Age and cross-cultural comparison of drivers' cognitive workload and performance in simulated urban driving

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AGE AND CROSS-CULTURAL COMPARISON OF DRIVERS' COGNITIVE WORKLOAD AND PERFORMANCE IN SIMULATED URBAN DRIVING

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ABSTRACT−Driving demands significant psychomotor attention and requires even more when drivers are engaged in secondary tasks that increase cognitive workload and divert attention. It is well established that age influences driving risk. Less is known about how culture impacts changes in attention. We conducted parallel driving simulations in the US and Korea to measure the extent to which age and culture influence dual-task performance. There were 135 participants divided into two groups: a younger group aged 20-29, and an older group aged 60-69. Whereas some differences by culture appeared in absolute control measures, the younger participants showed similar mean velocity and compensatory patterns associated with increased cognitive load in the urban setting; however, the results from the older samples were less similar.

KEY WORDS: Driving simulation, Culture, Age, Older driver behavior, Cognitive workload, Distraction

1. INTRODUCTION

It is well known that inattention and distraction strongly influence automotive accidents, and that safe driving necessitates properly managed and sustained attention. Driver engagement with secondary tasks is not only a major source of distracted driving but also leads to accidents (Stutts and Hunter, 2003). It is common for a driver operating a motor vehicle to engage in many non-driving tasks, such as talking and texting on a cell phone and operating navigational aids and entertainment systems (Cha and Park, 2006). User interfaces need to be designed in ways that reduce cognitive and physical demands associated with device operation. However, vehicle and aftermarket system designers have very little guidance as to how demanding secondary activity can be before posing a safety threat. Current practices rely largely on post design safety reviews. To enhance safety, it is important that guidelines be developed to provide designers with a better understanding of how drivers allocate their attention and manage workload while performing cognitive secondary tasks.

Although all drivers are impacted by additional workload, attention management capacity decreases with age (McDowd *et al.*, 1991; Rogers and Fisk, 2001). At the same time, despite older drivers' diminished attentional capacity, driving judgment increases with experience and age which may compensate for decreased capacity (Reimer *et al*., 2008).

Impaired judgment in younger drivers is frequently related to speeding and alcohol consumption (Boyle *et al.*, 1996). By contrast, older drivers are more likely to self-regulate behavior, acknowledge their own limitations, and reduce exposure to high risk situations (D'Ambrosio *et al.*, 2008). Yet, avoiding certain conditions is not always possible and further steps might be needed to drive safely. Some drivers have been observed performing compensatory behaviors, e.g., reducing their speed to manage the increasing workload (Harms, 1991; Reimer, 2009; Mehler *et al.*, 2009). Compared to younger drivers, late middle age drivers drive slower than younger drivers (Reimer *et al.*, 2006). Both age groups have been shown to decrease speed while performing secondary tasks (Mehler *et al.*, 2008).

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One aim of this study was to collect further data on the simulated driving performance of younger and older individuals during single and dual task situations. In addition, we wished to explore the possibility of cultural influences on driving performance by comparing participants from the US with participants from Korea. Previous research on cross-cultural driving behavior appears to be largely actuarial or compares only self-reported data (Matthews *et al.*, 1999; Nordfjaern and Rundmo, 2009; Warner *et al.*, 2009). The goal of this study was to discover what patterns of simulated driving behavior could be generalized across the two cultures and to discover how age impacts any observed cultural differences.

2. METHODS

2.1. Participants

Individuals were required to meet the following criteria to participate: age 20-29 or 60-69, drive on average more than twice a week, be in self-reported good health and free from all major medical conditions, not take medications for psychiatric disorders, score 25 or greater on the mini mental status exam (Folstein *et al.*, 1975) to establish reasonable cognitive capacity and situational awareness, and have not previously participated in a simulated driving study.

The study consisted of 72 participants in the US (36 in the younger group and 36 in the older group) and 63 participants in Korea (32 in the younger group and 31 in the older group). The mean age for each culture, age, and gender subgroup appears in Table 1.

