A field study assessing lane changing and lane choice across age and multiple levels of cognitive demand

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ABSTRACT

Previous research suggests that drivers change lanes less frequently during periods of heightened cognitive load. However, lane changing behavior of different age groups under varying levels of cognitive demand is not well understood. Moreover, the majority of studies which have evaluated lane changing behavior under cognitive workload have been conducted in driving simulators. Consequently, it is unclear if the patterns observed in these simulation studies carry over to field driving. In this paper, we evaluate data from an on-road study to determine the effects of age and cognitive demand on lane choice and lane changing behavior. Three age groups (20-29, 40-49, and 60-69) were monitored in an instrumented vehicle under varying levels of cognitive demand. The results show that the 40's age group had a 115% higher likelihood of exhibiting lane changes than the 60's group. In addition, drivers in their 20's and 40's travelled more often in the leftmost lane compared to drivers in their 60's. These results suggest that older adults adopt a more conservative driving style by not traveling in the leftmost lane as much as the younger groups and being less likely to change lanes than drivers in their 40's. Regardless of demand level, cognitive workload reduced the likelihood of lane changes for all age groups. This suggests a tendency in drivers of all ages to regulate their behavior in a risk reducing direction in response to added cognitive demand.

INTRODUCTION

Driving is a complex skill that can be considered as a combination of different functional or operational activities involving low level control of the vehicle guided by maneuvers and strategic decisions (1). Lane changing is a driving maneuver frequently associated with accidents (2) and requires engagement of a coordinated combination of sensory / perceptual, cognitive processing, and manipulative actions. Humans are generally considered to have finite information processing resources (3, 4) and situations that make multiple calls on these resources, particularly those that require divided attention, may tax capacity to the point that performance and safety margins suffer. Possible strategies for coping with increased demand might include limiting overall workload by reducing the frequency of optional maneuvers, such as non-critical lane changes, or through actions such as slowing driving speed.

In a naturalistic study of sixteen commuters using either interstate or state highways in southwestern Virginia, Olsen et al. (5) found that lane changes were most often initiated due to a slow lead vehicle and occurred more frequently on the interstate. In driving simulators, participation in a cognitive secondary task has been shown to interfere with the frequency of lane changes (6) and to impact the degree to which drivers monitor surrounding traffic conditions (7). In Cooper et al. (6), the effect of a hands-free cell phone conversation on lane-changing was investigated in three levels of traffic density. The results show that when drivers conversed on a cell phone, they made fewer lane changes, were more likely to remain behind a slow vehicle, and had a lower overall mean speed. The changes in driving behavior observed by Cooper et al. (6) can be seen as compensatory actions taken by the driver to reduce the workload associated with the driving task.

Cantin, Lavallière, Simoneau & Teasdale (8) showed that in a driving simulator study encompassing probe reaction times, the mental workload associated with a lane changing is higher than in straight driving. The relative increase in workload appears, however, to be greater for older adults. As drivers age, they self-report to be less likely to pass another vehicle (9). Under actual driving conditions, older drivers are also known to self regulate, e.g., drive slower, travel during less congested periods, and avoid distracting technologies (10, 11). However, lane changing behavior of different age groups under varying levels of cognitive demand is unclear. Moreover, the degree to which patterns of lane changing behavior with cognitive workload observed in previous driving simulator studies carry over to field driving is not well established.

This paper expands upon recently published work on physiological reactivity and changes in visual behavior in response to graded levels of cognitive demand across different age groups (12, 13) by examining lane changing behavior. The data were captured during an extended period of driving on a multi-lane interstate during which participants were free to maintain or adjust their lane positioning at will. Analysis was limited to cases that were previously classified as taking place in an environment of low to moderate traffic flow such that lane choice and the decision to make lane changes was effectively at the discretion of the drivers. The study was conducted during daytime and non-rush hour periods. The availability of this dataset provided an opportunity to examine the frequency of lane changing and lane selection under both single task driving and under conditions of objectively defined levels of cognitive secondary taskload. The age groups studied allow for the characterization of lane changing behavior and lane choice across the lifespan. This work also provides an opportunity to examine some aspects of the extent to which drivers of different ages do or do not compensate for the added demand of secondary cognitive workload during highway driving.

METHODS

As noted above, the lane choice and lane changing data presented here is drawn from a dataset collected as part of a larger project. An overview of subject selection and methods is provided below; for additional detail see (12, 13).

Participants

The sample considered here consisted of 106 individuals and was balanced by gender and across three age groups 20-29 (n=36), 40-49 (n=35), and 60-69 (n=35). The average age by group was 24.6 (SD: 2.7), 44.4 (SD: 3.0), and 63.3 (SD: 3.1). The male and female participants did not differ significantly by age within each group ($F(1,34)=.86$, $p=.36$; $F(1,33)=.83$, $p=.37$; $F(1,33)=.22$, $p=.64$). Participants were experienced drivers, driving more than three times a week and having held a valid driver's license for over three years. They were also required to be free of accidents for the past year. Compensation of $60 was provided for the 3-hour experiment.

Apparatus and secondary task

Participants drove an instrumented Volvo XC 90 equipped for time synchronized data collection. Data was recorded from the vehicle's CAN bus, a microphone mounted inside the vehicle, and from a camera mounted near the center of the vehicle facing forward.

