Effectiveness of a Smartphone-based Driver Support System for Reducing the Frequency of Risky Driving Behaviors in Novice Teenage Drivers

A Dissertation
SUBMITTED TO THE FACULTY OF
THE UNIVERSITY OF MINNESOTA
BY

Janet I. Creaser

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Michael P. Manser, Ph.D., Adviser

July 2015

ACKNOWLEDGEMENTS

First and foremost, I must extend significant thanks to my husband, Trent, for his constant encouragement and support during this journey. I also thank my children Cameron, Samantha, and Malcolm who put a smile on my face every day and made it easier to keep perspective during this process.

I thank Chris Edwards, who diligently provided feedback and support through the entire process. I send thanks to my sister, Julie Creaser, for being my long-distance support system through dark nights. Craig Shankwitz, Denis Foo Kune, and Megan Breit-Goodwin were significant sources of personal, professional and academic support, and their cheer leading was greatly appreciated.

My committee included exceptional individuals who all provided significant encouragement and advice. Dr. Caroline Hayes, Dr. Max Donath and Dr. Lucy Dunne served as wonderful role models and mentors. I also thank all the individuals who were on deck as support and who assisted in making this project a success: the HumanFIRST team of Nichole Morris, Jennifer Cooper, Brandy Swanson, Peter Easterlund, Alice Ton and the Clowd Lab engineering team of Alec Gorjestani, Eddie Arpin and Arvind Menon.

This project would not have been possible without the support and funding of the Minnesota Department of Transportation (Sponsor Award Number 99008, Work Order 17). Many thanks go to Sue Sheehan who served as the Technical Liaison on this project and its predecessor, and to Gordy Pehrson of the Minnesota Department of Public Safety for his critical insights throughout this project.

CONTRIBUTIONS

The successful completion of this project was dependent on a team of individuals and their intellectual contributions are recognized here (in alphabetical order).

Eddie Arpin, Alec Gorjestani and Arvind Menon (Clowd Lab, LLC) and Craig Shankwitz, PhD (Intelligent Vehicles Laboratory)

- Hardware and software development for the TDSS application; implementation of user interface design specifications for the TDSS application and parent website.

Lindsey Dietz and Yifan Gu (Statistical Consulting Service, University of Minnesota)

- Consulted to verify the appropriateness of the proposed Generalized Linear Mixed Model analysis and helped refine the model to account for non-equivalence of groups; programmed and executed the SAS 9.4 scripts.

Max Donath, PhD

- TDSS conceptual design and development; project management.

Christopher Edwards, MS

- Contributions to experimental design, recruiting methods, statistical analyses, and TDSS interface designs (application and website).

Nichole Morris, PhD

- Contributions to recruiting methods and parent website design.

DEDICATION

This thesis is dedicated to Trent, Cameron, Samantha and Malcolm who are my joys and loves in life.

ABSTRACT

Teenage driver support systems employ behavioral modification functions to assist the teenage driver in adopting safer driving behaviors. This study deployed a smartphone-based Teen Driver Support System (TDSS) that provided in-vehicle notifications to newly-licensed teenage drivers as well as sent (via text message) notifications to parents about detected risky driving behaviors (e.g., speeding, excessive maneuvers, seat belt no use). The application also blocked calling, texting and other phone applications to prevent phone-related distracted driving. This study evaluated the effectiveness of in-vehicle notifications combined with parent reporting functions to in-vehicle notifications alone in reducing certain risky driving behaviors among teenagers. Driving behavior data were collected from a control group (N=92) that engaged in naturalistic driving and two intervention groups: an in-vehicle only feedback group (partial TDSS, i.e. no feedback to the parent; N=92) and an in-vehicle feedback group in which parents also received system reports (full TDSS functionality; N=90). The results indicated an overall benefit of the full TDSS with parental feedback in significantly reducing the frequency of some risky driving behaviors, such as speeding, that are correlated with novice teenage driver crashes. In-vehicle feedback alone was less effective at reducing risky driving behaviors, indicating that parental feedback is a critical component of such systems. The cellular phone blocking functions worked effectively to reduce calling and texting in both treatment groups. The outcomes of this study indicated that monitoring applications that combine feedback and forcing functions are useful at reducing risky driving behaviors in novice teenage drivers primarily when combined with parental feedback.

Keywords: teenagers, driving safety, parents, support systems.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA – Analysis of Variance

arDAQ – Arduino Microprocessor Data Acquisition System

CDC – Centers for Disease Control

ESBR – Enhanced Seat Belt Reminder

GDL – Graduated Driver Licensing

GLMM – Generalized Linear Mixed Model

IIHS – Insurance Institute for Highway Safety

IRB – Institutional Review Board

ISA – Intelligent Speed Adaptation

NFC – Near Field Communication

NHTSA – National Highway Traffic Safety Administration

SSS – Sensation Seeking Score

TDSS – Teen Driver Support System

INTRODUCTION

According to the most recent data available, motor vehicle crashes are the leading cause of death for teenagers aged 15-20 years old in the United States (Centers for Disease Control [CDC], 2012). In 2012, 1,875 young drivers aged 15-20 were killed in motor vehicle crashes, of which 1,372 (73%) were male and 503 (27%) were female (National Highway Traffic Safety Administration [NHTSA], 2014a). Young drivers aged 15-20 accounted for 6% of the licensed drivers in the U.S. in 2012, but they accounted for 9.4% of all drivers involved in fatal crashes and 13% of drivers involved in police-reported crashes (NHTSA, 2014a). Sixteen-year-old drivers have the highest fatal crash risk per mile driven compared to other age groups, despite driving fewer miles per year, on average, than drivers of other ages (Ferguson, Teoh & McCartt, 2007). More importantly, age alone is a significant influencing factor on driving behavior in general (Steinberg, 2008; Keating, 2007). For example, during the initial one to two years of driving, novice teenage drivers are disproportionately at risk compared to novices of other ages (Cooper, Pinili, & Chen, 1995; Mayhew, Simpson, & Pak, 2003; McCartt, Shabanova & Leaf, 2003). Older novice drivers (age 25+) typically have lower crash rates even when compared to experienced teenage drivers (e.g., an 18-year-old with 2 years of experience). Younger drivers also report increased levels of risky behaviors and intentions to commit risky behaviors in studies that make age comparisons (Groeger & Brown, 1989; Laapotti, Keskinen, Hatakka & Katila, 2001; Reason, Manstead, Stradling, Baxter & Campbell, 1990; Renner & Anderle, 1999).

Teenage driver fatalities are frequently associated with specific behaviors leading to a crash, such as driving while impaired (2014a; 2014b), speeding (NHTSA, 2014c), lack of seat belt use (NHSTA, 2014d), and/or inattentive or distracted driving (Klauer, Guo, Simons-Morton, Ouimet, Lee, & Dingus, 2014; NHTSA, 2013). In 2012, Minnesota crash reports showed driver distraction (22.8%), illegal/unsafe speed (10.9%), and driver inexperience (9%) were three of the top five contributing factors cited in single-vehicle teenage driver crashes, while driver inattention was the most common factor cited in multiple-vehicle teenage driver crashes (MN Department of Public Safety, 2014). The behaviors involved in teenage driver crashes are well documented in the U.S. and other countries, and are also correlated with other factors, such as gender (Braitman, Kirley, McCartt, & Chaudhary, 2008; NHTSA, 2014a), personality characteristics (Arnett, 1996; Deery & Fildes, 1999; Jonah, Thiessen, Au-Yeung, 2001; Jonah, 1990), poorer hazard perception skills (Chapman, Underwood & Roberts, 2002; Groeger, 2000), and young age (Keating, 2007; Steinberg, 2008).

Implementing mandatory driver's education in the U.S. and other countries has not resulted in reduced crash rates for novice teenage drivers (Engstrom, Gregersen, Henetkoski, Keskinen, Nyberg, 2003; Williams, 2006). Programs over the past 20 years have focused, instead, on increasing licensing and driving restrictions for novice teenage drivers to combat the risks faced by this vulnerable group. The goal of Graduated Driver Licensing (GDL) programs, for example, is to protect novice teenage drivers by restricting driving during risky conditions, such as at night and/or with other teenage passengers (Williams, Tefft & Grabowski, 2012). GDL has significantly reduced the fatal crash rates of 16-year-old drivers by restricting driving during these risky conditions

(McCartt, Teoh, Fields, Braitman & Hellinga, 2010; Williams et al., 2012). Teenage drivers, however, are not necessarily more experienced or better drivers upon leaving GDL restrictions at age 18 (Karaca-Mandic & Ridgeway, 2010). Masten, Foss and Marshall (2011) examined teenage driver fatal crash involvement rates from 1986-2007 for each quarter of the year by all 50 states and the District of Columbia. After accounting for potential confounds in the analysis model, they found that GDL programs with at least a 3-month learner period, including passenger restrictions and nighttime driving restrictions, resulted in significantly lower rates of fatal driver involved crashes for 16-year-olds. However, they also found a significant increase in fatal driver involved crashes for 18-year-olds subjected to any GDL restrictions. They concluded that young teenage drivers exposed to GDL restrictions are at a decreased risk because of the reduced exposure to higher-risk driving conditions, but the protective effect disappears upon graduating from the GDL program. This suggests GDL programs are primarily protective when teenagers are subject to the restrictions, but do not necessarily improve safety over the long term.

Parents are primarily responsible for managing their teenager's driving in relation to GDL restrictions as well as teaching them how to drive. This means parents are a key focus of teenage driver safety research and programs. Simons-Morton (2007) highlighted the importance and effectiveness of parental management of teenage drivers. Because many parents are unaware of the unique risks associated with novice teenage drivers, new education programs targeting parents have been or are being developed (Fischer, 2013). The goal of such programs is to educate parents on the risks associated with teenage driving and how to manage those risks (Fischer, 2013; Simons-Morton, Hartos, Leaf &

Preusser, 2006). Parents who are educated on teenage driving risks and provided tools (e.g., such as parent-teenager contracts) for managing when, where and how often their teenager drives often impose stricter controls on their teenager's driving (Simons-Morton, 2007). Despite GDL and the introduction of parent education classes, teenage crash rates remain high and safety proponents are looking towards new solutions for teenage drivers, such as technology.

Lee (2007) drew an analogy that suggested in-vehicle technologies could act as an adult passenger to enhance teenage driver safety, such as by monitoring and providing feedback about behavior directly to teenage drivers and parents. Simons-Morton (2007) suggested that in-vehicle monitoring of risky driving behaviors could assist with parent management of teenage driving risks, provided efficacy of the monitoring system could be established. As technology becomes more sophisticated, it is important to identify what types of behavioral monitoring, in-vehicle feedback, and reporting of information to parents are sufficient to assist teenagers and parents in reducing crash-related risky driving behaviors. Ideally, if parents can be provided context-specific information about detected risky driving behaviors, they can serve as a mentor to their teenage driver by coaching their teenager towards safer driving habits (McGehee, Carney, Raby, Reyes, & Lee, 2007). Risky driving behaviors that can be monitored include excessive maneuver events associated with risky driving, such as hard braking, accelerating or turning (McGehee, et al., 2007), speeding (Farmer, Kirley & McCartt, 2010), seat belt use (Farmer et al., 2010; Manser, Edwards, Lerner, Jenness, & Huey, 2013), and/or the presence of passengers and driving after GDL curfew (Brovold, Ward, Donath, Simon, & Creaser, 2007; Manser et al, 2013).

Because of the rapid development of computing power available on smartphones and mobile devices, researchers have focused attention on using mobile device applications to support teenage drivers (Brovold et al., 2007). A mobile device application reduces the need to install monitoring equipment in the vehicle, while capitalizing on the device's existing visual and auditory interfaces. For example, a smartphone-based application has the potential to use the phone's visual and auditory feedback interfaces, as well as capitalize on its built-in sensors, such as Global Position Systems (GPS) and accelerometers, to monitor vehicle speed and maneuvers (Creaser, Hoglund, Manser, & Donath, 2009; Creaser, Gorjestani, Manser & Donath, 2011). A smartphone also has the capability to send data over the wireless network to parents via text message, email or to a website where parents can view details of detected risky behaviors, while minimizing or eliminating the need for special equipment in the vehicle. Finally, given the prevalence and concern about distracted driving due to mobile devices, a smartphone application can be programmed to block phone functions such as calling and texting while driving.

The purpose of this study was to deploy and evaluate the effectiveness of a smartphone-based Teen Driver Support System (known as TDSS) on the prevalence of teenagers' risky driving behaviors in the first year of licensure. The system provided in-vehicle alerts and information to teenagers about detected risky driving behaviors, such as speeding and excessive driving events, as well as blocked cellular phone use. The system provided near real-time feedback to parents via text messages about detected risky driving events to encourage parents to discuss safe driving behavior with their teenagers as soon as possible after an event occurred. The system deployed in this study was previously developed and evaluated using engineering methods as well as on-road usability testing to verify and validate the interfaces in three previous studies (Brovold et al., 2007; Creaser et al., 2009; Creaser et al., 2011). If a smartphone-based application is effective at reducing certain risky driving behaviors, it would provide an easily accessible tool for parents of teenage drivers to use to reduce the risks associated with teenage driver crashes.

This field study employed a quasi-experimental design (Shadish, Cook & Campbell, 2002; Cook & Campbell, 1979) that involved three groups (one control, two treatment) of novice teenage drivers who were recruited along with one parent (per teenager) from 18 Minnesota communities. One group was provided with the full TDSS with in-vehicle feedback and parental reporting, while a second group received a partial TDSS with the in-vehicle feedback functions. A third group of teenage drivers and parents served as a control group against which the treatment groups could be compared. It was expected that the full TDSS group that included parental reporting would have the lowest rates of observed risky driving behaviors across the study time period compared to the partial TDSS and control groups. The role of system reporting to parents has been previously established as a mechanism for reducing risky behaviors (McGehee et al., 2007; Simons-Morton et al., 2013). The partial TDSS group was expected to demonstrate lower rates of risky behaviors for which persistent, graded feedback existed (i.e., speeding) and for behaviors for which a forcing function existed. Persistent, graded in-vehicle feedback has been somewhat effective in a previous study (Manser et al., 2013). To establish the expected benefits of the TDSS's in-vehicle feedback alone and in combination with the reported information to parents on the frequency of risky driving behaviors, a full literature was conducted to examine the factors leading to teenage driver crashes, including observed behaviors (e.g., speeding) and motivating factors associated with the observed behaviors (e.g., age, inexperience, personality).

Literature Review

There are several observed behaviors that are associated with teenage driver crashes, as well as multiple motivational factors that lead to the expression of one or more behaviors. For example, speeding that arises because the driver finds the sensation thrilling is different from an inexperienced driver adopting an inappropriate speed for the roadway (e.g., sharp curve). In the former case, the behavior arises from a personality characteristic known as sensation seeking (Arnett, 1996; Jonah, 1990). In the latter case, the behavior occurs because the driver is unaware of how to judge a safer speed in an unfamiliar condition (i.e., the curve), which would not be uncommon for a novice teenage driver. Both behaviors are considered "speeding" (speeding or speeding too fast for conditions) and the potential outcome for both situations is a crash. These examples illustrate that the actual behavior of excessive speeding, previously defined as 5-10 mph over the posted speed limit (Farmer et al., 2010; Manser et al., 2013), could be easier to mitigate than the multiple factors known to cause speeding (e.g., personality, inexperience). For example, teenagers are taught that speeding is illegal and unsafe, but many engage in the behavior regardless (e.g., because they derive pleasure from it; Jonah, 1990). A system that could prevent the vehicle from going over the speed limit, no matter how far the accelerator pedal was depressed, would eliminate speeding behaviors even among drivers that desire to speed. Alternatively, if speeding behaviors are due to a lack of knowledge or experience with a situation, then feedback to the driver and/or an adult (e.g., parent) responsible for teaching the novice teenage driver could facilitate learning appropriate speed adoption in various driving situations.

For novice teenage drivers there are several behaviors that are frequently implicated in crashes, such as excessive speeding, aggressive or distracted driving, as well as behaviors that increase the risk of a fatality if a crash occurs, such as not using a seat belt while driving. The lack of seat belt use, for example, does not directly contribute to crashes but unbelted drivers are more likely to be killed or suffer severe injuries if a crash occurs. Distracted driving is also a topic of significant concern for teenage drivers and, in particular, the use of mobile devices while driving that can increase crash risk (Klauer et al., 2014). Previous research has identified speeding, alcohol use, seat belt non-compliance, and cellular phone use as behaviors that can be mediated by technological interventions (Brovold et al., 2007; Creaser et al., 2011). Previous research has also established a link between objectively measured behaviors such as hard braking, hard accelerating, and hard cornering to crashes (Simons-Morton, Ouimet, Zhang, et al., 2011; Simons-Morton, Zhang, Jackson, & Albert, 2012). The following sections describe the observed behaviors associated with teenage driver crashes, and the factors that often contribute to the behaviors. These behaviors should be considered when designing a system that has a goal of reducing crash-related behaviors.

Speeding

Speeding is the most significant behavior cited in fatal crashes in the U.S. and is estimated to be a factor in 30% of fatal teenage crashes (NHTSA, 2014c). Speeding and traveling too fast for conditions are associated with increased fatal crash risk for 16-year-old drivers (Williams, Ferguson, & Wells, 2005), and are also significant factors in non-fatal teenage driver crashes (McKnight & McKnight, 2003; Braitman et al., 2008). Braitman et al. (2008) interviewed teenage drivers involved in non-fatal crashes in Connecticut. They found that speeding too fast for conditions was involved in 21% of teenagers' at-fault crashes while exceeding the posted speed limit was involved in 12% of their at-fault crashes. In this study, however, speeding over the posted limit was only coded when it was included in the police report or during interviews, potentially resulting in an underestimation of speed involvement in this sample. In an 18-month naturalistic driving study of 42 novice teenage drivers, the frequency of speeding increased over the course of the study (Simons-Morton, Ouimet, Chen, et al., 2012). This study also found that teenagers who reported having more friends who engaged in risky driving behaviors (e.g., friends who speed, do not wear seat belts, etc) was predictive of pervasive speeding behavior. Teenagers who reported having more risky friends and who also had higher risk perception scores were more likely to engage in frequent speeding behavior over time.

Gender is often represented differentially in traffic crashes for certain behaviors, and speeding is one factor where gender plays a role. Young, male drivers are more frequently involved in speed-related crashes (NHTSA, 2014c). In 2012, speeding was a contributing factor in 37% of fatal crashes involving male drivers aged 15-20 in the US versus 24% of females in the same age group (NHTSA, 2014c). Braitman et al. (2008) found that teenage male drivers (48%) had speed as a contributing factor significantly more often than females (26%). Additionally, male teenage drivers in the study were more likely to lose control of their vehicle (46%) than females (29%). Previous research also found that male teenage drivers tended to demonstrate increased sensation seeking behaviors compared to females (Jonah, 1990; Prato, Toledo, Lotan, & Taubman - Ben-

Ari (2010), with speeding being one expression of this thrill seeking attitude in young male drivers.

Because speeding represents a significant factor associated with teenage driver crashes, and because teenagers are motivated by multiple factors to engage in speeding, it should be considered a primary target for countermeasures to reduce teenage driver crash risk. Teenagers increase their speeding behaviors in the first year of driving and beyond (Simons-Morton, Ouimet, et al., 2012), but are not necessarily ready or able to anticipate, detect and react to hazardous driving situations as well as older, more experienced driver are (Groeger, 2000). Increased driving speeds reduce the window of time in which a driver has to respond to a hazardous situation and when this is coupled with inexperience in detecting, anticipating and reacting to hazardous, it could have disastrous outcomes. Speeding is also associated with other observable behaviors, such as excessive driving events (e.g., hard braking, cornering), and is associated with run-off-road crashes (Liu & Subramanian, 2009; Lord, Brewer, Fitzpatrick, Geedipally, & Peng., 2011). Reducing the prevalence of speeding is likely to result in a reduction in other observable, risky behaviors while driving because of this association.

Excessive Driving Maneuvers

Excessive driving maneuvers are vehicle maneuvers that generate increased vehicle g-forces, such as occurs during hard braking, turning at high speed, or accelerating quickly from a stop. Increased speed, distraction, or inexperience can lead to drivers handling a vehicle in a manner that triggers significant g-forces (McGehee et al., 2007). As mentioned, speeding can contribute to excessive maneuvers, such as taking a curve too quickly, or can be associated with other factors, depending on the observed event. For example, hard braking might occur when an inexperienced driver misjudges how much time and room they need to stop smoothly at a traffic signal. Alternatively, the driver might have been distracted and failed to notice the signal, thus requiring them to brake suddenly and with more force than they would typically use. Af Wåhlberg (2004; 2006) focused on the hypothesis that higher acceleration rates, in any direction (e.g., acceleration, braking, left and right turns), lead to increased crash rates among drivers, and, in particular, among commercial drivers. Recent research, however, has expanded af Wåhlberg's hypothesis to the driving behavior of teenagers using in-vehicle accelerometers (i.e., sensors that detect g-forces) to detect crashes or near-crash events.

A naturalistic driving study that collected accelerometer data and associated event videos on 42 newly-licensed, teenage drivers over an 18-month period was able to identify crash events among the teenage drivers post hoc by applying algorithms to the data that analyzed vehicle g-forces (Lerner, Jenness, Singer, et al., 2010). Simons-Morton et al. (2011) compared this 42-car teenage data set to a 100-car adult data set to determine the differences between risky driving in teenagers and adults based on vehicle events that were classified as crashes and near-crashes. They defined risky driving by the following g-force events: hard braking ($\leq$-0.45 g), rapid starts ($\geq$ 0.35 g), hard left turns ($\leq$-0.50 g), and hard right turns ($\geq$ 0.50 g). Yaw rates of $\pm$ 6 degrees within 3 seconds were used as a measure of correction after a turn. Simons-Morton et al. (2011) used af Wåhlberg's (2007) method of counting each event over or under the threshold to create a composite variable of acceleration behavior for analysis. In this study, the algorithm identified 97.3% of 3,080 events to be valid driving events (i.e., crash or near crash event, as opposed to a non-valid event such as hitting a pothole). Approximately, 87% of the valid events were attributed, at least partially, to driver error, with speed management being the most commonly cited issue leading to an excessive event. Overall, the data showed that risky driving event rates were four times higher among the teenage driver sample compared with the adult driver sample. They also observed a decline in crash and near crash rates after six months of driving for the teenage drivers, even though overall crash and near crash rates remained higher than for adults after the first six months. Simons-Morton, Zhang et al. (2012) also reported that teenage drivers' rates of elevated g-forces were predictive of the likelihood of a crash or near crash in the near future (i.e., within the next month). Ultimately, crashes are rare and the use of near-crash data as a surrogate of risky driving based on accelerometer events was determined to be useful to estimate risk ratios for teenagers and adults.

Like speeding, excessive maneuver events can be caused by more than one factor, such as increased speed, distraction, or inexperience, and, although crash and near-crash event rates decrease for novice drivers over the first six months of driving, the rate remains higher than that of adults through the first year 18 months of driving. This further suggests that the first year or more of driving is riskiest for teenage drivers, even after they have gained several months of driving experience. The studies cited here that establish a link between excessive events and risk used video data to examine causal factors. Events, however, can be collected without video and, in this case, might require additional information (e.g., speed prior to event) appended to the event report to understand what caused the event.

Distracted Driving

Distraction is particularly problematic for teenage drivers who are still in the process of developing hazard perception skills. Novice drivers frequently have visual scan patterns that are less developed than more experienced drivers (Chapman et al., 2002; Mourant & Rockwell, 1972). Therefore, they are at an increased risk of not seeing a hazard because of their limited visual scan patterns even when attending vigilantly to the driving environment. Braitman et al. (2008) found that failing to detect another vehicle or traffic control device was one of the top three contributing factors to non-fatal teenage driver crashes in Connecticut. This issue was equally implicated along with speeding and losing control of the vehicle. Braitman et al. (2008) also found that female teenage drivers (48%) were more likely to have failure to detect another vehicle or traffic control device reported as a contributing factor compared with male teenage drivers in the study (32%). When inexperienced visual scanning patterns are coupled with deliberate distractions, such as using a cell phone, crash risk is likely increased should a hazardous situation arise.

Klauer et al. (2014) examined the naturalistic driving data of 42 novice teenage drivers over their first 18 months of driving. They found that the risk of a crash or near-crash was significantly increased if the teenager was dialing a cell phone, reaching for a cell phone, sending or receiving text messages, reaching for an item other than a cell phone, or looking at a roadside object. Simons-Morton, Guo, Klauer, Ehsani, and Pradhan (2014) further examined the secondary task engagement data from this study. They found that the single longest glance away from the road during a secondary task was a more consistent estimate of crash risk than the total time eyes were off the forward road scene. This finding aligned with the 100-car adult driving study set, in which it was determined that single glances of 2 s duration or longer away from the road resulted in double the crash or near-crash risk among adult drivers (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). For all secondary tasks examined for the teenage driver sample, the odds of a crash or near-crash were 1.7 times higher for single glances greater than 1 s compared to less than 1 s. When only wireless tasks, such as talking or listening to a cell phone, dialing, reaching for a phone, or texting/Internet tasks, were occurring, the odds of a crash were 5.5 times higher when the single longest glance was greater than 1 s. The findings of the teenage and adult driver studies suggest teenagers are potentially more susceptible to shorter glance durations (i.e., 1 s vs. 2 s) away from the roadway in comparison to adults.

The relationship between inexperienced visual scanning patterns and the increased risk associated with deliberate visual distraction is important because an increasing number of teenagers own smartphones. A 2013 survey indicated that approximately 70% of teenagers in the U.S. owned a smartphone (Kerr, 2013), and when teenagers bring their smartphones into the vehicle, the risk of a crash or near-crash increases substantially (Klauer et al., 2014). Because smartphones also serve a significant social function for teenagers and younger adults (Atchley, Hadlock & Lane, 2012), the probability that a teenager will engage in phone use while driving is high. Young drivers frequently report that they are aware of the distraction risks associated with phone use while driving, but they simultaneously report engaging in phone use regularly while driving (Atchley, Atwood & Boulton, 2011; Nelson, Atchley, & Little, 2009). One study found that rates of self-reported calling and texting while driving were correlated with increased sensation seeking scores as well as with the perceived approval of peers when drivers engaged in such behaviors (Carter, Bingham, Zakrajsek, Shope, Sayer, 2014). Based on the reported use of cellular phones and the impact of distraction on crash risk, management of cellular phone use among novice teenage drivers should be directly addressed by technology, when possible.

Presence of Teenage Passengers in the Vehicle

In addition to the distracting effects of mobile devices, previous research identified the presence of passengers as a significant factor in teenage driver crash risk. Preusser, Ferguson and Williams (1998) examined crash data and found that younger drivers (i.e., age 16-24) had more fatal, at fault crashes when there were passengers in the vehicle compared with older drivers (i.e., age 25). Simons-Morton, Lerner and Singer (2005) conducted an observational study of teenage drivers leaving a school parking lot. Video and laser ranging technologies were used to quantify the driving behaviors of the teenagers. High risk driving was operationally defined as speeding greater than or equal to 15 mph over the posted limit and/or a time headway while following another vehicle of less than or equal to 1 s. For male teenage drivers who had male passengers in the car, the observed rate of these behaviors was two times that of other drivers. One interesting finding was that male teenage drivers demonstrated longer headways when a female teenage passenger was in the vehicle, suggesting male teenage drivers potentially moderated their behavior based on the gender of the teenager passenger they are carrying. Further research, however, hypothesized that this effect on the driver was psychosocial, and not specifically gender-related.

