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Changes over 12 months in eye glances during secondary task engagement among novice drivers

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Abstract

During their first year of driving, crash rates among novice drivers are very high but decline rapidly. However, it is not clear what skills or knowledge they are acquiring in this period. Secondary task engagement while driving is a contributing factor to many traffic collisions and some of the elevated crash risk among novices could be explained by greater prevalence or longer periods of eyes off the road while engaging in these non-driving tasks. The current study looked at the eye glances of novice teen drivers engaging in secondary tasks on a test track at 0 and 12 months of licensure and compared their performance with their parents. Novices improved from 0 to 12 months on their longest single glance off the forward roadway and total percentage of time for eyes off the forward roadway, but parents remained stable. Compared with their parents, the longest single glance off the forward roadway was longer for novices at 0 months, but by 12 months there was no difference between the groups. However, for total percentage of time for eyes off the forward roadway, novices performed the same as their parents at 0 months and actually had shorter times at 12 months. These findings could reflect the combined development of driving skills over 12 months and the relative experience that modern teenagers have with portable electronic devices. The results suggest that novice drivers are particularly poor at engaging with secondary tasks while driving.

Keywords

Young Novice Drivers; Eye Glances; Secondary Task Engagement; Test Track; Experience

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Conflict of Interest

The authors declare that there are no conflicts of interest.

1. Introduction

Motor vehicle deaths represent a critical public health issue in the United States. According to the Centers for Disease Control and Prevention (2015), these deaths lead to an estimated 1.5 million years of potential life lost in the US in 2013. Motor vehicle collisions are leading cause of death among 15–24 year-olds and compared with other age groups these drivers are disproportionately involved in fatal motor collisions (NHTSA, 2010). It is not clear whether the high number of fatal accidents among young drivers is due to lack of driving experience or to an age effect e.g. poorer inhibitory control (e.g. O'Brien & Gormley, 2013). While Groeger (2006) reports that younger novice drivers do have a higher crash risk compared with older novices, the rate of crash risk does decrease with each subsequent year of driving experience, regardless of age of licensure (Twisk & Stacey, 2007). For young drivers in particular, the sharpest drop in crash risk occurs during the first year (McCartt et al., 2009), in part because it is so high right after licensure. However, it is not clear why crash rates decline so rapidly or why they remain high relative to adult rates into the early or mid-twenties.

Secondary task engagement (e.g. cell phone use, eating, talking to passengers etc.) is an issue of particular concern for novice drivers. Young drivers are more likely to manipulate handheld devices while driving (NHTSA, 2011) and cell phone use increases the odds of a crash for all drivers (McEvoy et al., 2005). Additionally, Klauer et al. (2014) found that the crash risk of novice drivers was much more affected by engagement in secondary tasks (e.g. texting, eating) compared with expert drivers, although prevalence of engagement was similar. Engaging in secondary tasks can influence crash risk in two main ways: “mind-off-the-road” and “eyes-off-the-road” (see Liang & Lee, 2010). Mind-off-the-road refers to the general cognitive distraction introduced by secondary task engagement (e.g. Lee et al., 2001), while eyes-off-the-road refers to drivers looking away from the forward roadway (e.g. Simons-Morton et al., 2014).

A number of studies suggest that eyes-off-the-road is a contributing factor to many collisions. In the 100 car study, Klauer et al. (2010) found that the total time that a driver's eyes are off the forward roadway is predictive of crash/near crash likelihood. Among novice young drivers engaging in a secondary task, the longest single glance off the forward roadway has been associated with increased crash/near-crash likelihood (Simons-Morton et al., 2014). Additionally, looking away from the forward roadway impacts the ability to maintain lane position (Peng et al., 2013).

