MEASURING YOUNG DRIVERS' BEHAVIORS DURING COMPLEX DRIVING SITUATIONS

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Summary: Driving behaviors of teenagers and adults in complex driving situations, viz., merges and intersections, from an 18-month longitudinal naturalistic driving study were analyzed. Variables from multiple sources were selected to create an *Unsafe Driving Index* to rate drivers' behaviors in these locations. Teenagers scored lower on this index, corresponding to safer driving behaviors, than adults. However, the teenagers' scores for the index increased across the study period. The interpretations of these findings are discussed with respect to the methodological aspects of the study and in terms of driver training and rule following.

INTRODUCTION

Teenage drivers are over represented in fatal and non-fatal crashes in the U.S. (NHTSA, 2009). Motor vehicle crashes are the leading cause of death for teenagers in the U.S., with teenagers' crash involvement being much higher than that of older, more experienced drivers. Teenagers make up 6.4% of the driving population but are involved in about 12% of fatal motor vehicles crashes (NHTSA, 2009). Various reasons have been postulated for this statistic, including inexperience, risk taking, and other factors related to adolescent development (Williams, 2003; Allen & Brown, 2008).

Safe driving requires multiple driving skills such as vehicle handling, judgment, situational awareness, risk awareness, etc. However, during the first few months of licensure and/or independent driving the skills are unlikely to have been developed sufficiently to manifest safe driving behaviors. As a result, it is exactly in these first few months that the young drivers are most vulnerable to crashes (Mayhew et al., 2003; Williams, 2003; Simons-Morton et al., 2011). Most of these skills develop and mature with added years of driving experience (Groeger, 2000).

There have been various attempts to understand young drivers' behavior during the initial months of licensure via crash data (Braitman et al., 2008; Foss et al., 2011), simulation studies (Pradhan et al., 2005), and naturalistic driving studies (Simons-Morton et al., 2011). It is of interest to explore the differences in various facets of the driving behaviors between young and experienced drivers and to study the trajectory of these behaviors over time as young drivers mature and gain experience. This has been done for various behaviors such as high gravitational-force (g-force) events (Simons-Morton et al., 2011) and risk perception abilities (Pradhan et al, 2011).

Safe driving requires the smooth and automatic performance of a number of individually complex tasks. These tasks have to be performed at the right moments and in synchrony. Moreover, these tasks have to be performed appropriately according to the state of the driving environment. Negotiating a merge ramp onto a higher speed freeway or taking a left turn at a four way intersection are relatively complex driving situations (Groeger, 2000). Studying young drivers' behaviors at these complex situations has the potential to yield important information offering insight into the development, evolution, and management of critical driving skills.

The Naturalistic Teen Driving Study (NTDS) provided unique data of a number of pre-selected complex driving environments including merges onto freeways and four-way intersections (Lee et al., 2011). Thus the purpose of this paper was to (1) explore the differences in safe driving behavior between teenagers and adults in complex driving situations using a naturalistic driving approach; (2) explore the evolution over time (18 months) of teenagers' driving behavior in such situations. Both safe driving behaviors and their trajectories over time were assessed by a measure derived from multiple data sources and named the *Unsafe Driving Index.*

METHODS

Participants

Forty two teen participants (22 females, 20 males, mean age = 16.4 years) with a provisional driver's license were recruited from the Blacksburg and Roanoke, Virginia regions. The provisional license allowed unsupervised driving for six months except between midnight and 4 am, and restricted driving with more than one passenger. At least one parent of each teen was also recruited for the study. Since both parents of some teens participated there were 55 adults (34 female, 21 male) recruited for the study. Identical twins and teens with Attention Deficit Disorder or Attention Deficit Hyperactivity Disorder were excluded. Parental consent and teen assent were obtained. The protocol was reviewed and approved by the Virginia Tech University Human Subjects Review Board.

Vehicle Instrumentation and Data Collection

The participants' vehicles were instrumented with a data acquisition and storage system for the 18-month period of the study. The system included multiple sensors including accelerometers to detect kinematic data such as longitudinal and lateral g-forces, radar, video recorders, Global Positioning System (GPS), and others. Video recordings were collected of the forward and rear view from the vehicle and of in-cabin views including multiple views of the driver. Recorded data were periodically retrieved by research assistants by physically swapping hard drives installed in the vehicles. (See Lee et al., 2011 for additional details on methods)

Data Sources and Measures

Sensor data and video footage of driver behavior were assessed in selected merges and intersections (see next section). The following categories of data were collected: kinematic, secondary task, eye movement, and question reduction. The kinematic data included vehicle sensor data including g-forces and speed. Secondary task data were coded by trained

reductionists viewing the videos and included variables such as phone and electronic device use, eating, reaching, etc. The eye-movement data included data derived from frame-by-frame coding of video data of glance location and glance durations, etc. The question reduction dataset included variables based on trained reductionists' observations of the multiple video streams regarding driver behavior, level of service, weather conditions, etc.

