual, on driving

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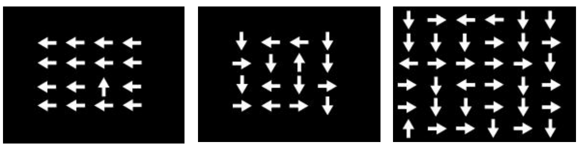
performance, two types of secondary tasks was selected. One is visual-manual task as a representative of the typical automotive user interface, and the other is auditory recall task which was adopted to surrogate in-vehicle voice interface.

Visual-manual secondary task - The arrow search task, which only required visual processing demand and minimal cognitive processing [8], were selected as a surrogate task of visual-manual interface. To create three levels of difficulty for the arrows task, i.e. level 0 (easy), level 1 (moderate) and level 2 (hard), three different arrangements of arrows were presented, each for 10s, forming a series of two minutes trials using 12 arrow pictures. The presentations of the displays are shown in Figure 1. On some occasions the upward pointing target arrow was present and on others it was not. The participant is to press the "Yes" or "No" button below the arrow matrix on the touch screen. When the participant does not respond for 5 seconds, the arrows are disappeared and scored as a miss.

Auditory secondary task - An auditory delayed digit recall task was used to create periods of cognitive demand at three distinct levels. This form of n-back task requires participants to say out loud the nth stimulus back in a sequence that is presented via audio recording [9]. The easiest n-back task is the 0-back where the participant is to immediately repeat out loud the last item presented. At the moderate level (1-back), the next-to-last stimuli is to be repeated. At the hardest level (2-back), the second-to-the-last stimulus is to be repeated. The n-back was administered as a series of 30 second trials consisting of 10 single digit numbers (0-9) presented in a randomized order at an inter-stimulus interval of 2.1 seconds. Each task period consisted of a set of four trials at a defined level of difficulty resulting in demand periods that were each two minutes long.

Procedure

Following informed consent and completion of a pre-experimental questionnaire, participants received 10 minutes of driving experience and adaptation time in the simulator. The simulation was then stopped and participants were trained in the n-back task or arrow task while remaining seated in the vehicle. The training continued until participants met minimum performance criteria, i.e. perfect in 0-back and more than 75% of correct answers in 1-back and 2-back tasks. When the simulation was resumed, participants drove in good weather through 37km of straight highway twice, one for visually distracted driving and the other for cognitive. Each driving took about 20 minutes, and participants performed a secondary task, i.e. n-back task or arrow task at a specified segment. The segment started after driving down 12.7km and continued for 10 minutes that comprised three of 2-min tasks and two of 2-min rest periods. The order in which secondary tasks were presented was balanced so that half of the participants drove under cognitive workload first.



Level 0 Level 1 Level 2

Figure 1. Three levels of difficulty for visual-manual tasks

Dependent variables

In order to compare the secondary task performance between two age groups, error rates on the n-back and arrow tasks were used to confirm the extent to which different conditions represented periods of higher cognitive and visual workload. The error rate is a percentage of the times when subjects responded with a wrong answer or gave no answer during the n-back and arrow experiment. It can be assumed that a higher error rate indicates higher cognitive or visual workload that induced by secondary task and driving task.

For the driving performance measures, speed control ability and lateral control ability were considered as driving performance measures for indicating the difficult level of cognitive and visual workload.

Questionnaire

The following questions in Table 1 were used to compare subjective difficulty and influence. Each question to measure participants' subjective ratings was repeatedly asked by types of interaction, i.e. auditory and visual.

Table 1. Questions for comparing auditory and visual tasks

Type	No	Questions
Both	Q1	Which type of secondary tasks was more distractive? a) N-Back Task b) Arrow Task
Auditory	Q2 (a)	How difficult is it to perform the N-back tasks while driving? 1("Very easy") to 10("Extremely hard")
	Q3 (a)	How nervous is it to perform the N-back tasks while driving? a) Not nervous at all b) A little nervous c) Quite nervous
	Q4 (a)	When comparing with typical in-vehicle tasks (e.g. operation air-conditioner or radio), how difficult is it to perform the N-back tasks while driving? 1("Not difficult at all") to 10("Severely difficult")
	Q5 (a)	How much were you influenced by performing the N-back tasks while driving? 1("Not affected at all") to 10("Severely affected")
Visual	Q2 (b)	How difficult is it to perform the Arrow tasks while driving? 1("Very easy") to 10("Extremely hard")
	Q3 (b)	How nervous is it to perform the Arrow tasks while driving? a) Not nervous at all b) A little nervous c) Quite nervous
	Q4 (b)	When comparing with typical in-vehicle tasks (e.g. operation air-conditioner or radio), how difficult is it to perform the Arrow tasks while driving? 1("Not difficult at all") to 10("Severely difficult")
	Q5 (b)	How much were you influenced by performing the Arrow tasks while driving? 1("Not at all affected") to 10("Severely affected")

Data Analysis

Statistical comparisons of the objective measures were computed using SPSS version 17. Comparisons were made using a repeated-measures general linear model (GLM) procedure and MANOVA. A Greenhouse-Geisser correction was applied for models that violated the assumption of sphericity. Post-hoc pair-wise comparisons were computed for significant effects using a least significant difference (LSD) correction.