Visual attention while driving is important since drivers cannot react to hazards that materialize while they are looking away. Perhaps the high crash rate among young drivers is due in part to their failure to attend to the forward roadway. Such a suggestion is supported by a number of simulator and naturalistic driving studies that point to a general visual skills deficit among novice drivers. In test-track studies, Lee et al. (2008) found that experienced adult drivers demonstrated more recognition of hazards and Pradhan et al. (2011) found that after 12 months of driving, novice drivers showed an improvement in hazard detection during some, though not all, secondary tasks measured. Underwood (2007) described a number of studies which suggest that, compared with advanced drivers, novice drivers scan

the forward roadway less frequently. Specifically, novice drivers have a decreased sampling rate, a longer processing time, and less broad scanning of the road (Konstantopoulos et al., 2010). Interestingly, Underwood presents evidence which suggests that a simple training exercise can reduce some of the visual skill deficits displayed by novice drivers.

The present study investigates changes in eye-glance behavior for novice drivers during the first year of independent driving. To our knowledge, this is the first study that investigates changes over time in the amount of time novice drivers to look away from the roadway during secondary task engagement. The hypothesis is that novice drivers look away from the forward roadway longer than adults do when engaging in secondary tasks and that this difference decreases with driving experience.

2. Materials and Methods

2.1 Participants

The current data were collected as a part of the Naturalistic Teenage Driving Study; Lee et al. (2011) provide a full description of the recruitment of the 42 teens (mean age of 16.5 years ($SD = 0.2$) at 0 months, 48% female) and 42 parents (mean age of 46.8 years ($SD = 5.3$) at 0 months, 40% female). Participants were recruited in 2006/2007 through driving schools and newspaper advertisements. All participants were licensed to drive in the Commonwealth of Virginia and had 20/40 corrected vision. Participants received \$20 per hour for their participation in this part of the study.

2.2 Design

Each of the 42 dyads was made up of one parent and their teenage child. There were 3 within-subjects independent variables: age group (Teen vs. Parent), time (0 vs. 12 months), and task-type (control vs. experimental); the classification of age group as a within-subjects variable reflects the potential covariation between a parent and their teen (e.g. Bingham et al. 2015). Participants completed three types of experimental task – the texting task, the directions task, and the iPod task. Based on video footage, trained coders recorded when participants were looking at the forward roadway (see Section 2.3 for more details). The dependent variables for each trial were the Longest single Glance Off the forward Roadway (LGOR) and the Total percentage of time for Eyes Off the forward Roadway (TEOR).

2.3 Procedure

The study took place at two time points: time of licensure (0 months) and 12 months post-licensure (12 months). Testing took place on the Smart Road at the Virginia Tech Transportation Institute; a 2.2 mile, controlled-access test track built to interstate standards which includes features such as traffic lights, a crossroads and a bridge. Participants were first familiarized with the test vehicle and the secondary task devices. The test vehicle was a 1997 Ford Taurus which recorded, among other things, simultaneous video footage from four cameras. These cameras were directed at the driver's face, out the windshield, at the pedals, and over the driver's shoulder. Participants drove on the smart road for roughly 90 minutes and were accompanied by two experimenters. Parents and teens were not present in the same car when teens and parents were driving, respectively. There were two types of trials: self-

selected speed (SSS) and self-selected following distance (SSFD). In the former trial type, participants were told to drive at a speed that they found comfortable. For SSFD trials, a vehicle drove ahead of the participant's at a constant speed of 35 mph and the participant was told to maintain a following distance that they found comfortable. A control task and the three experimental tasks were completed within both SSS and SSFD trial types. For counterbalancing, half the participants completed the SSS trials first while the other half completed the SSFD trials first. The order of tasks was reversed at the 12 month data collection time point.

