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RESEARCH ARTICLE

Distracted Driving, Visual Inattention, and Crash Risk Among Teenage Drivers

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Introduction: Distracted driving resulting from secondary task engagement is a major contributing factor to teenage drivers' crash risk. This study aims to determine the extent to which visual inattention while engaging in distracting secondary tasks contributes to teenage drivers' crash risk.

Methods: Real-world driving data were collected from a cohort of 82 newly licensed teenagers (average age 16.48 years, SD=0.33) recruited in Virginia. Participants' private vehicles were equipped with data acquisition systems that documented driving kinematics and miles driven, and made video recordings of the driver and driving environment. Data were collected from 2010 to 2014 and analyzed in 2017. The analysis of secondary task engagement was based on 6-second video segments from both crash and random samples of normal driving.

Results: Of a wide range of secondary tasks, only manual cellphone use (OR=2.7, 95% CI=1.1, 6.8) and reaching/handling objects while driving (OR=6.9, 95% CI=2.6, 18.6) were associated with increased crash risk. Drivers' duration of eyes off the road accounted for 41% of the crash risk associated with manual cellphone use and 10% of the risk associated with reaching/handling objects while driving.

Conclusions: Secondary tasks vary in the risk they introduce to the teenage driver. Manual cellphone use and reaching for objects were found to be associated with increased crash risk. These findings objectively quantify the effect of visual inattention resulting from distracting secondary tasks on teenage drivers' crash risk. Teenage drivers may benefit from technologic and behavioral interventions that will keep their eyes on the road at all times and discourage engagement in distracting secondary tasks.

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INTRODUCTION

Motor vehicle crashes are the leading cause of death and disability among teenage drivers between the ages of 15 and 20 years. Teens are overrepresented in fatal crash statistics, having the highest crash rate compared with other driver age groups.[1,2] Engaging in a non-driving–related activity that diverts the driver's attention from driving tasks is a prominent form of driver distraction.[3] According to the National Highway Traffic Safety Administration, 9% of the fatal crashes that occurred in 2015 involving teen drivers were attributed to driver distraction, the highest proportion of any drivers' age group. Although distracted driving is risky for drivers of all ages, it is of particular concern for young drivers. Compared with older and more experienced drivers, young drivers are more likely to engage in secondary tasks while driving,[3] and their crash risk may be greater when so engaged.[4] The underlying reasons for young drivers' increased crash risk resulting from secondary task engagement

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may include their limited driving experience, poor judgment about when to engage, long duration of eyes off the road during engagement, and underestimating the amount of resources needed to maintain safe driving.[5]

In naturalistic driving studies, drivers' behavior is continuously monitored using in-vehicle data acquisition systems that document driving kinematics and miles driven, and make video recordings of the driver and driving environment.[3] Naturalistic methods enable objective measurement of crashes, secondary task engagement, and their association. Gershon et al.[6] used randomly sampled real-world driving data to assess the prevalence of secondary task engagement among novice teenage drivers and found that in 58% of the samples drivers were engaged in at least one secondary task. Another naturalistic study reported that 76% of rear-end crashes among teenage drivers occurred proximal to performing some type of secondary task.[7]

Although secondary task engagement is associated with increased crash risk,[3] the extent of distraction and resulting crash risk may vary depending on the type of task, driver characteristics, and the driving environment. Engaging in tasks that take the driver's eyes off the forward roadway was associated with a dramatic increase in risk of crash/near-crash events.[8] Klauer and colleagues[4] found that crash risk of novice drivers was significantly higher when using a cellphone for dialing or sending/receiving text messages, reaching for an object, looking at a roadside object, and eating. However, talking on a cellphone (hand-held or hands-free) was not associated with increased risk of crash/near-crash events.[5] Simons-Morton et al.[8] found that when teenage drivers were engaged in secondary tasks, the duration of eyes off the road was positively associated with crash risk, meaning that the longer the duration of eyes off the road the greater the crash risk, regardless of the type of secondary task. Teenage drivers have also been found to spend higher percentages of time with their eyes off the road than adults while preforming a complex reading task.[9] Neyens and Boyle[10] showed that engaging in a visually demanding task, such as interacting with a cellphone or in-vehicle devices, was associated with increased crash risk as well as higher crash severity.