To test the role of gender versus psychosocial influences, Simons-Morton, Bingham, Oiumet, et al. (2014) used driving simulation to identify the effects of injunctive norms on teenage drivers' behavior. In this study, a male participant (age 16-77) and a male confederate passenger (who looked 16-18) participated together in the study. Prior to the study, the confederate passenger was assigned to be risk accepting (i.e., demonstrate opinions and driving behaviors that were risky, such as acceptance of speeding and driving unbelted) or to be risk averse (i.e., demonstrated safe opinions on driving and safer driving, such as accelerating evenly, braking gently, not speeding, driving belted). The participant was informed they were randomly assigned to be the driver for the experimental portion after being exposed to the confederate participant's tendencies. The confederate was assigned as the passenger and told to maintain his assigned personality throughout the drive. When the male confederate passenger demonstrated risk-acceptance behaviors, the teenage driver engaged in more risky driving during the simulated drive, such as speeding. In contrast, when the male passenger demonstrated risk-averse behaviors, there was no increase in risky driving behaviors. The results supported the hypothesis that perceived social norms influenced male teenage driver behavior in the presence of a peer who demonstrated risk-acceptance or risk-averse norms about driving.

In contrast to the effect of teenage passengers on drivers, teenage drivers also have an influence on passenger behavior. Lerner et al. (2010) reported that when teenage drivers in the 42-car naturalistic study were unbelted their passengers were over seven times more likely to be unbelted as well in comparison to an unbelted adult driving with passengers (i.e., an unbelted adult was not more likely to have unbelted passengers at the same rate teenage drivers did). Although teenage belt use was high in the study (95%) and is high nationally (86%, NHTSA, 2014d), teenagers appear to influence their peers' seat belt use. When crash data are examined for the U.S., 60% of the fatalities for vehicle occupants aged 16-20 in which restraint use was reported were due to the driver or passenger being unbelted (NHTSA, 2014d). The proportion of unrestrained killed passengers was highest for the back seats (61%) compared to the front passenger seats (50%), suggesting back seat passengers might be more likely to be unbuckled in this age group.

Because of the influence teenage passengers have on drivers and vice versa, most GDL programs currently limit the number of teenage passengers allowed in the vehicle during the first year of driving. For example, in Minnesota, novice teenage drivers are limited to one other teenage passenger under age 20 in the vehicle for the first six months of independent driving. Teenage siblings are exempt from the rule at all times (e.g., a teenage driver could have three teenage siblings in the car as soon as they are licensed) and after six months, teenagers are allowed up to three teenage passengers in the car. There are difficulties, however, in enforcing passenger laws because law enforcement must make assessments of the age of the driver by observation. Therefore, passenger presence detection and reminder systems, as well as seat belt reminder systems, could be useful for novice teenage drivers in the first six months of licensure.

Summary of Crash-Related Factors and Observed Behaviors

In summary, speeding, distracted driving, excessive maneuvers, and the presence of other teenage passengers are all significantly associated with teenage vehicle crashes and/or injury and fatality rates. Although alcohol is implicated in approximately 20% of teenage driver fatal crashes (NHTSA, 2014b) it is not discussed here because the mitigation of alcohol-impaired driving is beyond the scope of this research (i.e., difficult to implement with aftermarket sensors). The observable behaviors linked to the high fatality risk of teenage drivers are influenced by the inexperience of novice teenage drivers, and are also associated with social factors (e.g., peer and parental influence), the gender of drivers and passengers, and personality characteristics, such as sensation seeking, or over confidence in one's driving ability (Shope & Bingham, 2008). Shope and Bingham (2008) summarized the complexity of factors that influence the observed behaviors among drivers (e.g., personality, gender, age, inexperience) and suggested that single countermeasures are insufficient to address the complex factors that influence behavior. They indicated that certain factors such as improving parental monitoring and changing social norms around risky driving behavior were likely easier to improve than trying to address factors such as personality. Yet, they also suggested that factors that cannot be changed (e.g., personality, age) should be considered in the application of countermeasures for teenagers. Despite existing countermeasures, such as GDL and mandatory driver's education, the fatality rate of the youngest teenager drivers remains significantly higher than that of other age groups in the U.S. (NHTSA, 2014a) and suggests a need to creatively apply new methods to the teenage driver crash problem.

Countermeasures to Reduce Crashes Among Novice Teenage Drivers

Although enhanced driver's education and GDL tackle issues associated with gaining driving experience as well as limiting exposure to risky situations, they are less capable at directly addressing other factors, such as the unique issues associated with age and factors that lead to observable risky driving behaviors. Hazard detection and perception, vehicle handling (e.g., steering, braking), and other driving skills (e.g., learning to change lanes) can be improved with increased driving experience (Groeger, 2000). Moreover, experience leads to reductions in crashes in first several months of independent driving (Mayhew et al., 2003; McCartt et al., 2003). Age-related issues of self-regulation of behavior and emotions that influence driving behavior, however, only resolve over several years, with development of self-regulation being considered complete around age 25 (Steinberg, 2008). This differentiation between age and inexperience is important because age explains, in part, the high crash rates among the youngest driver groups (<24 years of age; NHTSA, 2014a).

Adolescence represents a developmental phase with its own influences on behavior. Steinberg (2008) reviewed research on adolescent development to understand the potential neurobiological influences that age has on risk taking behavior. He concluded that risk taking is partially neurobiological in nature and that only increased age can result in better control over risky behavior. He also concluded that risky behaviors, such as those that occur during driving, are socially and emotionally motivated in adolescents and that teenagers are primed to engage in reward-seeking in the presence of peers. Keating (2007) also discussed the neurobiological aspects of adolescent development with respect to existing and potential interventions. He noted that searching for a single factor, such as risk taking propensity, to address with respect to teenage driver safety is not productive when considering what interventions will reduce teenage driver crashes. Individual drivers can vary greatly from one another with respect to skill development (i.e., experience) and self-regulation abilities, and driving represents a situation in which behavioral regulation is critical when navigating roadway environments that vary in complexity and skill requirements.

For example, Keating noted that it is unrealistic to expect that fatigue and peer influences (e.g., distraction, peer expectations of driving behavior) in conjunction with the demands of night driving would not interact to create a potentially risky situation for a teenage driver. Reducing the interaction of external factors, such as occurs in GDL, is also beneficial because the teenager’s ability to self-regulate their mood or responses to a situation varies greatly. Indeed, research has demonstrated that states with GDL programs that included more restrictions and stronger laws had lower fatality rates, particularly for states with stricter nighttime and passenger restrictions (McCartt et al., 2010) that potentially limit the interaction of these two risky driving situations (passenger and nighttime driving). An individual teenager who is capable of managing internal and external distractions while driving with passengers one night might not be able to handle those influences another night because their self-regulation abilities are still developing and are influenced by mood, fatigue, and stress. An individual teenager’s internal attention and emotional regulation can reduce one’s ability to manage the normal, tactical demands of driving, while issues with social and behavioral regulation interact with other factors, such as the presence of peers (Keating, 2007).

One successful countermeasure to handle teenager’s development needs is for parents to be actively involved in managing their teenager’s driving. Research shows that parents who are actively involved in managing their teenagers’ driving have teenage drivers with lower self-reported risky behaviors. Research in the U.S. found that parents who are more involved tend to have teenagers with lower self-reported risky driving behaviors and crashes. Beck, Shattuck and Raleigh (2001) investigated the role of parental involvement in relation to driving risk. They interviewed 424 parent-teenager dyads in Maryland in which the teenager had a provisional driving license, meaning the teenager was able to drive without an adult driver present (except between midnight-5 a.m.). Parental involvement in teenage driving over the previous month was assessed using questions that focused on rules/restrictions, the frequency with which parents taught their teenagers to drive, and the frequency of parental supervision. Other questions assessed whether the teenager had engaged in certain risky traffic events since obtaining their license. The results showed that teenage drivers whose parents placed restrictions on their driving and did not allow them to drive unsupervised frequently reported fewer risky behaviors. Parents who place restrictions on teenage drivers limit the teenage driver's ability to engage in risky driving behaviors and to drive under riskier conditions (e.g., with passengers, in bad weather, at night).

In recent years, parents have had the support of the state laws, via GDL programs, to help them identify and enforce not driving in certain conditions. GDL has had a tremendous impact on reducing teenage driver crashes by limiting risk exposure in the first one to two years of driving for newly licensed teenagers (Hedlund & Compton, 2005; Masten & Foss, 2010; Neyens, Donmes & Ng Boyle, 2008; Shope, 2007; Williams at al., 2012). Restrictions for newly-licensed teenage drivers often include nighttime curfews, limitations on the number of teenage passengers allowed in the vehicle, bans on cell phone use, and a minimum number of supervised practice driving hours required before licensing can occur (Hedlund, Shults & Compton, 2003). Chen, Baker, and Li (2006) produced a comprehensive analysis of 10 years of crash data to measure the effectiveness of GDL laws on 16-year-olds. Adoption of GDL laws, overall, was found to decrease fatal crashes by 11%. Chen et al. also discovered that when a curfew was added to the GDL law, the overall fatality rate decreased by 21% compared with 16% for states without a curfew.

For distracted driving, GDL programs often restrict cellular phone usage for teenage drivers as the primary countermeasure. As of November 2014, 44 states and the District of Columbia (D.C.) had texting while driving bans for all drivers, 14 states and D.C. had hand-held cellular phone bans for all drivers, and 37 states and D.C. banned or restricted cellular phone use for novice or teenage drivers (Insurance Institute for Highway Safety [IIHS], 2014). Despite the implementation of such laws as part of GDL programs, however, research indicates that many young drivers continue to engage in calling and texting while driving (Atchley et al., 2011; Ehsani, Bingham, Ionides, Childers, 2014; Nelson et al., 2009). Ehsani, Brooks-Russell, Li, Perlus, Pradhan and Simons-Morton (2013) reported results from the second annual wave of the NEXT Generation Health Study conducted in 2011 in which eleventh graders were surveyed about various health behaviors. Overall, 80% of teenage participants who were independent drivers reported talking and driving in the past 30 days, while 72% reported texting while driving at least once in the past 30 days. Participants with easy access to a vehicle were more likely to have reported calling or texting while driving, and this finding is consistent with other research that indicates teenagers with their own vehicles are more likely to engage in risky driving (Shope & Bingham, 2008). Overall, the teenagers in this survey reported making calls on approximately 32% of days they drove and texting on approximately 40% of the days they drove. Ehsani et al. (2013) noted, importantly, that the calling and texting behavior of this teenage sample occurred despite the existence of cellular phone use restrictions for teenage drivers in most jurisdictions in the U.S. Other research has also demonstrated the ineffectiveness of bans on cellular phone use (Foss, Goodwin, McCartt, & Hellinga, 2009; Ehsani et al., 2014), and that usage continued even when knowledge of the law was high in the teenage population (Goodwin, O'Brien, & Foss, 2012).

The presence of laws specifically for teenagers, therefore, relieves some of the burden on parents for deciding when and how to manage driving, but does not fully address all of the issues or situations in which a teenager might decide to ignore the laws. Moreover, most of the supervision and enforcement of restrictions falls to parents, but parents are not always available to enforce the rules. For example, a teenager with no parent in the car has no oversight on whether they use their phone or not while driving. Despite the fact that parent monitoring and management of teenage driving can reduce risks (Simons-Morton & Ouimet, 2006), not all parents have the knowledge, skills, or motivation to successfully manage their teenage driver's access to a vehicle and the situations in which they drive. Identifying ways to successfully involve parents in teenage driving safety, therefore, has received a great deal of attention in the past several years, such as in the form of parent education programs. Fischer (2013) reviewed several parent programs and identified specific elements that were expected to result in the best outcomes. These included programs that: 1) discussed novice teenage driver risks, 2) explained GDL restrictions to parents, and 3) reviewed the critical role parents have in teaching, supporting, and managing their teenage driver. Simons-Morton (2007) reported on the Checkpoints program for parents and teenagers that encouraged limit setting and the use of parent-teenager contracts to set out driving expectations. In four randomized-controlled trials, the program was moderately successful in increasing limits set by parents. Teenage drivers in the program also self-reported fewer risky behaviors than participants in control groups.

In addition to problems with setting appropriate limits, parents are not always effective at providing driving instruction to their teenagers during supervised driving. Simons-Morton and Ouimet (2006), for example, reported that parents might not be providing sufficient exposure to different types of driving (e.g., night, in bad weather, variety of roads and speeds) for their teenager during the learner phase, which reduces the ability to gain experience across situations. Goodwin, Foss, Margolis and Harrell (2014) discovered that parents provided very little instruction to support the learning of driving skills that are generalizable across multiple situations. After collecting video data of 50 families during the first four months of the learner driver phase, they discovered that higher-order instruction, which is when a parent describes how events or situations generalize to future driving, was low (<7%) during this phase of learner driving. An example of higher-order instruction is when a parent says "I try to look a few cars ahead for brake lights, so I know when to slow down" rather than simply instructing the teenager to "slow down now." Parents more frequently engaged in functional instruction (59%) instead, which was primarily associated with how to handle the vehicle (e.g., "slow down", "change lanes ahead"). This means many parents are missing opportunities to help their teenagers develop knowledge that supports tactical (i.e., driving adjustments that take place over several seconds or minutes, such as changing lanes base don "if-then" rules) and strategic levels of driving (i.e., planning ahead, such as deciding on a route before starting the drive, or not driving when tired which are more knowledge-based in nature; Michon, 1989).

Although GDL and parental monitoring are excellent areas on which to focus resources to support teenage driver safety, there are still significant issues with providing education and support to parents of teenage drivers, such as getting parents to enroll in and attend the program. Modern parents and teenagers are busy and a licensed teenage driver is frequently seen as an opportunity to reduce the burden on parents to provide travel to activities. Simons-Morton (2007) suggested that technology could provide a solution for parents who wanted to better monitor and manage their teenage driver. For example, in-vehicle technology that monitors and reports a teenager’s driving behaviors back to a parent can balance the critical need for independent driving while using the system as a surrogate for having the parent in the vehicle. The parent retains the ability to know what is happening while their teenager is driving and can act on the information provided by the system. Although technological solutions are increasingly present in vehicles for the use of all drivers (e.g., blind spot monitoring, forward collisions warning systems), technologies for teenagers attempt to specifically address the age and experience-related issues associated with crash risk (Lee, 2007). Such systems could provide an opportunity for parents to be more actively involved in teaching safe driving habits during the critical first years of driving.

Technological Interventions for Novice Teenage Drivers

Technological solutions for teenage drivers involve installing an in-vehicle system into a teenage driver’s car or on a mobile device to provide feedback to the teenager and/or parents about detected risky driving behaviors (Creaser et al., 2011;

Farmer et al., 2010; Manser et al., 2013; McGehee et al., 2007). The main goal of systems for teenagers is to provide behavioral modification functions that assist teenagers in adopting safer driving behaviors, with the ultimate goal of reducing crashes. Lerner et al. (2010) identified five strategies that could be useful in altering the behavior of teenage drivers using monitoring and feedback technologies:

1. Providing *driver feedback* about the presence of risk factors such as speeding and/or excessive maneuvers,
2. Enabling *vehicle adaptation* that modifies operational characteristics of the vehicle when risk factors are detected,
3. *Reporting* the occurrence of risky behaviors to stakeholders such as parents,
4. *Coaching* teens on how to improve their driving performance or by providing an explanation of an error, and/or,
5. Providing *external motivation* in the form of positive or negative incentives such as a reduction in insurance rates for good driving.

Brovold et al. (2007) identified similar functional concepts and the benefits that function categories, such as *forcing*, *in-vehicle feedback* and *reporting*, could have for teenagers during the concept development phase of a teenage driver support system. *Reporting* involves sending data about risky driving behaviors to parents so they can use the information to coach their teenager on safer driving habits and manage their teenage driver's behavior more effectively. For example, parents might choose to provide incentives or consequences for certain behaviors, such as increasing and decreasing driving privileges. A parent might also determine their teenager needs more supervised driving if they receive a certain number or type of alerts. *In-vehicle feedback* directly to the teenage driver reminds them they are being monitored and also provides an opportunity for them to identify a risky event and potentially learn from the situation. *Forcing* functions prevent instances of risky behavior. For example, speeding over the posted limit can be prevented with speed regulation systems that actively inhibit the vehicle from going faster that the speed limit even if the driver attempts to increase speed (Spyropoulou, Karlaftis, & Reed, 2014). The limited research conducted to date on teenage driver systems demonstrates both the utility and the problems with the implementation of each function type.

Reporting to Parents

Most teenage driver systems that have been tested experimentally provide reporting to parents, as well as in-vehicle notifications to teenagers when events are detected (Carney, McGehee, Lee, Reyes, Raby, 2010; Farmer et al., 2010; McGehee et al., 2007; Simons-Morton, Bingham, Ouimet, et al., 2013). There are, however, significant differences in how each system selects to engage parents and teenagers with feedback. The number of behaviors monitored, the mechanism by which reporting is provided (e.g., report cards, videos, web-based summary of events), and the level of detail associated with the in-vehicle feedback (e.g., blinking lights, persistent audio or visual warnings) has resulted in varying outcomes across studies. A comparison of systems and outcomes was conducted to identify key elements critical to the success of a teenage driver system.

The DriveCam system was an acceleration-based monitoring device that recorded video of the interior and exterior driving scene when an event was triggered (Carney et al., 2010; McGehee et al., 2007; Simons-Morton et al., 2013). The system used accelerometer thresholds to initiate video recordings based on a shock trigger (i.e., severe impact), a longitudinal trigger representing positive or negative acceleration (i.e., hard braking or racing off a light), and a lateral trigger (i.e., hard cornering and swerving). McGehee et al. (2007) hypothesized that video-based feedback would provide the best contextual information associated with risky driving events when video was captured from inside and outside the vehicle during an event. The goal was to encourage learning from the recorded details of the event while also making it more difficult for teenagers to explain away the event to parents, such as by suggesting the system was less than reliable. The system captured audio as well as video for the vehicle interior. Therefore, distractions such as loud music could be identified and provide additional context. When an event was detected, video (and audio inside the vehicle) was saved for 10 seconds prior to and 10 seconds after the event. During video capture, lights on the DriveCam device (located on the windshield under rear-view mirror) flashed green for 10 s then flashed green and red for another 10 s while video was recorded. This provided simple, in-vehicle feedback to the teenager that an event had been captured. Researchers reviewed videos to determine if recorded events were incidents (i.e., valid trigger) or safety-relevant events (i.e., invalid trigger that might present a safety concern). A valid trigger, for example, could be a video depicting a distracted teenage driver who then has to brake hard and late for a red light. An invalid trigger could be a video showing the car going over a speed bump with no other information captured. However, if the speed bump video showed the driver had four teenage friends in the car during the phase of GDL when teenage passengers were prohibited, it would qualify as a safety-relevant event. Graphical report cards involving simple incident descriptions were sent to parents weekly along with a CD containing the relevant videos.

McGehee et al. (2007) reported the results of a study involving 25 (12 male; 13 female) rural teenagers aged 16-17 who had the DriveCam system in their vehicle for several months. Teenagers drove a 9-week baseline condition in which event video was captured but not reported via in-vehicle feedback or report cards to parents. After 9 weeks, the system was turned on for 40 weeks and during this treatment period the teenage drivers received the in-vehicle blinking light feedback and parents received the report card and video clips. The data reported by McGehee et al. (2007) covered the baseline period and 36 weeks of the treatment period. In the baseline period, there were 376 safety-relevant events (246 incidents, 130 invalid triggers with safety-relevant concerns) that represented an average of 8.6 events per every 1,000 miles driven. They also identified a high-frequency group of 7 teenagers who were representative of most of the events triggered in the baseline period (average of 23.4 per 1,000 miles driven compared with the other 18 teenagers that had a rate of 2.5 per 1,000 miles driven). The 36-week treatment data were broken down into 9-week blocks to match the baseline period. Overall, the group reduced their safety-relevant events from an average of 8.6 per 1,000 miles driven to 3.6 per 1,000 miles drive during the first 9-week treatment period. There was a further drop to an average of 2.1 events per 1,000 miles for the second treatment period and the average rate was 2.0 to 2.5 events per 1,000 miles for the final treatment phases. Overall, the high-frequency event group comprised most of the reductions in events, while the low-frequency group remained similar from baseline through the treatment phase. The intervention also resulted in an increase in seat-belt use from 81.8% in the baseline events to 96.9% in the treatment phase. Because of the rich context provided by video, the authors noted this reduction in events that were not directly tied to the device (e.g., seat belt use).

Carney et al. (2010) further investigated the effectiveness of DriveCam in a similar study by examining the behavior of 36 suburban teenage drivers. Due to study issues, only 18 participants finished the study that involved a 6-week baseline period, a 40-week treatment period, and a 6-week post-treatment period (i.e., system removed). Carney et al. (2010) found similar reductions in safety-relevant events during the first 8-week treatment period that McGehee et al. (2007) did, with an overall reduction of 61% in events. Braking events declined even further during the second 8-week treatment period. This study also identified a group of high-event drivers, in which most of their events were due to taking turns and curves too fast. In this study, 33% of teenagers said the intervention directly influenced their driving, while 67% reported they had conversations at least once a month with their parents about driving and 22% reported weekly conversations with their parents. About half of the teenagers said the intervention did not cause any conflicts between themselves and their parents, and 94% of the teenagers reported that they knew how to prevent a trigger.

One limitation identified for the one-group, quasi-experimental design used by McGehee et al. (2007) and Carney et al. (2010) was that the events could have declined over time due to improved driving skills related to experience rather than the system feedback. The authors concluded, however, that the sudden decline in the high-risk group during the first treatment segment was indicative of the system’s effect on behavior above and beyond improvement due to experience. In particular, teenagers who were riskier in the baseline period showed the largest decline in events with treatment and the authors further noted that extended interventions (i.e., over months) could have substantial benefits for teenage drivers. The context provided by the video-based feedback was sufficient to coach teenage drivers on multiple risky behaviors, including those not directly related to the excessive maneuver (e.g., seat belt use captured in the videos). A drawback of the video-based feedback, however, was that it required trained coders to review all the captured videos to determine which were coachable events that should be sent on to parents. Additionally, the report feedback occurred up to a week after an event (or events) happened, which meant the behavior potentially continued in the interim. A delay in reporting events could result in continued risk to the teenage driver and suggests that more immediate feedback could be beneficial.

Simons-Morton et al. (2013) conducted a randomized-controlled trial of DriveCam with the goal of identifying whether the in-vehicle feedback provided by the system could be used without parent feedback. They found that a group of teenagers that only received the in-vehicle blinking light feedback without the coaching report to parents did not show reductions in risky events over 15 weeks of driving compared to the group whose parents received the coaching summary. They concluded that parents must be included in the feedback loop as the in-vehicle blinking lights alone were not effective at reducing event rates. This conclusion, however, is not fully supported by results on other driver behavior modification systems. The DriveCam in-vehicle feedback is simplistic (20 s of small, flashing lights) and is intended only to alert the driver that an event was recorded. When considering the various types of alerting that could be designed and implemented, such as auditory or icon-based visual alerts, it is premature to assume blinking lights encompass the full range of influence on behavior with regards to in-vehicle feedback.

In-vehicle Feedback to the Teenage Driver

Intelligent speed adaptation (ISA) is a proposed mechanism for managing speeding behaviors in drivers of all ages (Regan, Triggs, Young, et al., 2006). ISA systems use GPS data to match a vehicle's speed and position to a speed limit database and then compare the actual vehicle speed to the database to determine if speeding is occurring. Passive ISA systems provide feedback and warnings to drivers who are speeding, while active ISA systems prevent the driver from speeding over the posted speed limit (i.e., speed regulation). Spyropoulou et al. (2014) found significant reductions in the maximum speed and average speed of drivers aged 17-46 using a passive ISA system that only provided auditory and visual alerts about speeding behaviors. Passive ISA systems are an example of persistent, in-vehicle alerting that could result in enough driver annoyance to motivate behavior change. Similar effects were found for enhanced seat belt reminders (ESBRs) that remain active until the seat belt is buckled. ESBRs have been demonstrated to increase seat belt compliance rates, including among groups of drivers for which use is typically low, such as teenagers (Freedmon, Lerner, Zador, Singer, & Levi, 2007). The concept of using persistent, in-vehicle alerting for teenage drivers has also been explored with and without parent reporting functions.

Farmer et al. (2010) examined in-vehicle feedback in conjunction with parent feedback using 84 teenage drivers aged 16-17 years. Participants were randomized to four different study groups and data were collected for longitudinal acceleration (i.e., hard braking, accelerating), seat belt compliance, and excessive speeding of 10 mph or more over the speed limit using an ISA system. Two treatment groups received in-vehicle feedback. Group 1's parents received feedback on a website immediately about all events detected while Group 2 teenagers were given a chance to cancel the alert to parents if they reduced the alerted behavior within a certain time period (e.g., slowed down up on being alerted in the vehicle within 20 seconds). Group 3 received no in-vehicle feedback and, instead, monitored event information went straight to the parent website. Group 4 was a control group with no intervention for teenagers or parents. Participants drove a two-week baseline period, a 20-week treatment period, and a 2-week follow-up baseline period and event data were reported as the average rate of events per mile driven. This system used graded auditory warnings that became more salient (e.g., louder, different tones) depending on the level of risky driving detected inside the vehicle, and the feedback to parents went directly to a website. The feedback was a single buzz for longitudinal acceleration events, a continuous buzz until the seat belt was fastened, a single, short beep at 2.5 mph over the speed limit, and then a continuous string of beeps at 10 mph over the speed limit that increased in pitch and frequency the longer a driver engaged in excessive speeding. With regards to the web-based feedback, the researchers discovered after installing the system in 31 vehicles that parents were rarely visiting the website. The remaining 53 participants, therefore, received website-based information as well as a weekly reminder email.

Changes in behavior with this system were inconsistent across the three treatment groups. Group 1, for example, showed a decrease in speeding initially during treatment, but then increased speeding behaviors in the last several weeks of the treatment session. Groups 3 and 4 showed no changes across the study period in speeding behavior, while

Group 2 was the only group to show a sustained reduction in speeding through most of the study. This was the group that had the chance to cancel alerts to parents before they were notified of the behavior. These results demonstrated that parents are a potentially strong behavioral regulator even when they are not alerted of an event or when they rarely review events via the website. This delayed reporting feature gave teenagers autonomy over their driving and the ability to take responsibility for their behavior while still ensuring parents received alerts if behaviors persisted. This type of design supports the need for the independent driving required to gain experience while encouraging the teenager to develop self-regulation over their behavior to avoid a consequence.

