Effects of age and cognitive workload on lane choice and lane changing behavior

Martin Lavallière
MIT AgeLab, Cambridge, MA, USA
Université Laval, Faculté de Médecine, GRAME, PEPS, Québec, Canada
Centre d'excellence sur le vieillissement de Québec, Centre de recherche FRSQ du CHA, Québec, Qc, Canada

Birsen Donmez
Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, ON, Canada

Bryan Reimer, Bruce Mehler, Kameron Klauber, Jarrod Orszulak, Joseph F. Coughlin
MIT AgeLab, Cambridge, MA, USA

Normand Teasdale
Université Laval, Faculté de Médecine, GRAME, PEPS, Québec, Canada
Centre d'excellence sur le vieillissement de Québec, Centre de recherche FRSQ du CHA, Québec, Qc, Canada

Abstract

Background: A growing body of literature suggests that cognitive distraction increases the likelihood of being involved in an automobile crash and impacts traffic flow. The physical and cognitive changes associated with advancing age are known to negatively impact driving performance. Driving behaviors on the other hand often indicate better judgment and reduced risk taking with advancing age. In this paper, we assess data from an on-road experiment to determine the effects of age and cognitive distractions on lane choice and lane changing behavior. Methods: Three age groups (20's: n=36, 40's: n=35, and 60's: n=35) were monitored in an instrumented vehicle. During a portion of the drive, a delayed auditory recall task ("n-back") was presented to increase demands on drivers' attention and working memory. The task required participants to attend to a series of aurally presented single digit numbers. Participants were asked to verbally respond with the digit presented "n" positions previously. There were three levels of demand: 0-, 1-, and 2-back. Video records were reviewed to identify lane changes and time spent in the leftmost lane. Results: Odds of making a lane change was assessed through an ordered logit model. Results revealed that the 40's age group had a 115% times higher likelihood of exhibiting lane changes than the 60's age group. In addition, drivers in the 20 and 40 year old groups travelled for a longer period in the leftmost lane compared to the 60 year olds (35.8% and 33.5% vs. 14.2%, respectively). Regardless of age, performing a cognitive task decreased the odds of lane changing (1.59, 1.57, and 1.95 times for baseline vs. 0-, 1- and 2-back task, respectively). Conclusion: Older adults adopt a more conservative driving style by not traveling in the left most lane as much as the younger groups and being less likely to change lanes than the 40 year olds. Cognitive workload reduced the likelihood of lane changes for all age groups. This suggests that drivers of all ages tend to regulate their behavior in a risk reducing direction in response to the added demand of the cognitive distractions.

Résumé

Introduction: Il est de plus en plus reconnu que les distractions cognitives au volant augmentent les risques d'êtres impliqués dans une collision en plus d'avoir des impacts sur la fluidité de la circulation. De plus, certains changements physiques et cognitifs normalement associés avec le vieillissement sont connus pour altérer les performances de conduite. Toutefois, on sait que certains comportements de conduite sont aussi associés à un meilleur jugement et à une prise de risque plus faible avec l'avancement en âge. Dans cette étude, une expérience sur route a été effectuée afin de déterminer les effets de l'âge et de la distraction cognitive sur le nombre de changements de voie effectués et les comportements qui y sont associés. Méthodes: Trois groupes d'âge (20's: n=36, 40's: n=35, et 60's: n=35) ont été évalués dans un véhicule instrumenté. Lors de la conduite, une tâche secondaire de rappel ("n-back") a été utilisée afin d'augmenter la charge cognitive du conducteur. Cette tâche requiert au participant d'écouter une série de chiffres qui lui est présentée. Le participant doit ensuite répondre par le chiffre présenté "n" position avant. Trois niveaux de difficulté ont été présentés : 0-, 1- et 2- chiffres précédemment. Des enregistrements vidéos ont été utilisés afin d'identifier le nombre de changements de voie et le temps passé dans la voie la plus à gauche. Résultats: Les résultats montrent que les conducteurs de 40's ont 115% plus de chance d'effectuer un changement de voie que les conducteurs du groupe 60's. De plus, les conducteurs dans les groupes 20's et 40's ont conduit pour une plus grande période de temps dans la voie la plus à gauche que le groupe 60's (35.8%, 33.5% vs. 14.2% du temps possible, respectivement). Sans égard au groupe d'âge, effectuer une tâche cognitive a eu pour effet de diminuer le nombre de changement de voie (1.59, 1.57, et 1.95 fois pour le *niveau de base* vs. 0-, 1- et 2-"back", respectivement). Conclusion: Les conducteurs âgés ont adopté une conduite dite plus conservatrice en n'utilisant pas la voie la plus à gauche autant que les conducteurs plus jeunes ainsi qu'en ne changeant pas de voie aussi régulièrement que les 40's. La charge cognitive associée à la tâche secondaire a eu pour effet de diminuer le nombre de changements de voie chez tous les groupes. Ces résultats suggèrent que les conducteurs de tout âge tendent à réguler leurs comportements de conduite afin de diminuer les risques potentiels de collisions en réponse à l'ajout d'une tâche secondaire à la conduite.