Merges & Intersections

Nineteen merge locations and 33 intersections within the geographic study area were pre-identified via GPS and the data retrieved and coded when a study participant drove through that location. The merge locations were on-ramps onto higher speed highway sections and the intersections were signal-controlled, four-way intersections.

Unsafe Driving Index

The dataset combining all data source categories yielded a total of over 500 variables. The task was then to select a subset of these variables as components of the index. A protocol was developed for the selection or exclusion of variables based on two broad criteria: data quality/sufficiency determined by frequency and distribution; and relevance to safe driving behavior. A large number of variables was excluded due to low variability and missing data.

After examining each variable for these criteria a substantially lower number of variables was identified, each considered to be an appropriate indicator of safe driving behavior for these complex driving situations. These variables were then used to create a composite to rate driving behavior on each intersection and merge. Given the inherent differences between the two types of maneuvers, each scenario merited its own composite variable.

Six variables (four from question reduction data, one from secondary task engagement data, and one from vehicle kinematics data) were selected to construct an index for the left-turn maneuver. Nine variables (four from question reduction data, one from secondary tasks data, and four from eye movement data) were selected for the index for the merge maneuver. The component variables for the index along with values for scores are shown in Appendix 1.

As can be seen in Appendix 1, the component variables of the *Indices* were scored 0 for no error and 1 or 2 for partial or full error, such that unsafe driving behaviors, or more driving errors, meant a higher error score. Some of the component variables were deemed by expert consensus of the investigators to have a higher influence on driving safety. In such a case the overall score of the component variable was weighted with a multiplier to reflect the greater influence of that variable. The error scores of these individual component variables were then averaged for the overall index. The *Unsafe Driving Index* was thus designed to reflect safety error, such that safe driving behavior would gather fewer points and unsafe driving would gather more points.

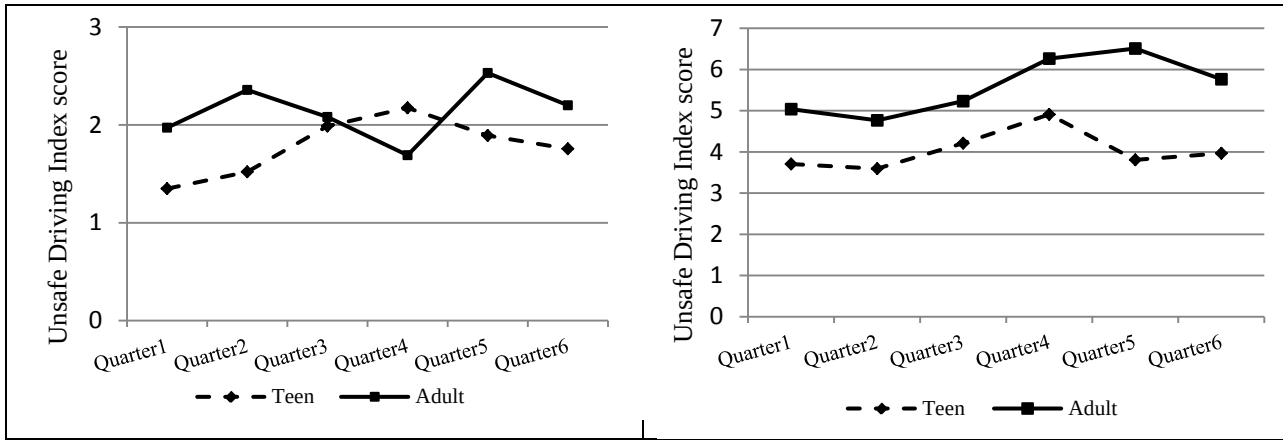
Analysis

The calculated *Unsafe Driving Index* scores for each left-turn and merge maneuver were aggregated for teen and adult drivers over six 3-month periods (Quarter1 through Quarter 6). T-

test was used to examine the difference in left-turn and merge *Index* scores between adults and teens in each quarter. Repeated measures ANOVA were used to examine the change of *Index* scores over the six quarters. Specifically, polynomial transformation was used to represent overall trend pattern of the change and profile and contrast transformation were used to represent the differences between time points.