2.2. Simulator

The fixed-base driving simulator "Miss Daisy" at the MIT AgeLab and New England University Transportation Center was used to conduct the study in the US. In Korea, a driving simulator was constructed to comparable specifications. Both simulators utilized the same DLP projector, screen, and model of personal computer and graphics card; however, the vehicles did vary somewhat in form factor (see Figure 1).

Graphical updates to the virtual environment were controlled through the STISIM Drive™ software based on inputs from the OEM accelerator, brake, and steering wheel. Data were sampled and the virtual roadway was updated at 20-30 Hz and displayed on a 2.44 m by 2.44 m (8 ft x 8 ft) 1024 x 768 resolution screen. Realistic auditory feedback was provided, which consisted of vehicle sounds asocaited with acceleration, braking, and movements off the road. The simulators also provided kinetic feedback through a steering-wheel force-feedback system. Adjustments were made to the US and Korean parameter files to reconcile vehicle form factor differences (eye height, view angle, and rear view mirror placement).

2.3. Secondary Task

Workload changes were induced using the n-back, an auditory delayed recall task used in previous simulation and field research (Mehler *et al.*, 2009; Reimer, 2009)

Comment [Ed1]: The correct word is "simulations". When I tried to make the edit, "simulations" moved to the next line and messed up the format. (Response from Bruce Mehler – yes – we find the same problem and have not been able to fix – we recommend leaving it as is. We would also like ot say that the recommendations by the editor were excellent and 99% were accepted.)

Table 1. Age statistics.

		Male	Female
US Drivers	Younger	23.7 (2.0) [18]	23.4 (2.4) [18]
	Older	62.8 (2.5) [18]	63.8 (3.4) [18]
Korean Drivers	Younger	25.1 (2.3) [16]	24.1 (2.2) [16]
	Older	63.7 (2.8) [16]	64.2 (2.8) [15]

Note: Means with standard deviations in parentheses and the number of participants in brackets.

Figure 1. MIT AgeLab driving simulator (left) and the DGIST simulator (right).

and recommended by Zeitlin (1993) for inducing secondary workload in driving research. In a procedural change from Mehler *et al.* (2009) and Reimer (2009), task training was given to participants prior to beginning the experimental portion of the protocol.

The n-back was administered as a series of 30 second trials consisting of a pre-recorded aural presentation of a series of single-digit numbers at an inter-stimulus interval of 2.25 seconds. With each digit presentation, the participants' task was to say out loud the "n^{th}" stimulus backin the sequence (for details, see Mehler et al., in press). The task was given as a set of six trials, employing a low demand in the first two trials (0-back), a moderate demand in the second two trials (1-back) and a high demand in the final two trials (2-back).

2.4. Questionnaire Data

Participants in both the US and Korea were given an appropriate translation of a questionnaire covering health conditions, driving behaviors, and attitudes (Reimer *et al.*, 2007). Question wording and response categories for the English version of two questions considered in the analysis appear in Table 2.

Table 2. Self-reported items used

Variable name	Question wording
Physical well-being	Thinking about how you feel today, how would you describe your current physical well-being? (a) Excellent, (b) Very Good, (c) Good, (d) Fair, (e) Poor
Driving frequency	How often do you drive a car or other motor vehicle? (a) Almost every day, (b) A few days a week, (c) A few days a month, (d) A few times a year, (e) Never

2.5. Procedure

Potential participants were first provided with a description of the experiment, eligibility was confirmed, and they were then required to read and sign an informed consent form. Training on each level of the n-back task then took place. To facilitate learning, participants were given a written guide to follow along with the research assistant's verbal description and presentation of practice trials. Task training was only complete if participants successfully met the following criteria: no errors on the 0-back, no more than 3 errors on two consecutive 1-backs and no more than 4 errors on two consecutive 2-backs. Following training on the n-back task, participants were seated in the simulator. A driving familiarization period followed that covered slightly more than 15 km of mixed environments; this training period was designed to provide a slow ramp up exposure to the simulation and familiarity with different stimuli that they would encounter later in the simulation and allow for some habituation.