INTRODUCTION:

Driver distraction has been a topic of interest since the early 1900's when the radio was first introduced to the vehicle [1]. The types of activities that can be safely undertaken in the vehicle beyond the basic driving task continue to be debated at the public and policy level and there is a clear need for objective research in this area. Distraction can be considered as "a diversion of attention away from activities critical for safe driving toward a competing activity" [2]. Although distractions can originate from outside the vehicle, the impact of the current proliferation of in-vehicle and nomadic devices are an increasing area of concern as activities that draw a driver's attention away from the driving task. The basic cognitive demand associated with a division of attention, the level of workload associated with both the primary and the secondary task, and the total physical and cognitive resources of a given individual, are all likely to contribute to the effective costs of divided attention. Numerous studies have investigated the impact of distracting activities on driver performance and a growing body of research suggests that distractions increase the likelihood of being involved in a crash [3-5].

Though less dramatic than an overt crash, distractions have also been shown to contribute to less efficient traffic flow [6, 7]. For example, in a simulation experiment, Cooper et al. [7] investigated the effect of a hands-free cell phone conversation on lane-change behaviors in three levels of traffic density. Results showed 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. [8] can be seen as compensatory actions taken by the driver to reduce the workload associated with the driving task. The increased mental workload associated with a lane changing behavior, such as an overtaking maneuver, has been demonstrated by Cantin et al. [9] using probe reaction times. Reaction times were found to increase during these complex lane change maneuvers as compared to straight driving. The degree to which patterns of lane changing behavior observed in simulated driving in response to the demands of secondary task workload carry over to field driving is not well established.

The relative increases in workload observed by Cantin et al. [9] associated with lane change maneuvers appeared to be greater for older adults. An inverse relationship also exists between the tendency to pass and age, that is, as age increases, the tendency to pass decreases [10]. Older drivers are also known to use compensatory driving strategies (slower speed) as a component of self-regulation [11]. Although older adults are likely to avoid distracting technologies [12] many situations arise when older adults use navigation systems, phones etc. The relative impact of these and other secondary tasks on older adult self regulation during driving is not clear. It is, however, well established that older adults do not perform as well as younger adults when attention is divided by complex cognitive tasks [13] and are particularly sensitive to the demands of simultaneous tasks [14]. This could provide a motivation to self-regulate driving behaviors to reduce overall workload.

In this paper we draw upon field data originally collected to examine how varying degrees of cognitive workload impact driving performance, physiological activity, and visual behavior across different age groups [15, 16]. The validity of the methodology for inducing stepped levels of secondary task workload had been previously established in young adult samples under simulated driving [17] and under actual on-road conditions [18, 19]. The availability of this multi-age field dataset provided an opportunity to examine lane changing behavior under conditions of single task driving and during defined periods of heightened workload associated with the divided attention from a secondary task. In this assessment we aim to (1) gauge the degree to which the results observed in previous simulation studies carry over to a field environment; (2) assess the degree to which different levels of secondary cognitive workload impact lane change behavior; and (3) determine the impact of age on lane changing behavior.

METHODS

Participants

A total of 108 drivers in three age groups, 20's, 40's and 60's, completed the study. Two participants, one in their 40's and another in their 60's, were excluded from the analysis due to poor video quality. The average age of participants in each group was 24.6 (SD 2.7), 44.5 (SD

3.0), and 63.3 (SD 3.1). Participants were recruited in a dense urban center (Boston, MA, USA) using online and newspaper advertisements. All participants were required to have held a valid driver's license for over three years, drive more than three times per week, be in self-reported good health, and understand and speak English. Participants were not allowed to participate if they had been involved in a police reported incident in the past year, wore glasses to drive, or were taking medications that cause drowsiness. Participants were compensated $60 for the 3 hour experiment.