During the control tasks, participants were asked to maintain a constant speed or following distance, depending on whether the control trial was part of the SSS trials or SSFD, respectively. For each experimental task, participants were given instructions and asked to repeat what the instructions were before beginning. For the texting task, participants were asked to send a text message (e.g. "Meet me in the lobby at 7pm") to the number 357-1501. For the directions task, participants were asked to read a list of directions on a card and then turn the card over and answer a simple question on the back e.g. "was the last turn in the list of directions a right or left turn?" For the iPod task, participants were asked to use an iPod Nano (2nd generation) to answer a simple question (e.g. "Say out loud what song comes after *Forever* on the iPod"). Participants were given slightly different questions in the SSS and SSFD trials (e.g. "Say out loud the last song by Kid Rock" for the iPod task). The same questions were always asked in SSS and SSFD trials, but, as mentioned above, the order of those trials was counterbalanced across participants. Eye glances were coded from the beginning of each task for a 30 second period by a team of 3 trained coders. The 30 seconds of video footage were transformed into 300 images (10 Hz). Coders analyzed each of these images to determine eye glance direction at each 100th of a second. Any glance away from the forward roadway was classified as being a glance *off the forward roadway*. The possible off road eye glance locations were: iPod, Phone, Cue Card (for directions task), left side-mirror, right side-mirror, rear-view window, passenger, over shoulder, eyes closed, center stack, instrument cluster, interior object, left windshield, right windshield. The software for this coding was custom built for this purpose. On dual 23 inch screens, coders were presented with a full screen image combining the footage of the four cameras at a specific time point. Coders could skip back and forth between images to determine the point at which an eye glance was directed away from the forward roadway and the point at which it was directed back to the forward roadway. The coding results of the 3 coders on 14 separate tasks were compared with those of a supervising reduction manager's. Agreement between the coders and the manager on these three tasks ranged from 71% to 96% accuracy. If a participant completed the task within this time they were given a second, similar question and coders could clearly see this. No participant completed more than one task within a 30-second period.

2.4 Measures and Analysis

In the 42 family dyads each of the 2 participants completed 4 tasks (1 control and 3 experimental), in 2 speed conditions (SSS and SSFD), at 2 time points (0 months and 12 months). Of these 1,344 trials ($42 \times 2 \times 4 \times 2 \times 2$), 86 (6.4%) were removed due to data loss, errors in the video recording or to participants not completing a specific task or group of

tasks. Eye glances were coded for the 300 frames of all of the 1,258 trials. There were two outcome variables for each trial: LGOR and TEOR. Differences between the speed conditions (SSS and SSFD) were not analyzed in the present paper and, as described in the design section, outcomes for the three experimental tasks were combined. Accordingly, LGOR was constructed by averaging the LGOR for the three separate experimental tasks across both SSS and SSFD conditions. At both time points and both age groups, these 6 measures (3 experimental tasks in both SSS and SSFD) had high correlations with one another and displayed Cronbach alphas ranging from .8 – .91. For example, the Cronbach's alpha for LGOR for adults at 0 months was .87. Total TEOR was constructed in the same manner with corresponding Cronbach alphas ranging from .7 – .94. These combinations were made since the focus of this study was on the general influence of secondary task engagement and not on the influence of these specific tasks. Additionally, with only 42 dyads, there was insufficient power to test for differences between all tasks in both SSS and SSFD trials. Table 1 displays the breakdown of the different independent variables and dependent variables.

Each of the outcome variables (LGOR and TEOR) were analyzed separately using generalized estimating equations (GEE) with family dyad as the repeated measures variable. The covariance structure type for each model was set to be exchangeable (additional covariance structures were tried but the results were not affected). This structure does not directly account for the nested design of the variables, but GEE is robust to misspecification of covariance structure (Overall & Tonidandel, 2004). GEE estimated with an exchangeable variance-covariance matrix produces similar results to a factorial repeated measures ANOVA. However, in the case of the latter, no interpretable estimates are produced and researchers instead can only focus on p values. In a generalized linear model with GEE estimates, the estimates are interpretable in the same way as estimates would be in an ordinary least squares regression model. Each of the two models investigated the main effects of the three variables and their two-way and three-way interactions. In all analyses, we controlled for whether participants completed one task or not within the 30 seconds using a binary variable. Additionally, we controlled for whether a task was part of the SSS or SSFD conditions. In each analysis, only the highest level interaction(s) was investigated. For each model, Cook's distance scores were calculated and any scores greater than 0.1 (4/42) were excluded (see Bollen & Jackman, 1990).

3. Results

A number of significant relationships were found in relation to Longest single Glance Off the forward Roadway (LGOR). These findings are outlined in Table 2. The three-way interaction between age group, time, and trial-type was the highest level significant interaction and so this was investigated further. A separate generalized estimated equations model was conducted for control trials and experimental trials (full results not shown). In both analyses, age group, time and their interactions were included while controlling for whether participants completed a task in the 30 seconds.