RESULTS

The teenagers had lower *Unsafe Driving Index* scores than the adults for both maneuvers (Figures 1a and 1b). For the first two quarters this difference in *Index* scores was statistically significant ($p < .05$) or marginally significant ($p < .10$).



a. Left-turn signal controlled intersection **b. Merge ramps**

Figure 1. Unsafe Driving Index: Teens & adults over six quarters

The *Index* score then increased (worsened) for the teens. A significant quadratic trend ($F_{df=1,28} = 8.66$, $p < .01$), i.e., increase over first quarters and then decrease, was found for the teens for the left turn maneuvers. But no significant trend was found for the merges. In comparison, there was no significant upward or downward trend in the adults' *Index* scores for both maneuvers (Table 1).

Table 1. Means of Unsafe Driving Index scores for merge and left-turn intersection by drivers and quarters

		Quarter 1			Quarter 2			Quarter 3			Quarter 4			Quarter 5			Quarter 6		
		N	M	SD	N	M	SD	N	M	SD	N	M	SD	N	M	SD	N	M	SD
LT	T	37	$1.35^{\dagger a, b}$	0.90	40	1.52^{*}	1.07	38	1.99	1.41	38	2.17	1.27	39	1.89	1.36	37	1.75	1.47
	A	26	1.97	1.55	20	2.36	1.49	20	2.08	1.42	21	1.69	1.23	20	2.53	2.21	17	2.20	1.23
MR	T	36	$3.71^{\dagger}$	2.62	30	3.59†	2.26	31	4.21	3.37	31	4.91	3.30	33	3.81^{*}	2.63	31	3.96^{*}	2.95
	A	23	5.04	2.95	20	4.77	2.35	18	5.23	4.17	23	6.26	3.90	21	6.51	4.50	17	5.77	2.77

T=teen; A=adult; LT=left-turn intersection; MR=merge ramp; $^{*}p < .05$ and $^{\dagger}.05 < p < .10$ comparing with adults in the same quarter; $^{a}p < .05$ comparing between the nth and the 6th quarter; $^{b}p < .05$ comparing between the nth and the n+1 quarter.

DISCUSSION

The finding that the teenagers actually scored lower than adults on the *Unsafe Driving Index* ran counter to our expectations. As with other measures of risky driving such as g-force event rates and crash/near crash we expected to see worse performance in teenagers in the initial months, which then declined and stabilized to values closer to those of adults.

Surprisingly, teenage drivers made fewer errors than adults, at least initially. While teenage driving behavior gradually worsened over time for intersection management, it remained somewhat less unsafe than adult driving for most of the study period. It appears that teenage drivers more routinely exhibited the driving behaviors learned through training, while the experienced drivers were less consistent in their safety behaviors. This finding is surprising because crash/near crash rates were higher among the novice drivers than the experienced drivers (Simons-Morton et al., 2012). One possible explanation for this finding is that consistently employing safe driving practices may not always assure safety. Alternatively, adults may have been able to "get away" with less consistent safe driving behavior because they would have learned from experience when it was most important to employ the safety behavior. For example, adults may have been more likely to turn on their turn signal when in traffic, while novices may do it routinely. The teenagers consistently performed behaviors learned during driver training such as using turn signals or looking at blind spots.

This behavior then deteriorated over time, potentially due to increased familiarity and driving confidence, and *Unsafe Driving Index* scores approached those of the adults. This decay in performance of trained skills is evident in other domains (Anderson, 1981). The evidence seems to indicate that novices learned the safety behaviors during driver training.

There are few if any valid measures of driving behavior. The NTDS provided an unusual opportunity to examine the use of a wide range of measures by novice teen and experienced adult drivers under complex driving situations represented by signalized, 4-way intersections and merges. However, we found that many of the measures we considered did not provide useful discrimination. Moreover, we found that the best measures, those we included in the *Unsafe Driving Index,* mainly reflected novice teenagers' recency of learning these behaviors and may not have truly represented consistent and automatic safe driving behavior. Clearly, it is preferable for all drivers always to signal their intentions, look carefully for traffic, manage speed, and so on, but the safety implications of these behavior may depend on higher order application consistent with road conditions and not simply their rote use. A limitation of this research is that the driving behavior was followed for an 18-month period, and it is of interest to examine the trajectory over a longer period. Another limitation is the small sample, limited number of intersections and merges, and their diversity.