Apparatus

Participants drove an instrumented Volvo XC 90 equipped for time synchronized data collection from onboard sensors. Driving performance data was recorded from the vehicles CAN bus at 10 Hz. Cameras facing towards the front, sides and rear of the vehicle captured the surroundings. A microphone mounted inside the vehicle recorded participants responses to a series of secondary tasks. Three levels of a delayed auditory recall task (n-back) were presented to increase drivers' workload. Each trail of the task consisted of 10 randomly presented digits (0 – 9). At the lowest level of demand, 0-back, drivers were asked to repeat each digit after it was presented. At the moderate level of demand, 1-back, drivers repeated the next to last digit. Finally, at the highest level of demand, 2-back, drivers repeated the second to last digit. The moderate level of the task has been shown by Zeitlin [20] easily mastered and suitable for use during actual on-road driving without impacting safety. Wang et al. [21] has shown the pattern of workload engendered by the task to be consistent across repetitions.

Procedure

After intake, informed consent, eligibility verification and questionnaire participants were extensively trained on the secondary task. The training included guided instructions and multiple practice trials at each level of difficulty. Additional repetitions of the instructions and practice trails were presented at each task level until participants demonstrated a minimum proficiency of 7 correct responses on the 0 and 1-back (out of 10 & 9 items respectively) and of at least 4 (out of 8) on the 2-back. After a break, participants were escorted to the instrumented vehicle where instructions included additional training on the secondary task. 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. Once underway, there was approximately 30 minutes of driving for the participant to habituate to the operation of the vehicle. At this point, the formal assessment period began. A 2 minute single task "baseline" was followed 30 seconds later by the instructions for the first secondary task. Each secondary task period was 2 minutes in duration and consisted of 4 trials. Two minutes of single task driving separated each dual task period. The order of presentation of the three n-back task conditions was counterbalanced across the sample.

The experiment was conducted on Interstate 93 traveling north from Boston Massachusetts. When entering the highway, participants were instructed: "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 where the formal assessment occurred was 104.6 km/h (65 mph).

Data Analysis

The experiment was designed as mixed factorial design with age as a between-subject variable (20's, 40's, and 60's) and demand as a within-subject variable (baseline, 0-back, 1-back and 2-back). Recorded audio was used to assess participants' accuracy in responding to each of 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 was extracted by the fifth author through a manual analysis of video recordings taken during the drive. Analogous to Cooper et al. [8], an event was classified as a lane change when a participant left their current lane and fully entered an adjacent one. Continuous data (i.e., secondary task performance, speed, and time spent in the leftmost lane) were analyzed by a repeated measures ANOVA. Pairwise comparisons were conducted through Tukey post-hoc tests. An ordered logit model was developed to analyze the number of lane changes (α=.05).

RESULTS

Secondary task performance

Figure 1 presents the secondary task performance for each age group by the level of cognitive task difficulty. A significant main effect of age group ($F(2,103)=4.13$, $p=.02$) and cognitive task difficulty ($F(2, 206)=28.51$, $p<.001$) appear in the model. The age x demand interaction was not significant ($p>.05$). A decomposition of the main effect of cognitive task difficulty indicates that performance at each of the three demand levels differs significantly from each other (2-back vs. 1-back: $t(210)= 4.14$, $p<.001$; 2-back vs. 0-back: $t(210)= 6.49$, $p<.001$; 1-back vs. 0-back: $t(210)= 3.11$, $p=.002$). This effect suggests that as in Mehler et al. [17] and Reimer [18] error rates increased with higher levels of cognitive task difficulty. The effect of age indicates that the 20 years old group responded correctly to a higher percentage of stimulus than the 60 years old group ($t(69)=2.69$, $p=.009$). No significant differences appear between the younger and middle age or the middle age and older groups ($p>.05$).