One key finding of the Farmer et al. (2010) study was that parents often failed to review the website-based feedback from the system. Because of this, the researchers changed the feedback mechanism from web-based to an email-based weekly report half way through the study. The email notification, however, did not increase visits to the website. Parents needed easier access to the information to feel motivated to use it and this finding it critical because it highlights the earlier assertion that parents are busy and monitoring teenage driving is something they find difficult to incorporate into their schedules. The authors concluded that the variability in results across the treatment groups were most likely due to the limited involvement of parents in reviewing and acting on the website-based information. Therefore, although this system employed graded and persistent auditory warnings, the study results suggested that in-vehicle alerting alone might not be sufficient to alter behavior. More than half of the teenagers in this study also reported that they found the alerts to be annoying, even though over 80% in each of the three treatment groups reported the device improved their driving skills.

This suggests that perceptions of the device are not always consistent with the perceived utility of the device, and that teenagers might appreciate—to some extent—the presence of the system while driving.

Despite the potential limitations of in-vehicle feedback to influence teenage drivers' behavior without parent involvement, two studies to date have specifically examined the role of technology in reducing risky behavior when parents are not included in the feedback loop. Lotan, Musicant and Grimberg (2014) demonstrated that incentives (i.e., winning t-shirts for the driver's scout troop) could motivate teenage drivers to use a smartphone-based driving application that monitored driving behavior without parental feedback. Teenagers in this study were motivated to use to the application and adhere to the in-vehicle feedback while driving provided they were able to achieve a reward. Once the opportunity to achieve awards was eliminated (i.e., teenager received all five allowed shirts), teenagers stopped using the application. For application usage, 34% of the teenagers used the application during "all trips" while an additional 57% reported using it for at least "half" or "most" of their trips taken during the five-week study period. Overall, 84% of the teenagers reported that the application encouraged them to pay more attention to their driving while it was active. The results suggest that parents can be removed from the reporting feedback loop, but that an external motivation is still required to encourage teenagers to both turn on the system and change their behaviors based on the feedback while driving.

Manser et al. (2013) did not employ incentives for teenage driving nor involve parents in the feedback loop. The Safer Teen Car system tested in that study provided increasingly salient warnings when risky behaviors increased or occurred in conjunction with one another (e.g., speeding and not wearing seat belt at the same time). This study took the approach that the features of the feedback would be sufficiently annoying (i.e., consequence) that teenagers would adjust their behavior accordingly to avoid having it continue. The feedback combined visual icons, such as a red speed limit sign when speeding, with increasingly persistent auditory alerts if the behavior continued. The combination of a visual icon with the auditory alert was intended to provide context about the behavior as well as provide redundant cuing. The results showed that speeding and excessive driving events among 16 and 17-year-old teenager drivers were moderately influenced by the in-vehicle alerts over the study duration (i.e., six weeks of driving without parent involvement). Although no incentives were provided in this study, the feedback was more contextual, persistent and graded than that described by Simons-Morton et al. (2013) and Farmer et al. (2010).

The investigations of contextual, persistent and graded in-vehicle feedback suggested that in-vehicle feedback can be designed to moderate risky driving behaviors, particularly if an incentive (Lotan et al., 2014) or a potential consequence such as an eventual alert to parents (Farmer et al., 2010) are included. In-vehicle feedback serves multiple purposes for teenage drivers when parental monitoring is included with the system. It notifies the teenager that their behavior has exceeded a pre-determined, risky threshold, that the behavior is unacceptable, and that a potential consequence has or will arise, which is the notification to parents. The in-vehicle feedback is also error-based feedback that is intended to encourage the driver who made the error to process what occurred and develop solutions to prevent the occurrence in the future (Ivancic & Hesketh, 2000). Although research is mixed on in-vehicle alerting alone for teenagers, there are results that support a potential, if limited, benefit of persistent, graded alerts (Manser et al., 2013; Spyropoulou et al., 2014). Overall, in-vehicle feedback and reporting to parents are considered the most acceptable functions of a system (Brovold et al., 2007). If, however, the goal of a system is to support the reduction of a number of risky behaviors associated with the high rate of teenage crashes, forcing functions can and should be considered for novice teenage driver systems.

Forcing Functions

Forcing functions prevent behaviors outright or guide an individual towards the desired behavior (Norman, 1988; 2002). Forcing functions could be ideal for preventing behaviors that arise due to the variability in self-regulation during adolescence or for which social norms are highly ingrained and, thus, the perceived risk of the behavior is not considered to be significant—even if the actual risk is. For example, blocking a teenager's ability to interact with a mobile device while driving can reduce instances in which the driver feels compelled to respond to a phone notification due to habit or insufficient ability to regulate responses in the moment (e.g., eagerly awaiting a call from a friend). Another example of a forcing function is an active ISA system in which the vehicle is designed to prevent the driver from exceeding the posted speed limit. Spyropolou et al. (2014) found greater reductions in speeding for an active ISA compared with a passive ISA system. Creaser et al. (2011) also described the use of a transmission interlock in which drivers were unable to shift a running vehicle from park into drive unless their seat belt was fastened. The advantage of forcing functions is that their implementation ensures certain behaviors cannot occur while driving. The use of forcing functions in combination with other monitoring functions means the number of alerts a teenage driver and/or parent receives can be limited. This could be a useful way to maximize safety while minimizing the burden on parents to monitor a large number of alerts.

Summary

As technology and sensors improve, the ability to successfully monitor and report on teenage driving behaviors increases. Systems must be designed to address driving behaviors that meet safety goals (i.e., reductions in risky behaviors associated with crashes) as well as support parents' abilities to use the information to mentor safer driving habits. Systems also need to be carefully designed so as not to overwhelm the teenage driver who is still gaining experience. Applying theoretical constructs related to behavior change to system design can improve the potential for an intervention to succeed. Thus far, studies on teenage drivers have focused on different aspects of behavioral influences such as the role of parents versus the type of in-vehicle feedback provided that might be effective. Reporting to parents supports the need to adjust the beliefs and attitudes towards teenage driving among parents who not adequately understand the risk to their teenage driver. When considering behavioral change, the Theory of Planned Behavior (Ajzen, 1991) posits that beliefs and attitudes influence intentional behavior. A parent who does not believe their teenager is at risk is potentially less likely to intentionally monitor and manage driving compared with a parent who is aware of the risks. Therefore, receiving system feedback can calibrate parents' understanding of risks and help motivate them towards behaviors that improve their teenager's safety while driving.

Parents receiving feedback from a system not only experience information that changes their beliefs about their teenagers' driving, but also gain control over monitoring driving that cannot otherwise occur unless they are in the vehicle with their teenager. If feedback is relatively easy to obtain and contains the needed information about risks parents are expected to discuss the safety issues with their teenage driver and/or implement better management of driving. Brovold et al. (2007) identified text messaging as one method that would alert parents in near real-time to an event, and which could be tailored to provide enough detail on which the parent could act (e.g., "speeding 65 mph in a 40 mph zone") even if they did not have a chance to review a website. Removing barriers to engaging in behavioral changes, such as increasing monitoring of teenage driving for a busy parent, also increases the control parents have over the situation. Increased control over situations is associated with engagement in related intentional behaviors according to the Theory of Planned Behavior (Azjen, 1991), which suggests that having near real-time system feedback about individual events could encourage parents to tackle problems one issue at time. Individual event data could also be perceived as less overwhelming than a larger coaching report for a longer time period.

For teenagers, the parental reporting feature influences their perceptions that parents will act on the information, with or without applied consequences or incentives. It could be expected, therefore, that teenagers might engage in more effort to maintain safer driving behaviors. Efforts to engage in safer driving would allow learning to occur without the added risks associated with deliberate risk taking or unintentional risky behaviors that occur when vigilance to driving is reduced. Novice drivers require more effort to manage their driving, which is one reason why distractions, such as other passengers or a cell phone, are problematic. When considering design features, the delayed feedback to parents employed by Farmer et al. (2010) could support the development of teenagers' self-regulation during driving by providing increased control over their driving. Having some control over system notifications could increase the probability teenagers will accept and comply with the system as it provides them with real-time information on how to intentionally manage their driving behaviors.

Although teenagers would ideally adopt safer attitudes towards driving simply by knowing the risks, their developing self-regulation skills are expected to interact with other factors, such as social norms, to influence driving behavior. For example, Atchley et al. (2012) concluded that young drivers find cellular phone use to be a normative (i.e., socially acceptable while driving) even though they can accurately describe the risks. Therefore, the use of forcing functions for certain behaviors are likely to provide support to these instances of normative behavior by preventing them outright. Forcing functions can also reduce the number of alerts and reports the system generates, which could allow parents and teenagers to focus on specific driving behaviors while minimizing the risks associated with combined behaviors. For example, monitoring and alerting speeding behavior while blocking cellular phone use would address the dangers of speeding, while preventing the behaviors from occurring simultaneously which could reduce overall risk.

Limitations in technology must also be considered such that incorrect or unreliable alerting is minimized. The goal of teenage driver systems is to support the novice teenage driver and the parent during the first one or two years of driving when risk is highest. Poor reliability is one issue that could lead to disuse of a monitoring and feedback system (Parasuraman & Riley, 2007). Poor reliability in a system could become a source of friction between the teenage driver and parents, particularly if parents are not exposed to the system frequently and are unaware of potential issues with the technology. Alternatively, if the implementation of the feedback interfaces and information to teenagers and parents is not clear (e.g., the meaning of an alert or report is not clear), it could reduce motivations to use the system. For example, if a parent does not understand how or why an alert is triggered, the teenager could attempt to explain it away, as was suggested by McGehee et al. (2007). McGehee et al. (2007) felt the details afforded by video data prevented the ability of the teenage driver to rationalize away events as a system aberration rather than a true event. However, the use of near real-time, event-based feedback to parents has not been evaluated and, therefore, conclusions about the type of feedback parents need is linked to system reliability. A reliable system with slightly less detailed event data might function as well as a less reliable system for which the data can be easily vetted and cleaned to only include valid data to parents.

Overall, a number of issues have been identified in previous studies that support the need for further research on teenage driver feedback and monitoring systems. First, the systems were rarely implemented with novice teenage drivers (i.e., newly licensed with limited or no experience with independent driving). The reviewed studies typically included a baseline period of several weeks of driving as well as teenage drivers with varying experience levels that reduced the opportunity to determine the effectiveness of such systems on the earliest phases of independent driving. Second, parent feedback in previous studies had overhead or problems associated with it that could affect the ability to deploy a system widely or to encourage parents to use the system. For example, DriveCam required trained coders to evaluate the videos and that is a resource cost. The

Farmer et al. (2010) study employed a website to host the data, which could theoretically reduce costs, but it increased the overhead in time and effort on parents to login and look frequently at the data. Furthermore, the web-based feedback employed by Farmer et al. (2010) did not resolve the issue of whether contextual feedback could be provided to parents in another format. Finally, although research has clearly highlighted the crucial role parents have in mitigating risky teenage driving, there is a need to identify whether the graded in-vehicle feedback provided by Farmer et al. (2010) could be useful when deployed with more contextual, in-vehicle interfaces to the teenage driver. Discriminating the meaning of multiple auditory alerts is potentially difficult which represents an opportunity to employ more contextual feedback to teenage drivers about the specific behavior being alerted, such the speed limit icons used by Manser et al. (2013). Additionally, the results of passive ISA systems suggest that in-vehicle speeding feedback that is persistent and graded could minimize speeding behaviors and it should be tested more rigorously on teenage drivers.

To address these issues, a 12-month quasi-experimental field study was designed and conducted to evaluate the effectiveness of a teenage driver support system (known as TDSS) that was smartphone-based software application. The TDSS monitored and reported on speeding, excessive maneuvers (i.e., acceleration events), seat belt use, passenger presence, and driving during GDL curfew. The system also blocked cellular phone use. A 12-month study duration was selected because teenagers are at the highest risk within the first 1-2 years of driving based on crash data and research on teenage driver crash risk (McCartt et al., 2003). Teenage driver behavior can change significantly over the first year of driving as they gain experience and confidence, and it is important to evaluate such tools for long-term feasibility while crash risk is highest and driving habits are developing. The study included data collection from a control group engaged in naturalistic driving and two intervention groups, an in-vehicle only feedback group (partial TDSS) and an in-vehicle feedback with parental feedback group (full TDSS). Novice, teenage drivers were recruited prior to receiving their driving licenses so that they could be enrolled in the study as soon as they passed their test. This allowed the study to address whether the use of such a system could be beneficial in the earliest months of independent driving when teenagers are at the most significant risk of a crash (Mayhew et al., 2003). The TDSS used near, real-time parent feedback in the form of text messages to parents about events, as well as provided a weekly event summary via email, and archived reported behaviors to a secure website. This allowed an examination of whether immediate reporting that required less effort for parents to access and process could be effective in assisting parents and teenagers in managing and mentoring driving behavior.

The TDSS also included visual in-vehicle alerts as well as employed spoken, auditory messages played over the smartphone's interfaces (i.e., screen and speakers) to improve the contextual meaning of the monitored behaviors to teenagers. Moreover, the system employed a graded, persistent ISA system that allowed teenagers to cancel an excessive speeding alert to parents if they reduced their speed within a certain time frame. This allowed an examination of the overall effectiveness of this design feature on driving behavior regulation with parent feedback. It also allowed further comparisons between persistent, graded feedback to simple feedback (e.g., one-time, post-event alerts such as those associated with an excessive maneuver event) on teenagers' driving behavior. Data collection and analyses took into account other factors that influence teenage driving behavior, such as gender, personality (i.e., sensation seeking), and whether the teenager had easy access to a vehicle which is shown to increase the frequency of risky driving behaviors. Finally, teenagers and parents were surveyed about their perceived reliability and utility of the overall system.

The hypotheses associated with this study were related to four categories: 1) the influence of reporting to parents and in-vehicle feedback on novice teenage drivers during first year of independent driving, 2) the overall acceptance and utility of the near real-time reporting to parents, 3) how teenagers' perceptions of reliability and utility will influence their acceptance of the system, 4) the influence of different types of in-vehicle feedback and functions on teenage drivers in the first year of driving with and without reporting to parents. Overall, it was expected that teenage drivers in the full TDSS group who received both in-vehicle and parent reporting would have lower rates of one or more monitored behaviors during the first few months of driving, and, possibly, throughout the study time period compared to the control group. Previous research has identified that excessive maneuver behaviors can be reduced and seat belt compliance increased with parent reporting (McGehee et al., 2007), and this study expands the range of behavior for which reporting is provided.

It was also expected parents would report making decisions (e.g., incentives, consequences) about managing their teenagers' driving based on the system feedback, and that there might be greater management of teenagers' driving in the parent feedback group because of their access to this additional driving behavior information. The system reports to parents were expected to have a similar effect to education for parents about teenage driving risks, such as prompting them where to direct their efforts to mentor their teenager. Parents were expected to show a preference for the immediate feedback interfaces, such as the text message and the weekly email summary in comparison to the website because they reduce the effort associated with accessing the information. In contrast, website use in previous research has been limited (Farmer et al., 2010). For both parents and teenagers, the perceived reliability of the system and its feedback were expected to influence how they interpreted or used the feedback, as perceptions of reliability are known to influence use or disuse of a system (Parasuraman & Riley, 2007).

Finally, it was expected that the speeding alerts, seat belt alerts, and the cellular phone blocking function would have effects on behaviors for both the full and partial TDSS groups (i.e., without parent feedback). This is because previous research on passive ISA (Spyropolou et al., 2014) and ESBR (Freedmon et al., 2007) has shown benefits of persistent and annoying alerts in encouraging behavior change in drivers across ages. Blocking functions, like the cellular phone function, outright prevent behavior without the need for parental involvement. It was unknown how well the combined in-vehicle feedback mechanisms (i.e., persistent and post-event alerting) would affect behaviors. Previous research has examined error-training with respect to logical consequences, such as receiving a traffic ticket or experiencing a simulated crash (Ivancic & Hesketh, 2000), as error-learning strategies, but it is unknown how post-event feedback will be interpreted by teenage drivers. It is possible their inexperience with driving will not allow them to fully internalize why an event occurred.

METHOD

Participants

Three hundred novice teenage drivers and 298 consenting parents (2 sibling pairs participated in the study with one parent) were recruited into one of three experimental groups. The goal for the teenage driver sample was to recruit approximately 100 novice drivers per study group, with the expectation that attrition would occur given the 12-month study duration. Previous long-term field studies of teenage driver devices have seen attrition rates up to 50% (Carney et al., 2010). Recruiting approximately100 teenagers per group meant that if attrition occurred at rates seen in previous studies (e.g., up to 50%), there would be enough participants remaining in each group to conduct between-subjects statistical testing. Moreover, a larger sample size accounted for potential wide variability in behaviors for novice teenage drivers and ensured the each sample group was more likely to be representative of the Minnesota teenage driving population as a whole. Although the teenage drivers recruited for this study were homogeneous overall in terms of age and driving experience, which can improve power in a quasi-experimental design (Shadish et al., 2002), they tend to be highly variable with respect to their driving abilities within the first months of driving (Farmer et al., 2010; McGehee et al., 2007) which potentially reduces power to identify group differences.

Shadish et al. (2002) also suggest matching variables that are stable and reliable, of which age and gender are considered appropriate when they are correlated with the expected outcomes. As noted in the literature review, age and gender are correlated with expected outcomes for teenage drivers with respect to risky behaviors and crashes, with younger novices (i.e., 16 year olds) and males considered to be most at risk. This study sought novice teenage drivers with a very small age range (< age 17 when possible) and balanced gender across the groups. There were only two participants who started the study who were 17, however, Minnesota GDL laws require all teenage drivers under age 18 to adhere to a full 12 months of restrictions even if they turn 18 during that year. Therefore, these two teenagers were subjected to the same driving laws and restrictions as the other teenagers in the study. The teenage drivers in all three groups were recruited at similar levels of driving experience (i.e., all recruited during the learner period) and all tested for their license during a 5-month window of February-July 2013). The teenage drivers were recruited prior to licensure so that they could begin driving as soon as possible with the system after licensure, with most receiving the system within a week of obtaining their license to drive independently.

Community Selection for Recruiting

Participants were recruited from 18 rural and suburban Minnesota communities using matching criteria to ensure the groups would be as equivalent as possible across a range of variables. Population size and commuting rates were selected as the main criteria for community identification and selection. Commuting rates, or the degree to which residents leave the area where they live to go to work, provide a better understanding of how people travel between locations in the state. Population statistics from the 2010 U.S. census were examined to divide communities into three population sizes: low (under 20,000), medium (20,000-40,000), and high (over 40,000). Labor shed rates from the 2010 U.S. census were examined to determine the percentages of each community's residents who work in a different municipality than the one in which they live.

Commuting rates were divided into two groups: low (less than 60% commuting to work) and high (more than 60% commuting to work). All of the communities were within a two-hour radius, approximately, of the University of Minnesota campus, which meant that the geography in which the teenagers were driving was similar across communities. Triplets of communities were created based on the three levels of population size and the two levels of commuting rate, with one community from the triplet assigned to each of the three study groups (i.e., 6 communities per study group). The recruiting plan aimed to recruit approximately the same number of participants (*N*=20) from each community, with the final range of parent-teenager dyads including a low of 8 dyads in one community and a high of 23 dyads in another community. The control group communities were mostly geographically separated from the two treatment communities to prevent exposure of this group to knowledge of the treatment conditions.

Teenage Drivers

The final teenage driver sample consisted of 274 teenage drivers (see Table 1). Sixteen of the original 200 participants withdrew from the study prior to finishing data collection and 10 had inadequate data (e.g., greater than 40% missing data) for analysis at the end of the study. There were no statistically significant differences in gender or mean age between groups (p's >0.05) or in the number of teenagers in each group who shared a vehicle with another family member versus being the primary driver of a vehicle ($p>0.05$; see Table 2). One teenager in the full TDSS group withdrew because neither he nor his parent was happy with the system and how it operated. One teenager in the control group and one teenager in the full TDSS group withdrew due to crashes that totaled their vehicles and prevented them from continuing in the study. All teenagers owned either a smartphone or another cellular phone with calling and texting capabilities prior to entering the study. The majority reported using their phones often or very often for texting friends and family, calling friends and family, and surfing the Internet and using social media.

Table 1. Average age and gender of teenage participants.

		Age		Gender	
	N	Mean	SD	Males	Females
Control	92	16.02	0.15	43	49
Partial TDSS	92	16.04	0.29	42	50
Full TDSS	90	16.03	0.18	45	45
Total	274	16.03	0.22	130	144

Table 2. Teenager participant sample sizes for shared vehicles and unshared vehicles by study group.

	Control	Partial TDSS	Full TDSS	Totals
Shared	56	61	59	176
Unshared	36	31	31	98
Total	92	92	90	274

Teenagers estimated how many hours of supervised driving they received, on average, per week prior to taking their test. There were no statistically significant differences between the groups for the average number of reported supervised driving hours during the learner phase (p>0.05) between the control group (M=5.15, SD=10.95), the partial TDSS group (M=6.90, SD=11.13) or the full TDSS group (M=4.39; SD=2.88). Teenagers also reported how many times they tested before receiving their license. This information was collected to further understand the similarities between the study groups.

The majority of teenagers received their license on the first try in each group (see Table 3), and the passing rate the second and subsequent times were similar between groups.

Table 3. Percentage of teenagers reporting how many times they took their driver's test.

	Took test once, passed the first time	Took test twice, passed second time	Took test three times, passed third time	Took test four times, passed fourth time
Control	79%	19%	3%	0%
Partial TDSS	76%	21%	1%	2%
Full TDSS	72%	24%	4%	0%

Parents/Guardians of Teenage Drivers

Parents/guardians consisted of 203 female and 69 male participants ranging in age from 31-62 (*M*=46.29, *SD*=5.57; see Table 4). Teenagers reported that mothers and fathers were equally the primary person who taught them to drive during their learner phase (see Table 5). In contrast, the parents who participated in the study were primarily mothers in all three groups. There was a statistically significant difference in the number of males participating in the full TDSS group compared to the control and partial TDSS groups (χ^2=8.09, p=0.18). This discrepancy in the number of mothers enrolled in the study versus the percentage of mothers indicated as having taught teenagers to drive is likely related to household management. Mothers might be more likely to engage in activities with their teenager, particularly when involvement requires signing the teenager up for the activity. Because only one parent per teenager was consented into the study, the questionnaire data were related to the parent enrolled in the study. Feedback was potentially missing from parents who continued to be involved in supervising or managing their teenagers' driving but who were not participating in completing study materials. It was determined at the end of the study, however, that many of the consented parents reported answering survey questions using input from the non-consented parent (non-consenting parents, however, did not complete any of the surveys). There were no statistically significant differences for the average number of years parents were licensed as drivers across groups ($p>0.05$). There is a potential bias for parents in all groups in that they self-selected into a study about teenage driving and might be somewhat different than parents who did not opt to enter the study in the ways that they manage their teenagers. However, parents were not aware of what study group they would be in prior to contacting the study researchers and few parents opted not to participate once they were aware of the study conditions.

Table 4. Parent sample descriptive data for final analysis set.

	N	Age		Gender		Years Licensed
		Mean	*SD*	Males	Females	*M (SD)*
Control	92	45.91	5.63	22	70	29.33 (5.92)
Partial TDSS	91	46.76	5.52	15	76	30.34 (5.74)
Full TDSS	89	46.18	5.59	32	57	29.51 (5.55)
Total	272	46.29	5.57	69	203	29.74 (5.74)

Table 5. Percentage of teenagers who reported person type as main driving teacher.

	Mother	Father	Female Guardian	Male Guardian	Older Sibling	Other Adult	Both Mom & Dad
Control	51%	45%	1%	0%	0%	1%	1%
Partial TDSS	44%	49%	1%	1%	1%	2%	1%
Full TDSS	39%	53%	0%	1%	0%	1%	5%

There were no reported differences in the number of years licensed for parents, household income, the average number of people in the household, the number of licensed drivers in the household, or the number of vehicles per household (p's > 0.05).

Apparatus and Materials

Teenage Driver Support System (TDSS) Components

The TDSS consisted of a software application that was loaded onto a 2013 Samsung Galaxy S3 smartphone and which used the smartphone's capabilities to monitor the teenagers' driving. Because of the need to ensure a robust software application that could easily be maintained for all participants across 17 months of data collection (data collection ran from January 31-June 30, 2013) a single phone platform (the Galaxy S3) and the Android operating system (4.1.2) were selected for the development of the software in this study. Therefore, one of the recruiting requirements was that participants had to agree to use the study phone and cancel or suspend service on their existing phones for the study duration. Parents were informed of this requirement prior to joining and agreed to it as one of the study tasks during the consent process. The minimum phone requirements for the study software were onboard accelerometers, an inertial measurement unit, and a global satellite navigation system with GPS (GNSS) function. If participants lost or broke a study phone, it was replaced with a Galaxy S3 and the software reloaded onto the new phone. Later in the study, the Galaxy S3 became unavailable and phones were replaced with a 2013 Motorola Moto X, which had the same sensor capabilities and met the software requirements for the study.

The in-vehicle interfaces were comprised of the smartphone screen as the visual interface and the smartphone speakers were the auditory interface. The architecture of the study equipment also included an in-vehicle Arduino microprocessor (ArDAQ) that was specifically created and used to support data collection and validation for the study. It contained a GPS unit as well as a Bluetooth connection. The ArDAQ was wired into a vehicle power switch, which required installation by a third-party installer (mechanics at 10 automotive service shops were trained to install the equipment for this study). Additional sensors included a seat belt sensor attached to the driver's buckle that was wired to the ArDAQ, and passenger sensors in the front passenger and outboard rear passenger footwells that were also wired to the ArDAQ. These sensors were installed in the participant's vehicle to demonstrate the potential utility for monitoring seat belt use and the presence of passengers. The TDSS application was loaded on the teenager's study smartphone. The TDSS application was set to permanently run in the background and "listen" for a connection to the in-vehicle ArDAQ device with Bluetooth, which turned on when the vehicle was started. When the phone made a connection with the ArDAQ, the TDSS launched automatically on the smartphone and then ran as a foreground process until the vehicle was turned off and the Bluetooth connection was disabled. The TDSS application was programmed to force itself into the foreground while the vehicle was on, which meant teenagers were unable to access the smartphone's main screen while driving even after pushing the home button on the smartphone. The TDSS smartphone application monitored driving behavior and provided feedback to the teenage driver, sent collected data to the TDSS server, and sent SMS text messages to parents.

The in-vehicle ArDAQ primarily served as the conduit to launch the TDSS application on the smartphone. It also collected total vehicle miles traveled and communicated this data to the smartphone upon pairing. This data was collected to compare how many miles were driven with the TDSS smartphone application running versus how many total vehicle miles were driven. The total vehicle mileage was reported to parents in the TDSS full system group, which allowed them to compare this mileage to the miles driven with the application running to determine if the teenager was driving without the system active (i.e., teenagers could shut the phone off while driving or they could drive without the phone).