Results and discussion

Subjective Rating of Difficulty and Influence

As shown in Table 2, most of younger drivers reported that the visual task was more difficult than the auditory task, but older drivers rated the tasks as having similar difficulty. These ratings were consistent with the ratings of subjective difficulty and relative difficulty comparing with typical in-vehicle operation. In addition, older drivers felt slightly more nervous while performing auditory task than younger drivers. Age and type significantly affected subjective ratings (F(1,56) =5.695,p=.020, F(1,56)=5.080, p=.028, respectively).

Age interacts significantly with the secondary task type (age*type) on subjective difficulty (F(1,56) = 8.237, p=.006), relative difficulty (F(1,56) = 4.060, p=.049), and influence (F(1,56) = 6.345, p=.015).

Table 2. Comparisons of subjective ratings on difficulty and influence between two different interaction types

Questions	Auditory		Visual	
	Young	Old	Young	Old
Q1. Which type is more difficult? (Visual vs. Auditory)	13.3%	46.7%	86.7%	53.3%
Q2. Subjective Difficulty (10-pts-scale)	3.6 (1.50)	5.3 (2.13)	5.1 (1.62)	4.0 (2.20)
Q3. Subjective Nerve (3-pts-scale)	1.8 (0.41)	2.1 (0.35)	2.1 (0.52)	2.1 (0.59)
Q4. Relative Difficulty comparing with typical in-vehicle operation (10-pts-scale)	3.9 (1.73)	5.7 (2.61)	5.9 (2.05)	5.5 (2.23)
Q5. Subjective influence (10-pts-scale)	3.5 (1.55)	6.0 (2.45)	5.9 (1.94)	5.9 (1.73)

* Table entries are mean percentages with the s.d. in parentheses

Secondary Task Performance

Error rates on the difficulties of easy, moderate and hard to perform auditory and visual tasks appear in Table 3. According to the error rates on two different task types, the difference between auditory and visual tasks in the easiest level and the hardest level were not significantly different (F(1,28)=3.946, p>.05, F(1,28)=1.085, p>.05), but the moderate level showed significant difference (F(1,28)=6.392, p=.017). These results suggested at least the comparison between auditory and visual tasks in the easiest and hardest level can be conducted.

As shown in Table 3, the error rate was significantly increased by the level of task difficulty in auditory and visual user interaction (F(1.4,39.2)=55.927, p<0.001), F(1.7, 48.9)=31.002, p<.001, respectively).

The result reflected that both of the N-back and arrow tasks could manipulate cognitive and visual workload systematically. A main effect of age reflected the higher error rate of auditory task in the older drivers (F(1,28)=30.858, p<.001), and a task difficulty by age interaction reflected the dramatic rise in error rate in the older drivers relative to the younger group at the hardest auditory task(F(1.4, 48.9)=29.981, p<0.001).

Table 3. Comparisons of error rate on the different user interaction tasks

	Difficulty	Auditory		Visual	
		Young	Old	Young	Old
Error Rate	**Easy (Level 0)**	0.0% (0.00)	0.67% (1.14)	1.67% (6.46)	3.89% (6.96)
	Moderate (Level 1)	4.63% (7.48)	6.49% (6.69)	9.45% (13.32)	15.00% (12.67)
	Hard (Level 2)	7.10% (6.84)	37.31% (17.46)	20.56% (18.59)	22.99% (13.29)

* Table entries are mean percentages with the s.d. in parentheses

Driving Performance Measures

To observe the compensatory behaviors and performance changes under different levels of auditory and visual tasks by age, average speed and the standard deviation of lane position were examined. As presented in Figure 2, both age groups decreased vehicle speed while performing secondary tasks. Although the mean speed profiles did not show a simple correlation with the level of cognitive workload (N-back), the longitudinal control ability was significantly impacted by the auditory tasks (F(3.1,85.9)=13.462, p<.001). While performing the visual tasks, both age groups significantly decreased vehicle speed with the visual task difficulty (F(2.791, 78.154) = 38.957, p < .000). Especially, the older group did show a simple correlation with the level of visual demand.

Lateral control ability expressed as the standard deviation of lane position (SDLP) is shown in Figure 3. The SDLP was significantly impacted by the difficult level of cognitive workload (F(3.3,93.7)= 6.822, p<.001) and by age (F(1,28)=5.153, p=0.031). For the visual task condition, the standard deviation of lane position profiles showed a consistent correlation with the level of visual task difficulty in both age groups (F(2.675, 74.895) = 31.547, p<.000). The SDLP was impacted by age as well (F(1, 28) = 12.865, p = .001).