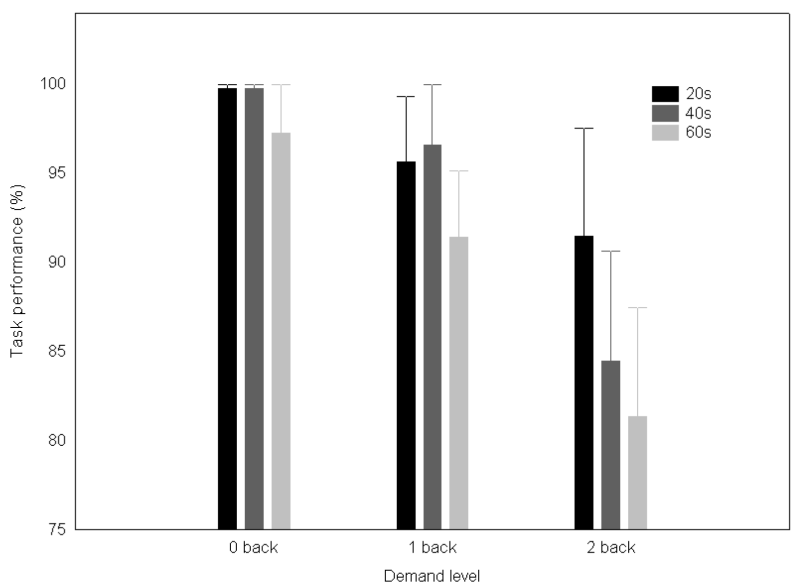

Figure 1. Secondary task performance (%) for each age and demand level (0, 1, and 2 - back task). Error bars indicate the between-subject 95% confidence intervals.

Number of lane changes

Table 1 shows the frequency of lane changes by age and demand level**.** 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 [22] and is represented with a set of equations as:

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

where p_1 represents the probability of having 2 or more lane changes and p_2 represents having 1 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 $\boldsymbol{\beta}$ is the matrix of coefficient estimates for predictor variables, **X**. Repeated measures were accounted for by creating a population-average model. Because the data consists of repeated measures, a generalized estimating equation (GEE) was used for estimation. GEE can handle continuous, categorical and time dependent explanatory variables. The model was fitted using PROC GENMOD in SAS 9.1, with the specifications of cumulative logit link function and multinomial distribution.

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*

Table 1: Frequency of lane changes by age and demand level.

Wald statistics revealed that age (χ^2(2)=7.64, p=.02) and demand level (χ^2(3)=7.85, p=.049) were statistically significant. The age x demand level interaction was not significant (p>.05). The 40's group exhibits a 115% higher odds of having lane changes when compared to the 60's group (Table 2). No other differences were found between age groups. Regardless of demand level, performing a cognitive task decreased the odds of making lane changes (Table 3).

Age	**Estimate (Δ)**	**$\chi^2(1)$**	***p***	**95% Confidence Interval (CI)**
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

Table 2: Multiplicative increase in odds of lane changes for different age groups.

Comparisons for demand level	**Estimate (Δ)**	**$\chi^2(1)$**	***p***	**95% Confidence Interval (CI)**
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

Table 3: Multiplicative increase in odds of lane changes for different demand level

Mean Speed

Figure 2 presents the mean speed for each age and demand level. The 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 and 40 year old groups, drivers in their 60's drove significantly slower (105.4 and 105.3 vs. 101.6 km/h, respectively) (60's vs. 20's: $t(69)=2.58$, $p=.01$; 60's vs. 40's: $t(68)=2.79$, $p=.007$). 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: $t(210)=2.13$, $p=.034$; baseline vs. 1-back: $t(210)=2.25$, $p=.026$; baseline vs. 2-back: $t(210)=3.87$, $p<.001$). No significant differences were observed between the three n-back periods ($p>.05$).

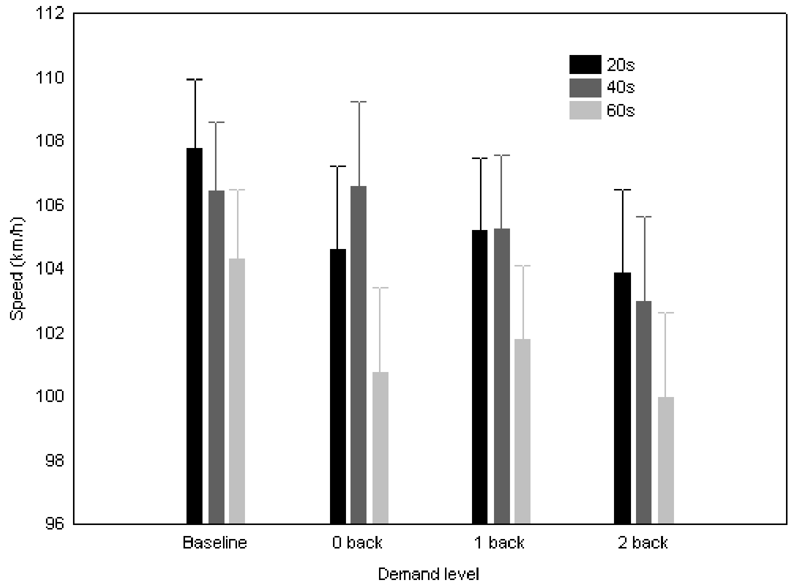

Figure 2. Mean speed for each age and demand level.
Error bars indicate the between-subjects 95% confidence intervals.