A map containing speed limit, stop sign, and curve location information (and the associated licenses for 300 phones) was obtained commercially from Navteq (now Nokia Here). The map was parsed to work with the smartphone application because its overall size was too large for mobile phone storage. Map tiles were sent to teenagers in the study as new GPS positions were acquired during driving. The map manager associated with the TDSS application was programed to predict and pre-fetch the next tile while the teenager was driving to prevent lags, to delete tiles not used for a period of time to maximize phone storage efficiency, and to monitor phone storage availability and report back to the office data server (i.e., teenager could fill up phone storage with other items, such as photos, music, etc). In rural areas, where cellular service was potentially less reliable, the map tiles were large; a single tile could encompass a large segment of roads or roadways. Cellular service only needed to be present for one area to pull a tile. After a tile was downloaded to the phone via the TDSS, the vehicle and associated speed limit on the cached tile could be located by GPS if service was lost in the area covered by the tile. This provided for a robust presentation of map-based information using GPS even when cellular service was limited. The cellular phone service provider used for the study indicated almost universal coverage within the study areas during the study period, providing either 3G or 4G LTE service in and around all the study communities.

Participants who shared a vehicle with another driver could turn off the data collection when they were passengers in the vehicle equipped with the ArDAQ. Parents were given a Near Field Communication (NFC) key chain to use for the study. When the NFC chip was held to the phone the TDSS recognized the NFC code and deactivated the TDSS software. When the participant (parent) entered “parent mode” the deactivation of the TDSS software was indicated by a visual dialog box. The dialog box asked if the parent wanted to “exit the TDSS” and if the user responded “yes” the system would confirm the decision through an auditory alert that said “Parent mode on.” Parent mode turned off all functions and data collection during a drive. Because the application launched each time the vehicle started, it required parent mode to be activated each time the teenage participant was a passenger in the vehicle containing the ArDAQ. The purpose of this shut-off mechanism was to ensure that the data collected were primarily for the teenage drivers and not other vehicle users.

The TDSS software application and sensors were verified for accuracy during beta testing and revised as needed prior to the study beginning. A description of the software beta testing (verification) is located in Appendix A.

TDSS Monitored Behaviors and In-vehicle Alert Sequences

The TDSS monitored several of the behaviors and situations related to teenage driver crashes that were reviewed in the Introduction chapter. Behaviors and situations that were monitored included excessive speeding, seat belt non-compliance, the presence of passengers in the vehicle, excessive maneuvers (braking, turning, accelerating), and GDL curfew violations. In addition, the TDSS map database included stop signs for four of the study communities, which provided a potential opportunity to examine stop sign violations for the teenage driver sample, as missing traffic control signals has been identified in previous research on teenage driver crashes (Braitman et al., 2008). Stop sign violations (i.e., running a stop sign) can be indicative of distracted driving and/or inexperienced visual scanning for traffic control devices (i.e., miss seeing the stop sign) or can be associated with deliberate risky driving behaviors, such as rolling through a stop sign rather than coming to a full stop. The TDSS software prevented accessing all smartphone functions while driving, including sending and/or receiving cellular phone calls and text messages.

Parents in the full TDSS group were notified of behaviors via text message, a weekly summary email, and/or on the website depending on the behavior detected. For example, because the passenger identification alert was less reliable, it was alerted to the teenage driver at the end of the drive and then only in the weekly email and on the website to avoid nuisance alerts to parents via text message. The system provided specific event information to parents, but all decision-making on how to interpret and use the information was at the parents' discretion for this study.

In-vehicle feedback about detected behaviors was provided using auditory and visual messages via the smartphone interfaces to the full and partial TDSS study groups. Verbal auditory warning messages (e.g., speeding) consisted of two parts: 1) a description of the behavior detected (e.g., "Exceeding speed limit"), and 2) a description of how the driver can rectify the warning (e.g., "Reduce speed now"). Verbal messages were selected over simple auditory tones to provide richer context to the system alerts. Verbal alerts are potentially more useful when one alarm is associated with one event and/or an immediate response is required (Stanton & Baber, 1999). For the TDSS, behaviors were alerted individually (i.e., one at a time) and the speeding and seat belt feedback required immediate responses. For all behaviors, if criteria for a text message to parents were met, the teen was informed that parents had been notified. The TDSS visual interface displayed only one image at a time while the teenager was driving and this image as dependent on the driving condition detected. Visual messages and auditory messages were tested in previous studies to ensure they were easily and quickly comprehended and to determine that they were not distracting to the driver (Creaser et al., 2011). All participants were provided with an in-vehicle phone mount and power charger in which they were instructed to mount the phone for every drive. Mounts were placed in accordance with Minnesota state statutes that indicate where in-vehicle devices can be mounted for viewing during driving. Mounts were primarily located immediately to the right or left (in line with the A-pillar) of the steering wheel and as low to the dash as possible to allow the driver to view visual alerts using peripheral vision or during normal scanning of the environment and control cluster (but without obscuring the outside road environment).

Phone in Mount Alert

Because the excessive maneuver algorithm required the phone to be securely mounted and vertical in the vehicle, an algorithm was created to detect the phone's orientation when the software launched. If the phone was not correctly mounted in the provided study mount, participants received an auditory message that said, "Please place phone in mount now." Participants received a second "out of mount" warning if the phone was still not mounted within two minutes of starting to drive. This warning was primarily to alert the participant that certain functions would not work if the phone was not properly mounted. All participants were given specific instructions not to manipulate the phone while driving, even if it meant leaving the phone un-mounted for a drive. If the algorithm did not detect that the phone was in the correct position, it would not provide alerts or collect data for excessive maneuvers. All other behaviors (e.g., speeding, seat belt) continued to be monitored, alerted and reported if the phone was not mounted in the provided holder.

Cellular Phone Blocking

The cellular phone blocking function silenced all incoming phone alerts (i.e., sounds, visual icons, and vibrations) associated with calls, text messages, and other active applications (e.g., email). Teenagers were unaware of arriving incoming messages until they finished driving and could then see that a message was received. The only phone feature that was available while the teenagers were driving was a 911 button (see bottom left of Figure 1), which allowed them to call for help if an emergency occurred (it is legal to dial 911 while driving). There were no alerts to parents regarding cellular phone use as it was intended to be a function that prohibited use while driving.

Seat Belt Reminders and Alerts

Because teenage drivers are considered at-risk for lower seat belt use compared to drivers of other ages (NHTSA, 2014d), this study sought to demonstrate and evaluate the use of aftermarket sensors as a mechanism for creating enhanced seat belt reminders (ESBRs) for all teenage drivers. Only the driver's seat was equipped with a sensor and the driver was the intended recipient of the alert. Seat belt alerts were associated with two conditions: not wearing a seat belt at the time the vehicle was started (i.e., when software launched), or removing the seat belt while driving. For both conditions they received a visual alert on the phone interface and an auditory message that was dependent on the situation detected (e.g., "fasten seat belt before driving" or "fasten seat belt now; see

Table 6). If the participant buckled up, the message was terminated. If the seat belt remained unbuckled for 30 seconds in the full TDSS with feedback to parents, a text message was sent to parents and the information was included both in the weekly email sent to parents and on the parent website. The seat belt notification was persistent and repeated itself every three minutes if the participant failed to buckle up while driving.

Figure 1. Seat belt image displayed when seat belt was unbuckled.

Passenger Presence Detection and Reminder

Passenger detection was passively acquired through detection plates (i.e., foot pressure from a seated passenger) mounted underneath the vehicle's carpeting on the passenger side and each of the rear passenger areas. If more than one sensor was triggered (i.e., exceeded the maximum allowed 1 passenger under age 20) during a drive in the first six months of the study, the participants in both TDSS groups received a notification at the end of the drive before the software shut off (see Table 6). There was no way to detect the age of a passenger in the vehicle, thus all passengers detected were reported. The decision to present the passenger notification at the end of a drive was also supported by the usability testing results (Creaser et al., 2011). In the usability testing, participants found that the passenger alert was often presented to them just as they had begun driving and it was rated moderately distracting. Participants were either distracted by this notification while backing up or preparing to navigate (e.g., pull out of parking lot) and it was already too late to let passengers out of the vehicle at that point. In the full TDSS group, a passenger detection notification was included in the weekly email summary and on the website. Because the reliability of these sensors was only moderate during beta testing, it was decided that parents and teenage drivers might find the notification to be a nuisance; therefore, no text messages were sent alerting parents of passenger detection.

Advance Speed Limit and Curve Notifications

Participants were provided with advanced speed notification when the speed limit changed between sections of roadway. If a speed change was detected by the TDSS, based on the speed database, the participants received an auditory alert (e.g., “Speed limit changes to XX miles per hour ahead”) and the visual icon with the speed changed. Because speeding is a factor in run-off-road crashes (Lord et al., 2011), particularly in curves, the TDSS presented participants with a curve advance notification when the information was available in the map database. When available, this notification was intended to help the teenage drivers prepare for upcoming curves by encouraging them to slow down accordingly. A visual icon was also presented that corresponded to the direction of the curve (see Figure 2). These are advance notice alerts only and are not associated with any parent feedback.

Figure 2. Advanced curve notification.

Speeding Alerts

The speeding feedback provided by the system was based on previous research on intelligent speed adaptation (ISA), which is a system that continuously monitors speed to alert the driver of speeding events and/or changes in speed limits along a road way. In both TDSS groups, the in-vehicle feedback was graded and persistent to encourage participants to avoid excessive speeding (i.e., > 7 mph over the posted speed limit). Excessive speeding was set at 7 mph or greater over the speed limit for this study because of previous research which identified a range of 5-10 mph over the speed limit as "excessive" speeding (Farmer et al., 2010; Manser et al., 2013) as well as based on results of the TDSS usability study in which parents indicated they would not enforce a speeding alert until it reached at least 7-10 mph over the posted limit (Creaser et al., 2011). In the full TDSS group, parental feedback also acted as a motivation to reduce speeding. By reducing speed after the warning sequence began, participants in this group were able to cancel the speeding alert and prevent a text message from being sent to their parents. This ability to cancel the alert was similar to that described by Farmer et al. (2010).

The TDSS provided speeding notifications when posted speed limits were available in the Navteq database. The first speeding alert occurred at 2.5 mph above the speed limit, with the speed limit icon's background changing to yellow to warn the driver that his or her speed was increasing. If the teenage driver exceeded 7 mph over the limit the speed limit icon turned red and an auditory message was played immediately ("Exceeding speed limit. Reduce speed now."). This auditory message was played twice if the speed did not drop. These speeding alerts applied to both TDSS groups. The warning sequence for both groups repeated every three minutes until speed was reduced.

For the full TDSS group, a third message played after the first two messages that said: "Reduce speed now or parents will be notified." This third message triggered a random timer countdown between 0 and 15 seconds for sending the text message to parents. Because the countdown varied, it was hoped that participants who were caught with a 0-second countdown would reduce their speed earlier in the sequence the next time. Once a text message was sent, participants received an auditory message that indicated the event was sent to parents ("Text message sent"). For the partial TDSS group, the third message was "Reduce speed now. Speeding is dangerous" and then the system reset itself and would continue auditory warnings at the 3-minute intervals until excessive speeding stopped. Figure 3 shows the visual alert sequence for speeding that was displayed on the smartphone interface, while Table 6 lists the in-vehicle warnings for the partial TDSS and full TDSS groups.

Figure 3. Speed warning sequence.

Excessive Maneuvers

Excessive maneuvers consisted of hard accelerations (e.g., from a stop), hard braking, and hard right or left turns. The system could determine acceleration, braking, and turning but did not differentiate the direction of turns in the feedback. The participant received a visual warning and an auditory warning, “Excessive braking [acceleration, turning] detected. Use caution” if any of the described events were detected (see Figure 4 and Table 6). Parents were text messaged immediately after an excessive event was detected.

Figure 4. Excessive maneuver visual warning used for braking, turning, and acceleration events.

Stop Sign Violations

Stop sign violations were alerted to the driver and parents when the speed of the vehicle was registered at greater than 5 mph and the database identified a valid stop sign location. The alert occurred after driving through a stop sign at 5 mph or greater. When these conditions were met, the participants were presented with a visual icon warning (see Figure 5) that was displayed for 10 seconds after the violation occurred, in addition to the auditory warning, "Stop sign violation" (see Table 6). Parents were text messaged immediately after an excessive event was detected.

Figure 5. Stop sign violation visual warning.

Table 6. Summary of in-vehicle auditory messages by warning type for full and partial TDSS groups.

	Full TDSS Group	**Partial TDSS Group**
Seat belt: Vehicle Start-Up	1. “Fasten seat belt before driving or parents will be notified.” 2. “Fasten seat belt now or parents will be notified.” 3. “Fasten seat belt now. Parents have been notified.	1. “Fasten seat belt before driving.” 2. “Fasten seat belt now.” 3. “Fasten seat belt now. Driving without seat belt is dangerous.”
Seat belt: While Driving	1. “Fasten seat belt now or parents will be notified.” 2. “Fasten seat belt now. Parents have been notified.”	1. “Fasten seat belt now.” 2. “Fasten seat belt now.” 3. “Fasten seat belt now. Driving without seat belt is dangerous.”
Passenger Presence	“[#] passengers detected. Parents notified.”	“[#] passengers detected.”
Advance Speed Notification	“Speed limit changes to XX miles per hour ahead.”	“Speed limit changes to XX miles per hour ahead.”

	Full TDSS Group	Partial TDSS Group
Excessing Speeding	1. "Exceeding speed limit. Reduce speed now." 2. "Exceeding speed limit. Reduce speed now." 3. "Reduce speed or parents will be notified." 4. "Text message sent."	1. "Exceeding speed limit. Reduce speed now." 2. "Exceeding speed limit. Reduce speed now." 3. "Reduce speed now. Speeding is dangerous."
Advance Curve Notification	"Left/Right [if available] Curve ahead."	"Left/Right [if available] Curve ahead."
Excessive maneuver - Braking	"Excessive braking detected. Use caution."	"Excessive braking detected. Use caution."
Excessive maneuver - Acceleration	"Excessive acceleration detected. Use caution."	"Excessive acceleration detected. Use caution."
Excessive maneuver - Turning	"Excessive turning detected. Use caution."	"Excessive braking detected. Use caution."
Stop sign	"Stop sign violation. Parents notified."	"Stop sign violation."
Phone Mounting Alert	"Please place phone in mount now."	"Please place phone in mount now."
Parent Mode	"Parent mode on. "	"Parent mode on. "

In-vehicle Warning Dependencies

Only one visual and auditory warning at a time was presented to the teenage driver. When multiple violations occurred, they were displayed and played in the order that the behaviors were detected and queued from a warnings list. For example, if a participant was detected speeding after the warning sequence began for a seat belt violation (i.e., removing the belt), the seat belt warning would finish being displayed before the speeding alert would be presented.

Parental Feedback in Full TDSS Group

Parents in the full TDSS group received text messages, a weekly email notification and were able to access event data on a secure website at their discretion. Text messages were sent to parents for GDL curfew violations, speeding, excessive maneuvers, seat belt non-compliance, and stop sign violations. The passenger detection information was only included in the weekly email summary and online.

GDL Curfew Alert

If the TDSS application was active and the teenager was driving their TDSS-equipped vehicle between midnight and 5 a.m. during the first six months of licensure, parents were notified of a curfew violation (see Table 7). Because certain exclusions are allowed within the parameters of the Minnesota GDL, it was up to the parents to identify intentional violations of curfew versus violations due to work/school schedules. There were no in-vehicle alerts for either TDSS group for curfew violations.

Parental Text Messages

Text messages provided near real-time monitoring of the teen driver to keep the parent apprised of current driving behaviors. The text messages were designed to provide enough information for parents to use to make decisions on how to discuss the event with their teenagers. The text message contained the type of infraction (e.g., excessive maneuver), the location of the violation (e.g., nearest intersection to where the teenager was driving), and the information related to the event (e.g., speed of the vehicle, posted speed limit). For example the excessive speeding alerts provided the ability for parents to know how fast their teenager was speeding over the posted limit and the location allowed them to infer potential hazards associated with speeding. For example, a driver going 45 mph in a 30 mph zone might be at risk of encountering pedestrians or other road hazards associated with lower-speed, suburban streets. Parents would also have the location information on which to determine the potential risks associated with where the event occurred (e.g., rural road, neighborhood street). Table 7 presents examples of text messages for each alert type while Figure 6 shows a screen capture of a series of TDSS text messages captured during a demonstration drive.

Table 7. Example text messages to parents to demonstrate format and content.

Alert	Text Messages
Excessive Speeding	<*Timestamp*>. Speed violation: 37 in a 30 mph zone. 17^{th} Ave SE and 4^{th} St. SE.
Stop Sign Violation	<*Timestamp*>. Stop sign violation. 5^{th} Ave NE and 4^{th} St. NE. Speed limit: 30 mph. Vehicle Speed: 9 mph.
Seatbelt Compliance	<*Timestamp*>. Seat belt not fastened while driving.
GDL Curfew Alert	<*Timestamp*>. Driving after curfew.
Excessive Maneuvers	<*Timestamp*> Vehicle experienced hard excessive braking/acceleration/turning. 5^{th} Ave NE and 4^{th} St. NE.

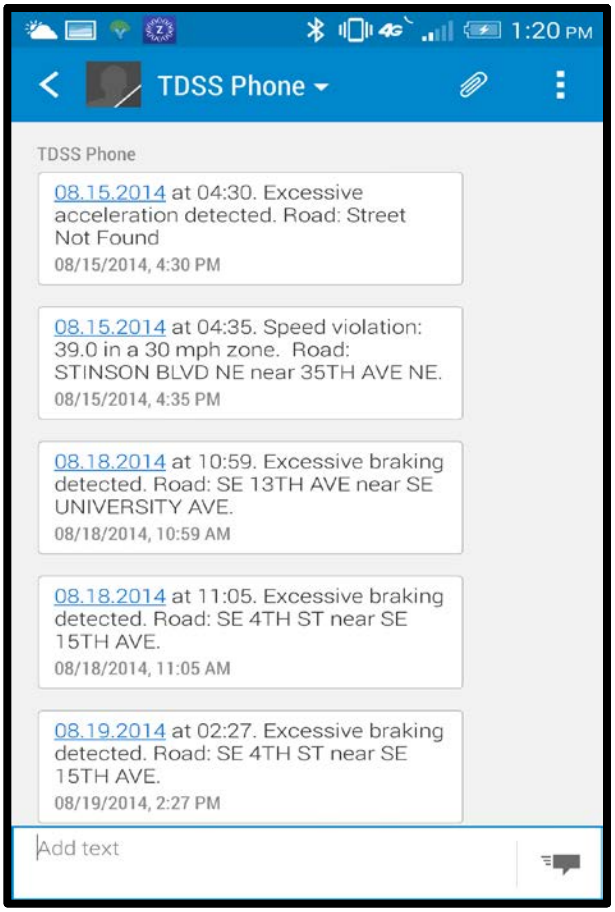


Figure 6. Sample violation parental text message.

Email Parental Summary Report

The weekly email summary provided a snapshot of the previous seven days' event history. The emailed summaries were intended to provide parents with a quick reminder and overview of the week's events. For example, a parent might remember receiving a number of text messages during the week, but the weekly email would serve as a reminder for how many of each event type occurred (e.g., 10 speeding events). The weekly email included positive behavior information as well to encourage parents to praise and reinforce safe driving behaviors. For example, if the teenage driver wore their seat belt every time they drove this would be noted on the weekly summary for parents. The email summary was included because previous research (Farmer et al., 2010) reported that emailed report cards were more likely to be viewed than web-based ones. Providing access to three types of feedback mechanisms allowed parents to determine the best interaction for their lifestyle with respect to the system.

Parent Website

The parent website contained the summary information provided in the weekly email reports in addition to information related to recorded events and other teen driver resources. The main page was a dashboard that contained the same information as the weekly email summary. Additional pages included a weekly events list, event locations map, teenage licensure information, and a history of events since the TDSS was activated. The website was constructed to be easily navigated through the use of tabs on the top of the page and hyperlinks within each page. Additional hyperlinks provided parents a method to navigate to additional outside teen driver website resources (e.g., GDL requirements).

The weekly summary contained several pieces of information that allowed parents to quickly review their teenager’s driving behavior for the week. The weekly summary page, or landing page after log in, provided parents with the current week’s date, total hours of driving accumulated, unsafe driving events, safe driving events, the teenager’s rating based on his or her full TDSS peers, and web links to other information. Based on the number of driving events that occurred each week per teenage driver, the participants were rated as below average (1 standard deviation (SD) below the mean number of events), average, and above average (1 SD above the mean number of events) assuming a

Gaussian distribution of events. The purpose of rating the teenage drivers was similar to that used by McGehee et al. (2007), in which the ranking provides context to an individual driver about how they performed in comparison to their peers. This rating was also intended to calibrate parents to their teenage drivers' ability to manage the behaviors that were monitored by the system in comparison to peers also using the system. Overall, the majority of teenage drivers would fall into the "average" category frequently and this could serve as a reminder to parents to continue to mentor safe driving habits.

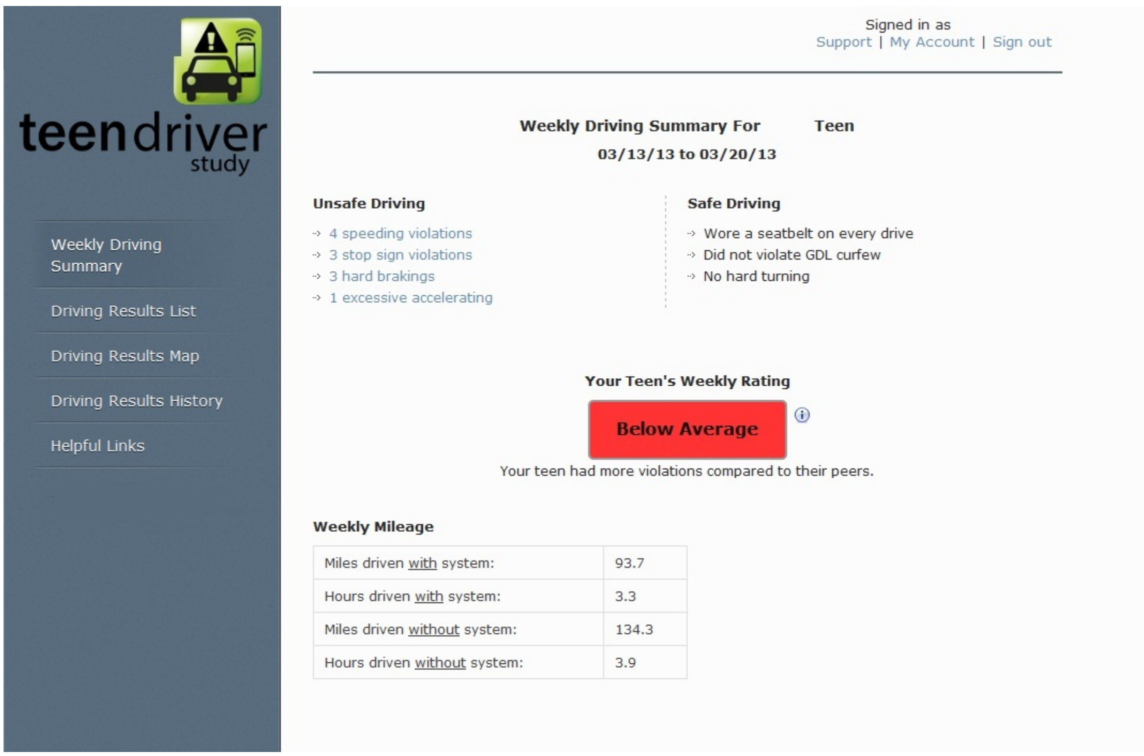


Figure 7. Weekly summary page of parent website (main landing page).

There were four other pages that provided information to parents. One page provided a simple weekly event list of all the participant's driving events. The list included information for each of the events similar to what was contained in the text message. A key feature of this page was the ability to click on an event and view an event location map on another page. The weekly summary event map showed the location where each event occurred and was displayed via a Google map. The summary event map page was available via hyperlink through the weekly summary page or through the weekly driving results list page. A single event, identified by an event icon (e.g., stop sign, excessive maneuver, or speeding) was displayed on the map where the event was detected. The events were both shown on the map and highlighted in a short summary list next to the map. Parents were able to switch between maps by clicking on the different events. Parents could also see a larger map showing all the events that occurred for the week. Driving routes for any start-to-finish drive were also displayed for the drive in which an event occurred. This allowed parents to gauge the frequency of events during a single drive as well as determine if their teenager was driving where they expected them to be driving. This information provided parents with another mechanism against which to determine when and where their teenager drove.

A driving history page allowed parents to review all of the historical violations and events for their teenage driver by week or month across the 12 months of the study. Parents could select up to eight weeks of data to review at one time. Event tallies by week and type were displayed in graphical form and parents could select one or more event types. For example, a parent could look specifically at speeding events over an 8-week period and identify whether their teenager had improved by reducing the number of reported events. Finally, the website provided an information page that included a set of links that parents could use to explore additional teenage driver safety information. The information page contained links to teenage licensing laws for Minnesota drivers, teenager-parent driving contracts, and other relevant information. The informational page was intended to serve as a conduit for parents to investigate additional resources for supporting or mentoring their teenage driver during the first year of independent driving.

TDSS Study Data Collection

All data were collected via the smartphone application except the vehicle's number of total miles driven, which represented all miles driven by the instrumented vehicle each week regardless of whether the phone software was active. Data were collected in real time, encrypted and sent over the wireless network to a secure server at the University of Minnesota. If cellular service was not available during portions of a drive, the data were cached in an encrypted format on the phone and sent when a connection to the wireless data network for the cellular service provider was available. Cached data were deleted from the phone once they were sent to the server. Participants finished the study with 52 weeks of data collection. Alerting and data collection could only occur when certain conditions of the monitoring and detection algorithms of the TDSS were met. For example, speeding alerts were provided and speeding data were collected only when GPS was available and a posted speed limit was available in the software database. If these two conditions were not met, participants were informed via the visual interface that a "speed limit is not available, please look for signs." Accelerometer events and data (i.e., excessive maneuvers) were only triggered and collected when GPS was available, the vehicle was moving above 5 mph, and the system detected that the phone was securely mounted in the upright position to ensure the data from the algorithm was valid. This meant an excessive maneuver would not inadvertently be detected if the phone were dropped in the vehicle or when in the wrong orientation (i.e., could not determine direction of forces unless phone was correctly oriented).

Data validation occurred throughout the study to ensure minimal losses due to equipment problems. Validation variables, such as number of trips, number of miles driven with phone on, total number of vehicle miles from the arDAQ, percentage of seat belt use, and percentage of passenger detection per passenger seat for the previous seven-day period per participant were calculated each morning at 5 a.m. by the system. This validation information was then sent to the validation website where it could be reviewed by the researcher. This allowed the researcher to determine if a participant's system was functioning properly. For example, a significant drop in seat belt use was often indicative of the sensor having become dislodged from the buckle I.e., needed to be repaired). The researcher was able to contact participants and instruct them on how to troubleshoot problems. The primary criteria for contacting a participant was having no data posted to the website for the previous seven days. In this case, the researcher would contact the parent participant to determine if there was a software or hardware problem that required troubleshooting. If the reason for the lack of data collection was determined to be due to reasons other than system problems (e.g., teenager was on vacation, grounded, etc), the parent was thanked and reminded that they retained discretion over when and how often their teenager drove. The validation data also allowed data associated with faulty sensors or hardware to be eliminated from analyses.