The tendency to engage in secondary tasks while driving, limited driving experience, and limited ability to dynamically allocate visual resources between driving and a secondary task may place the teenage driver at greater crash risk. The purpose of the current study is to identify distracting secondary tasks and determine if the duration of eyes off the road during secondary task engagement modified their association with crashes. The study uses mediation analyses to objectively quantify the effect of eyes off the road on crash risk resulting from secondary task engagement. The authors hypothesize that visual inattention accounts for a substantial proportion of the increase in crash risk resulting from engagement in distracting secondary tasks.

METHODS

Data were drawn from the Supervised Practice Driving cohort study, which followed teenage drivers during supervised prelicensed practice and independent driving. Data were collected from 2010 to 2014 for a period of up 12 months of provisional licensure (more details on the Supervised Practice Driving study in Gershon and colleagues[11] and Ehsani et al.[12]). Participants' private vehicles were installed with data acquisition systems[13] that collected naturalistic driving data using (1) a computer to record continuous driving kinematics data used to assess speed, three-dimensional acceleration, and g-force events; (2) GPS to assess mileage; and (3) video cameras (frame rate 15 Hz) to monitor the driver's face, hand, and body positioning; driver's forward and rear views; and the car dashboard. This study used data obtained after licensure, when teens could drive without mandatory adult supervision. The total miles driven during this period was ≅380,000 miles, with an average of 4,636 miles (SD=3,244, range, 5.2 to 14,895) per participant.

Study Sample

A total of 82 newly licensed teenage drivers (53% female) with an average licensure age of 16.48 years (SD=0.33) participated in the study. All participants were recruited through local media and high schools in southwestern Virginia. Participants received $800 for completing the study, paid in installments as they completed key milestones. Identical twins and teenagers diagnosed with attention-deficit/hyperactivity disorder were excluded from the study.

Measures

Crashes, the primary outcome, were operationally defined as any physical contact between the vehicle and another object. To identify crashes, a filter was run over the continuous accelerometer data detecting any threshold value ≥0.65 g-force. Each flagged event was evaluated by experienced coders who viewed a 6-second video segment before each event and employed a systematic protocol to determine the occurrence, severity, type, and possible contributing factors to the event, including secondary task engagement.[3] Accordingly, 71 crashes were identified, with 11 police-reported crashes. Of the 82 drivers, 43 had no crashes, 25 had one crash, and the remaining 14 had two or more crashes per driver (median=3, range, 2–8).

Randomly sampled, non-crash 6-second video segments served as baselines (to compare with the pre-crash footage), representing normal driving behavior. A total of 1,196 baseline segments were sampled on the basis of each participant's driving exposure (proportion of hours traveled). Three participants with extremely low mileage (<50 miles) aged out of the study soon after licensure and were excluded from the analysis. The median number of baseline samples per participant was 15 (minimum=1, maximum=40). This sampling strategy provided an unbiased distribution of driving conditions.

Table 1. Definition of Secondary Tasks

Task type	Definition
Cellphone manual use (dialing/texting/browsing)	Cell phone texting/browsing/locating/reaching/answering/dialing hand-held/ talking or listening hand-held
Dancing	Dancing in seat to apparent music
External distraction	Looking at an object/pedestrian/animal that was external to the vehicle
Food and drink intake	Eating without utensils/drinking with lid and straw/drinking with lid, no straw/ drinking from open container
Interaction with in-vehicle systems	Adjusting/monitoring climate control/radio/other devices that are integral to vehicle
Interaction with a passenger	Interacting with passenger (adult, child, unknown) in adjacent/rear seat
Personal hygiene	Removing/adjusting contact lenses/glasses/clothing/applying make-up/or any other personal hygiene behavior
Reaching/handling objects in the vehicle	Interacting with or reaching for an object inside the vehicle including personal body-related item/food or drink-related item
Talking/Singing (no passenger)	Talking/singing to self/hands-free cell phone/ using voice-activated/not with a passenger

The exposure variable was secondary task engagement. Secondary tasks were identified and documented by two coders who viewed the 6-second video segments of each crash and baseline datasets. Following a strict protocol, the coders identified 41 types of secondary tasks that were each assigned to one of the nine categories specified in Table 1.

Total time of eyes off the road (in seconds; TTEOR) was calculated as the total amount of time that the driver spent looking away from the forward road during the 6 seconds of baseline and crash segments.