Three levels of a delayed auditory recall task (n-back) were employed to increase drivers' workload. Each level consisted of four 30-second trials during which 10 single digit numbers (0 – 9) were presented randomly at a spacing of 2.25 seconds. At the lowest level of demand (0-back), drivers were to repeat each digit as it was presented. At the moderate level of demand (1-back), drivers were to respond with the next to last number presented. At the highest level of demand (2-back), the number two places back in the sequence was to be repeated. The form of this task was identical to earlier studies conducted in our laboratory (14-16) and was based on recommendations by Zeitlin (17).

Procedure

Participants signed an informed consent and completed a questionnaire covering driving and health history. They were then extensively trained on the secondary task prior to entering the vehicle with a minimum of n+1 practice trials per task level (e.g. 3 practice trials for the 2-back). Additional repetitions of the instructions and practice trials were presented for each demand level until participants demonstrated a minimum proficiency of 7 correct responses on the 0 and 1-back (out of 10 and 9 items respectively) and of at least 4 (out of 8) on the 2-back. Participants who were unable to meet the criteria for the 2-back within nine practice trials were excluded. Upon being seated in the vehicle, an audio recording reviewed the secondary task and presented an additional n+2 practice trials for each demand level.

A research associate, seated in the back of the car, operated the data collection equipment, provided driving directions, and monitored the participants to ensure that they had adequate control of the vehicle at all times. Approximately 30 minutes of driving were provided for habituation prior to the study period which consisted of an initial six minutes of single task driving followed by the three levels of the n-back task. Each task was presented over a two-minute interval (four 30-second trials) and each task was followed by 2 minutes of single task driving. The presentation order for the three levels of the task was counterbalanced across the sample.

The experiment was conducted on Interstate 93 traveling north from Boston, Massachusetts and the area of data collection was consistent for all participants. When entering the highway, participants were prompted: "We are going to be driving north on 93 for approximately 40 minutes. You can continue driving in this lane or move into another lane so that you are comfortable with the traffic flow". The posted speed limit on the portion of the highway studied here was 104.6 km/h (65 mph).

Data coding and data periods used in analysis

Recorded audio was used to assess participants' accuracy in responding to the n-back tasks. Task performance was scored as a percentage of the number of correct responses out of the total number of expected responses. Lane change and lane choice data were extracted through a manual analysis of video recordings. The lane change count was verified by the first author. The procedure for classification of lane changes was analogous to Olsen et al. (5) and consistent with Cooper et al. (6). The onset of each lane change was classified as the point when the vehicle was observed to be first moving in a lateral direction towards the destination lane. The completion of each lane change was recorded as the point where the vehicle was fully centered in the destination lane. For the time spent in the leftmost lane, time was obtained by subtracting the lane crossing when entering the lane by lane crossing when leaving the lane. A lane crossing was classified as when the middle of the car crossed the lane marker.

Three data periods were analyzed: pre-task, n-back, and recovery. The pre-task period consisted of six minutes of single task driving prior to the initiation of the first n-back task. The n-back period consisted of the six minutes of dual task data corresponding to the aggregate of the three separate two-minute-long secondary tasks. The six minutes of data for the recovery period was drawn from the two minutes of single task driving that followed each of the three dual task periods. Also considered was an analysis of each of the three task demand levels (0, 1, and 2-back). Since each task was two minutes long, a two-minute reference "baseline" period was used for comparison. Consistent with Mehler et al. (12) and Reimer et al. (13), the two-minute baseline period was selected as minutes 3.5 to 5.5 of the pre-task period. For the purpose of classifying frequencies, a lane change was assigned to the period in which it was initiated.

RESULTS

Secondary task performance

Figure 1 presents the secondary task performance for each age group by the level of cognitive task difficulty. The rate of correct responses was analyzed with a Poisson model due to the high level of non-normality in the data. There were 40, 36, and 32 stimuli that required responses in the 0-back, 1-back, and 2-back conditions, respectively. The logarithm of the number of stimuli was used as an offset variable in the model. Because the data consisted of repeated measures, generalized estimating equations (GEE) were used for estimation. The model was fitted using PROC GENMOD in SAS 9.1, with the specifications of log link function and Poisson distribution. Significant effects were observed for cognitive task difficulty ($\chi^2(2)=79.03$, $p<.0001$) and its interaction with age ($\chi^2(4)=10.18$, $p=.04$). Follow-up contrasts revealed that, regardless of age, increasing demand resulted in degraded secondary task performance (0-back vs. 1-back: $\chi^2(1)=37.0$, $p<.0001$; 0-back vs. 2-back: $\chi^2(1)=64.5$, $p<.0001$; 1-back vs. 2-back: $\chi^2(1)=30.4$, $p<.0001$). This effect suggests that as in Mehler et al. (16) and Reimer et al. (15), error rates increased with higher levels of cognitive task difficulty. The differences between age groups depended on the cognitive task demand. Under the highest demand condition (2-back), the 20's age group responded correctly to a higher percentage of stimuli than both the 40's

($\chi^2(1)=4.0$, p=.045) and 60's ($\chi^2(1)=3.11$, p=.078) age groups, although the comparison to the 60's group was only marginally significant. There were no differences across the age groups for the 0-back or 1-back conditions (p>.1).