For the control trials, there was a significant effect of age, with adults having a larger LGOR compared with teens, $\beta = -3.32$ ($SE = 1.04$), $p < .01$. However, there was no effect of time

and there was no interaction between these two variables. These results are represented in Figure 1. For the experimental trials, there was a significant interaction between age group and time, $\beta = 6.22$ ($SE = 1.65$), $p < .001$. These results are represented in Figure 2. Accordingly, the three-way interaction in the main LGOR model was due to the presence of a two-way interaction (between age group and time) for experimental trials, and the absence of such an interaction for control trials.

The two-way interaction within experimental trials (between age group and time) was investigated by additional GEE models. These revealed that teens had a significantly longer LGOR than adults at 0 months, $\beta = 4.62$ ($SE = 1.37$), $p < .001$, but there was no significant difference between the groups at 12 months. Additionally, while there was no significant change in LFOR for adults between 0 and 12 months, there was a significant change for teens, $\beta = 5.74$ ($SE = 1.3$), $p < .001$, with their LGOR reducing by almost 0.6 seconds.

Significant effects were also found in the analysis of Total percentage of time for Eyes Off the forward Roadway (TEOR). Table 3 displays the results from the main GEE model and the three-way interaction between age group, time, and trial-type was again found to be significant. As described above, additional GEE models were conducted to investigate the effects of age group, time, and their interaction separately for control and experimental trials (full results not shown).

For control trials, there was a significant effect of time on TEOR, $\beta = -2.58$ ($SE = 0.88$), $p < .01$ with participants having a larger TEOR at 12 months. There was no main effect of age group and there was no interaction between age group and time. For experimental trials, there was a significant interaction between age group and time $\beta = 3.15$ ($SE = 1.52$), $p < .05$. As before, the initial significant three-way interaction was due to a significant two-way interaction (between age group and time) for experimental trials, but not for control trials.

The two-way interaction within experimental trials was investigated with separate GEE models. These revealed that there was no significant difference in TEOR at 0 months, but that teens had a significantly smaller TEOR at 12 months, $\beta = -3.77$ ($SE = 1.87$), $p < .05$. Additionally, while adults' TEOR remained the same from 0 months to 12, teens' TEOR significantly reduced during the 12 month period, $\beta = 3.8$ ($SE = 1.2$), $p < .01$.

4. Discussion

This study investigated changes in eye glances during secondary task engagement among novice drivers across 12 months of driving. The hypothesis was that driving experience gained between 0 and 12 months would lead to safer eye glance behavior when engaging in secondary tasks. This hypothesis was broadly supported as the younger driver had a reduced LGOR and TEOR at 12 months for the experimental tasks. There was no change in either LGOR or TEOR for adults between the two time points. During secondary task engagement young drivers' LGOR decreased by 0.6 seconds after 12 months of driving experience. The young drivers had a longer LGOR than adults did at 0 months and there was no difference between the groups at 12 months. This was in line with the original hypothesis which suggested that novice drivers look away from the forward roadway longer than adults do

when engaging in secondary tasks and that this difference decreases with driving experience. For TEOR, the results also supported the hypothesis; young drivers showed a decrease in dangerous eye glance behavior. During secondary task engagement their total time spent looking away from the forward roadway decreased by almost 4 percentage points (roughly 1.2 seconds) between months 0 and 12. However, the results from TEOR were slightly different compared with LGOR. At 0 months young drivers' performance was similar to adult drivers, while at 12 months these drivers actually had a shorter TEOR than the adults did.