Following the familiarization period, participants stopped driving and completed a non-driving assessment of the n-back task (six trials) and a questionnaire presented in English or Korean. Instructions for the primary simulation protocol followed. Subjects were told that in addition to the base compensation of \$40 (25,000 KRW), an additional \$20 (10,000 KRW) could be earned during their drive by performing a series of secondary tasks. 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 crashing and traveling too fast or too slow in relation to the posted limit. This financial incentive was used to encourage people to maintain speed, obey the traffic laws, and devote attention to the secondary cognitive tasks (Mehler *et al.*, 2009;Reimer *et al.*, 2006).

In the simulation, participants drove in good weather through two environments: an 18 km urban setting and 55 km of highway. The simulated environment in both conditions consisted of two straight and level travel lanes in each direction. Other traffic appeared in the direction of travel at cross streets and exits. The urban and highway road segments were surrounded by other roads that acted to enhance the face validity of the driving experience. Overall, the experiment encompassed 69 km of roadway. Participants were not given a rest period. The order in which conditions were presented was balanced so that half of the participants drove in the urban environment first.

Driving performance measures were assessed over three equidistant segments of roadway (before, during, and following the dual task load). Approximately one third of the way through both the urban and highway portions of the simulation, the n-back task was presented. To maintain an elevated workload for all participants over an equal driving distance, participants were given additional trials of the 2-back as needed to compensate for individual variation in driving speed. The second non-driving n-back task was presented after the simulation.

This paper addresses a cross cultural analysis of the urban segment of the simulation. This segment contained the same stimulus elements in both the US and Korean settings with one exception: the US scenario included occasional cars parked along the roadway as is typical of many US cities. During the development of the Korean version, it was noted that parking for cars along the sides of city streets is not typical of urban centers in Korea. Therefore, parked cars were not included in the Korean scenario.

2.6. Data Analysis

Variables were computed over data gathered from two 305 m (1,000 ft) segments in each period of the simulation that represented steady state driving. The two segments were separated by an intersection where drivers were required to stop at a traffic signal. Data from this stop and start interval were not considered in the analysis. Data were normalized to reduce the impact of speed on sampling differences in time. The normalization was performed by creating 40 intervals over the 305 m that were comprised of the average raw measures (forward velocity and lane position) recorded over each consecutive 7.62 m (25 ft) road segment. Overall statistical measures were then calculated over the interval data. Statistical comparisons were computed using SPSS version 11.5. Comparisons were made using a general linear model (GLM) repeated measures analysis with age and gender as independent variables. Post-hoc pair-wise comparisons were computed for significant effects using a least significant difference (LSD) correction.

3. RESULTS

3.1. Self-Ratings

Physical well-being self-ratings differed by culture ($F(1,127) = 54.72$, $p < 0.001$), with Korean participants reporting less positive well-being ratings than US participants. US participant's average ratings were 1 and 0.75 for the younger and older group, respectively, whereas the two Korean age groups reported scores of 1.97 and 1.90, respectively (lower scores indicate more positive well-being ratings). Whereas there was not a significant effect of culture and age on driving frequency, there was a significant interaction, $F(1,126) = 5.83$, $p = 0.017$. Older US participants drove more frequently than younger US participants, whereas in Korea the opposite was true.

3.2. Secondary Task Performance

The error rates for the cognitive secondary task reported in Table 3 were computed as the percentage of incorrect or non-responses. Error rates increased under dual-task conditions, $F(1,127) = 49.96$, $p < 0.001$. Older participants committed an error 26.73% more often than younger participants ($F(1,127) = 70.63$, $p < 0.001$). Although a significant effect of culture appears ($F(1,127) = 13.66$, $p < 0.001$), with US participants showing fewer errors than Korean participants, the effect is best interpreted in light of the significant age*culture interaction ($F(1,127) = 9.25$, $p = 0.003$). Younger participants from the two cultures do not differ significantly from each other, whereas older Korean participants had significantly more errors on the n-back task than older US participants. The error rate increased under dual task conditions more for older participants ($F(1,127) = 9.84$, $p = 0.002$). There was a marginal interaction between the repeated measure and culture ($F(1,127) = 3.49$, $p = 0.062$), suggesting that the Korean participants had a greater percentage increase in error rates while operating the simulator.