Time spent in the leftmost lane

Figure 3 presents the time spent in the leftmost lane for each age and demand level. Only the main effect of age was significant ($F(2, 102)=6.60$, $p=.002$). Drivers in the 20's and the 40's group spent more time in the left lane than the 60's group (42.9 sec and 40.2 sec vs. 17.1 sec, respectively). The demand level and interaction between age and demand level were not significant in the model ($p>.05$).

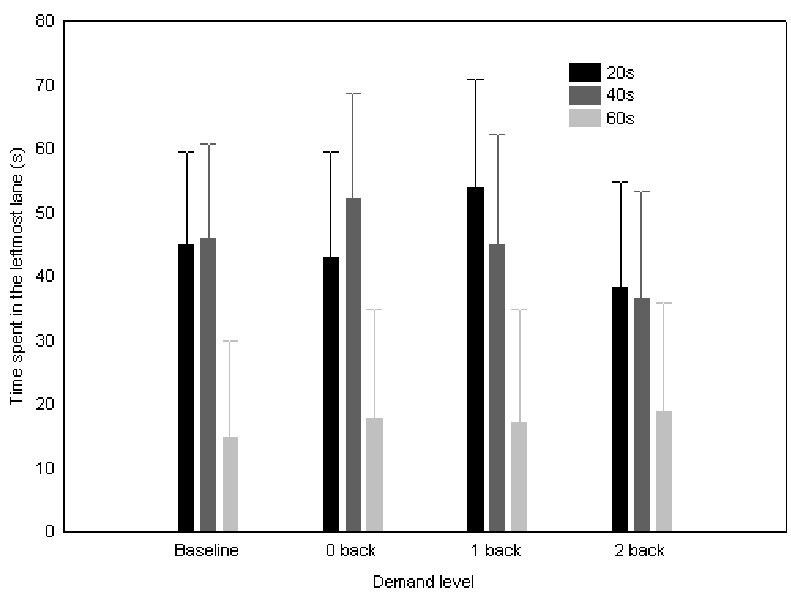

Figure 3. Time spent (seconds) in the leftmost lane for each age and demand level.
Error bars indicate the between-subjects 95% confidence intervals.

DISCUSSION

An analysis of an on-road experiment was conducted to examine lane change and 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 maneuvers. Compared to a baseline period of single task driving, fewer lane changes were observed under periods of secondary cognitive task load. A similar effect was observed by Cooper et al. [8] in a simulator experiment. Given that our study was an on-road assessment, it provides additional ecological validity to this finding. A reduced number of lane changes with age was also observed in the significant difference between the 40's and 60's age groups. This result suggests that as expected the older adults in this study had adopted a generally more conservative driving style than middle age adults.

Speed selection also was influenced by age and demand level. The 60's group showed a significantly slower speed than the 20's and the 40's. As often reported by on-road and simulator studies [23-25], older drivers maintained slower speeds than younger drivers. Moreover, older drivers in our study responded to the introduction of cognitive task load with the same compensatory strategy as the 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. [8] and Horberry et al. [26], who showed that drivers reduced their speed during a conversation similar to a hand-free cell phone task.

A major concern around cognitive distraction during driving is that the drivers are not always aware of any associated performance decrements [27] 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 with all secondary tasks. Cooper and Strayer [28] 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 indicate that practice is unlikely to eliminate the disruptive effects of concurrent 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 detection systems that provide information to drivers when they are distracted so that they can modify behavior appropriately [29-31].

To our knowledge, this is the first time that the time spent in the leftmost lane as a function of age and cognitive load has been evaluated. Results showed that less time was spent in the leftmost lane by the 60's group when compared to the 20's and 40's group. This pattern remained consistent across single task driving and with the addition of the secondary cognitive task load. Self-regulation could explain why the participants in the 60's group differ from their younger counterparts (20's and 40's) 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. [32] investigated the self regulation issue of older drivers by a survey. 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 [33, 34] 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 [12].