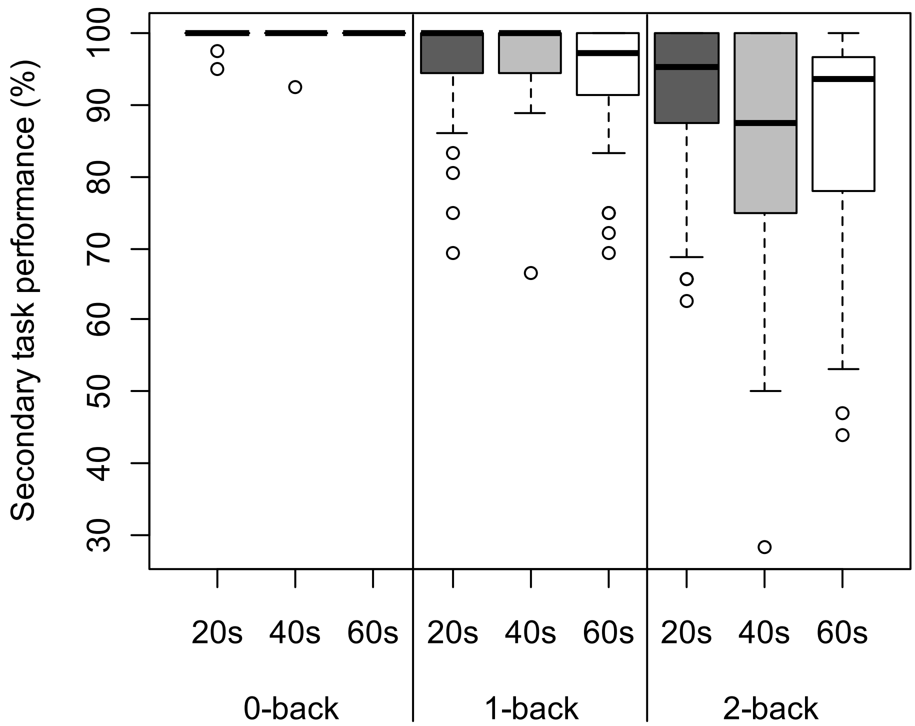

FIGURE 1 Secondary task performance (%) for each age and demand level (0, 1, and 2-back task)

Number of lane changes

A negative binomial model was developed to compare the number of lane changes across different age groups for three study periods: the six-minute period prior to the admission of the n-back tasks (pre-task), the aggregate of the three two-minute-long n-back tasks (n-back), and the combination of the three two-minute intervals of single task driving following each n-back task (recovery). Each of these three periods was six-minutes in duration. The model was fitted using PROC GENMOD in SAS 9.1, with the specifications of log link function and negative binomial distribution. Repeated measures were accounted for by using GEE. Figure 2 shows histograms for the number of lane changes across different age groups and study periods.