Statistical Analysis

ORs comparing each type of secondary task in crashes relative to baselines were estimated by using mixed effects logistic regression models with participant-specific random intercept to account for correlations between multiple observations from the same driver. Because this is a case-cohort study design with baselines sampled in proportion to driving exposure, ORs can serve as an approximation of incidence rate ratios.[14,15] The models included time of day as a covariate with no secondary task as the reference group. Secondary tasks that were associated with a significant increase in crash risk (i.e., OR>1) are subsequently referred to as distracting secondary tasks. Linear regression assessed whether TTEOR varied according to secondary task engagement in crash and baseline events. Mixed effects logistic regression models with random intercept were used to evaluate the association between TTEOR and crash risk.

Mediation analyses examined TTEOR as a possible mechanism that affects the association between secondary task engagement and crash risk (illustrated in Figure 1). The analyses decomposed the total effect of secondary task engagement on crash risk into direct and indirect effects, quantifying how much of the crash risk associated with a secondary task engagement was due to the driver looking away from the forward road.

Mediation of the association between distracting secondary tasks and crash risk by TTEOR was performed using R statistical software, version 3.4.1, mediation package.[16] The mediation analyses required two fitted regression models: one for the mediator (TTEOR) and one for the outcome (crashes).

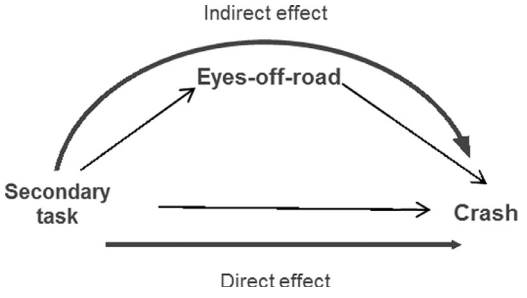

Figure 1. Direct and indirect effects of secondary task engagement on crash risk.

A mixed effects linear regression model, adjusting for time of day and all other secondary tasks, was used to fit the association between distracting secondary task and TTEOR. Next, crash risk was modeled using mixed effects logistic regression with random intercept, adjusting for time of day and all other secondary tasks, thereby evaluating the association of secondary tasks and crashes while controlling for TTEOR. The average causal mediation effect and average direct effect were estimated based on the two fitted models using Monte Carlo draws for nonparametric bootstrapping with 1,000 samples, generating 95% CIs. A significant mediation effect is indicated by confidence limits that do not overlap zero. The sequential ignorability assumption was satisfied, and unmeasured confounding factors were examined with a sensitivity analysis using the function medsense() in the R mediation package.[17,18] Figure 1 illustrates the hypothesized direct and indirect paths of the association between secondary tasks and crashes.

RESULTS

The prevalence of secondary task engagement while driving was relatively similar in crashes and baselines (Figure 2). Drivers engaged in at least one secondary task in 51% of crashes and 56% of baseline segments. The most prevalent type of secondary task was