Table 3. Secondary task error scores.

		Non-driving	Dual-task
US Drivers	Younger	3.83 (9.19)	6.59 (7.37)
	Older	14.83 (13.95)	22.05 (18.85)
Korean Drivers	Younger	4.43 (6.77)	9.22 (9.42)
	Older	28.81 (24.09)	41.21 (21.95)

Note: Table entries are composite scores across task levels expressed as mean percentage values with the standard deviations in parentheses.

3.3. Driving Performance

3.3.1. Forward velocity

The forward velocity data are presented in Figure 2. Consistent with Mehler et al. (2008), forward velocity is significantly affected by the secondary task, $F(2, 254) = 20.37$, $p < 0.001$.

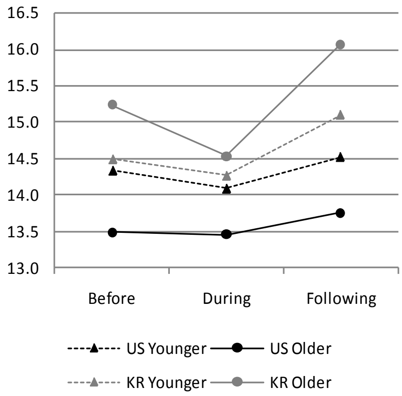

Figure 2. Mean forward velocity in m/s before, during and following the secondary cognitive task.

Averaged over participants, velocity decreased by 0.31 m/s during the secondary task and recovered by 0.47 m/s afterwards (both pairwise comparisons $p < 0.01$).

A main effect of culture was observed, $F(1,127) = 18.39$, $p < 0.001$, with US participants driving slower than their Korean counterparts by 1.0 m/s. Although age does not appear as a significant main effect, it does interact significantly with culture, $F(1,127) = 9.11$, $p = 0.003$. Inspection of the means shows that the forward velocity of the younger group did not vary across culture, 14.32 m/s to 14.62 m/s for the US and Korean participants, respectively. On the other hand, older US participants drove slower than the younger groups while the older Korean group drove the fastest.

Culture also interacted significantly with the secondary task on forward velocity, $F(2, 254) = 6.18$, $p = 0.002$. Interpreting this effect suggests that differences appear in how participants across cultures adapt to the added demands of the secondary task. Before, during and following the secondary tasks, the average of the two US groups' velocities varied only slightly, 13.92 m/s, 13.78 m/s and 14.14 m/s, respectively. Korean drivers, however, appeared to moderate their velocity in response to the added demand of the dual task. Velocity averaged across the Korean drivers varies from 14.86 m/s before the secondary task to 14.40 m/s during the dual task period and to 15.58 m/s afterwards. This pattern suggests that following the dual task the Korean drivers may overcompensate for the disruption in attention that occurred. This pattern was present in both younger and older Korean drivers, but was most pronounced in the older Korean drivers, who also had the highest velocity in the city overall.

Comment [Ed2]: How are these velocities obtained? Are the velocities of the older and younger group averaged or are all of the velocities of all US participants averaged? The same questions apply to the velocities of the Korean drivers below. (From Bruce mehler – yes, you are correct, velocity averged across young and old drivers for each culture. Your recommended wording change makes this clear.)

3.3.2. Speed control

Figure 3 displays speed control expressed as the percent coefficient of variation in velocity. Contrary to our expectations, no main effect of the secondary task appears on the speed control measure; however, culture interacts with the secondary task ($F(2, 254) = 3.63$, $p = 0.028$). Inspection of the means shows that differing responses to the dual task across culture cancel each other. US drivers' speed control increases slightly, seen as a drop in the coefficient of variation in velocity with the addition of the secondary load; during the same period, Korean drivers' speed control becomes more variable, seen as an increase in the coefficient. Following the dual task period, the US groups show no meaningful change, whereas the Korean older group shows a modest recovery in the direction of their pre-task levels. Following the secondary task, younger Korean drivers show a further increase in the coefficient of variation on velocity.