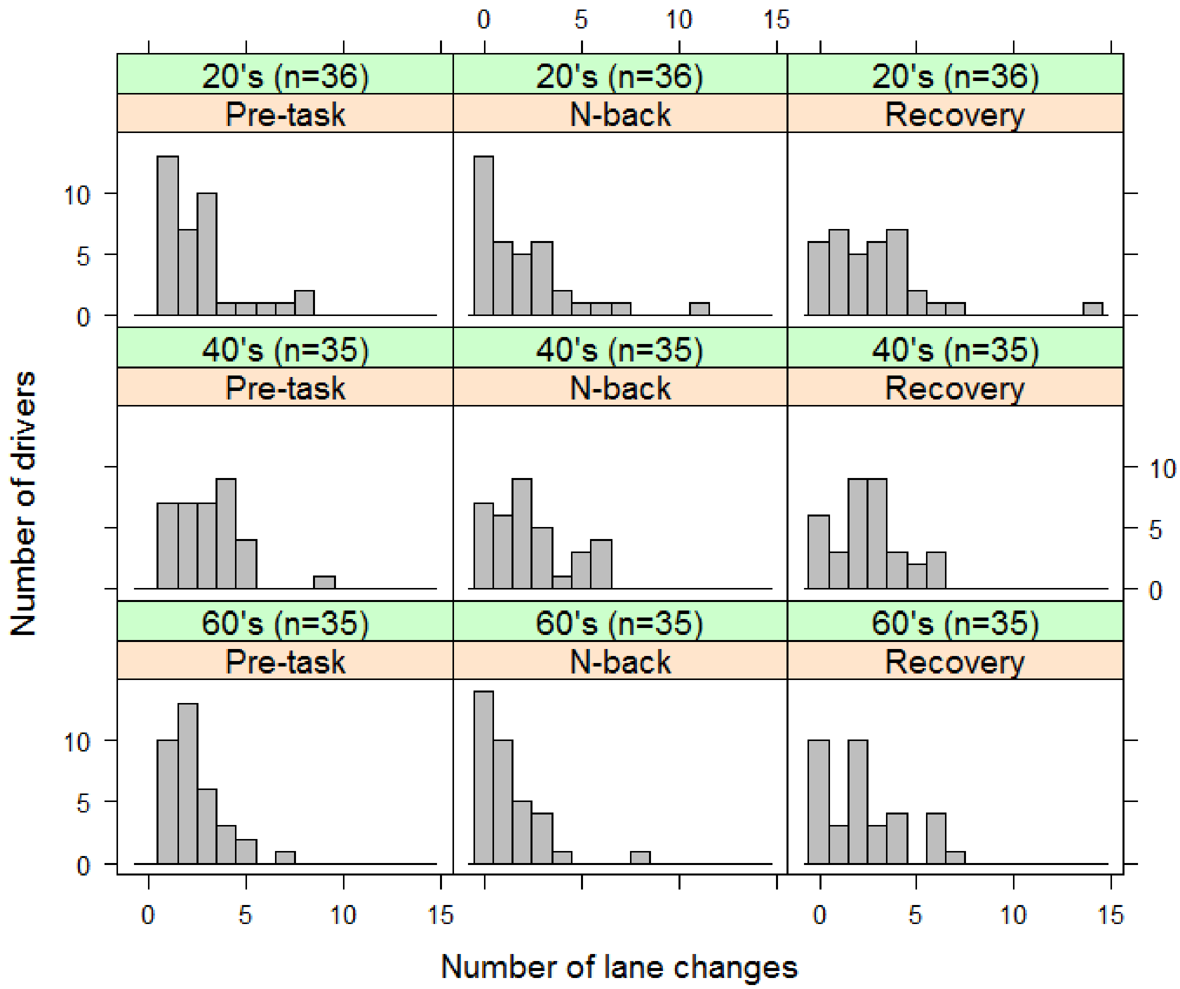

FIGURE 2 Histograms for number of lane changes across age groups and study periods

Both the pre-task and the recovery periods were associated with a higher number of lane changes compared to the n-back task period. The pre-task period was estimated to result in a multiplicative increase of 1.49 in the expected number of lane changes (95% CI: 1.21, 1.82, $\chi^2(1)=14.73$, $p<.0001$) and the recovery period was estimated to result in a multiplicative increase of 1.39 (95% CI: 1.17, 1.67, $\chi^2(1)=13.39$, $p=.0003$). No significant difference in lane change rate was observed between the pre-task and the recovery periods. Thus, there was no evidence to suggest a carry-over effect of lane change behavior observed in the n-back task period to the lane change behavior observed in the recovery period. Age x study period interaction was not significant ($p>.05$). Considering the entire analysis period, the 40's group had a higher number of lane changes compared to the 60's group, a multiplicative increase of 1.39 in the expected number of lane changes (95% CI: 1.03, 1.86, $\chi^2(1)=4.79$, $p=.03$).

A finer break-down of the n-back task period is provided in Table 1. These data are based on the two-minute windows represented by the three separate cognitive difficulty levels (0, 1 and 2-back) and where "baseline" represents two-minutes prior to the first n-back task. Given the short intervals, there were only a few design cells with more than two lane changes. Thus, we grouped the response variable into three categories: 0, 1, and ≥2 lane changes. An ordered logit model, specifically proportional odds, was developed to predict the number of lane changes for different age groups and demand level. A proportional odds model provides a strategy that takes into account the ordinal nature of the data (18) and is represented with a set of equations as:

$$\ln\left[\frac{p_1}{1-p_1}\right] = \beta_{01} + \mathbf{\beta X}$$
$$\ln\left[\frac{p_1+p_2}{1-p_1-p_2}\right] = \beta_{02} + \mathbf{\beta X} \quad (1)$$

where p_1 represents the probability of having two or more lane changes and p_2 represents having one lane change. Thus, the equations represent the log-odds of a lane change for: "≥2-lane changes" versus "1-lane change" and "0-lane changes"; "≥2-lane changes" and "1-lane change" versus "0-lane changes". β_{0i} represents the intercept and $\mathbf{\beta}$ is the matrix of coefficient estimates for predictor variables, **X**. Repeated measures were accounted for using GEE. The model was fitted using PROC GENMOD in SAS 9.1, with the specifications of cumulative logit link function and multinomial distribution.

Table 1 Frequency of lane changes by age and demand level (baseline, 0, 1, and 2-back task)

Age	Demand level	Number of lane changes 0	1	≥2
20's (n=36)	Baseline	19	8	9
	0-back	20	8	8
	1-back	23	9	4
	2-back	23	7	6
	Total	85	32	27
40's (n=35)	Baseline	14	10	11
	0-back	17	11	7
	1-back	14	10	11
	2-back	22	7	6
	Total	67	38	35
60's (n=35)	Baseline	19	8	8
	0-back	25	7	3
	1-back	25	6	4
	2-back	23	10	2
	Total	92	31	17

Wald statistics revealed that age ($\chi^2(2)=7.64$, $p=.02$) and demand level ($\chi^2(3)=7.85$, $p=.049$) were statistically significant. Age x demand level interaction was not significant ($p>.05$). The 40's group exhibited 115% higher odds of making lane changes compared to the 60's group (Table 2). No other differences were found between age groups. These findings are in line with the results of the negative binomial model reported above for the different study periods.

Regardless of demand level, performing a cognitive task decreased the odds of making lane changes (Table 2).

TABLE 2 Multiplicative increase in odds of lane changes for different age groups and demand levels (baseline, 0, 1, and 2-back task)

Comparisons		Estimate (Δ)	$\chi^2(1)$	p	95% Confidence Interval (CI)
Age	20's vs. 40's	0.65	1.86	0.17	0.35 - 1.20
	20's vs. 60's	1.41	1.14	0.29	0.75 - 2.63
	40's vs. 60's	2.15	7.58	0.006	1.25 - 3.71
Demand level	Baseline vs. 0-back	1.59	3.55	0.059	0.98 - 2.56
	Baseline vs. 1-back	1.57	3.74	0.053	0.99 - 2.49
	Baseline vs. 2-back	1.98	7.31	0.007	1.21 - 3.23
	0-back vs. 1-back	0.99	0.00	0.97	0.62 - 1.58
	0-back vs. 2-back	1.25	0.78	0.38	0.77 - 2.02
	1-back vs. 2-back	1.25	0.92	0.34	0.79 - 1.99