CONCLUSION

To our knowledge, this is the first attempt to assess if older drivers differ in their lane changing behaviors compared to younger drivers through an on-road study with a relatively large sample size. We also investigated the effects of varying levels of secondary task cognitive load and the associated distraction on lane change and choice behaviors of different age groups. More research needs to be conducted in order to evaluate if the observed reduction in lane change represented a conservative approach to driving under dual task load or a basic saturation of the driver cognitive capacities.

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the US Department of Transportation's Region I New England University Transportation Center at MIT and The Santos Family foundation for the publication of this material and Ford Motor Company for the development of this data source and the instrumented vehicle. In addition, Martin Lavallière was supported by a doctorat scholarship and by a FRSQ-RQRV International Internship Grant from the Fonds de la Recherche en Santé du Québec. Special thanks to all drivers that participated in the project and to Paulo Opperman for data collection.

REFERENCES

1. GOODMAN, M.J., BENTS, F.D., TIJERINA, L., WIERWILLE, W.W., LERNER, N., BENEL, D., An investigation of the safety implications of wireless communications in vehicles, United States Department of Transportation, 1997, National Highway Traffic Safety Administration, Washington, DC.
2. REGAN, M.A., LEE, J.D., YOUNG, K.L., Driver distraction theory, effects and mitigation. Boca Raton, FL: CRC Press, Taylor and Francis Group. 654. 2009.
3. KLAUER, S.G., DINGUS, T.A., NEALE, V.L., SUDWEEKS, J.D., RAMSEY, D.J., The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data. 2006, National Highway Traffic Safety Administration, Washington, D.C. .
4. LABERGE-NADEAU, C., MAAG, U., BELLAVANCE, F., LAPIERRE, S.D., DESJARDINS, D., MESSIER, S., et al., Wireless telephones and the risk of road crashes. *Accid. Anal. Prev.*, 35(5): p. 649-660. 2003.
5. REDELMEIER, D.A., TIBSHIRANI, R.J., Association between cellular telephone calls and motor vehicle collisions. *N. Engl. J. Med.*, 336: p. 453. 1997.

6. BRACKSTONE, M., MCDONALD, M., Driver headway: How close is too close on a motorway? *Ergonomics*, 50(8): p. 1183-1195. 2007.
7. COOPER, J.M., VLADISAVLJEVIC, I., MEDEIROS-WARD, N., MARTIN, P.T., STRAYER, D.L., An Investigation of Driver Distraction Near the Tipping Point of Traffic Flow Stability. *Hum. Factors*, 51(2): p. 261-268. 2009.
8. COOPER, J.M., VLADISAVLJEVIC, I., STRAYER, D.L., MARTIN, P.T., Drivers' Lane Changing Behavior While Conversing On a Cell Phone in a Variable Density Simulated Highway Environment, in *Transportation Research Board*. 2008, Washington D.C.
9. CANTIN, V., LAVALLIÈRE, M., SIMONEAU, M., TEASDALE, N., Mental workload when driving in a simulator: Effects of age and driving complexity. *Accid. Anal. Prev.*, 41(4): p. 763-771. 2009.
10. BOYLE, J., DIENSTFREY, S., SOTHORON, A., National Survey of Speeding and Other Unsafe Driving Actions. 1998, National Highway Traffic Safety Administration: Washington D.C.
11. LANGFORD, J., KOPPEL, S., Epidemiology of older driver crashes - Identifying older driver risk factors and exposure patterns. *Transport Res F Traffic Psychol Behav*, 9(5): p. 309-321. 2006.
12. D'AMBROSIO, L.A., DONORFIO, L.K.M., COUGHLIN, J.F., MOHYDE, M., MEYER, J., Gender differences in self-regulation patterns and attitudes toward driving among older adults. *J. Women Aging*, 20(3-4): p. 265-282. 2008.
13. MCDOWD, J.M., CRAIK, F.I.M., Effects of aging and task difficulty on divided attention performance. *J. Exp. Psychol. Hum. Percept. Perform.*, 14(2): p. 267-280. 1988.
14. BROUWER, W.H., WATERINK, W., VAN WOLFFELAAR, P.C., ROTHENGATTER, T., Divided attention in experienced young and older drivers: lane tracking and visual analysis in a dynamic driving simulator. *Hum. Factors*, 33(5): p. 573-82. 1991.
15. MEHLER, B., REIMER, B., COUGHLIN, J.F., Physiological reactivity to graded levels of cognitive workload across three age groups: An on-road evaluation, to appear in *54th Annual Meeting of the Human Factors and Ergonomics Society*. 2010: San Francisco, CA.
16. REIMER, B., MEHLER, B., WANG, Y., COUGHLIN, J.F. The impact of systematic variation of cognitive demand on drivers' visual attention across multiple age groups. to appear in *54th Annual Meeting of the Human Factors and Ergonomics Society*. San Francisco, CA. 2010.
17. MEHLER, B., REIMER, B., COUGHLIN, J.F., DUSEK, J.A., The impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers. *Transp. Res. Rec.*, 2138: p. 6-12. 2009.
18. REIMER, B., Cognitive task complexity and the impact on drivers' visual tunneling. *Transp. Res. Rec.*, 2138: p. 13-19. 2009.
19. REIMER, B., MEHLER, B., COUGHLIN, J.F., GODFREY, K.M., TAN, C. An On-Road Assessment of the Impact of Cognitive Workload on Physiological Arousal in Young Adult Drivers. in *AutomotiveUI*. Essen, Germany: ACM. 2009.
20. ZEITLIN, L.R., Subsidiary task measures of driver mental workload: A long-term field study. *Transp. Res. Rec.*, 1403: p. 23-27. 1993.
21. WANG, Y., REIMER, B., MEHLER, B., ZHANG, J., MEHLER, A., COUGHLIN, J.F., The Impact of Repeated Cognitive Tasks on Driving Performance and Visual Attention, in *3rd International Conference on Applied Human Factors and Ergonomics*. 2010.
22. STOKES, M.E., DAVIS, C.S., KOCH, G.G., Categorical data analysis with the SAS System. 2nd ed. Cary, NC: SAS Institute Inc. 2000.
23. HAKAMIES-BLOMQVIST, L., MYNTTINEN, S., BACKMAN, M., MIKKONEN, V., Age-related differences in driving: Are older drivers more serial? *International Journal of Behavioral Development*, 23(3): p. 575-589. 1999.