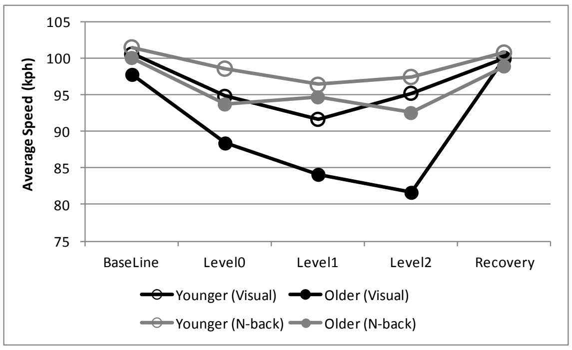


Figure 2. Average speed by age & interaction type

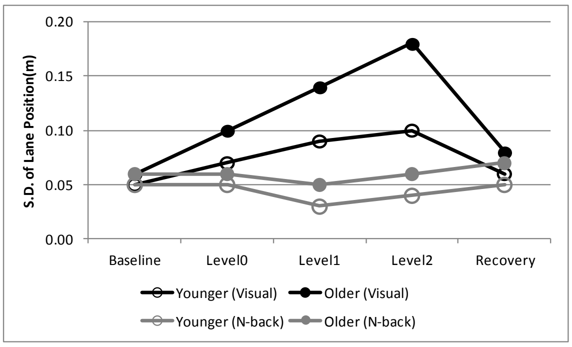


Figure 3. SDLP by age & interaction type

Concluding Remarks

The results in this study seemed to suggest that both younger and older drivers were impacted by auditory and visual interaction in their driving performance but the auditory interface showed better driving performance. However, it is questionable whether keeping their normal speed while performing a secondary task is safer behavior, because the secondary task may affect their reaction time and situational awareness. The SDLP measure also is known to have some limitation when considering situational awareness [9].

In fact, the results of self-reported difficulty of visual and cognitive task were different from the driving performance measures, that is, older drivers said that the visual task was less difficult than the cognitive task but younger said the cognitive task was easier.

Since an individual's capacity for managing multiple tasks simultaneously is known to generally decrease with age [7, 10], and older drivers' driving performance and constriction in eye movement are more affected by cognitive tasks [9].

The modality of in-vehicle interfaces provides younger and older drivers with different levels of task difficulty, although the difficult level of visual and cognitive tasks was almost same. Especially, older drivers were more vulnerable in auditory interaction. Thus, the vehicle manufacturers need to understand age differences in designing automotive user interface.

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References

[1] Ranney T. A.: Driver distraction: A review of the current state-of-knowledge, Washington DC: National Highway Traffic Safety Administration, DOT HS 810 704, 2008

[2] Horberry T., Anderson J., Regan M. A., Triggs T. J. and Brown J.: Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance, Accident Analysis & Prevention, 38: 185-191, 2006

[3] Stutts J. C., Reinfurt D. W., Staplin L. and Rodgman E. A.: The role of driver distraction in traffic crashes. Washington DC: AAA Foundation for Traffic Safety, 2001

[4] Wickens C.D.: Information processing, decision making and cognition, in Cognitive engineering in the design of human-computer interaction and expert systems, G. Salvendy, Elsevier: Amsterdam, Editor, 1987

[5] Robinson G. H., Erickson D. J., Thurston G. L. and Clark R. L.: Visual search by auto- mobile drivers, Human Factors 14, (4): 315–323, 1972

[6] Sivak M.: The information that drivers use: is it indeed 90% visual?, Perception, 25(9): 1081–1089, 1996

[7] Rogers W. A. and Fisk A. D.: Understanding the role of attention in cognitive aging research. In J. E. Birren & K. W. Schaie (Eds.), Handbook of the psychology of aging. Oxford, UK: Elsevier Science, 2001

[8] Östlund J., Peters B., Thorslund B., Engström J., Markkula G., Keinath A., Horst D., Juch S., Mattes S., and Foehl U.: Driving performance assessment – methods and metrics, Information Society Technologies, No. IST-1-507674-IP, 2004

[9] Reimer B., Mehler B., Wang Y. and Coughlin J.F.: A field study on the impact of variations in short-term memory demands on drivers' visual attention and driving performance across three age groups, Journal of the Human Factors and Ergonomics Society, 54(3): 454-468, 2012

[10] McDowd J. M., Vercruyssen M., and Birren J. E.: Aging, divided attention, and dual-task performance. In D. L. Damos (Ed.), London: Taylor & Francis Ltd, Multiple-task performance, 387-414, 1991