The decreases of 0.6 and 1.2 seconds for LGOR and TEOR, respectively, may seem to represent a small change. However, as Simons-Morton et al. (2014) showed, changes of only 1 second in looking away from the roadway can have a large effect on the odds of being in a crash/near-crash. The differences in the results for TEOR and LGOR raise the question as to whether these measures address different constructs. LGOR could be seen as the amount of time that a participant believes, implicitly or explicitly, that it is safe to look away from the forward roadway. In contrast, TEOR may be more of a reflection of proficiency with the secondary tasks. The young drivers in this study have grown up in a time of ubiquitous portable electronics while these technologies are more novel for their parents. Collectively then, TEOR results could suggest that young people are more skilled with these secondary tasks, while the LGOR results could suggest that these same drivers are less aware of how risky it can be to take one's eyes off the road. However, these interpretations are relatively speculative and further research is needed to address them. In particular, we did not obtain a baseline, non-driving, performance assessment of teens and adults with regard to general speed and accuracy when using electronic devices such as cell phones (for texting) and iPods.

It is worth considering that not all glances away from the forward roadway are "dangerous" or examples of "bad driving." Checking blind spots are one example where it can be positively safer to look away from the forward roadway. Nonetheless, while a look away from the forward roadway may be well intentioned, it means the driver is hampered in the degree to which they can respond to changes in front of them; the direction in which changes happen quickest. Simons-Morton et al. (2014) found that long glances away from the forward roadway increase chances of being in an accident, regardless of whether such glances were for safety reasons.

None of the results of this study, particularly with regard to TEOR, should be interpreted as indicating that it's safer for novice drivers to engage in secondary tasks as they gain experience. At 0 months, the novice drivers in this study performed worse with regard to LGOR and Simons-Morton et al. (2014) found that crashes and near-crashes were associated this measure. Secondary tasks can distract drivers either through taking their eyes off the road or through cognitively distracting them (see Liang & Lee, 2010). This study only looked at the former of these possible effects. There could be differences between novice and experienced drivers while they are engaging in, or under what driving conditions they engage in, secondary tasks even if they are looking at the roadway. The current study investigates how teens and adults perform when engaging in secondary tasks when instructed to do so. In the real world, drivers have a choice of when to engage in secondary

tasks. For example, texting while at a standstill in heavy traffic is not likely to result in a collision. Conversely, trying to answer a phone call, while driving at a fast speed on an unfamiliar road, could probably be considered a more risky endeavor. The current study provides no information as to which conditions participants would be willing to actually engage in secondary task behavior. Tivesten and Dozza (2015) found that, in general, drivers do seem wait for less demanding driving conditions before using their phone. They speculate that novice drivers may have yet to learn such a skill, though they do not provide evidence to back this claim up. On a positive note, evidence does suggest that young people are just as aware of the potential dangers of texting/emailing while driving (Tison et al., 2011).

The differences between the novice and experienced groups were not in line with a previous test track study which did not find differences in eye glances between novice and experienced drivers (Smahel, Smiley, & Donderi, 2008). However, their novice participants ranged from 0 to 6 months of driving experience. As demonstrated in the current paper, 12 months experience can have a large effect on eye glance behavior, and so such a mixture of experience levels may have reduce any trends among their small sample of 18 novices. Smahel et al.'s (2008) study concerned only with eye glances while making, receiving, and terminating a call. The latter two of these tasks require very little eyes off the road time.

There are a number of limitations in the present study. We did not take into account participants' previous experience with the devices used in the tasks i.e. the specific model of iPod and cell phone. It's probable that young people have more experience with portable music devices compared with their parents. Eye glances were measured in a relatively crude manner i.e. were participants looking at the forward roadway or not any given millisecond? Studies which have utilized precise eye tracking tools have shown that even within the forward roadway, there is a large area of space that driving may be focusing on (see Underwood, 2007). Such precise measures could give a fuller description of what participants are actually looking at –both within and outside of the vehicle. Additionally, the relatively small sample, recruited from a single region limits the generalizability of the findings.

Test-track research provides a good opportunity to investigate risky driving behaviors in a controlled and safe environment. Driving a car on a track offers a great deal more external validity compared with a driving simulator. However, the findings in the current study should be investigated in a more naturalistic environment. The obvious extension of the current findings would be to see how LGOR and TEOR change over time in real-world driving scenarios for novice drivers. On the basis of such real world investigations, it may be possible to develop targeted training programs that focus on teens' eye glance behavior. A question raised by the current study is whether the change in eye glance behavior among the novice drivers over 12 months was due to more experience with driving in general, or to more experience with driving and engaging in secondary tasks.