24. PLANEK, T.W., FOWLER, R.C., Traffic accident problems and exposure characteristics of the aging driver. *J. Gerontol.*, 26(2): p. 224-30. 1971.
25. SZLYK, J.P., SEIPLE, W., VIANA, M., Relative effects of age and compromised vision on driving performance. *Hum. Factors*, 37(2): p. 430-6. 1995.
26. HORBERRY, T., ANDERSON, J., REGAN, M.A., TRIGGS, T.J., BROWN, J., Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accid. Anal. Prev.*, 38(1): p. 185-91. 2006.
27. HORREY, W.J., LESCH, M.F., GABARET, A., Assessing the awareness of performance decrements in distracted drivers. *Accid. Anal. Prev.*, 40(2): p. 675-682. 2008.
28. COOPER, J.M., STRAYER, D.L., Effects of Simulator Practice and Real-World Experience on Cell-Phone–Related Driver Distraction. *Hum. Factors*, 50(6): p. 893-902. 2008.
29. REIMER, B., COUGHLIN, J.F., MEHLER, B., Development of a Driver Aware Vehicle for Monitoring, Managing & Motivating Older Operator Behavior, in *ITS-America*. 2009, Washington, DC.
30. DONMEZ, B., BOYLE, L., LEE, J.D., Mitigating driver distraction with retrospective and concurrent feedback. *Accid. Anal. Prev.*, 40: p. 776-786. 2008.
31. DONMEZ, B., BOYLE, L.N., LEE, J.D., Safety implications of providing real-time feedback to distracted drivers *Accid. Anal. Prev.*, 39(3): p. 581-590. 2007.
32. DONORFIO, L.K.M., D'AMBROSIO, L.A., COUGHLIN, J.F., MOHYDE, M., To drive or not to drive, that isn't the question—the meaning of self-regulation among older drivers. *J. Saf. Res.*, 40: p. 221-226. 2009.
33. HOLLAND, C.A., RABBITT, P.M., People’s awareness of their age-related sensory and cognitive deficits and the implications for road safety. *Appl. Cognit. Psychol.*, 6(3): p. 217-231. 1992.
34. HOLLAND, C.A., RABBITT, P.M., The problems of being an older driver: comparing the perceptions of an expert group and older drivers. *Appl. Ergon.*, 25(1): p. 17-27. 1994.