Procedures

Parents or legal guardians completed the Informed Consent process to participate in the study and also provided consent for their teenager to participate. The study received University of Minnesota Institutional Review Board (IRB; see Appendix B). Teenage participants were provided with an assent process. During the consent process parents and teenagers were informed about the study tasks and requirements, as well as about their legal obligations as drivers in Minnesota, including information about Minnesota's GDL laws. During recruiting all three groups were provided with the same information regarding involvement in a teenage driving study, were provided with the same criteria for participation, and all were informed of the IRB-approved incentives to join the study. A Certificate of Confidentiality was also obtained from the National Institutes of Health to protect the participants' data from being obtained for by law enforcement (e.g., in the event of a crash or violation; see Appendix B). Participants were encouraged not to disclose their participation in the study to further protect their confidentiality.

The same study expectations and tasks were described to participants in all groups. The only difference in the recruiting scripts across the three study groups was the description of the condition into which the participants were being recruited. The control group was informed they were being recruited to understand normal teenage driving in the first year of licensure. The partial TDSS group was informed they were being recruited to understand normal teenage driving in the first year of licensure in the presence of in-vehicle feedback. The full TDSS group was informed they were being recruited to understand normal teenage driving in the first year of licensure in the presence of in-vehicle feedback and parental monitoring and feedback.

Once participants completed the consent process, parents and teenagers were sent enrollment surveys and were instructed on how to get the study equipment installed in their vehicle. Teenagers and parents were asked to make an appointment to get the equipment installed in the vehicle that the teenager would primarily drive during the study. There were 10 commercial installers (e.g., local dealership maintenance shops) that were hired and trained to install the TDSS to accommodate. The 10 installers were selected to ensure participants from all 18 communities would have easy access to an installer (i.e., within 30 minutes one way). At the time of the hardware installation, the teenagers received and activated the smartphone and downloaded the TDSS application (control downloaded a data collection application only). All hardware and software was required to be installed within 4 weeks of the teenager receiving their driver's license, or the teenager was removed from the study. Parents and teenagers also received a written set of study instructions, a written set of Minnesota's GDL laws, and the treatment groups received instructional materials about how the teenage driver application functions worked based on their level of support (e.g., partial versus full TDSS).

Electronic surveys were sent to parents and teenagers at Month 1, Month 6 and Month 12. Surveys that were common to all three groups included (see Appendix C):

1. Demographics (parents and teenagers)
2. Self-reported frequency of driving (teenagers)
3. Self-reported frequency of supervised driving with parent or another adult (age 21 or older) (teenagers)
4. Self-reported frequency of driving behaviors, including cellular phone use and seat belt use (parents and teenagers)
5. Arnett Inventory of Sensation Seeking (AISS; Arnett, 1994) (teenagers and parents)

6. Teenagers' self-reported traffic tickets or crashes
7. Parents' self-reported comfort with discussion driving safety with their teenager
8. Parents' self-reported comfort with setting limits on their teenager's driving
9. Self-reported driving privileges and consequences related to driving behavior (teenagers and parents)
10. Self-reported driving privileges and consequence related to non-driving behaviors (e.g., poor grades, breaking household rules; teenagers and parents)
11. Self-reported use of other resources (e.g., parent-teenager driving contracts, educational materials) to encourage safe driving habit (parents)

Additional group questionnaires were administered for each of the partial and full TDSS groups (see Full TDSS Condition and Partial TDSS Condition sections below). Parents were informed that they retained control over their teenagers' driving, but that ongoing data validation procedures meant they would be contacted if data were not received in a previous seven-day window for their teenager.

Full TDSS Condition

The full TDSS group received in-vehicle feedback and their parents received the parental notifications related to detected risky behaviors. The purpose of this group was to examine the role of parents and in-vehicle feedback on teenage driving behavior in the first year of driving. Participants recruited into this group were provided with an explanation of how the system worked and were provided with basic instructional materials that described the system functions. This instructional material did not provide any information to parents about how they should use the information sent to them from the system. The materials simply provided pictures of the alerts and described in general terms when and how they would be alerted. The instructional materials did not describe the thresholds for the system, just the types of alerts that were presented (e.g., speeding, excessive maneuvers) and a brief description of the visual icon (picture shown) and associated auditory messages. For example, speeding was described as “excessive speeding”, the handbook showed the three speeding icons, and described the associated auditory alerts. Additionally, the handbook discussed specific study instructions such as ensuring data collection was turned off using Parent Mode when the teenager was a passenger in the vehicle. A step-by-step description of how to use the NFC tag to disable the TDSS was included with the instructional materials. The instructional materials also included IRB-required safety information, such as informing participants of the applicable GDL laws (e.g., no cell phone use), that they should never manipulate the phone while driving, and that their driving decisions took precedence over the system if the situation warranted it (e.g., in the case of wrong information, such as an incorrectly presented speed limit). Parents participating in the full TDSS group were required to have a phone that could receive text messages from the system. Parents in this group received the text messages, weekly email summary, and had access to the website.

The full TDSS group completed the general survey questions (see Appendix C) answered by all participants across the study groups as well as a set of questions specific to the full TDSS group were intended to identify potential differences in parent-teenager interactions compared to the groups without parent feedback (see Appendix D). Survey questions specific to this group included asking parents and teenagers to describe how the system feedback to parents was used to incentivize or provide consequences related to driving. Parents also reported which monitored behaviors (e.g., speeding, excessive maneuvers) they were most likely to use when determining whether consequences or incentives should be employed. Teenagers also completed a trust survey adapted from Lee and Moray (1994) to evaluate the TDSS and completed usability questions about whether the system was beneficial in helping them learn to drive and/or influenced their interactions with their parents when discussing driving. Parents completed usability questions related to the three feedback mechanisms (i.e., text messages, weekly email, website). Finally, teenagers and parents were asked whether they would recommend the system such as the TDSS to other parents and teenagers to use.

Partial TDSS Group

The partial TDSS teenage participants received the in-vehicle feedback only. The purpose of including this group was to examine the role of in-vehicle feedback alone on teenage driving behaviors in the first year of driving. In particular, the intent was to examine potential differences in the types of feedback provided, including comparing persistent, graded alerting to one-time, post-event alerts. Although parents were consented into the study for this group and participated in filling out the surveys, there was no feedback directly to parents from the TDSS in this group. Similar to the full TDSS group, this group also received instructional materials about how the in-vehicle system functions worked and the required safety information associated with the study. This group also received the NFC chip to turn off data collection while the teenager was not driving the vehicle with the study equipment. Information about parental feedback from the TDSS was omitted from the instructional materials and only the in-vehicle alerts were identified.

The survey questions for this group overlapped with several of the questions asked of the full TDSS group (see Appendix D); however, questions directly related to parent feedback from the TDSS were omitted for this group. Teenagers in this group also completed the trust survey and usability questions about whether the system was beneficial to them in learning to drive.

Control Group

The control group provided naturalistic driving data against which to compare the findings from the two TDSS groups. This group followed the procedures identified above and completed the surveys common to all groups. Teenage participants and parents in this group were provided with the study instructions that all participants received as well as instructional materials on how the data collection software application worked, and the study safety information. Teenage participants were informed that they should place the phone in the mount at the beginning of each drive and were also provided with an NFC chip to turn off data collection when the teenager was a passenger in the vehicle. To ensure participants in this group had some feedback about the status of the data collection software (e.g., on/off when driving versus passenger), a small "TDS" (Teen Driver Study) icon appeared in the top left of the phone's notification tray while the application was running. This group also received the out of mount alert if the phone was not mounted as a reminder that data collection (excessive maneuvers only) required the phone to be mounted. There was a possibility that the teenagers might alter their driving behaviors due to being reminded they were collecting data for a research study at the beginning of each drive. The results of previous studies, however, seem to indicate that teenage drivers tend to forget or not be bothered that they are being monitored and tend not to change their behaviors significantly as a result of monitoring when in-vehicle feedback from a system is present (e.g. Farmer et al., 2010; Simons-Morton et al., 2013). There is always the possibility of participants attempting to anticipate and meet research study expectations, but it was hoped that the longer duration of the study would nullify this potential bias over the long term for teenage driving behaviors.

Study Debrief

At the end of the 12-month study, parent and teenage participants were debriefed about their role in the study and informed of the overall study goals, including the existence of the other experimental groups and the purposes of those study groups. Per IRB requirements when deception is used, participants in all groups were offered the opportunity to withdraw their data from the study once they knew the full study design. No participants selected to withdraw their data from the study after being debriefed. Teenage participants were remunerated $25/month ($300 total) upon completion of the study and were allowed to keep the study smartphone. Parents and teenagers were thanked for their commitment and participation upon exiting the study.

RESULTS

Dependent Variables

Dependent variables were collected for speeding, excessive maneuvers, cell phone use, seat belt use, passenger detection, stop sign violations, and curfew alerts (see Table 8). There were three speeding variables: percentage of excessive speeding miles, number of times the excessive speeding warning was triggered per mile driven, and the number of times per mile driven that parents were sent a text message (or would have received a message in the case of the control and partial TDSS groups). There were three excessive maneuver variables: the number of acceleration, braking and turning events per mile driven. Finally, there was a single variable for seat belt use, stop sign violations, calls made and texts messages sent by the teenager while driving, and curfew alerts.

Percentages and rates of behaviors were calculated by dividing the number of behavior events by the mileage driven with the TDSS for each variable. Dividing event rates or total number of miles driven during a risky behavior such as speeding by mileage standardizes the comparison between individuals. For example, a teenager who drives more miles has an increased opportunity to engage in risky behaviors compared to a teenager who drives fewer miles. Using mileage to calculate a rate or percentage controls for this effect of exposure. Mileage was calculated specifically for each variable based on the algorithm requirements outlined in the Methods section (TDSS Study Data Collection), such that the counts of events for each behavior or alert were based on mileage driven only when the behavior could have been detected. Speeding mileage included only mileage collected during times when the system was able to provide a speed limit notification to the teenage driver (i.e., there was a posted limit in the database against which to compare the vehicle speed). For excessive maneuvers, mileage was only collected when the phone was detected to be stable in the mount meaning that detection and alerting of events was possible (see TDSS Data Collection). For calls made and text messages sent while driving, seat belt use, passenger detection, the total mileage driven while the TDSS data collection application was active was used.

Survey variables were calculated based on the type of scale used for the survey or questions (i.e., frequency, percentage, or average score). The question scales and calculations (when applicable) used for this study are described in conjunction with the associated results in the Results chapter and are also located in Appendices C and D.

Table 8. Vehicle-based dependent variables and descriptions.

Variable Name	**Dependent Variable**
Driver Seat Belt Use	Percentage of miles driven while buckled
Passengers Detected	Percentage of miles driven with passenger(s) detected
Excessive Speeding Miles	Percentage of miles driven at or above 7 mph over the posted speed limit
Excessive Speeding Warnings	Rate per mile driven that excessive speed warning was triggered
Speeding Text Messages to Parents	Rate per mile driven that parents received a text message
Stop Sign Violations	Rate per mile driven of stop sign violations
Acceleration Events	Rate per mile driven of acceleration events
Braking Events	Rate per mile driven of braking events
Turning (left or right) Events	Rate per mile driven of turning events
Phones Calls Made by Teenager	Rate per mile driven of calls made
Texts Sent by Teenager	Rate per mile driven of text messages sent
Curfew Alerts	Number of curfew alerts per curfew mile driven (midnight – 5 a.m.)

Data Screening

The percentage and rate-based vehicle dependent variables were not normally distributed because the counts of the detected behaviors were near zero or no behaviors were observed. This means the dependent variables were positively skewed and overdispersed. Overdispersion occurs when data contain a large number of zeros. Therefore, to account for overdispersion in the data, the analysis models applied a Poisson regression analysis using Generalized Linear Mixed Models (GLMM) procedures in SAS 9.4 using the GLIMMIX procedure with a residual offset (Berk & MacDonald, 2008; Cameron & Trivedi, 1990). The GLMM analyses also accounted for random and fixed factors. Random factors are those that are expected or known to influence the variability of the distribution, while fixed factors are the effects of interest tested by the model. For the GLMM analyses, random effects were modeled to account for the subject variability and potential community variability effects (and interactions). It was expected that there would be wide variability among the teenage drivers in terms of observed behaviors, as this was noted in previous studies (e.g., McGehee et al., 2007; Carney et al., 2010). The recruiting method was also a potential source of variability because there was no pre-treatment data collection within each group to determine whether the groups were equivalent prior to treatment (Shadish et al., 2002). Therefore, the random effect modeled for community (N=18 communities) was intended to account for the fact that the groups are potentially non-equivalent due to the study design. For all analyses, random effects accounted for the largest amount of variability in the observed behavior, indicating wide differences in driving behaviors between subjects (p's<0.0001) and between communities (p's<0.01).

Because of the expected variability between subjects, the data were not cleaned for outliers prior to analyses. This is because there was no reliable way to identify what was truly a behavioral outlier and what was normal driving because large variability was expected between the teenage drivers. In the absence of a good rationale (i.e., being able to determine why an outlier occurred) to eliminate outliers from the analysis, a decision was made to analyze the full dataset. Spaghetti plots showing the group trend lines and data lines for all participants for the full dataset for each dependent variable are located in Appendix E.

Data Reduction

The data for this study were aggregated into 13 four-week time periods for analysis and to facilitate presentation of the data for the 12-month study. Event rates and mileage were summed for each four week period and then the rate or percentage for that period was calculated. This reduction minimized the number of cells with missing data for the analyses. Missing data in this study occurred when no mileage was recorded for a time period. Overall, the total number of time periods with missing data was 1.45% for speeding mileage, 1.63% for excessive maneuver mileage, and 1.31% for total phone mileage. The data reduction provided a month-to-month representation of teenage driver behavior that allowed a more consistent comparison to previous research in which data were aggregated monthly or by longer time periods (e.g., 6-8 weeks). Teenagers in this study completed the majority (>90%) of their driving during the daytime hours of 5 a.m.–9 p.m. with very little driving occurring at night or during the GDL curfew. For this reason, data were analyzed for the full data set and were not broken down by time of day.

Event Rate Graphs

Although outliers were not removed for analysis, the graphs for event rates (i.e., excessive speeding triggers, excessive speeding text messages to parents, excessive maneuvers, calls made, texts sent) presented in this Results chapter were cleaned post analysis because the extreme values obscured the general trends for some variables. Mileage was examined per participant for each four-week time period to determine whether the mileage value fell below one mile for the time period. If mileage fell below one mile for a four-week time period for a participant the event rate for that time period was not included in the graph. This minimized changes to the graphs to ensure the trends graphed matched the analysis outcomes, while preventing large outliers from skewing the graph for data presentation. For example, one excessive maneuver detected in a half mile of driving would result in an event rate of two events per mile driven for that time period, whereas almost all event rates across time periods and participants were <1/mile driven. The turning rate graphs are presented here as an example of the method used to account for extreme outliers when graphing the data to see trend lines. Figure 8 shows the excessive maneuver for turning rate graph using the raw data, while Figure 9 is the graph created by removing outliers using the method described above. The large bumps are due to several extremely high values in Figure 8 that obscure the trend line visible in Figure 9 and Figure 10 (spaghetti plot showing trend line and individual participant data lines to demonstrate subject variability). The minor cleaning of the data for graphical presentation ensures the trends observed in the data are visible in the graphs. Overall, fewer than 2% of time periods per graph were cleaned (see Table 9).

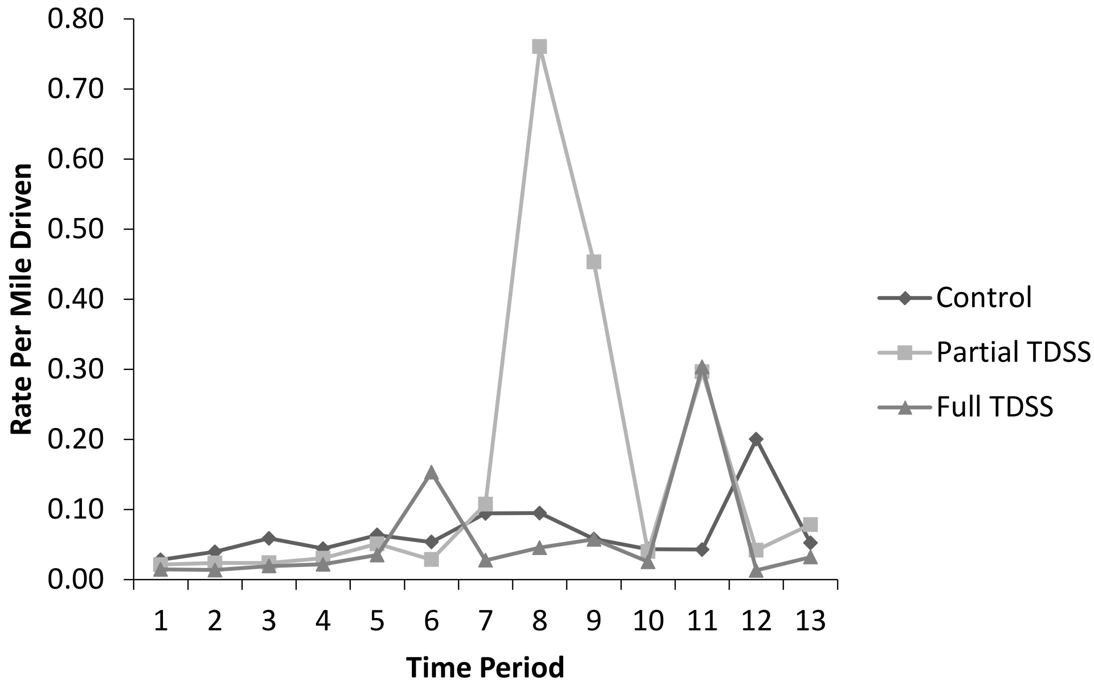


Figure 8. Turning event rates graph raw data (outliers included).

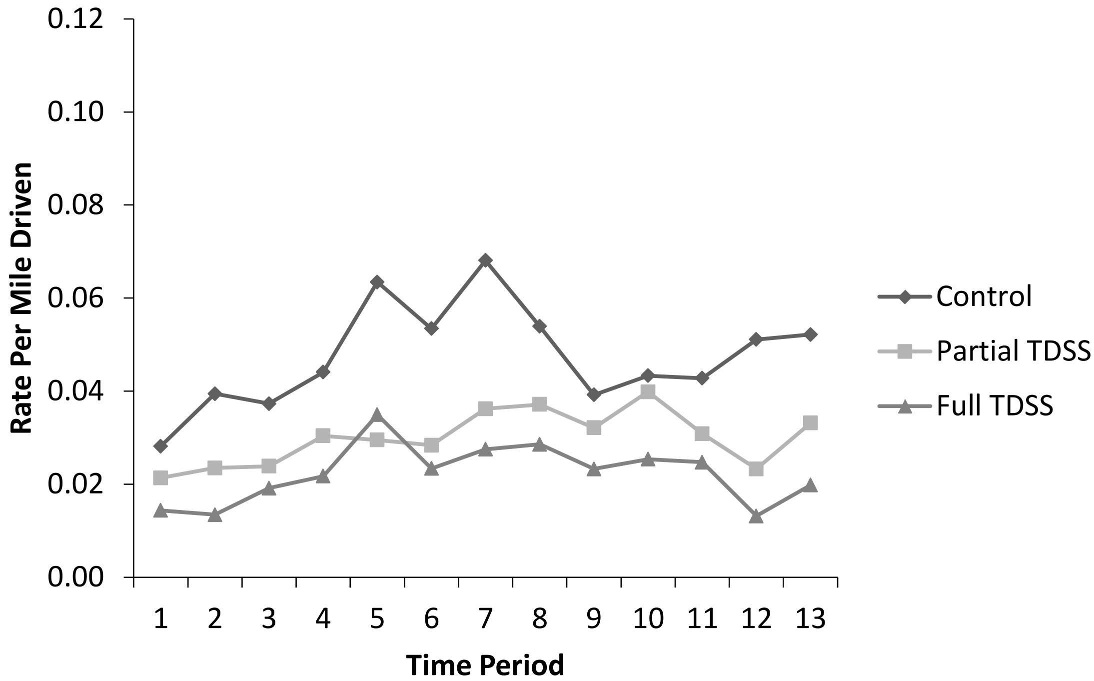


Figure 9. Turning event rates graph outliers removed.

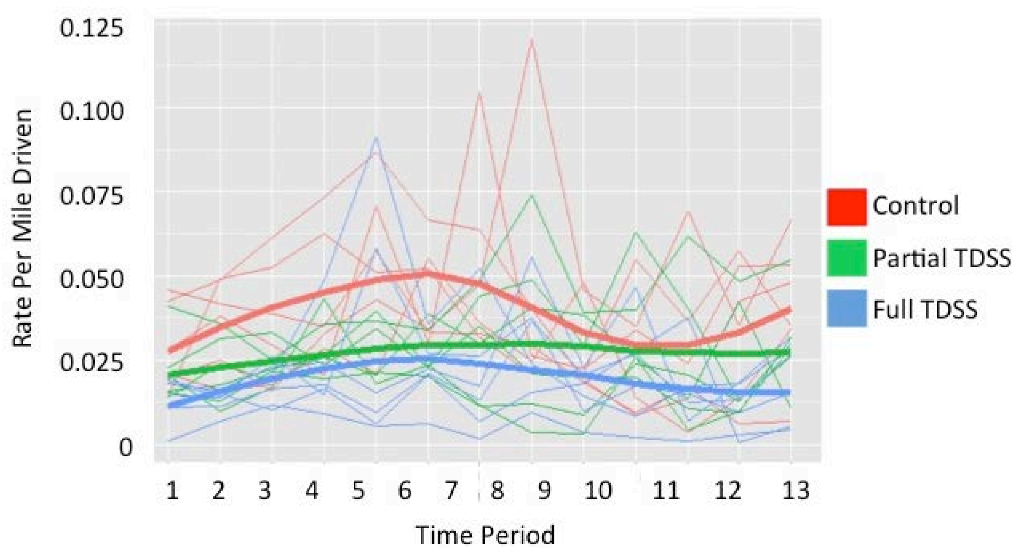


Figure 10. Turning event rates spaghetti plot showing data trend line for each group as well as participant lines.

Table 9. Percentage of time periods removed per group per dependent variable for associated graphs.

	Control	Partial TDSS	Full TDSS	Total
Excessive Speed Warnings Triggered	0.66%	0.43%	0.48%	1.57%
Speeding Text Messages to Parents	0.62%	0.39%	0.79%	1.80%
Acceleration Events	0.92%	0.66%	0.52%	2.09%
Braking Events	0.91%	0.51%	0.40%	1.83%
Turning Events	0.98%	0.72%	0.55%	2.24%
Calls Made	0.57%	0.37%	0.37%	1.31%
Texts Sent	0.60%	0.37%	0.37%	1.34%

Parent Mode Usage

The rate of Parent Mode usage was examined across groups to determine the frequency with which teenagers and parents shut off the data collection when the teenager was not driving. This examination of Parent Mode indicated similar usage between the partial TDSS (activated 1727 times) and full TDSS groups (activated 1679 times), but statistically significantly less usage in the control group (activated 460 times) compared to both the partial TDSS and full TDSS groups (p<0.05). The difference in usage from the TDSS groups is possible for a number of reasons, but it is difficult to ascertain exactly why that group had fewer parent mode activations. For example, it is possible that teenage participants in the control group drove less frequently with their parents; however, the self-reported data on supervised driving indicated that, at least early in the study, parents reported supervised driving as often in the control group as in the partial TDSS group (see Supervised Driving below).

It is more likely that teenagers and parents in the control group were less motivated to turn off the data collection application because the teenager was able to use their phone as a passenger in the vehicle. Control group participants received two out-of-mount warnings at vehicle start-up to alert them the system was running, but after that there were no other alerts other than the Teen Driver Study (TDS) icon in the application tray to indicate the software was running. In contrast, the TDSS group participants could not use their phones and would experience the system warnings as a passenger, thus providing more impetus to turn off the data collection as a passenger. Based on this evaluation, it is possible that the control group data for teenagers who shared a vehicle with another driver might contain data from other drivers. Parents in both TDSS groups, however, reported during debriefing that data collection was not always turned off when their teenager was a passenger either.

The control group served the important purpose of providing a naturalistic view of teenage driver behavior across the first year of driving, and served as the baseline against which behavior in the TDSS groups was examined. Therefore, it was important to determine the extent to which the full data set was representative of the teenage drivers in the study. To accomplish this, the data set associated with teenagers who did not share a vehicle with their parents was examined for each of the variables to determine if the trends between groups were similar for unshared vehicles compared with the entire data set. Unshared vehicles made up approximately 30% of each group, which was a sufficient sample size to conduct supplementary comparisons of trends between groups. The unshared vehicle data represent a subset for which it is highly probable the observed behaviors are those of the teenager participants. If the behavioral trends for the unshared vehicle subset match the full dataset the analyses can be conducted on the larger dataset are likely representative of the teenage participants' behavior. Overall, the behavioral trends observed for unshared vehicles and the full dataset were similar when the data were visually inspected, with the exception of vehicle mileage driven (see Driving Characteristics of the Teenage Sample section below).

Vehicle status was also included as a predictor of behavior in the analyses to identify variables in which sharing or not sharing a vehicle might have influenced behavior. However, differences in how teenagers drive, in general, likely exist when teenagers share a vehicle versus not sharing a vehicle. For example, sharing a vehicle naturally lends opportunities for parents to sit in the passenger seat while the teenager drives somewhere, allowing for more supervised driving time, regardless of treatment condition. The unshared data alone are, therefore, insufficient for identifying the main differences between the treatment groups and the potential differences between teenagers who share and do not share a vehicle with another family member were evaluated.

TDSS Dependent Variables Not Analyzed

Throughout the study and at the conclusion of the study, data for each identified variable were examined to determine whether the variable was being collected accurately. Although evaluation of the map database for stop signs indicated it might be sufficient to make some estimates of stop sign violations, it was determined early in the study that the commercial database for stop signs in the Twin Cities Metro area was insufficient. This was likely due to recruitment in suburban communities of the Twin Cities Metro area that had lower coverage than expected for the map because of their proximity to uncovered rural areas. It was known that non-Metro areas would not have a stop sign database and, thus, data were only expected to be collected for the Metro area communities. Participants in some areas reported a significant number of stop sign violation detections because the stop sign had been replaced with a traffic light between the last time the map was updated and the beginning of this study. Additionally, although instructions were provided to help participants more effectively interact with the passenger detection sensors (i.e., keep the footwells clear of bags and equipment), there was still a high rate of false positives reported by participants who found it difficult to adhere to the need to keep the footwells clear. The problems with passenger detection in this study were similar to issues encountered in the study conducted by Manser et al. (2013), such as not being able to distinguish a backpack from a passenger. Therefore, stop sign and passenger data were not evaluated in this study.