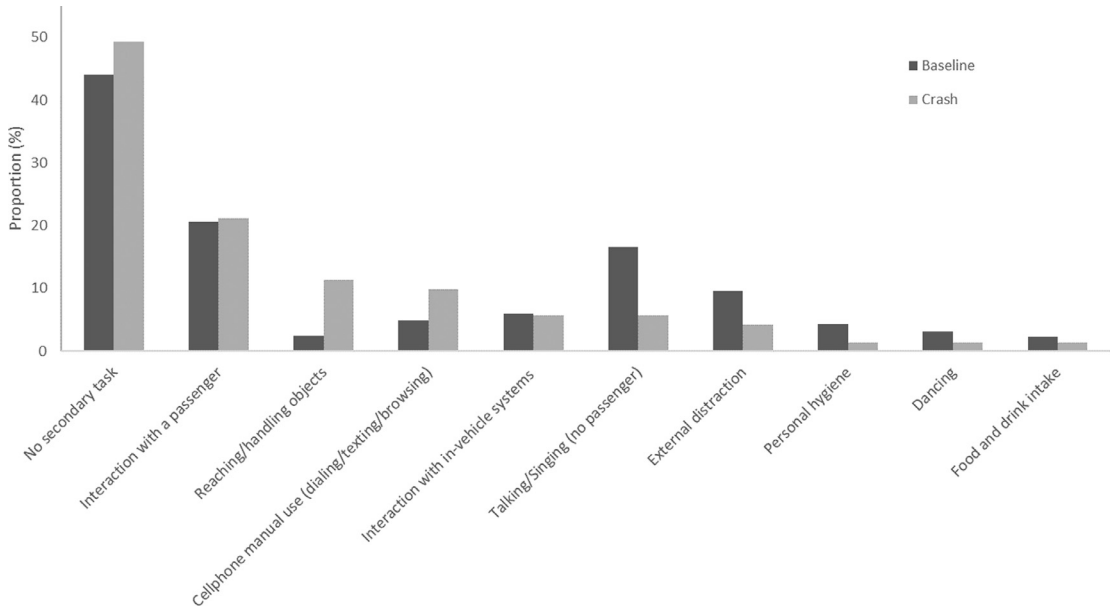

Figure 2. Prevalence of secondary tasks in baselines and crashes.

interaction with a passenger, which occurred in 21% of both crashes and sampled baselines. The next most common secondary tasks were talking/singing not with a passenger (17%) and external distraction (i.e., attending stimuli outside the vehicle; 10%). Manual use of cellphone, including dialing and texting, was twice as prevalent in crashes (10%) than in the sampled baselines (5%). However, tasks that included talking/singing not with a passenger were observed in about 6% of the crashes, but were evident in 17% of the baselines. Finally, reaching/handling objects in the vehicle was >3.5 times as prevalent in the event of a crash (11%) compared with baselines (3%).

Figure 3 shows the ORs and corresponding 95% CIs for each type of secondary task. Reaching/handling objects in the vehicle increased crash risk almost 7 times (OR=6.9, 95% CI=2.6, 18.6). Similarly, manual cellphone use (including holding, texting, dialing, and browsing the web) more than doubled the risk for a crash (OR=2.7, 95% CI=1.1, 6.8). Finally, talking/singing not with a passenger (i.e., either to self or on the cellphone hands-free) was associated with a decrease of >70% in the risk of a crash (OR=0.3, 95% CI=0.1, 0.8).

Visual inattention associated with secondary task engagement was evaluated using the prevalence and TTEOR measured during crashes and baselines. In the absence of a secondary task, the average duration of TTEOR was 0.83 seconds (SD=0.97) and 1.30 seconds (SD=1.32) in baselines and crashes, respectively. Secondary task engagement while driving was associated with significantly longer duration of TTEOR in baselines (1.51 seconds, SD=1.35, $p<0.001$) and crashes (1.98 seconds, SD=1.62, $p<0.0085$) compared with driving without a secondary task. Analysis of the association between TTEOR and crash risk indicated that the risk for a crash increased 28% with the increase of 1 second of TTEOR from the mean (OR=1.3, 95% CI=1.1, 1.5). TTEOR was longer during manual cellphone use in crashes (2.94 seconds, SD=1.72) versus baselines (2.40 seconds, SD=1.50) and lower while reaching/handling objects in crashes (1.63 seconds, SD=1.73) versus baselines (2.25 seconds, SD=1.46).

The effect of TTEOR on the associations between distracting secondary task engagement (i.e., manual cellphone use and reaching/handling objects in the vehicle) and crash risk was evaluated in mediation analyses. Results indicated that the duration of TTEOR significantly mediated the association between manual cellphone use and crash risk (average causal mediation effect=0.03[a], 95% CI=0.01, 0.05, $p=0.004$). The direct effect of manual cellphone use on crash risk when controlling for the duration of TTEOR was no longer significant (average direct effect=0.04[a] 95% CI= −0.03, 0.13, $p=0.39$), indicating that TTEOR drove the association between manual cellphone use and crash risk. The indirect effect of TTEOR (Figure 1) accounted for 41% of the increase in crash risk resulting from manual

[a]The model uses logit link function; as such the estimate is on a logarithmic scale.