Mean Speed

A repeated measures ANOVA was conducted to compare mean speed across the three age groups for the three study periods previously discussed: pre-task, n-back, and recovery (Figure 3). The main effects of age ($F(2,102)=5.53$, $p=.005$) and study period ($F(2,204)=16.79$, $p=<.0001$) and their interaction ($F(4,204)=3.91$, $p=.004$) were all significant. In general, participants in the 20's age group drove significantly faster than those in the 60's group ($t(102)=3.06$, $p=.003$). The 40's group also drove significantly faster than the 60's group, but only during the n-back task ($t(169)=3.08$, $p=.003$) and recovery ($t(169)=3.39$, $p=.001$) periods and not during pre-task. The 20's and 60's groups drove significantly faster prior to the n-back task period than they drove during n-back task and recovery periods (20's pre-task vs. 20's n-back: $t(204)=4.05$, $p<.0001$; 20's pre-task vs. 20's recovery: $t(204)=3.77$, $p=.0002$; 60's pre-task vs. 60's n-back: $t(204)=4.72$, $p<.0001$; 60's pre-task vs. 60's recovery: $t(204)=4.39$, $p<.0001$). Thus, the results suggest that in general the 40's group's average speed profile stayed fairly constant across the three study periods, whereas the 20's and 60's groups reduced their speeds when presented with the n-back task and maintained these slower speeds during the recovery periods. These results are based on aggregate speed profiles for six-minute study periods. A more detailed analysis on speed maintenance across the three demand levels follows.

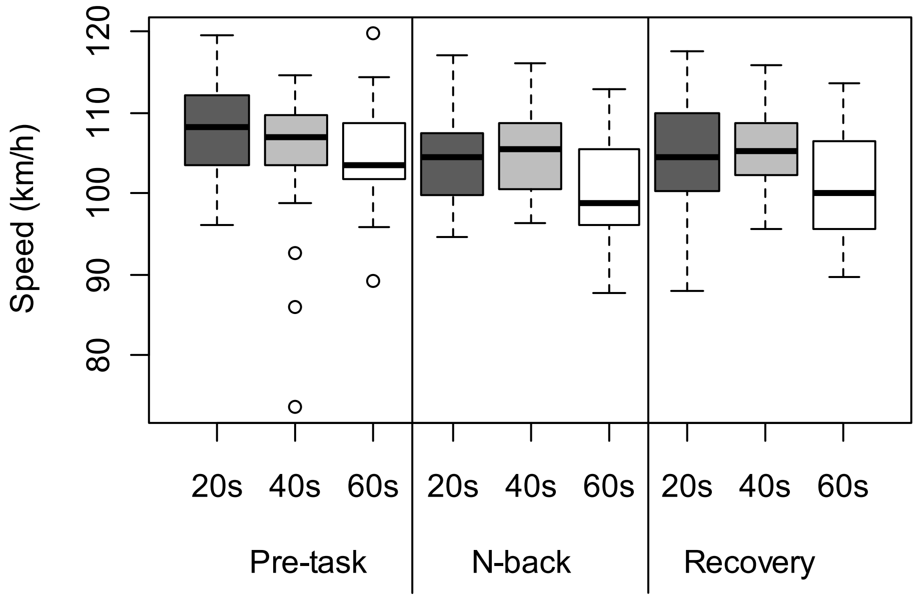

FIGURE 3 Mean speed across different age groups and study periods

Figure 4 presents the mean speed for each age and demand level. This data also had an outlier, which was determined to be not influential, and hence was included in the statistical analysis. The repeated measures ANOVA yielded significant main effects of age (F(2,103)=5.05, p=.008) and demand level (F(3,309)=8.79, p<.0001). The interaction between age and demand level was not significant (p>.05). Compared to the 20's and 40's age groups, drivers in their 60's drove significantly slower (105.4 and 105.3 vs. 101.7 km/h, respectively) (60's vs. 20's: t(103)=-2.78, p=.006; 60's vs. 40's: t(103)=-2.73, p=.008). During single task driving (baseline), drivers of all ages drove faster than during all three demand level periods (baseline: 106.1 km/h, 0-back: 103.9 km/h, 1-back: 104 km/h, and 2-back: 102.3 km/h)(baseline vs. 0-back: t(309)=2.87, p=.004; baseline vs. 1-back: t(309)=2.76, p=.006; baseline vs. 2-back: t(309)=5.12, p<.0001). 0 and 1-back tasks both resulted in faster average speeds than the 2-back task (0-back vs. 2-back: t(309)=2.26, p=.02; 1-back vs. 2-back: t(309)=2.36, p=.02).