Primary Analyses

The GLMM models were conducted in SAS 9.4 (GLIMMIX procedure) and used the pseudo-likelihood estimation technique and were modeled to account for overdispersion and random effects. The model was a 3 (Group: control, partial TDSS, full TDSS) x 13 (Time Period, 1-13) analysis where group was a between-subjects analysis and time period was a within-subjects analysis. Interactions for group by time period were analyzed to determine if any changes in behavior that occurred over time were different between groups. For example, it could be expected that the control group would increase their speed over time as identified in previous naturalistic studies of teenage drivers (Simons-Morton, Ouimet, et al., 2012), whereas the full TDSS group might show the same increase over time due to the effect of the system monitoring and reporting features. The following fixed effects were included in the model based on the study goals and on the literature review:

- Group: identified whether the groups differed from each other in behavior, but did not distinguish which groups differed from one another,
- Time: main effect of changes in behavior over time,
- Time x Group: interaction effect of changes in behavior within a group over time compared to changes in other groups over time,
- Gender: evaluation whether being male or female influenced teenager driver behavior,
- Vehicle status: evaluation of whether a teenager shared a vehicle or did not share a vehicle influenced teenager driver behavior, and
- Sensation seeking: Arnett Inventory of Sensation Seeking (Arnett, 1994; see Appendix C) scores were calculated and included in the model (continuous variable) to evaluate whether sensation seeking influenced behavior.

Variables were entered into the model in one step and were evaluated using Type III tests for fixed effects (SAS 9.4). If a statistically significant main effect of group was identified, Tukey-Kramer post hoc tests with an adjusted alpha to account for Type I error were conducted to identify specific group differences. The Tukey-Kramer is a single-step, multiple comparison procedure and is considered a conservative between-groups mean comparison. The adjustment to the alpha for the Tukey-Kramer took into account the number of tests being conducted (i.e., alpha is automatically adjusted to be lower than 0.05 for the post hoc tests between the three groups).

The results are presented in the following order:

1. Driving characteristics of the teenage sample
2. Speeding

3. Excessive maneuvers
4. Cellular phone use while driving
5. Seat belt use
6. Self-reported crashes and violations
7. Self-reported parent and teen interaction outcomes
8. System usability results

Driving Characteristics of the Teenage Sample

Because of the lower use of parent mode in the control group, the average mileage driven between groups was analyzed for each group to determine if differences in mileage occurred between the groups. It was expected that average mileage for the control might be higher because of the less frequent use of parent mode in that group. These analyses considered the differences between groups for the entire data set, as well as examined differences in the shared and unshared vehicle data sets to determine where differences in mileage occurred for these groups. For this analysis, the data were analyzed using 3 (Group: control, partial TDSS, full TDSS) x 13 (Time period: 1-13) mixed-model analysis of variance (ANOVA) in which group was a between-subjects factor and time period was a within-subjects factor. Independent t-tests were conducted as follow-ups with a Bonferonni correction to adjust for the number of tests (alpha of 0.05/3=0.016) for each ANOVA (full, shared, unshared).

For all vehicles (full data set), there was a main effect of group, $F(2,271)=10.50$, $p<0.001$, in which the control group (M=303.84; SD=254.13) drove, on average, statistically significantly more miles over the study time period than the partial TDSS (M=231.87; SD=198.02) and full TDSS groups (M=203.43; SD=183.02), (see Figure 11).

There was no statistically significant difference between the partial TDSS and full TDSS groups for mileage driven across the study ($p > 0.05$).

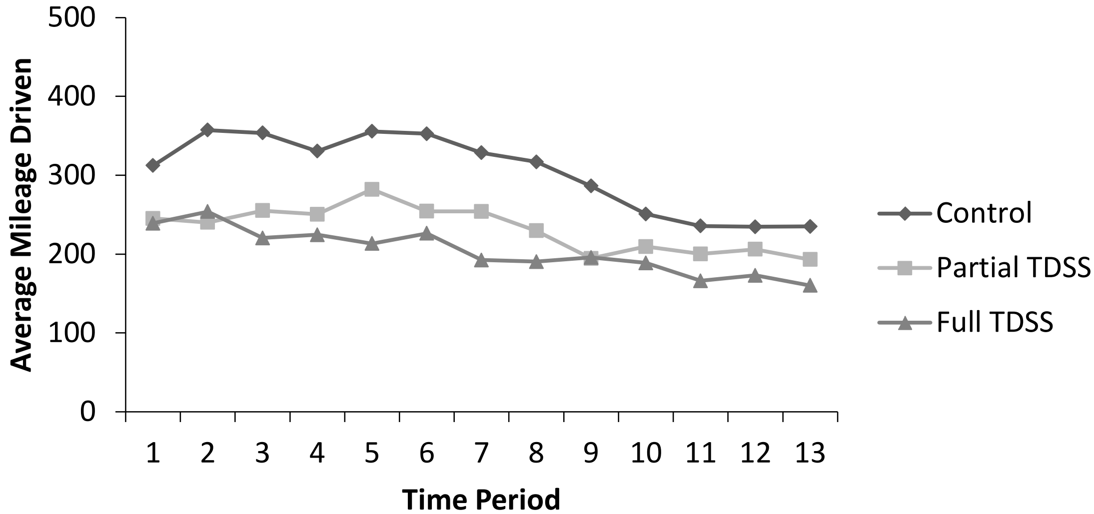


Figure 11. Comparison of average mileage driven across time periods by group for full data set.

For the unshared vehicles, there was a statistically significant main of group, $F(2,95)=10.35$, $p<0.001$, in which both the control ($M=369.42$; $SD=288.06$) and the partial TDSS ($M=319.92$; $SD=225.24$) groups drove significantly more miles, on average, than the full TDSS group ($M=192.74$; $SD=157.75$; p's<0.016). The partial TDSS group had the highest mileage across the study periods for unshared vehicles. There was no difference in average mileage driven between control and partial TDSS groups ($p>0.016$). There was also a statistically significant main effect of time in which the average mileage per group decreased from the beginning to the end of the study, $F(12,1140)=11.66$, $p=0.001$ (see Figure 12).

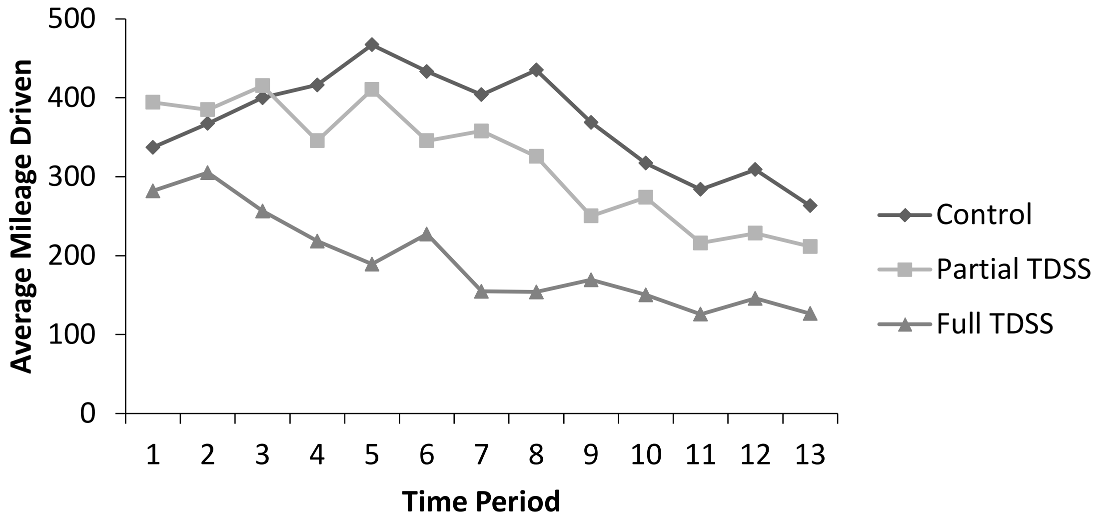


Figure 12. Comparison of average mileage driven across time periods by group for unshared vehicle data set.

For the shared vehicle dataset there was a statistically significant effect of group, $F(2,173)=4.58$, $p=0.01$, in which the control group ($M=261.68$; $SD=219.78$), on average, drove statistically significantly more miles on average than the partial TDSS ($M=187.12$; $SD=165.72$) and the full TDSS groups ($M=209.05$; $SD=194.85$). There was also a marginally statistically significant main effect of time in which the average mileage per group decreased from the beginning to the end of the study, $F(12,2076)=4.05$, $p=0.05$ (see Figure 13).

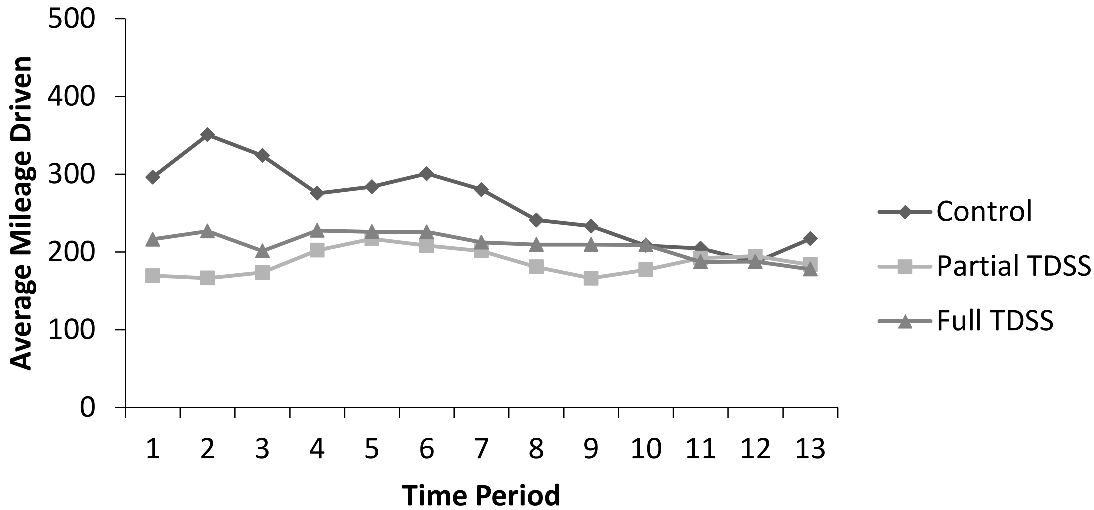


Figure 13. Comparison of average mileage driven across time periods by group for shared vehicle data set.

<u>Supervised Driving After Licensure</u>

Parents were asked to report how frequently they engaged in supervised driving with their teenager in the previous month at three points in time (Month 1, Month 6, and Month 12 of the study). A majority (69% plus at Month 1 and 87% plus at Month 12) of parents in both the shared and unshared vehicle datasets reported most commonly that they “never,” “hardly ever” or only “sometimes” engaged in supervised driving with their teenagers after they received their licenses. Teenagers who shared a vehicle with another family member had parents who reported they engaged more frequently (e.g., often, very often, or always) in supervised driving during the previous month at each survey period (see Table 10). Although reported supervised driving (i.e., parent in the vehicle) decreased over time for all teenagers, frequent supervised driving remained equivalent across the three study groups for shared vehicles in the final month of driving. The only group with any reported frequent supervised driving in the unshared vehicle group at Month 12 was the full TDSS group.

Table 10. Percentage of parents reporting how frequently they supervised their teen's driving*

	Month 1		Month 6		Month 12	
	Unshared	Shared	Unshared	Shared	Unshared	Shared
Control	9%	31%	6%	11%	0%	11%
Partial TDSS	3%	31%	6%	20%	0%	13%
Full TDSS	13%	17%	0%	16%	10%	10%

* Combined often, very often, or always responses

Summary of Mileage and Supervised Driving Results

- Teenagers in the control and partial TDSS groups who drove their own vehicle (unshared) drove more miles, on average, than teenagers in these groups who shared a vehicle with another family member.
- Teenage drivers of shared and unshared vehicle drove fewer miles on average as the study progressed.
- For average mileage driven, the shared vehicle dataset matched the full data set (i.e., partial and full TDSS similar), while the unshared vehicle data were different (i.e., control and partial TDSS similar). The similarity between the shared data set and the full data set for mileage driven lends support to the assumption that some data in the full data set are likely not associated with the teenage drivers for any of the groups.
- Parents who shared a vehicle with their teenage driver self-reported engaging in supervised driving more frequently.

- Parents in the full TDSS group reported more supervised driving of teenagers who did not share a vehicle than did parents in the control and partial TDSS groups.
- Supervised driving of teenagers who shared a vehicle with another family member was highest in the control and partial TDSS groups in the first month of driving, but was similar across all three groups at Month 6 and Month 12.

Speeding Behaviors

Speeding was analyzed by examining several variables related to excessive speeding: percentage of excessive speeding, rate of excessive speeding warnings triggered, and rate of text messages sent (or would have been sent) to parents. Based on previous research, the expected outcomes for this study associated with speeding were hypothesized to differ based on whether teenagers and/or parents received feedback:

1. The percentage of excessive speeding (i.e., driving 7 mph or greater over the posted speed limit) miles would be lower for both the partial and full TDSS groups compared to the control group because the alert was persistent and repetitive in both groups. The full TDSS group was expected to have the lowest percentage of speeding miles because of the parental notification.
2. The full TDSS group was expected to have the lowest rate of text messages sent for speeding because of parental notification (i.e., they would slow down to cancel the text message).
3. It was expected that the percentage of time spent of speeding in the control group would increase over time as drivers gained experience.

Excessive Speeding

There was a statistically significant main effect of group, in which the full TDSS and partial TDSS groups both had significantly lower percentages excessive speeding miles, on average, compared to the control group (see Table 11, Figure 14). The differences between the partial and full TDSS groups and the control existed during daytime and nighttime driving in addition to the full driving data. There was also a statistically significant effect of time on speeding behavior. On average, the percentage of excessive speeding miles increased across all groups from the beginning of the study to the end of the study. Figure 15 shows the data trends for the unshared vehicle group data, which follow the same trends for each study group as the full data set.

Participants in the control (11%) and partial TDSS (5%) groups with their own vehicles had marginally significantly higher percentages of excessive speeding miles compared to participants in the same groups who shared vehicles with another family member (9% in Control; 3% in partial TDSS). The overall percentage of excessive speeding miles was consistent between shared (2%) and unshared (2%) vehicles for the full TDSS group compared to the other groups.

Table 11. Summary of statistical results for the percentage of excessive speeding miles.

	Statistic	*p*-value
Group	$F = 42.84$	<0.0001*
Full TDSS vs. Control	$t = -7.90$	<0.0001**
Partial TDSS vs. Control	$t = -5.71$	<0.0001**
Full TDSS vs. Partial TDSS	$t = -2.31$	0.083
Time	$F = 56.16$	<0.0001*
Time x Group	$F = 2.51$	0.104
Vehicle Status	$F = 3.81$	0.052
Gender	$F = 0.01$	0.936
SSS	$F = 3.33$	0.069

* Significant at p<0.05
** Significant using Tukey-Kramer adjusted *p*-values to account for Type I errors in post hoc testing.

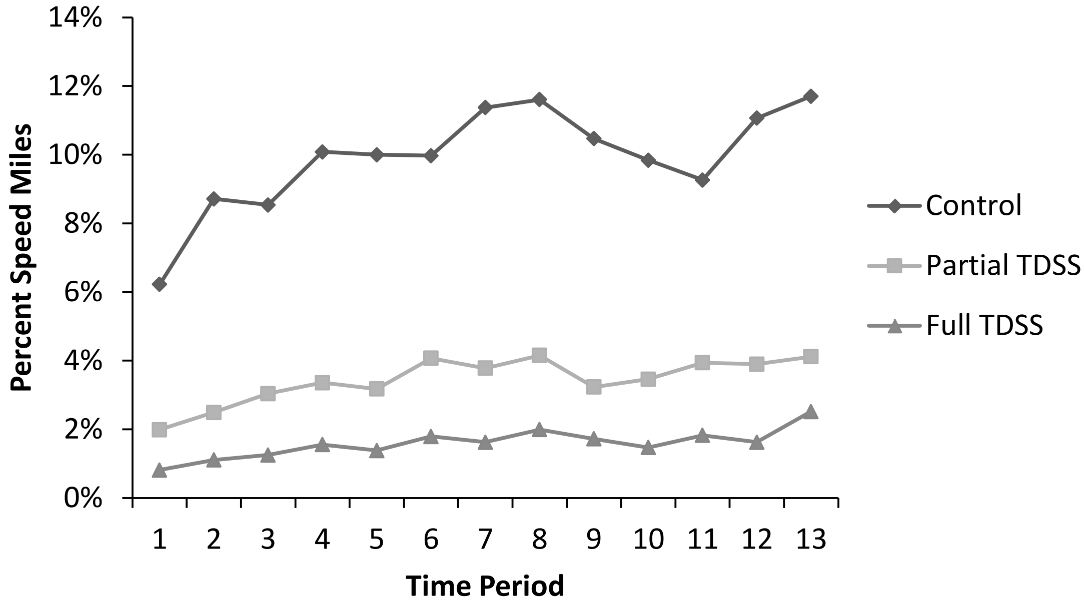


Figure 14. Percentage of excessive speeding miles by group and time for the full dataset.

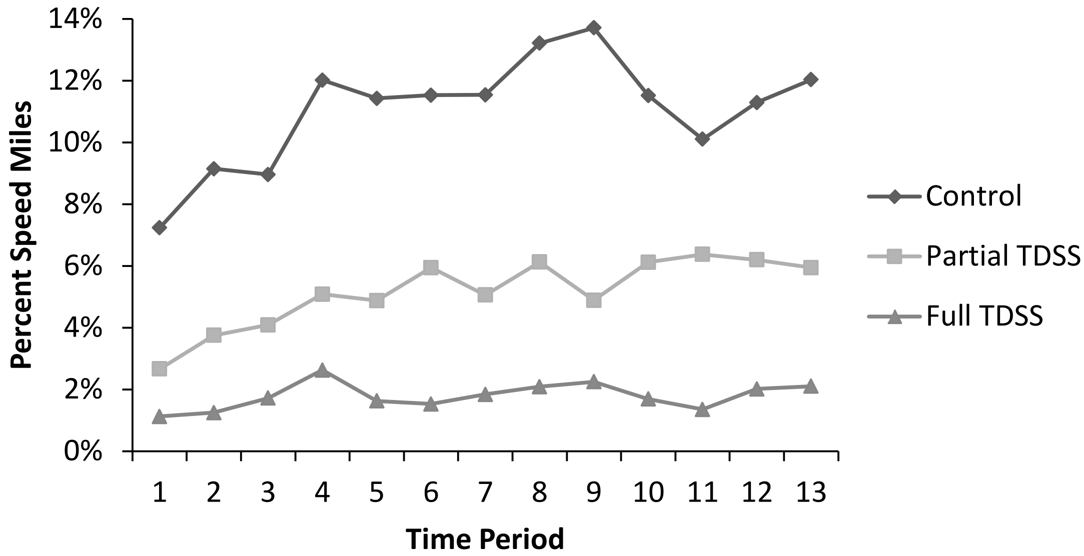


Figure 15. Percentage of excessive speeding miles by group and time for unshared vehicle dataset.

Excessive Speeding Warnings

An excessive speeding warning occurred when the driver hit 7 mph. Because speeding behavior increased over time for all groups, it was expected that the participants in the partial and full TDSS groups would spend a higher percentage of miles driving near the threshold that triggered the excessive speeding warning. Examining the rate of excessive speeding warnings provided an understanding of how teenage drivers adapted to the system’s feedback and thresholds over time.

There was a statistically significant main effect of group, in which the full TDSS and partial TDSS groups both had significantly lower rates of excessive speeding warnings than the control group (see Table 12, Figure 16). A statistically significant effect of time also existed in that, on average, the rate of excessive speed warnings increased from the beginning to the end of the study. Figure 17 shows the data trends for the unshared vehicle group data, which follow the same trends for each study group as the full data set.

Table 12. Summary of statistical results for rate of excessive speeding warnings for full dataset.

	Statistic	*p*-value
Group	F = 23.30	<0.0001*
Full TDSS vs. Control	t = -5.49	0.0002**
Partial TDSS vs. Control	t = -4.86	0.0007**
Full TDSS vs. Partial TDSS	t = -0.71	0.762
Time	F = 97.50	<0.0001*
Time x Group	F = 0.66	0.529
Vehicle Status	F = 2.72	0.101
Gender	F = 0.04	0.841
SSS	F = 2.05	0.154

* Significant at $p<0.05$
** Significant using Tukey-Kramer adjusted *p*-values to account for Type I errors in post hoc testing.

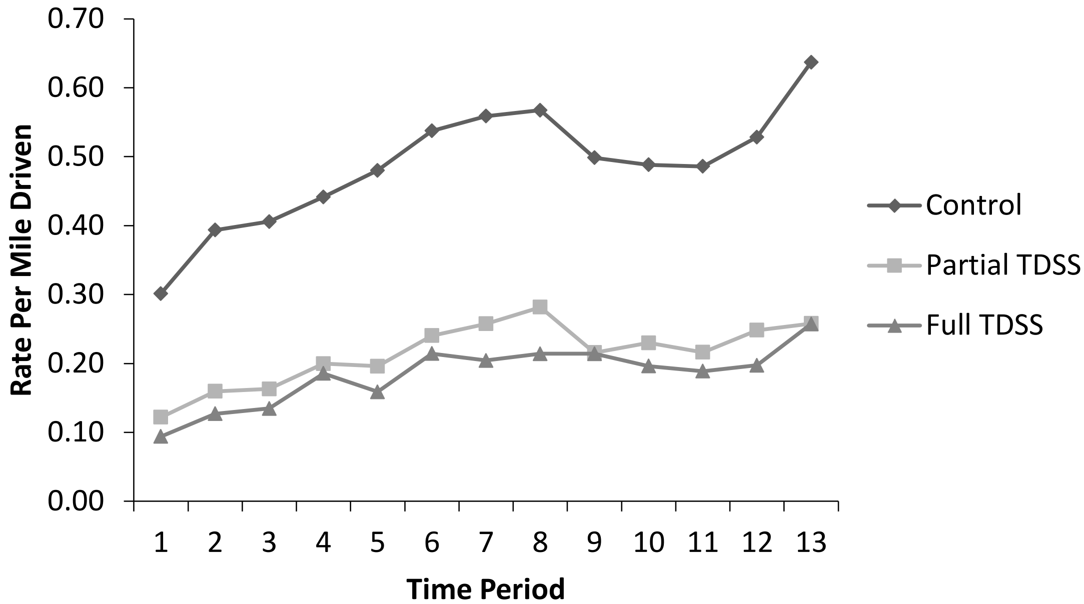


Figure 16. Rate per mile driven of excessive speeding warnings by group and time for full dataset.

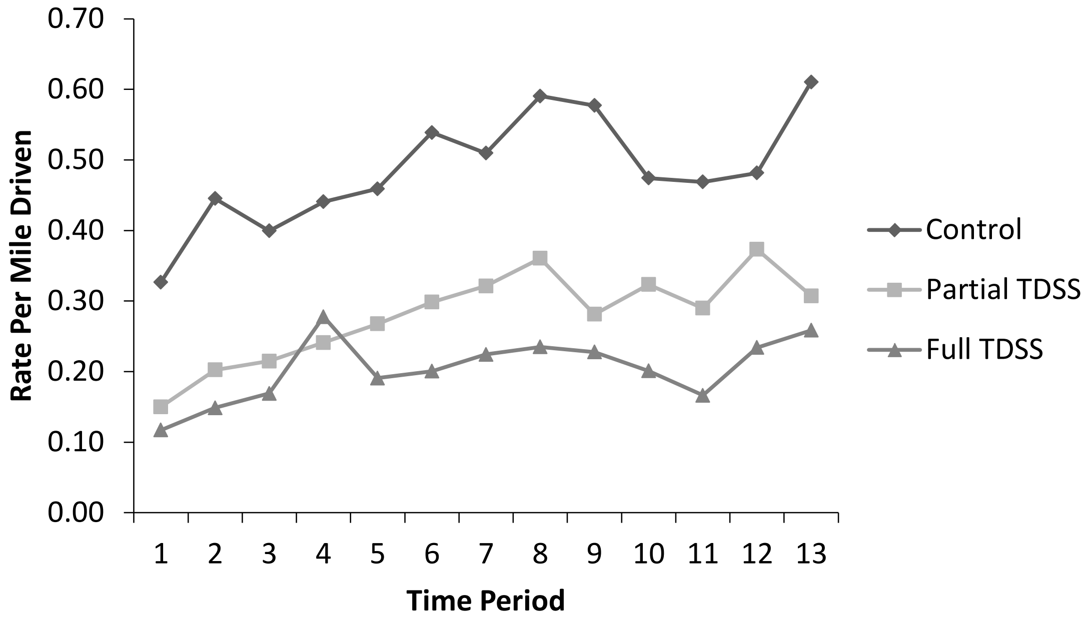


Figure 17. Rate per mile driven of excessive speeding warnings by group and time for the unshared vehicle dataset.

<u>Speeding Text Messages Sent to Parents</u>

The rates of speeding-related text messages that were sent to parents or would be sent to parents based on the TDSS speeding algorithm were collected and analyzed. In the full TDSS group, parents received a text message if the teenage driver failed to cancel the excessive speeding alert by slowing down. No messages were sent in the partial TDSS or control groups, but the algorithm was applied to the data collected in real-time based on speeding behaviors, and if a text message would have been sent, it was logged in the data files for the partial TDSS and control groups.

There was a statistically significant main effect of group, in which both the partial TDSS and the full TDSS groups had significantly lower rates of text messages sent compared to the control group (see Table 13, Figure 18). There was also a statistically significant difference between the partial TDSS and full TDSS groups in which the full TDSS group had a significantly lower rate of text messages sent to parents, on average, than the partial TDSS group. Figure 19 shows the data trends for the unshared vehicle group data, which follow the same trends for each study group as the full data set.

That average rate of text messages sent across all groups statistically significantly increased from the first month of the study through the last month of the study, although the interaction of time x group was marginally significant (p=0.08). The marginal interaction effect is due to the full TDSS group maintaining an almost consistent rate of speeding text messages to parents over time while the other two groups showed increases over time. Higher sensation seeking scores were statistically significantly associated with increased rates of text message to parents.

Table 13. Summary of statistical results for speeding text messages sent to parents for full dataset.

	Statistic	*p*-value
Group	F = 52.44	<0.0001*
Full TDSS vs. Control	t = -10.48	<0.0001**
Partial TDSS vs. Control	t = -6.18	<0.0001**
Full TDSS vs. Partial TDSS	t = -4.61	0.0002**
Time	F = 22.26	<0.0001*
Time x Group	F = 2.80	0.080
Vehicle Status	F = 2.35	0.127
Gender	F = 0.29	0.592
SSS	F = 4.16	0.043*

* Significant at p<0.05
** Significant using Tukey-Kramer adjusted *p*-values to account for Type I errors in post hoc testing.