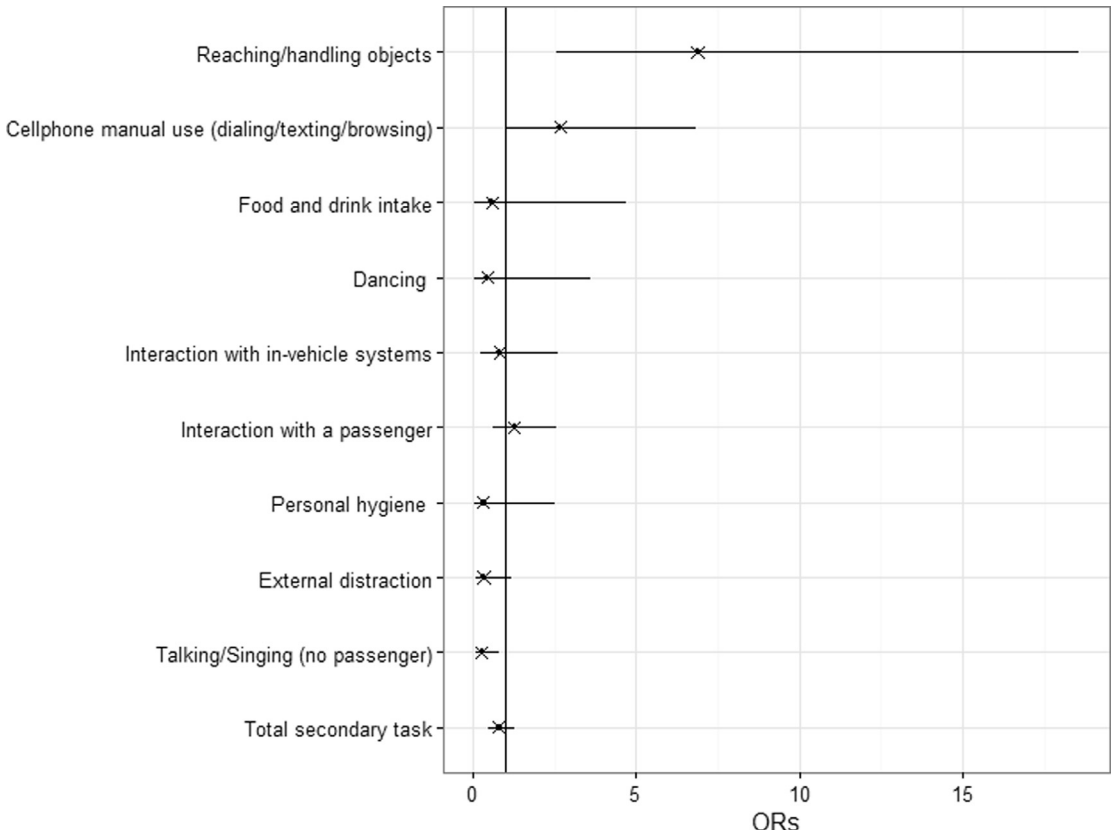

Figure 3. ORs and corresponding 95% CIs (represented by horizontal lines) for secondary task categories.

cellphone use. That is, 41% of the increase in crash risk when manually engaging with the cellphone was due to the driver's TTEOR. The effect of reaching/handling objects in the vehicle was also mediated by TTEOR (average causal mediation effect=0.02[a], 95% CI=0.01, 0.04, $p<0.01$), accounting for 10% of the total effect. The direct effect of reaching/handling objects in the vehicle while controlling for TTEOR was also significant (average direct effect=0.19[a], 95% CI=0.06, 0.36, $p<0.01$).

Sensitivity analyses for unmeasured confounding variables indicated that some of the variances in TTEOR and crash risk were not explained by secondary task engagement, yielding a sensitivity parameter value (ρ) of 0.2 for both manual cellphone use and reaching/handling objects in the vehicle. As such, it is plausible that other unmeasured covariates not accounted for in the current models (e.g., traffic conditions, passenger presence) may affect both the mediator (TTEOR) and the outcome (crash).

DISCUSSION

Distracted driving resulting from secondary task engagement is a major contributing factor for motor vehicle crashes among teenage drivers.[4,19] The current study used naturalistic driving data to assess the prevalence of teenagers' secondary task engagement while driving, estimate the associations of distracting secondary tasks with crash risk, and evaluate the mediation of these associations by visual inattention. This study is the first to objectively quantify the extent to which visual inattention during engagement in a distracting secondary task contributes to crash risk of teenage drivers.