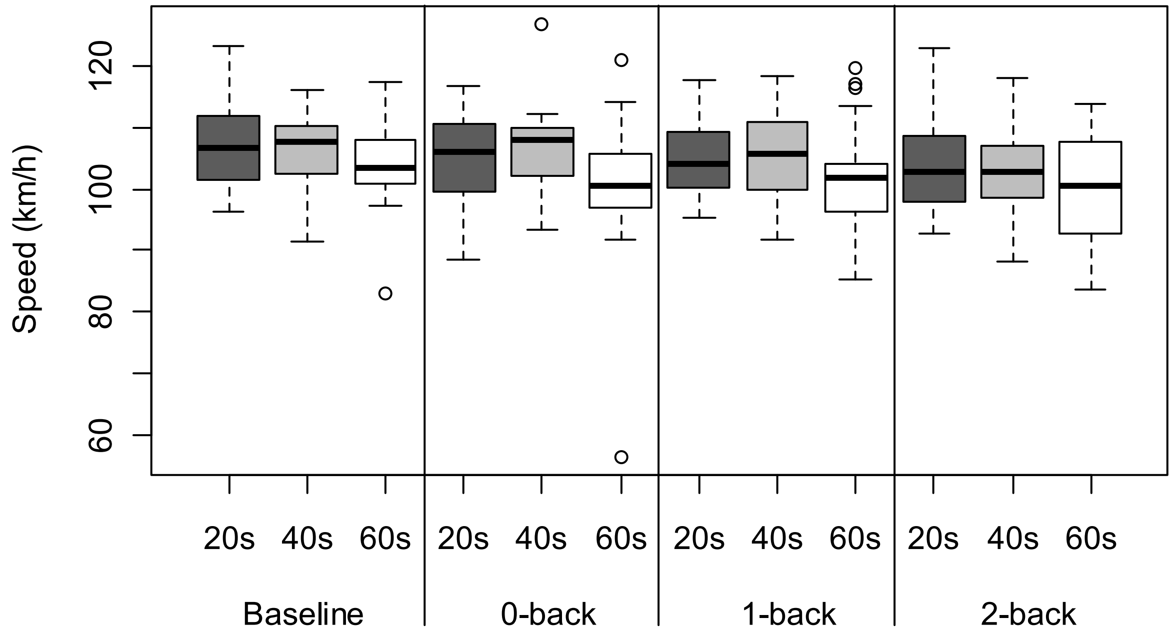

FIGURE 4 Mean speed for each age and demand level (baseline, 0, 1, and 2-back task)

Lane choice

Table 3 presents the frequency of drivers who did or did not at all drive on the leftmost lane across the three study periods. A logistic regression model was built to predict the tendency to drive on the leftmost lane. Repeated measures were accounted for using GEE. The model was fitted using PROC GENMOD in SAS 9.1, with the specifications of logit link function and binomial distribution. The 60's group had lower odds of driving on the leftmost lane than both the 20's and the 40's group ($\chi^2(2)$=24.16, p<.0001). Compared to the 60's group, the 40's group was estimated to have a 617% and the 20's group was estimated to have a 312% higher odds of driving on the leftmost lane. N-back task decreased the odds of driving on the leftmost lane ($\chi^2(2)$=8.05, p=.02). The odds of driving on the leftmost lane was 312% higher during the pre-task period and was 617% higher during the recovery period.

We analyzed time spent on the leftmost lane for non-zero observations. Both age (F(2,101)=2.99, p=.054) and study period (F(2,151)=3.36, p=.04) were significant. In line with the findings reported above, 20's and 40's groups spent a larger portion of their time on the leftmost lane (39% and 37% vs. 24%, respectively) (60's vs. 20's: t(107)=-2.28, p=.02; 60's vs. 40's: t(105)=-2.04, p=.04). N-back task (39%) resulted in a larger portion of driving time spent on the leftmost lane compared to the pre-task (31%) and recovery periods (31%). Thus, given that a driver was on the leftmost lane in a study period, the time spent on the leftmost lane during that period was longer if the period was n-back task rather than the other two. Coupled with the findings from the lane change analysis reported previously, this finding suggests that the drivers, who were on the leftmost lane during the n-back task, were likely to stay on that lane.

TABLE 3 Frequency of drivers who drove in the leftmost lane across different age groups and study periods

Age	Study period	Drove in the leftmost lane	
		Yes	No
20's (n=36)	Pre-task	23	13
	N-back	29	7
	Recovery	32	4
40's (n=35)	Pre-task	29	6
	N-back	30	5
	Recovery	32	3
60's (n=35)	Pre-task	17	18
	N-back	13	22
	Recovery	21	14

Table 4 presents the frequency of drivers who did or did not drive in the leftmost lane across different task demand levels. Another logistic regression model was built to analyze this data. Drivers in the 60's age group had lower odds of driving in the leftmost lane than both the 20's and the 40's groups ($\chi^2(2)=14.02$, p=.0009). Compared to the 60's group, the 40's group was estimated to have a 191% and the 20's group a 217% higher odds of driving on the leftmost lane regardless of task demand.

For the drivers who drove on the leftmost lane for a given demand level, the time spent in the leftmost lane during that demand level differed based on age (F(2,87)=4.75, p=.01). In line with the logistic regression findings above, the 20's and 40's groups spent more of their time in the leftmost lane than the 60's group (55% and 56% vs. 35%, respectively) (60's vs. 20's: t(93)=-2.74, p=.008; 60's vs. 40's: t(93)=-2.79, p=.006).

TABLE 4 Frequency of drivers who drove on the leftmost lane across different age groups and demand levels

Age	Demand level	Drove on the leftmost lane	
		Yes	No
20's (n=36)	Baseline	21	15
	0-back	24	12
	1-back	24	12
	2-back	18	18
40's (n=35)	Baseline	20	15
	0-back	20	15
	1-back	20	15
	2-back	22	13
60's (n=35)	Baseline	9	26
	0-back	12	23
	1-back	11	24
	2-back	14	21

DISCUSSION

An analysis of an on-road experiment was conducted to examine lane change and lane choice behavior of three different age groups (20's, 40's and 60's) under varying levels of cognitive load. The findings reveal that both age and demand level were associated with lane choice and lane change behavior. Compared to periods of single task driving, fewer lane changes were observed under secondary cognitive task load. A similar effect was observed by Cooper et al. (6) in a simulator experiment. Given that our study was an on-road assessment, it provides additional ecological validity to this finding. An age effect was observed in the significantly lower number of lane changes in the 60's age group compared to drivers in their 40's. This result suggests that, as expected, older adults in this study adopted a generally more conservative driving style than middle aged adults.