A main effect of culture ($F(1,127) = 41.57$, $p < 0.001$) suggests that, regardless of age, US drivers had a higher degree of speed variation. The main effect of age ($F1,127) = 18.40$, $p < 0.001$) shows that, across cultures, older participants had more difficulty than younger participants controlling speed.

3.3.3. Lateral control

Lateral control expressed as the standard deviation of lane position is shown in Figure 4. Consistent with earlier field studies on younger participants using

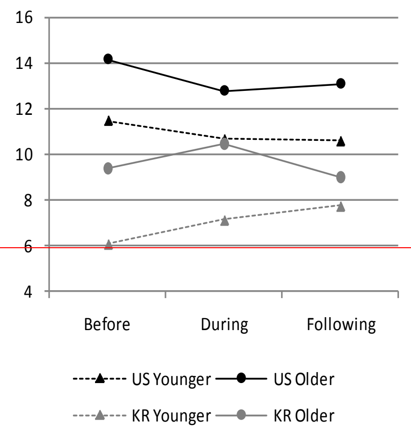

Figure 3. Percent coefficient of variation on velocity before, during and following the secondary task.

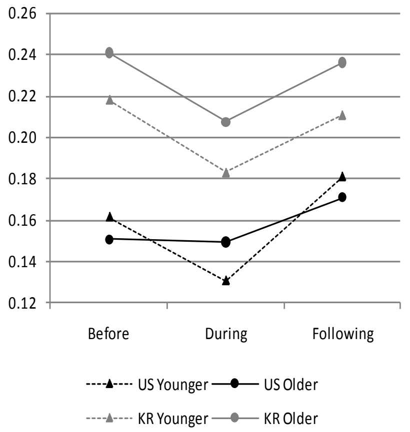

Figure 4. Standard deviation of lane position before, during and following the secondary task.

n-back tasks (Reimer, in press), drivers across age and culture groups showed a significant reduction in lateral variation with the dual task, $F(2, 254) = 7.54$, $p = 0.001$. Interestingly, the 0.025 m reduction in the standard deviation of lane position that is observed across the participants with the addition of the secondary load is followed by a nearly equivalent recovery (0.032 m) observed in the period following the task.

No significant age, culture or three way interactions with the dual task effect exist. A main effect of culture on lateral control ($F(1,127) = 26.64$, $p < 0.001$) suggests that Korean drivers have more difficulty maintaining lane control.

4. DISCUSSION

The age and culture subgroups showed relatively parallel decrements in accuracy on the n-back task (i.e., increased errors) during simulated urban driving relative to their performance under non-driving conditions. The fact that the performance declines were relatively proportional across the groups is consistent with a position 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. Whereas the performance of the younger US drivers was nominally better on the n-back task relative to their Korean counterparts, this difference was not statistically significant and both groups of younger drivers showed relatively high levels of accuracy. As would be expected based on age related declines in cognitive capacity (McDowd *et al.*, 1991; Rogers and Fisk, 2001), both older groups had significantly more difficulty with the cognitive task under both non-driving and driving conditions. However, the older Korean participants had markedly greater difficulty with the n-back task; this will be considered in more detail below.

The younger US and Korean drivers were quite similar in several aspects of their behavior in the urban setting. There were no differences between younger US and Korean drivers in terms of absolute speed in the city setting and they showed the same modest drop in velocity during the dual task and similar increases following the task. The younger groups showed comparable variability in maintaining velocity but did diverge on measures of lateral control. The US participants showed better lateral control, but the drop in the standard deviation of lane value during the secondary task and rebound following were strikingly similar across all of the groups.