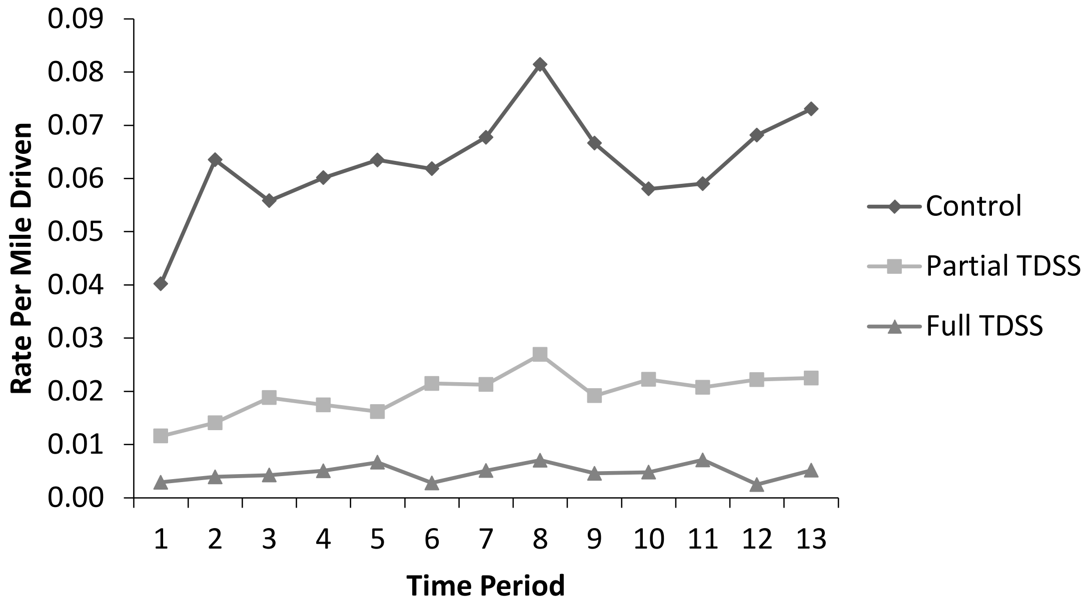


Figure 18. Rate per mile driven of speeding text messages sent to parents for full dataset.

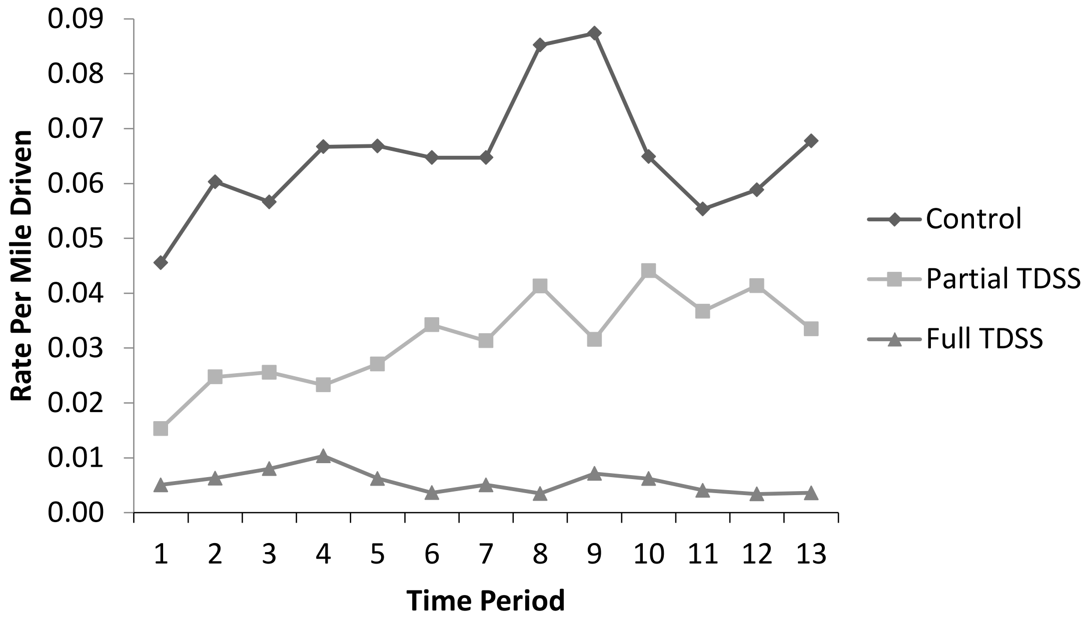


Figure 19. Rate per mile driven of speeding text messages sent to parents for unshared vehicle dataset.

The average rate of speeding text messages sent to parents in the full TDSS group with parent monitoring remained low throughout the study. However, the rate at which teenager drivers in this group triggered the excessive speeding warning increased, indicating that participants adapted to the system warnings and were driving closer to the threshold more often. Figure 20 shows the comparison of triggered warnings for excessive speeding compared to the rate of text messages. Participants in the full TDSS group triggered the alert more frequently over time, but remained responsive to slowing down to cancel the alert before a message was sent to parents.

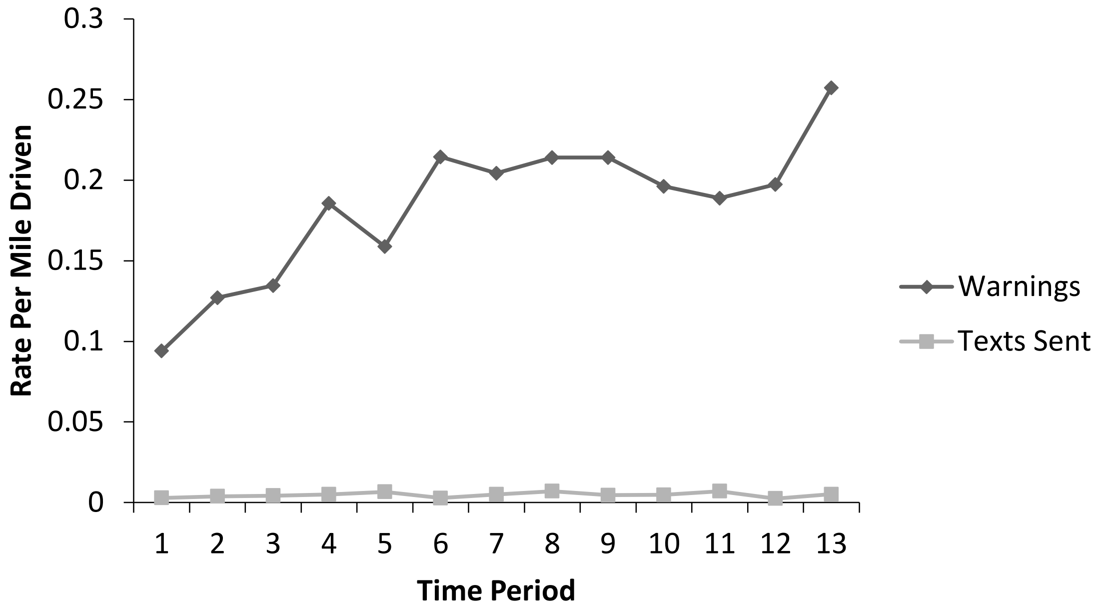


Figure 20. Comparison of the rate of excessive speeding warnings and speeding texts sent to parents for the full TDSS group.

<u>Summary of Speeding Results</u>

- The full TDSS group had significantly fewer miles driven while speeding, a significantly lower rate of triggered excessive speeding warnings, and a significantly lower rate of speeding text messages sent to parents than the control group.
- The partial TDSS group also had significantly fewer miles driven while speeding, a significantly lower rate of triggered excessive speeding warnings, and a significantly lower rate of sent text messages than the control group.
- There was a statistically significant main effect of time for all the speeding variables, with speeding behaviors increasing from the beginning to the end of the

study. The full TDSS group started with lower speeding behaviors and those behaviors remained below those of the other groups for all variables.

- Higher propensity towards sensation seeking was associated with an increased rate of text messages sent to parents (or would have been sent for control and partial TDSS groups).
- Vehicle status was marginally associated with increased excessive speeding, with unshared vehicle drivers, on average, having a higher percentage of miles driven while speeding compared to those who shared a vehicle with another family member.

Excessive Maneuvers

Alerts triggered for excessive maneuvers were analyzed by examining the three variables: excessive acceleration, excessive braking, and hard turning (left and right combined). Based on previous research, it was expected that differences would exist depending on the influence, or lack thereof, of parental feedback and system monitoring. Overall, it was expected that:

1. The rate of excessive maneuvers would be lowest in the full TDSS group (with parent monitoring).
2. The rate of excessive maneuvers would be lower in the partial TDSS group (in-vehicle feedback only) compared to the control group.
3. The rate of excessive maneuvers would decline over time for groups receiving in-vehicle and/or parent monitoring feedback (partial TDSS and full TDSS, respectively).

Acceleration Events

On average, the full TDSS group had a significantly lower rate of acceleration events for the full dataset and the daytime data (see Table 14, Figure 21). Vehicle status was statistically significant associated with acceleration events, with shared vehicle drivers (*M*=0.02; *SD*=0.08) having a lower rate of acceleration events per mile driven than drivers who did not share a vehicle (*M*=0.03; *SD*=0.07). Figure 22 shows the data trends for the unshared vehicle group data, which follow the same trends for each study group as the full data set. Despite the significant difference in acceleration rate between unshared and shared vehicles, the practical difference (0.01) was nominal and the unshared data set trends matched the full data set (Figure 24)

Table 14. Summary of statistical results for the rate of acceleration events.

	Statistic	*p*-value
Group	$F = 4.59$	0.028*
Full TDSS vs. Control	$t = -3.07$	0.021**
Partial TDSS vs. Control	$t = -0.64$	0.801
Full TDSS vs. Partial TDSS	$t = -2.44$	0.069
Time	$F = 0.66$	0.425
Time x Group	$F = 0.23$	0.793
Vehicle Status	$F = 5.30$	0.022*
Gender	$F = 1.10$	0.296
SSS	$F = 0.02$	0.897

* Significant at p<0.05
** Significant using Tukey-Kramer adjusted p-values to account for Type I errors in post hoc testing.

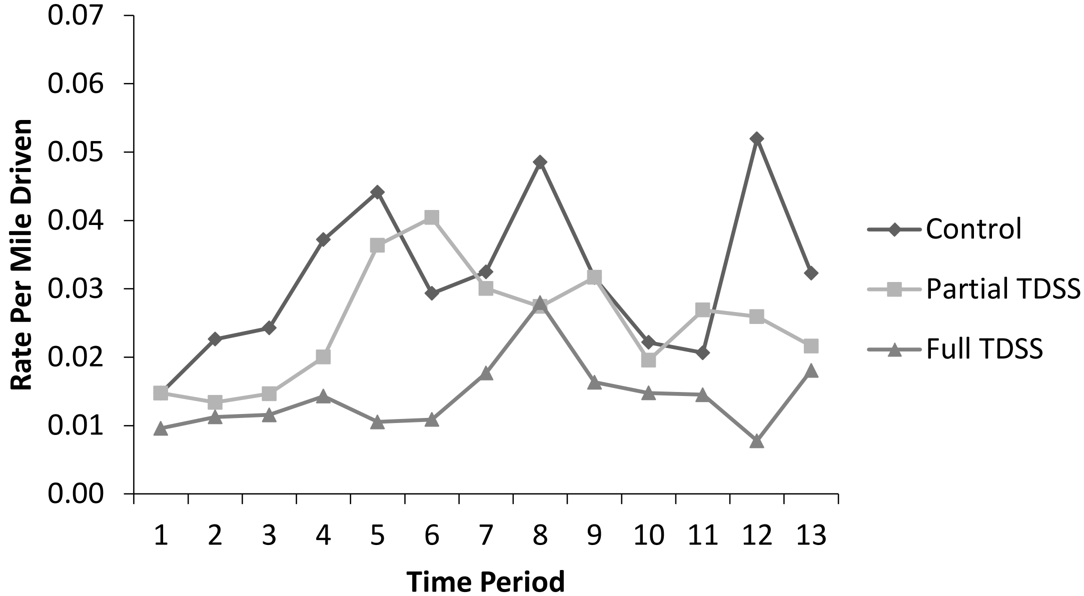


Figure 21. Rate of acceleration events by group and time for the full data set.

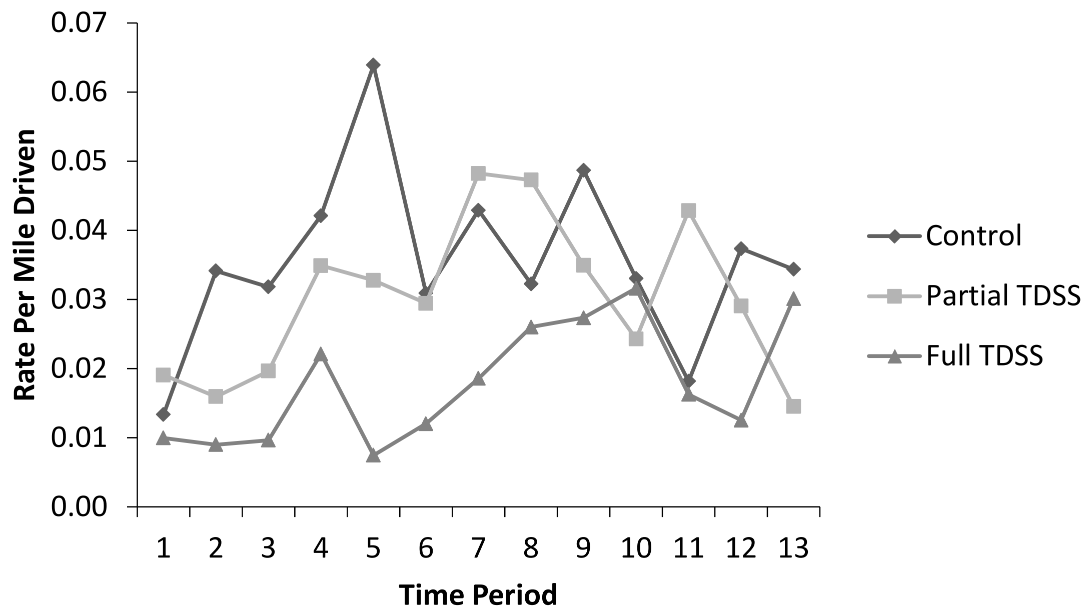


Figure 22. Rate of acceleration events by group and time for the unshared vehicle dataset.

<u>Braking Events</u>

There was a statistically significant main effect of group for the rate of braking events per mile driven; however, post hoc testing indicated only a marginally significant difference between the full TDSS group and the control group (see Table 15). The trend indicated a lower rate of triggered braking events for the full TDSS group compared to the control group (see Figure 23). The unshared vehicle trends are similar to the full dataset (see Figure 24).

There was a statistically significant main effect of time, where, on average, the rate of braking events decreased throughout the study.

Table 15. Summary of statistical results for the rate of braking events.

	Statistic	p-value
Group	F = 5.84	0.013*
Full TDSS vs. Control	t = -2.45	0.065
Partial TDSS vs. Control	t = 0.38	0.924
Full TDSS vs. Partial TDSS	t = -2.07	0.128
Time	F = 76.85	<0.0001*
Time x Group	F = 1.75	0.206
Vehicle Status	F = 0.01	0.916
Gender	F = 1.35	0.246
SSS	F = 0.31	0.578

* Significant at p<0.05

** Significant using Tukey-Kramer adjusted p-values to account for Type I errors in post hoc testing.

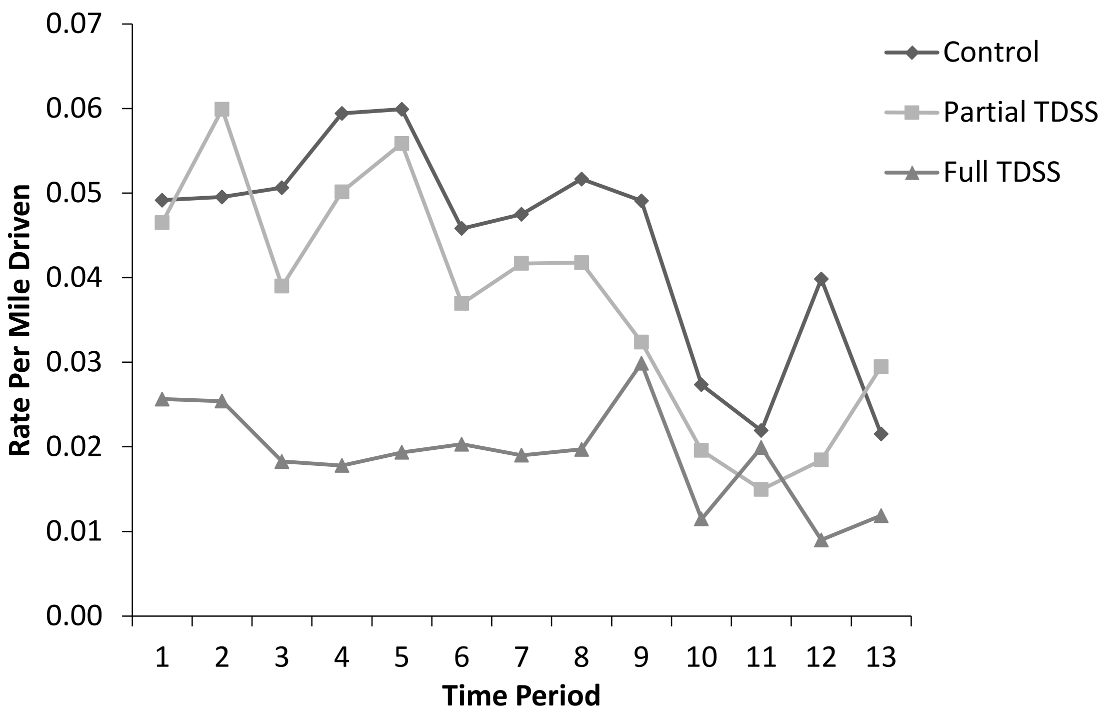


Figure 23. Rate of braking events by group and time for full data set.

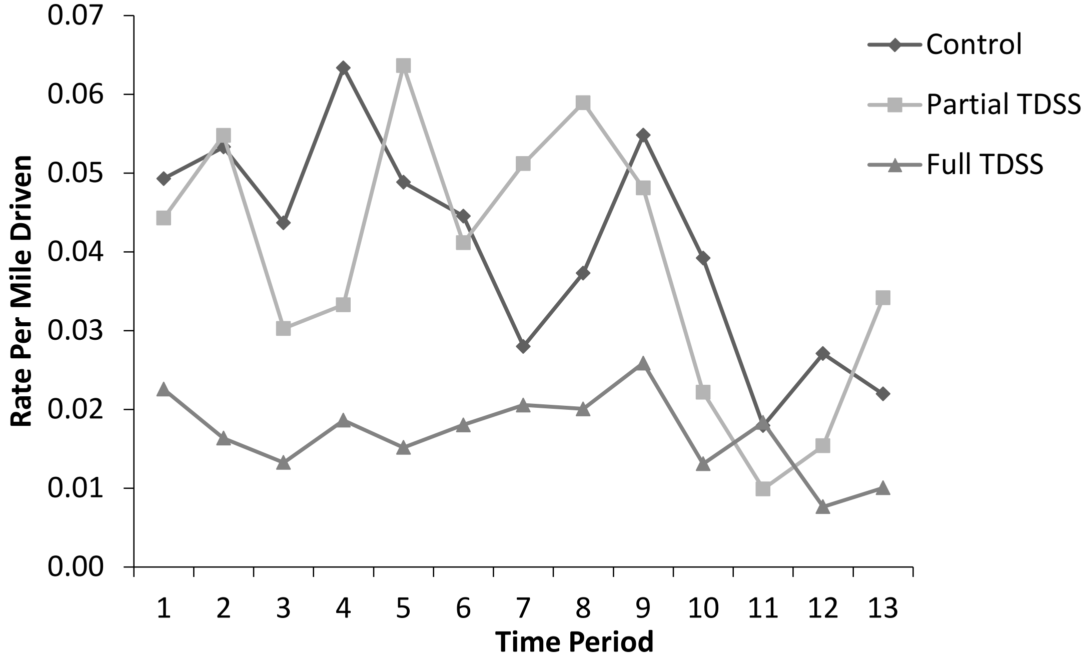


Figure 24. Rate of braking events by group and time for the unshared vehicle dataset.

Turning Events

The full TDSS group had a statistically significantly lower rate of turning events (left and right combined) compared to the control group (see Table 16, Figure 25). There were no differences between the partial TDSS and control groups for rate of turning events, and no main effects or interactions of time occurred. Gender was statistically significant overall; male participants (*M*=0.043; *SD*=0.12) had a significantly higher rate of turning events across the entire study compared to female participants (*M*=0.029; *SD*=0.09). Vehicle status was also a statistically significantly associated with turning events overall, with drivers of unshared vehicles (*M*=0.047; *SD*=0.11) having a higher rate of events compared to drivers who shared a vehicle with another family member

(M=0.029; SD=0.10). The trends for the unshared vehicle data were somewhat different from the full dataset with higher rates at different time periods visible for the control and partial TDSS groups in particular, but the higher rates for the full TDSS group also exist (see Figure 26).

Table 16. Summary of statistical results for the rate of turning events by dataset

	Statistic	p-value
Group	F = 6.11	0.012*
Full TDSS vs. Control	t = -3.16	0.017**
Partial TDSS vs. Control	t = -1.09	0.533
Full TDSS vs. Partial TDSS	t = -2.07	0.131
Time	F = 0.25	0.622
Time x Group	F = 1.34	0.291
Vehicle Status	F = 10.07	0.002*
Gender	F = 5.33	0.022*
SSS	F = 0.06	0.811

* Significant at $p<0.05$

** Significant using Tukey-Kramer adjusted p-values to account for Type I errors in post hoc testing.

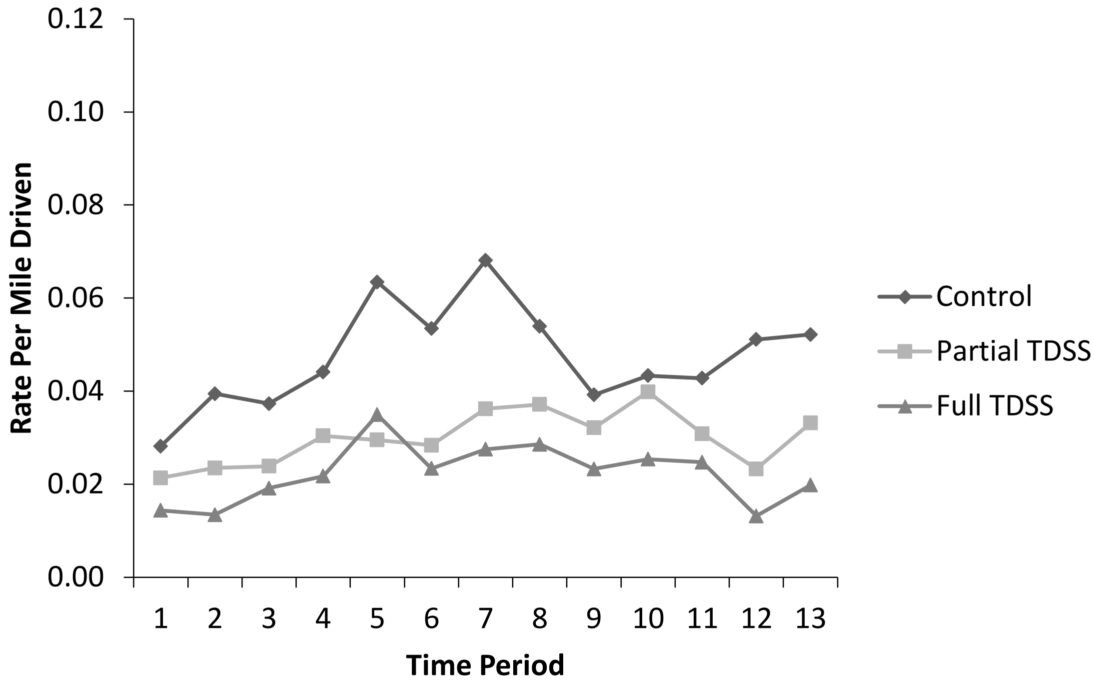


Figure 25. Rate of turning events by group and time for the full dataset.

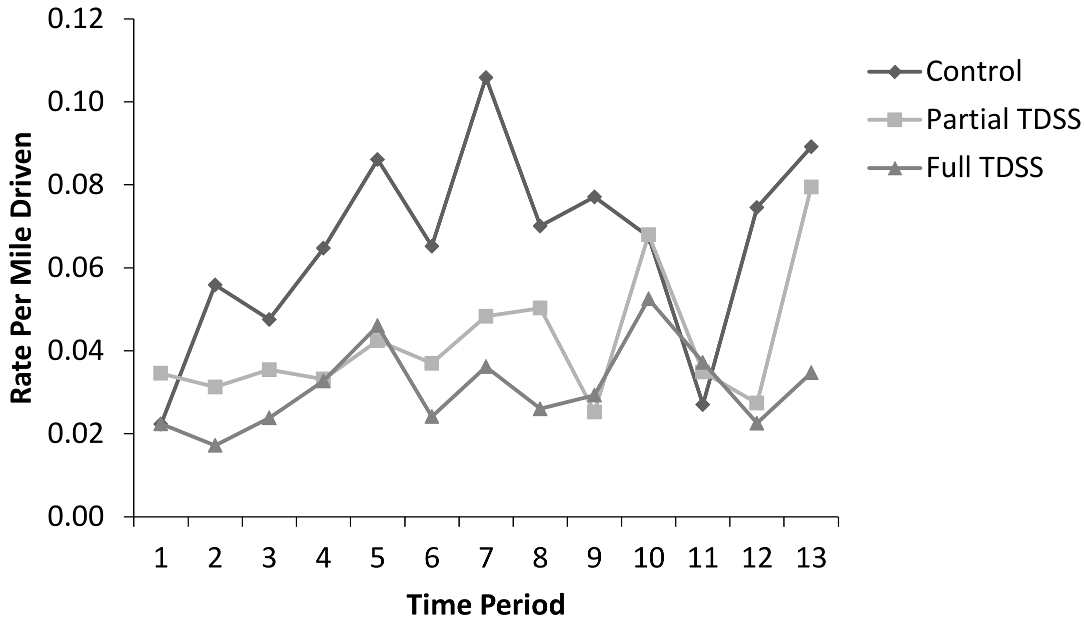


Figure 26. Rate of turning events by group and time for the unshared vehicle dataset.

Summary of Excessive Maneuver Results

- The full TDSS group with parent monitoring and feedback had lowest rates, on average, of acceleration and turning events compared to the control group.
- The full TDSS group had lower rates of braking events early the study in comparison to the partial TDSS and control groups.
- There were no differences for any variables when comparing the partial TDSS to the control group.
- Participants who had their own vehicles also had higher acceleration and turning event rates (all) compared to participants who shared a vehicle with another family member.

- In general, there was significant variability in the accelerometer data, particularly for the control and partial TDSS groups compared with the full TDSS group (see Appendix E).

Cellular Phone Use While Driving

Outgoing phone calls and text messages sent by the participants while they were driving were logged throughout the study period. The control group was the only group that had open access to all phone functions while driving. It was expected that the full and partial TDSS groups would have significantly lower rates of calls and texts sent per mile driven than the control group because these behaviors were blocked by the smartphone application. Parents were surveyed about their frequency of phone use while driving. This provided information about the parent groups to determine similarity between the three groups of parents and to identify the extent to which parents were modeling phone use while driving to their teenagers.

Calling Behavior

The calling dependent variable was based on the number of calls made by the participants per mile driven. There was a statistically significant main effect of group for the number calls made per mile driven (see Table 17, Figure 27). There was a statistically significant difference in the rate of calls made, on average, between the partial TDSS and full TDSS groups compared to the control group. There was also a statistically significant main effect of time period, in which the average number of calls made per mile driven increased over the duration of the study period.