Speed selection also was influenced by age and demand level. The 60's group showed a significantly slower mean speed than drivers in their 20's and 40's. This finding is in agreement with other on-road and simulator studies where older drivers maintained slower speeds than younger drivers (19-21). Moreover, older drivers in our study responded to the introduction of cognitive task load with the same compensatory strategy as younger drivers, that is, they reduced their speed by a similar amount. During the baseline, drivers travelled at greater speeds then they did when they had to perform each of the cognitive secondary tasks. These results are consistent with Cooper et al. (6) and Horberry et al. (22), who showed that drivers reduced their speed while conducting a conversation similar to a hand-free cell phone task.

A major concern around added cognitive demand during driving is that drivers are not always aware of the extent of the resulting attentional distraction or any associated performance decrements (23) and thus tend to be willing to engage in potentially risky distracting activities while driving. One might expect that as drivers become more skilled at a given task with practice, the effective task load will decrease, resulting in less impact on their performance. However, this may not be the actual result for all secondary tasks. Cooper and Strayer (24) found that groups reporting both high and low real-world experience with cell phones exhibited similar driving impairments when conversing on a hands-free cell phone. These data suggest that practice is unlikely to eliminate all disruptive effects of cell phone use on driving. Familiarity and confidence in one's ability to carry out a task like conversing on a cell phone may actually increase an individual's comfort with and absorption in this secondary activity, reducing their overall attention to what should be the primary task. Concern over this pattern of behavior is one reason behind the call for the development of detection systems that provide information to drivers when they are distracted so that they can modify their behavior appropriately (25-27). Donmez, Boyle, & Lee (28) found that young drivers, who exhibit the riskiest distraction behavior among their peers, benefit most from distraction-related feedback. This finding provides more evidence on drivers' risk unawareness when engaged in distracting activities and the potential benefits of providing feedback to guide appropriate behavior.

To our knowledge, this is the first time that time spent in the leftmost lane as a function of age and cognitive load has been evaluated. The results show that the 60's age group drove less often on the leftmost lane compared to the 20's and 40's cohorts. This pattern remained consistent across single task driving and with the addition of the secondary cognitive task load. Self-regulation could explain why participants in the 60's age group differ from their younger counterparts in their utilization of the leftmost lane. Since the attentional and control demands of travel in this lane are generally higher, avoiding the leftmost lane is one strategy for reducing overall demand. Donorfio et al. (29) used a survey to investigate self-regulation in older drivers. Driving was described as a way to remain connected to society and their results revealed that, for older drivers, self-regulation represents one method of coping with changing capabilities due to declining health and cognitive abilities that allows them to maintain that connection. In order to self-regulate appropriately, drivers need to be aware of their limitations and their capacity to find an effective balance. Unfortunately, older drivers are not always good at self-evaluation of their driving performance (30, 31) and older drivers have been found to error both on the side of driving beyond their capabilities and of sometimes curtailing their driving behavior prematurely (11).

CONCLUSION

Lane change frequency was found to decrease during periods of heightened cognitive load across all age groups and drivers in their 60's were found to make fewer lane changes than those in their 40's. Older drivers also spent less time in the left hand travel lane. More research is required to determine if the observed reduction in lane changes represents a conservative, compensatory approach to driving under dual task load or simply results from a basic saturation of the drivers' cognitive capacities that limits engagement in other activities.

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REFERENCES

1. Michon, J. A., A critical view of driver behavior models: What do we know, what should we do?, in Human Behavior and Traffic Safety, *Evans, L. and R. Schwing*, Editors. Plenum Press: New York. p. 520. 1995.
2. Pande, A. and M. Abdel-Aty, Assessment of freeway traffic parameters leading to lane-change related collisions. *Accident Analysis & Prevention*, Vol. 38, No. 5, 2006. p. 936-948.
3. Wickens, C. D., Processing resources in attention, in Varieties of attention, *Davies , D.R. and R. Parasuraman*, Editors. Academic Press: New York, NY. 1984.
4. Wickens, C. D. and J. S. McCarley, *Applied Attention Theory*. CRC Press. New York, 2008.
5. Olsen, E. C. B., S. E. Lee and W. W. Wierwille. Analysis of distribution, frequency, and duration of naturalistic lane changes. in *Human Factors and Ergonomics Society 46th Annual Meeting*. Baltimore, MD. 2002.
6. Cooper, J. M., I. Vladisavljevic, N. Medeiros-Ward, P. T. Martin and D. L. Strayer, An Investigation of Driver Distraction Near the Tipping Point of Traffic Flow Stability *Human Factors*, Vol. 51, No. 2, 2009. p. 261-268.
7. Zhou, H., M. Itoh and T. Inagaki. Effects of cognitive distraction on checking traffic conditions for changing lanes. in *Proceedings of the Human Factors and Ergonomics Society 53rd Annual Meeting*. San Antonio, TX. 2009.