The ability to manage varying levels and types of workload is an essential aspect of safe driving. When demands on attention and reaction time are high relative to available resources, one compensatory strategy for increasing safety margins is to moderate driving speed (Haigney *et al.*, 2000). Because an individual's capacity to manage multiple tasks simultaneously generally decreases with age (McDowd *et al.*, 1991; Rogers and Fisk, 2001), older drivers might be expected to be more likely to show evidence of a velocity related compensatory pattern. We reported in Reimer *et al.* (2009) that under highway driving conditions, older drivers drove slower than younger drivers from their respective cultures. When mental workload demands increased with the introduction of the secondary cognitive task (n-back), all participants as a group showed a reduction in highway driving speed. This reduction in velocity was most pronounced in the older Korean drivers. In the urban driving scenario considered in this study, the older Korean drivers again showed the largest drop in driving speed in response to the dual task condition. However, in contrast with the highway environment, the older Korean participants drove at a higher rate of speed than the other three groups during the initial single task phase of the city driving environment and throughout the rest of the urban scenario, even with the marked drop that occurred during the dual task. The older US drivers drove at the slowest rate of speed overall and maintained a steady rate across the single and dual task conditions. Main effects of culture appear in both of the variability measures, with Koran drivers having a higher degree of speed control but reduced lane keeping ability.

The most parsimonious explanation of difference in the older driver group by culture may be an interaction of effective aging and driving experience. Whereas the chronological ages of the US and Korean older driver groups are similar, the Korean participants rated themselves less positively in current physical well-being. They also performed at a significantly lower level of accuracy on the secondary cognitive task, both at baseline and during the dual task condition. Even though this is not definitive, this suggests that in terms of capacity to manage the tasks, the effective age (not the chronological age) of the older Korean drivers may have been relatively older than the US group. Whether this reflects a cultural difference or a sampling difference is not apparent from the available data.

The older Korean drivers also indicated that they drove somewhat less frequently than older US drivers and this experience level difference may have also impacted their driving behavior. This lower level of experience may have translated into the older Korean drivers being less confident in selecting an appropriate speed to employ in the urban setting, resulting in their driving faster than the other groups during the initial single task phase and then showing the largest drop in speed with the increased load of the dual task. Older US drivers appeared to place more emphasis on driving slower in the urban setting and maintaining a lower variability of lane position than the older Korean drivers; greater driving experience might contribute to a greater focus on these variables.

5. CONCLUSIONS

Whereas there were some differences between younger Korean and younger US drivers in this study, their patterns of measured behavior were reasonably comparable in both the simulated urban driving setting and during highway driving (Reimer *et al*., 2009). However, differences between the older Korean and US groups were fairly dramatic, beginning with baseline performance on the cognitive task. As discussed, it is possible that some of the differences between the two older groups reflect greater driving experience in the older US participants and perhaps greater effective aging in the older Korean participants. Thus, these differences may arise to some extent from sampling variations in recruitment of the older subjects. Additional data collection will be required to clarify if the differences observed here between the older groups can be traced to these factors or reflect age associated cultural differences.

Setting aside these issues for the moment, the older US participants drove slowest overall in the urban setting in line with D'Ambrosio *et al.* (2008) observations on age associated self-regulation. In contrast, the older Korean participants drove faster and with more variability in lane discipline and, like their younger Korean and US cohorts, adjusted their driving behavior under added cognitive load by slowing and adopting more rigid control over variability of lane position to compensate for the added demand of the secondary task. Similar behaviors have been found in field and simulation studies of young adult drivers (Reimer, 2009; Mehler *et al*., 2009).

Performance errors on the n-back task were higher for older participants from both cultures in the non-driving assessment and increased markedly during driving. This finding is compatible with previous work showing that older drivers have less total capacity for engaging in secondary tasks (McDowd et al., 1991; Rogers and Fisk, 2001). Designers need to keep this fact in mind when developing functional controls and informational, navigation, and entertainment interfaces for the automobile such that the workload required to attend to these while driving does not tax the capacity of older drivers.

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