5. Conclusions

We found that while engaging in secondary tasks while driving on a test track, novice drivers looked away from the forward roadway for a longer time than their parents were. For both

longest glance and total eye glances, novice drivers displayed clear improvement over a 12-month period. This offers support for the assertion that more risky secondary task engagement may explain some of the increased crash risk of novice drivers. The extent to which this risky secondary task engagement interacts with other aspects of driving, e.g. traffic, weather conditions, etc. is a question for future research.

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Highlights

Novice teen drivers engaged in secondary tasks while drive on a test track at 0 and 12 months of licensure

Their single longest glance off the forward roadway and their total time looking away from the forward roadway were examined

Novice drivers showed an improvement on both measures from month 0 to month 12 while their parents show no improvement

Glances away from the forward roadway while driving could explain higher crash rates among young novice drivers

Figure 1.
LGOR on control trials for teens and adults at both time points. Error bars represent ± 1 SE.

Figure 2.
LGOR on experimental trials for teens and adults at both time points. Error bars represent ± 1 SE.

Figure 3.
TEOR on control trials for teens and adults at both time points. Error bars represent ± 1 SE.

Figure 4. TEOR on experimental trials for teens and adults at both time points. Error bars represent ± 1 SE.

Table 1

Independent and Dependent variables

Within-Subjects Independent Variables			Dependent Variables
Novice Teen Driver	0 Months	Experimental	LGOR
			TEOR
		Control	LGOR
			TEOR
	12 Months	Experimental	LGOR
			TEOR
		Control	LGOR
			TEOR
Adult Driver	0 Months	Experimental	LGOR
			TEOR
		Control	LGOR
			TEOR
	12 Months	Experimental	LGOR
			TEOR
		Control	LGOR
			TEOR

Note. LGOR – Longest single Glance Off the forward Roadway. TEOR – Total percentage of time for Eyes Off the forward Roadway.

Table 2

Main effects and interactions for the generalized estimating equations model of LGOR

Effect	Estimate (95% CI)	P value
Task Completion ^a	-1.02	
Condition (SSS vs. SSFD) ^b		
Age Group ^c	-3.18 (-5.33, -1.03)	<.01
Time ^d	0.71 (-0.73, 2.15)	.33
Trial-Type (Control vs. Experimental) ^e	5.9 (3.87, 7.93)	<.001
Age Group × Time	-1.81 (-3.99, 0.36)	.1
Age Group × Trial-Type	1.35 (-1.87, 4.57)	.41
Time × Trial-Type	1.06 (-1.37, 3.5)	.39
Age Group × Time × Trial-Type	-3.59 (-6.79, -0.38)	<.05

^aTask Completion was a binary control variable (reference group: did not complete a task within 30 seconds).

^bCondition (reference group: self-selected speed) was a binary control variable in the analyses.

^cReference group: Adult.

^dReference group 12 months.

^eReference group: Control.

Table 3

Main effects and interactions for the generalized estimating equations model of TEOR

Effect	Estimate (95% CI)	P value
Task Completion ^a		
Condition (SSS vs. SSFD) ^b		
Age Group ^c	-2.69 (-6.5, 1.12)	.17
Time ^d	-2.68 (-4.42, -0.93)	<.01
Trial-Type (Control vs. Experimental) ^e	33.4 (30.61, 36.17)	<.001
Age Group × Time	-0.3 (-3.53, 2.9)	.86
Age Group × Trial-Type	-1.11 (-5.43, 3.32)	.64
Time × Trial-Type	3.34 (0.97, 5.7)	<.01
Age Group × Time × Trial-Type	3.45 (0.05, 6.86)	<.05

^aTask Completion was a binary control variable (reference group: did not complete a task within 30 seconds).

^bCondition (reference group: self-selected speed) was a binary control variable in the analyses.

^cReference group: Adult.

^dReference group 12 months.

^eReference group: Control.