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REFERENCES

Allen, J.P., & Brown, B.B. (2008). Adolescent, peers, and motor vehicles: The perfect storm? *American Journal of Preventive Medicine*, *35*(3S), s289-s293.

Anderson, J.R., (Ed.) (1981). *Cognitive Skills and their Acquisition*. Hillsdale, NJ: Erlbaum.

Braitman, K.A, Kirley, B.B., McCartt, A.T., & Chaudhary, N.K. (2008). Crashes of novice teenage drivers: characteristics and contributing factors. *Journal of Safety Research*, *39*(1), 47-54.

Foss, R.D., Martell, C.A., Goodwin, A., & O'Brien, N.P. (2011). Measuring changes in teenage driver crash characteristics during the early months of driving. *AAA Foundation for Traffic Safety*.

Groeger, J.A., (2000*). Understanding Driving: Applying Cognitive Psychology to a Complex Everyday Task*. Hove, UK: Psychology Press.

Lee, S.E., Simons-Morton, B.G., Klauer, S.G., Ouimet, M.C., & Dingus, T.A. (2011). Naturalistic assessment of novice teenage crash experience. *Accident Analysis and Prevention*, *43*(4), 1472-1479.

Mayhew, D.R., Simpson, H.M., & Pak, A. (2003). Changes in collision rates among novice drivers during the first months of driving. *Accident Analysis and Prevention*, *35*(5), 683-91.

National Highway Traffic Safety Administration (2009). Traffic Safety Facts 2008: Young Drivers. U.S. Department of Transportation. Available at: http:// www-nrd.nhtsa.dot.gov/pubs/811169.pdf. Accessed November 16, 2012.

Pradhan, A.K., Simons-Morton, B.G., Lee, S.E., & Klauer, S.G. (2011). Hazard perception and distraction in novice drivers: effects of 12 months driving experience. *Proceedings of the sixth international driving symposium on human factors in driver assessment, training and vehicle design* (pp. 614-620).

Pradhan, A.K., Hammel, K.R., DeRamus, R., Pollatsek, A., Noyce, D.A. & Fisher, D.L. (2005). Using eye movements to evaluate effects of driver age on risk perception in a driving simulator. *Human Factors*, *47*(4), 840-852.

Simons-Morton, B.G., Zhang, Z., Jackson, J.C., & Albert, P.S. (2012). Do elevated gravitational-force events while driving predict crashes and near crashes? *American Journal of Epidemiology*, *175*(10), 1075-1079.

Simons-Morton, B.G., Ouimet, M.C., Zhang, Z., Klauer, S.G., Lee, S.E., Wang, J., . . . Dingus, T.A. (2011). Crash and risky driving involvement among novice adolescent drivers and their parents. *American Journal of Public Health*, *101*(12), 2362-2367.

Williams A.F. (2003). Teenage drivers: patterns of risk. *Journal of Safety Research*, *34*(1), 5-15.

Appendix 1. Scoring scheme for individual component variables of Unsafe Driving Index

Left-turn signal controlled intersection		
Variable		**Error Score**
Turn Signal during lane change	Activated before intersection	0
	Activated while in intersection	1
	Not activated	2
Secondary task	No	0
	Yes	1
Eye glance away from forward roadway	No	0
	Yes	1
Appropriate destination lane	Yes	0
	No	1
Appropriate cornering	Yes	0
	Too fast or too sharp	1
	Too fast and too sharp	2
Lateral acceleration	< -0.4g	1
	-0.4g to 0	0

Merge ramp		
Variable		**Error Score**
Turn Signal during merge	Activated before gore	0
	Activated after gore or while merging	1
	Not activated	2
Secondary task	No	0
	Yes	1
Looked at blind spot over shoulder	Before merging	0
	During merge	1
	No	2
Appropriate gap from lead & following vehicles	Yes	0
	No, inappropriate gap with both lead/following vehicles	2
Mirror check before merge	Yes, before	0
	Only during	1
	No	2
# of glances to left mirror just before and during merge	Reasonable (1-2 glances)	0
	Too many (>2)	1
	None	2
# of glances to rearview mirror just before and during merge	Reasonable (1-2 glances)	0
	Too many (>3)	1
	None	2
% duration of glances to blind spot just before and during merge	0 - 10%	0
	> 10%	1
	0	2
% duration glances in-vehicle just before and during merge	0	0
	0 – 10%	1
	> 10%	2