8. Cantin, V., M. Lavallière, M. Simoneau and N. Teasdale, Mental workload when driving in a simulator: Effects of age and driving complexity. *Accident Analysis & Prevention*, Vol. 41, No. 4, 2009. p. 763-771.
9. Boyle, J., S. Dienstfrey and A. Sothoron, National Survey of Speeding and Other Unsafe Driving Actions. 1998, National Highway Traffic Safety Administration: Washington D.C.
10. Langford, J. and S. Koppel, Epidemiology of older driver crashes - Identifying older driver risk factors and exposure patterns. *Transportation Research, Part F: Traffic Psychology and Behaviour*, Vol. 9, No. 5, 2006. p. 309-321.
11. D'Ambrosio, L. A., L. K. M. Donorfio, J. F. Coughlin, M. Mohyde and J. Meyer, Gender differences in self-regulation patterns and attitudes toward driving among older adults. *Journal of Women and Aging*, Vol. 20, No. 3-4, 2008. p. 265-282.
12. Mehler, B., B. Reimer and J. F. Coughlin. Physiological Reactivity to Graded Levels of Cognitive Workload across Three Age Groups: An On-Road Evaluation. in *Human Factors and Ergonomics Society 54th Annual Meeting*. San Francisco, CA. 2010.
13. Reimer, B., B. Mehler, Y. Wang and J. F. Coughlin. The Impact of Systematic Variation of Cognitive Demand on Drivers' Visual Attention across Multiple Age Groups. in *Human Factors and Ergonomics Society 54th Annual Meeting*. San Francisco, CA. 2010.
14. Reimer, B., B. Mehler, J. F. Coughlin, K. M. Godfrey and C. Tan. An On-Road Assessment of the Impact of Cognitive Workload on Physiological Arousal in Young Adult Drivers. in *AutomotiveUI*. Essen, Germany: ACM. 2009.
15. Reimer, B., Cognitive task complexity and the impact on drivers' visual tunneling. *Transportation Research Record*, Vol. 2138, No., 2009. p. 13-19.
16. Mehler, B., B. Reimer, J. F. Coughlin and J. A. Dusek, The impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers. *Transportation Research Record*, Vol. 2138, No., 2009. p. 6-12.
17. Zeitlin, L. R., Subsidiary task measures of driver mental workload: A long-term field study. *Transportation Research Record*, Vol. 1403, 1993. p. 23-27.
18. Stokes, M. E., C. S. Davis and G. G. Koch, *Categorical data analysis with the SAS System*. 2nd ed. SAS Institute Inc. Cary, NC, 2000.
19. Hakamies-Blomqvist, L., S. Mynttinen, M. Backman and V. Mikkonen, Age-related differences in driving: Are older drivers more serial? *International Journal of Behavioral Development*, Vol. 23, No. 3, 1999. p. 575-589.
20. Planek, T. W. and R. C. Fowler, Traffic accident problems and exposure characteristics of the aging driver. *Journal of Gerontology*, Vol. 26, No. 2, 1971. p. 224-30.
21. Szlyk, J. P., W. Seiple and M. Viana, Relative effects of age and compromised vision on driving performance. *Human Factors*, Vol. 37, No. 2, 1995. p. 430-6.
22. Horberry, T., J. Anderson, M. A. Regan, T. J. Triggs and J. Brown, Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis and Prevention*, Vol. 38, No. 1, 2006. p. 185-91.
23. Horrey, W. J., M. F. Lesch and A. Gabaret, Assessing the awareness of performance decrements in distracted drivers. *Accident Analysis & Prevention*, Vol. 40, No. 2, 2008. p. 675-682.
24. Cooper, J. M. and D. L. Strayer, Effects of Simulator Practice and Real-World Experience on Cell-Phone–Related Driver Distraction. *Human Factors*, Vol. 50, No. 6, 2008. p. 893-902.

25. Reimer, B., J. F. Coughlin and B. Mehler, Development of a Driver Aware Vehicle for Monitoring, Managing & Motivating Older Operator Behavior, in *ITS-America*. 2009: Washington, DC.
26. Donmez, B., L. Boyle and J. D. Lee, Mitigating driver distraction with retrospective and concurrent feedback. *Accident Analysis & Prevention*, Vol. 40, No., 2008. p. 776-786.
27. Donmez, B., L. N. Boyle and J. D. Lee, Safety implications of providing real-time feedback to distracted drivers *Accident Analysis & Prevention*, Vol. 39, No. 3, 2007. p. 581-590.
28. Donmez, B., L. Boyle and J. D. Lee, Differences in off-road glances: The effects on young drivers' performance. *ASCE Journal of Transportation Engineering, Special Issue: Applications of Advanced Technologies in Transportation*, Vol. 136, No. 5, 2010. p. 403-409.
29. Donorfio, L. K. M., L. A. D'Ambrosio, J. F. Coughlin and M. Mohyde, To drive or not to drive, that isn't the question—the meaning of self-regulation among older drivers. *Journal of Safety Research*, Vol. 40, No., 2009. p. 221-226.
30. Holland, C. A. and P. M. Rabbitt, People's awareness of their age-related sensory and cognitive deficits and the implications for road safety. *Applied Cognitive Psychology*, Vol. 6, No. 3, 1992. p. 217-231.
31. Holland, C. A. and P. M. Rabbitt, The problems of being an older driver: comparing the perceptions of an expert group and older drivers. *Applied Ergonomics*, Vol. 25, No. 1, 1994. p. 17-27.
32. Lavallière, M., B. Donmez, B. Reimer, B. Mehler, K. Klauber, J. Orszulak, et al. Effects of age and cognitive workload on lane choice and lane changing behavior. in *20th Canadian Multidisciplinary Road Safety Conference*. Niagara Falls, Ontario. 2010.