The results of the study indicate that the overall prevalence of secondary task engagement was similar for baselines and crash events. However, some tasks were more prevalent in crashes whereas others were observed more frequently during normal driving (baselines). These findings show that the safety implications of secondary task engagement varied by task type. Of these tasks, manual cellphone use (e.g., texting, dialing, and browsing the web) and reaching/handling objects in the vehicle were associated with a significant increase in crash risk among teenage drivers. Previous studies also identified these tasks as highly associated with teenagers' increased crash/near-crash events[4,19] as well as having impact on the driver's eye-glance behaviors.[5,20]

The elevated risk associated with secondary task engagement could be explained by visual inattention,

cognitive load, and the physical demands introduced by the secondary task.[4,5,10] In a meta-analysis of 28 studies on texting while driving, Caird and colleagues[21] confirmed that engaging in visually demanding secondary tasks, such as texting, can impair driving performance, especially among teenage drivers. However, the contribution of visual inattention to crash risk has not been established. The current analysis found that crash risk increased by 28% with the increase of every second of TTEOR.

In the current study, mediation analyses were used to quantify the effect of visual inattention on teenagers' crash risk related to two distracting secondary tasks: manual cellphone use for texting/dialing/browsing the web and reaching/handling objects while driving. The analyses found that 41% of the association between manual cellphone use and teenagers' crash risk was mediated by the duration of eyes off the road. Essentially, 41% of the risk caused by the manual use of a cellphone was due to the driver looking away from the forward road. The remaining 59% of the association between manual cellphone use and crash risk may be attributed to the physical demands of operating the phone while driving and possibly additional cognitive load that the driver endures. The analysis indicates that 10% of the crash risk associated with reaching/handling objects while driving is attributed to TTEOR. It is possible that when reaching/handling objects while driving, drivers can maintain their eyes on the forward road, but their attention is on the manual search (i.e., looking at but not seeing the forward road).

The growing availability of mobile electronic devices, their increasing functionality, and connectivity will likely inform the future of distracted driving. Maintaining the dominant reliance of these tasks on visual resources will increase drivers' visual inattention and, thereby, increase crash risk. Of particular concern are teenage drivers, who might overestimate their ability to multitask while driving, who are considered to be early adopters of technology, and who have the highest proportion of fatal crashes attributed to driver distraction.[22] As such, teenage drivers' engagement in distracting secondary tasks should be targeted in teenagers' education, possibly using parents' interventions and legislation and enforcement. Future research should evaluate alternative methods of interaction, such as haptics and auditory, that can relieve the burden from the visual channel.

Limitations

The study findings are limited by the sample of volunteer teenage drivers, which was derived from a specific region and, as such, might not be nationally representative. Future research will benefit from a larger and more diverse sample of participants. The current analysis considered only a subset of key factors in association with teenage drivers' crash risk. Furthermore, the analyses could not control for potential changes in crash risk over time, given the method of sampling baseline segments. Further work is needed to understand how other potential confounding factors may affect these associations (e.g., gender differences in secondary task engagement, at-fault versus not at-fault crashes).

CONCLUSIONS

This study is the first to use naturalistic driving data to quantify the role of visual inattention in the association between high-risk secondary task engagement and teenage drivers' crash risk. Although not all secondary tasks are equally risky, two prevalent tasks, manual cellphone use and reaching for objects, were found to be associated with increased crash risk. Visual inattention to the forward roadway accounted for 41% of the risk associated with cellphone use and 10% of the risk associated with reaching for objects. Basically, drivers increased their crash risk by looking away from the forward roadway to accomplish tasks secondary to driving. The current study extended the understanding of the ties between engaging in distracting secondary tasks and crash risk by quantifying the contribution of visual inattention. Findings confirm the need for technologic efforts to reduce drivers' visual inattention resulting from secondary task engagement (e.g., voice-operated interfaces) and behavioral preventions (e.g., real-time monitoring and alerting on frequent or extensive visual inattention) to discourage high-risk secondary tasks and encourage teenage drivers to keep their eyes on the road at all times.

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Dr. Gershon conceptualized the study, supervised data management and analysis, drafted the manuscript, and revised and finalized the manuscript. Dr. Simons-Morton assisted with the design of the study and reviewed and critically revised the manuscript. Ms. Sita assisted with the manuscript preparation and reviewed and commented on manuscript drafts. Dr. Zhu conducted the data management and analyses. Drs. Ehsani, Klauer, and Dingus reviewed and commented on manuscript drafts. All co-authors approved the final manuscript as submitted. The authors have no conflicts of interest to report.

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