There was a statistically significant main effect of gender, with male participants (*M*=0.007; *SD*=0.025), on average, making fewer calls than female participants (*M*=0.008; *SD*=0.019). Vehicle status was also a statistically significant predictor of calling behavior overall, with shared vehicle drivers (*M*=0.006; *SD*=0.022) making a significantly lower rate of calls than unshared vehicle drivers (*M*=0.009; *SD*=0.023). The trends in the unshared vehicle data set match those in the full dataset, however, the increased rates for unshared vehicles are observable in Figure 28.

Table 17. Summary of rate of calls made.

	Statistic	*p*-value
Group	F = 66.98	<0.0001*
Full TDSS vs. Control	t = -7.04	<0.0001**
Partial TDSS vs. Control	t = -7.61	<0.0001**
Full TDSS vs. Partial TDSS	t = 0.41	0.91
Time	F = 12.27	0.003*
Time x Group	F = 0.95	0.408
Vehicle Status	F = 4.51	0.035*
Gender	F = 4.71	0.031*
SSS	F = 0.26	0.609

* Significant at p<0.05
** Significant using Tukey-Kramer adjusted *p*-values to account for Type I errors in post hoc testing.

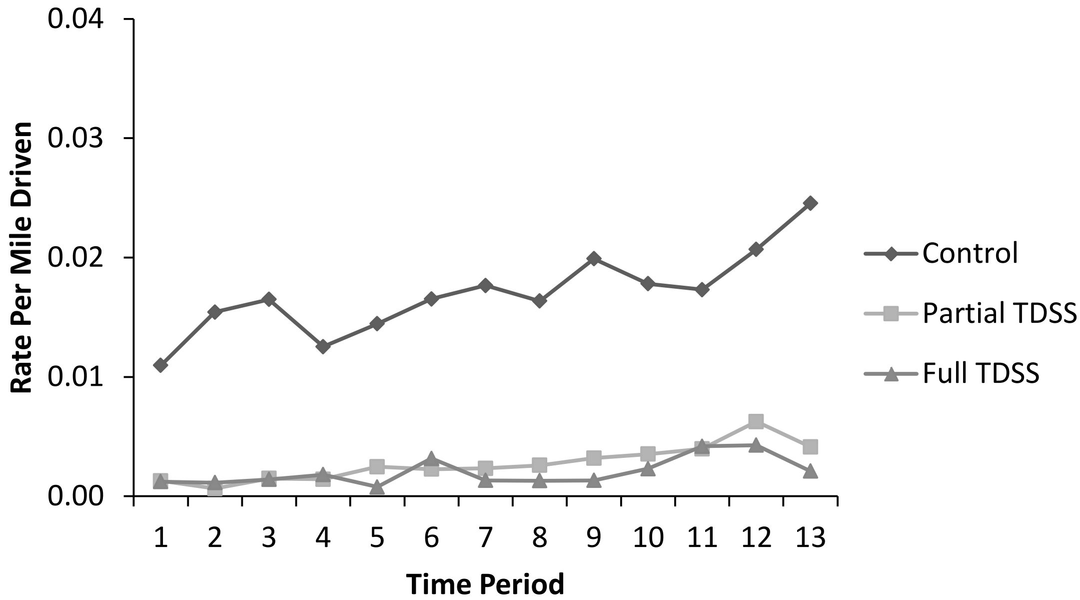


Figure 27. Calling rate per mile driven by group and time for full dataset.

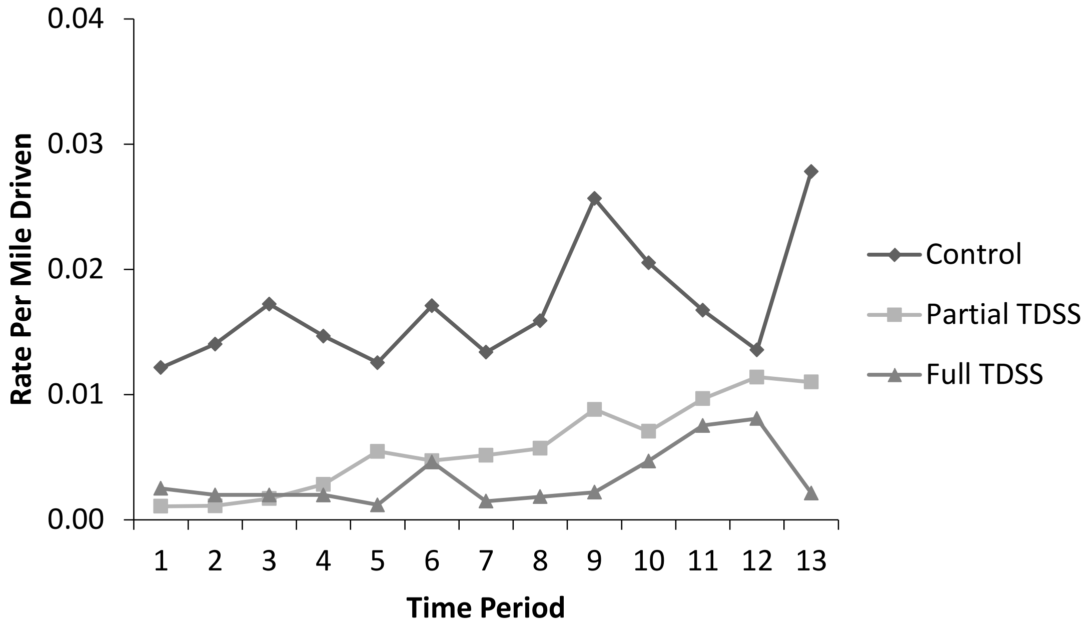


Figure 28. Calling rate per mile driven by group and time for unshared vehicle data set.

Texting Behavior

The texting dependent variable was the number of text messages sent by the participant per mile driven. There was a statistically significant main effect of group for the number texts sent per mile driven (see Table 18, Figure 29). The partial TDSS and full TDSS groups had a significantly lower rate of text messages sent while driving than the control group. Overall, the rate of texting increased from the beginning to the end of the study, particularly for the control group. The frequency of calling rates is likely lower than texting rates because one call can result in a single, lengthy conversation, whereas text messages tend to be short and require multiple messages to create a conversation. Neither gender nor vehicle status were statistically significantly associated with texting rates. The trends for the unshared vehicle group were similar to the full dataset (Figure 30).

Table 18. Summary of statistical results for texting while driving rates.

	Statistic	*p*-value
Group	*F* = 17.13	<0.0001*
Full TDSS vs. Control	*t* = -5.02	0.0002**
Partial TDSS vs. Control	*t* = -5.32	<0.0001**
Full TDSS vs. Partial TDSS	*t* = 0.25	0.805
Time	*F = 27.15*	<0.0001*
Time x Group	*F* = 1.50	<0.248
Vehicle Status	*F* = 0.28	0.596
Gender	*F* = 2.90	0.090
SSS	*F* = 0.14	0.706

* Significant at p<0.05
** Significant using Tukey-Kramer adjusted *p*-values to account for Type I errors in post hoc testing.

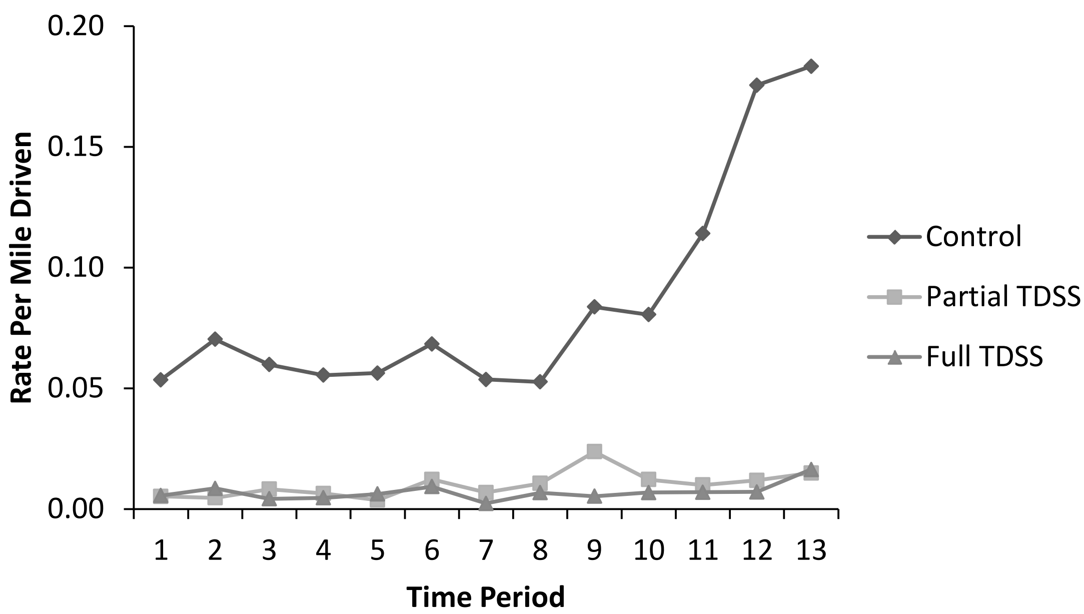


Figure 29. Average rate of text messages sent while driving by group and time for full dataset.

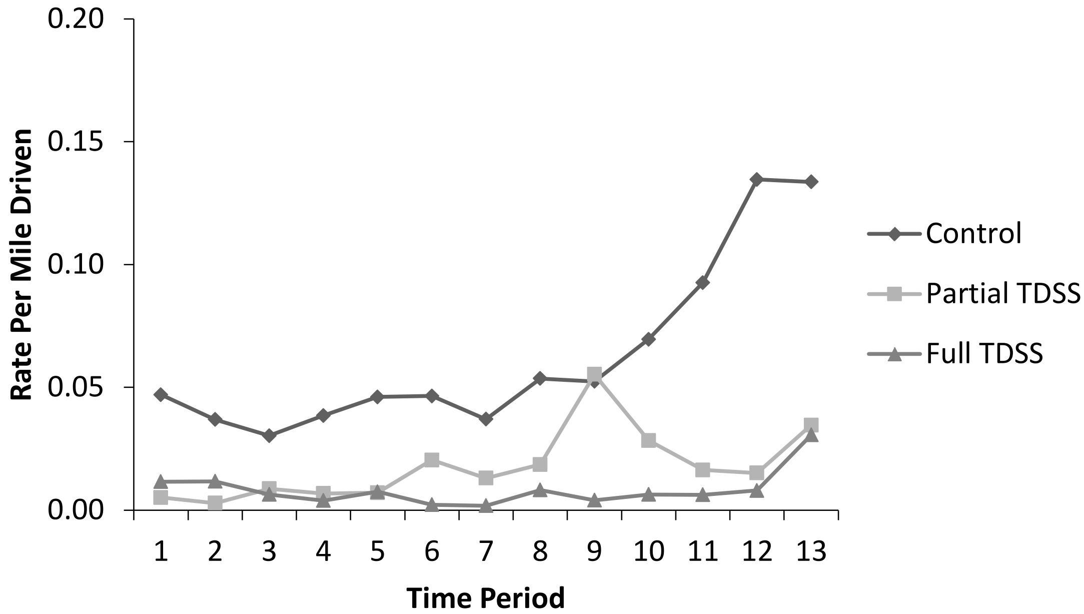


Figure 30. Average rate of text messages sent while driving by group and time for unshared vehicle dataset.

Self-Reported Phone Use

Teenage participants were asked to self-report how frequently they talked on the phone or engaged in text messaging while driving. The self-reported patterns of calling and texting match the objective data, which indicated both calling and texting increased in all groups, on average, across the study period. As expected, a higher percentage of teenagers in the control group self-reported calling and/or texting while driving compared to the teenagers in the groups with the blocking software (see Table 19, Table 20).

During the exit survey at Month 12, participants in the TDSS groups were asked about whether they had tried to bypass the blocking application so that they could call or text while driving. Approximately 15% of participants in each treatment group reported that they figured out a way to bypass the system. The most common way to bypass call blocking was to begin a call prior to starting the vehicle because the software was not programmed to shut down a call in progress when it paired with the in-vehicle device. The participants could then continue the call until they hung up, at which point they would not be able to make another call. Several participants also figured out how to make calls using background calling and texting applications that became available during the study. Using the open Bluetooth port, they were able to run voice-to-call or voice-to-text applications in the background of the teen driver application. This is important to note because the TDSS was able to force itself to the foreground of the phone, preventing other applications from being launched and visible in the foreground, but it was not designed to block background applications. Finally, a small subset of participants reported sometimes borrowing a friend's phone while driving if the friend was in the vehicle.

Table 19. Percentage of teens reporting the rate at which they talk on the phone while driving.

		Month 1	Month 6	Month 12
Control	Never	65%	36%	28%
	Rarely	28%	43%	40%
	Sometimes	8%	17%	24%
	Often	0%	3%	7%
	Always	0%	1%	1%
Partial TDSS	Never	90%	78%	72%
	Rarely	5%	15%	22%
	Sometimes	4%	6%	4%
	Often	1%	1%	0%
	Always	0%	1%	1%
Full TDSS	Never	92%	79%	72%
	Rarely	7%	15%	22%
	Sometimes	1%	3%	4%
	Often	0%	1%	1%
	Always	0%	1%	0%

Table 20. Percentage of teens reporting the rate at which they text while driving.

		Month 1	Month 6	Month 12
Control	Never	59%	45%	33%
	Rarely	33%	34%	48%
	Sometimes	8%	18%	15%
	Often	1%	2%	2%
	Always	0%	1%	1%
Partial TDSS	Never	87%	84%	81%
	Rarely	9%	11%	16%
	Sometimes	4%	4%	2%
	Often	1%	0%	0%
	Always	0%	0%	1%
Full TDSS	Never	95%	83%	79%
	Rarely	3%	9%	16%
	Sometimes	3%	7%	6%
	Often	0%	1%	0%
	Always	0%	0%	0%

Parents were also asked to report their frequency of calling and texting while driving. Like their teens, parents reported talking on the phone more frequently than texting while driving (see Table 21).

Table 21. Percentage of parents reporting the rate at which they talk on the phone and text while driving at enrollment and at Month 12 in the study.

		Enrollment		Month 12	
		Talk	Text	Talk	Text
Control	Never	3%	58%	8%	47%
	Rarely	29%	34%	30%	31%
	Sometimes	45%	7%	46%	20%
	Often	22%	1%	17%	1%
	Always	1%	0%	0%	1%
Partial TDSS	Never	2%	74%	2%	57%
	Rarely	32%	21%	36%	33%
	Sometimes	49%	4%	51%	9%
	Often	14%	0%	9%	2%
	Always	2%	0%	2%	0%
Full TDSS	Never	5%	65%	6%	64%
	Rarely	39%	30%	40%	31%
	Sometimes	43%	5%	44%	3%
	Often	12%	0%	10%	1%
	Always	1%	0%	0%	0%

Summary of Cell Phone Use Results

- The full TDSS group had significantly lower rates of calling and texting compared to the control group.
- The partial TDSS group had significantly lower rates of calling and texting compared to the control group.
- Overall, calling and texting rates increased across the study. This was observed in both the phone data and the self-report data from teens.
- Drivers of unshared vehicles had higher rates of calls made than drivers of shared vehicles.
- Female participants had higher rates of calls made than male participants.

- Parents in each study group self-reported similar frequencies of cellular phone behavior.

Seat Belt Use

Seat belt use was based on the percentage of the total miles for which the seat belt was worn while driving. However, in many vehicle installations, the aftermarket seat belt sensors were insufficiently robust for the duration of the study (i.e., the full 12 months). Approximately one-third of the seat belt sensors were known to be broken during the study. The following process was used to identify and clean the seat belt data to avoid including unreliable sensor data in the analysis:

- Removing data associated with lack of seat belt use, back-dated to when the participant reported problems with the sensor, and/or,
- Cleaning data by identifying when seat belt use dropped linearly from a point that had been stable for seven days or longer prior to the drop-off.

Because of this, summary results are reported for the percentage of belt use between groups but a statistical analysis was not conducted.

An examination of the cleaned data indicated that seat belt use was high across all groups throughout the study, ranging from a low of 93% for the control group at Month 7 to a high of 99% for the control and partial TDSS groups in other months. However, across the study period, a few teenage participants in each group began reporting lower belt use in the surveys. In total, nine (five males, four females) of the remaining 274 teenagers in the data analysis reported not wearing their seatbelt "always" during the study. At Month 1, 100% of participants in each group reported they wore their seat belt "always." At Month 6, one female in each of the study groups reported only wearing their seat belt “often” rather than “always.” At Month 12, five participants in the control group reported wearing their seat belt less than “always.” This included the same female participant who reported “sometimes” again at Month 12 as she did at Month 6. Three of the other four participants who reported something other than “always” at Month 12 (two males, one female) reported “often.” The fourth participant, a male, reported he “never” wore his seat belt at this point in the study, after reporting “always” in the previous two survey periods. In the partial TDSS group, the same female teenager who reported “often” at Month 6 reported “often” again along with a male who reported he wore his seat belt “sometimes.” In the full TDSS group, the same female from Month 6 reported “often” again, as did another male teenager.

Summary of Results

- Seat belt use rates were high across the study (>93% at all time periods) for all study groups.
- Subjective seat belt use rates were slightly lower in the control group at the end of the study, compared with the partial and full TDSS groups. Five participants in the control group reported they were no longer wearing their seat belt all the time at Month12 compared with Month 1. Two participants in each of the partial and full TDSS groups also reported they were no longer wearing their belts all the time at Month 12 compared with Month 1.
- Approximately half of the participants in each group reported that they had at least one friend who did not always wear their seat belt while driving at the end of the study.

Self-Reported Crashes and Violations

Self-Reported Violations

Teenage participants were asked to self-report the number of traffic tickets or warnings they received at each period in the study (see Table 22). Overall, the self-reported results indicated that participants received more tickets and warnings as the study progressed, with little difference between the groups in terms of the percentage that received tickets or warnings at each stage. Participants were also asked to report the type of ticket or warning they received, but not all participants who reported a ticket also reported a type. Therefore, Table 23 is not representative of all the reported tickets. Overall, speeding was the primary infraction for which participants received tickets. The control group had the highest number of speeding tickets, which corresponded with their increased rate of excessive speeding observed in the vehicle data.

Table 22. Percentage of teenagers who reported they got a ticket or warning at each survey period

	Month 1		Month 6		Month 12	
	Ticket	Warning	Ticket	Warning	Ticket	Warning
Control	0%	5%	3%	4%	8%	8%
Partial TDSS	0%	2%	2%	8%	4%	12%
Full TDSS	1%	3%	5%	5%	8%	14%

Table 23. Number and type of tickets received during the study.

	Control	Partial TDSS	Full TDSS
Speeding	7	2	3
Stop sign violation	1	0	1
Traffic light violation	1	0	0
Not wearing seatbelt	0	0	0
Impaired driving due to alcohol or drugs	1	0	0
Careless/dangerous driving	0	1	1
Graduated driver licensing violation	0	0	0
Texting while driving	0	0	0
Received a warning	0	1	1
Other	1	1	3
Total	11	5	9

Self-Reported Crashes

One intended outcome for the use of the TDSS is an associated reduction in crashes that corresponds to the reductions in observed risky driving behaviors; or a reduction in the severity of crashes if they occur (e.g., reduced speeds reduce crash forces and with that there is a potential to reduce fatalities and injuries associated with the crash). It is possible crashes were missing as self-reported data are not always 100% accurate. Participants were asked to report if they had any crashes and, if yes, to classify the type of crash (e.g., rear-end collision, run off road, hit an object, etc). The number of participants who had a crash during the study differed between the control (N=36; 20 male, 16 female) partial TDSS (N=22; 12 male, 10 female) and full TDSS (N=21; 9 male, 13 female) groups (see Table 24). The total number of crashes reported for the control was 47 crashes (for 36 teenagers), 28 crashes for the partial TDSS group (for 22 teenagers), and 27 crashes for the full TDSS group (for 21 teenagers). Unshared vehicles made up approximately one-third of each study group and as a reflection of that approximately one-third of crashes per group occurred in the unshared vehicle groups.

There were no statistically significant differences in crash rates (per mile driven) between the study groups, nor were any of the covariates significantly related to crash rate (*p*'s>0.05).

Table 24. Number of participants who had one or more crashes and total number of crashes reported per group.

	Control		Partial TDSS		Full TDSS	
	Shared	Unshared	Shared	Unshared	Shared	Unshared
Number of participants	24	12	15	7	14	7
Number of crashes	25	22	19	9	16	11

*Does not include two drivers, one teen each in control and full TDSS groups who had to withdraw because their vehicle was damaged due to a crash and thus were unable to continue in the study.

Participants were asked to report the types of crashes they had according to this taxonomy:

- I rear ended another vehicle
- I hit another vehicle (not rear-end collision)
- I hit a stationary object, such as a parked car, lamp post, object in a parking lot, etc.
- I hit another road user that was not a vehicle (i.e., pedestrian or cyclist)
- I ran off the road but did not hit another vehicle.
- Another vehicle hit me—any crash type.
- Other crash type (unspecified).

The first six statements indicate a potential at-fault crash on the part of the driver; however, the fault for crashes in which a driver hits another vehicle or road user can be shared to varying degrees between all drivers or road users involved. The final category indicates the other driver was at fault. The control group had more instances of hitting a stationary object or running off the road than did the partial and full TDSS groups (see Table 25), and these two crash categories seem to make up the discrepancy in the number of crashes observed in the control group versus the partial and full TDSS groups. Of particular interest is the high number of run-off-road crashes in the control group compared to the partial and full TDSS groups, particularly for participants who did not share vehicles with another family member. The control and the full TDSS groups had similar numbers of rear-end collisions, while all three groups had similar numbers of crashes in which they indicated another vehicle hit them.

Table 25. Number of each crash type reported per group.

	Control		Partial TDSS		Full TDSS	
	Shared	Unshared	Shared	Unshared	Shared	Unshared
Rear-end	4	4	4	0	5	2
Hit a vehicle	1	1	1	0	0	0
Hit an object	11	4	5	1	4	3
Hit road user	0	0	0	0	0	0
Run off road	5	10	1	2	2	3
Another vehicle hit me	4	3	3	4	3	3
Other	0	0	5	2	2	0

*Four teens in the control reported a crash but not the crash type.

Parent-Teenager Interactions

Survey questions were developed to identify whether the full TDSS with parent feedback facilitated different interactions between parents and teenagers with respect to learning how to drive and/or managing driving. Parents were asked to report whether they had engaged in managing their teenager's driving privileges for various reasons during the study (see Table 26). Parents reported more changes in increasing or decreasing driving privileges in the first month of the study than they did in the last month of the study. Parents in each group reported that increases in driving privileges during the first month of driving were frequently related to the teenager demonstrating safe driving behaviors (as interpreted by the parent). In the full TDSS group, 40% of parents compared with 33% in control and 27% in partial TDSS reported increasing privileges in the first month of driving. Parents were also similarly likely to remove privileges when teenagers violated agreed upon driving rules or engaged in risky or unsafe driving witnessed by the parent.

Parents in all groups also reported increasing driving privileges due to non-driving behaviors (e.g., good grades) similarly at the beginning and the end of the study. When it came to reducing driving privileges, parents were most likely to remove privileges due to a non-driving reason (e.g., not completing chores) rather than for a driving reason (e.g., violating agreed upon rules for driving or for risky driving). The full TDSS group showed a drop in reducing driving privileges related to non-driving reasons at the end of the study compared to early on and compared to the control and partial TDSS groups at both time periods.

Table 26. Percentage of parents who reported changes in driving or non-driving privileges in the past month at the end of the study.

	Control		Partial TDSS		Full TDSS	
	Month 1	Month 12	Month 1	Month 12	Month 1	Month 12
Driving privileges taken away for violating a rule about when, where or with whom they can drive	13%	8%	7%	5%	10%	3%
Driving privileges reduced or taken away for risky or unsafe driving behaviors	6%	3%	2%	1%	7%	3%
Driving privileges increased because of demonstrated safe driving behaviors	33%	7%	27%	14%	40%	12%
Driving privileges reduced or taken away for a non-driving reason (e.g., not completing chores, problems at school, etc)	13%	15%	13%	12%	13%	3%
Increased privileges for non-driving reason (e.g., good grades, doing chores, etc)	8%	4%	6%	2%	8%	9%
Reduced non-driving privileges because of risky or unsafe driving behaviors	0%	4%	0%	0%	1%	0%
Reduced non-driving privileges because teen violated a driving rule, such as when or where he or she was allowed to drive	2%	3%	2%	1%	1%	0%

Parents reported that discussions about safe driving occurred sometimes, often, or very often most frequently at each time period, which indicated parents in all study groups were engaged in discussing driving with their teens throughout the first year of driving.

Table 27. Percentage of parents reporting how frequently they discussed driving habits and safety with their teenager in the previous month.

		Month 1	Month 6	Month 12
Control	Not at all	0%	0%	3%
	Seldom	6%	15%	7%
	Sometimes	27%	40%	38%
	Often	41%	36%	37%
	Very often	26%	9%	14%
Partial TDSS	Not at all	0%	1%	1%
	Seldom	2%	11%	16%
	Sometimes	29%	41%	41%
	Often	44%	34%	29%
	Very often	25%	13%	12%
Full TDSS	Not at all	0%	0%	0%
	Seldom	0%	5%	9%
	Sometimes	29%	41%	51%
	Often	44%	45%	33%
	Very often	27%	9%	8%

Parents rated how comfortable they were discussing safe driving and driving habits with their teenagers ("I am very comfortable discussing my teen's driving skills or habits with them when it comes up in conversation") on a scale from 1 (strongly disagree) to 7 (strongly agree). On average, parents in all groups strongly agreed throughout each time period that they felt comfortable discussing driving safety and habits with their teenagers (see Table 28). Additionally, parents reported being comfortable with setting and enforcing rules for their teenage drivers ("I am very comfortable setting and enforcing rules about driving, such as when, where and with whom my teen can drive"). Teenagers also reported how comfortable they were discussing driving with their parents and with the rules set for driving (Table 29).

Table 28. Mean ratings of parents for comfort with discussing driving habits, and setting and enforcing rules for teenage drivers.

		Month 1 M (SD)	Month 6 M (SD)	Month 12 M (SD)
Comfort with discussing driving	Control	6.77 (0.77)	6.48 (1.18)	6.50 (1.21)
	Partial TDSS	6.62 (1.06)	6.45 (1.18)	6.70 (0.72)
	Full TDSS	6.61 (0.99)	6.57 (1.11)	6.42 (1.4)
Comfort with setting and enforcing rules	Control	6.77 (0.77)	6.40 (1.21)	6.52 (1.16)
	Partial TDSS	6.71 (0.96)	6.47 (1.19)	6.67 (0.74)
	Full TDSS	6.60 (0.96)	6.58 (1.03)	6.41 (1.39)

Table 29. Mean ratings of teenagers for comfort with discussing driving habits, and with parents' set rules and enforcement of rules for driving.

		Month 1 M (SD)	Month 6 M (SD)	Month 12 M (SD)
Comfort with discussing driving	Control	6.13 (1.16)	6.07 (1.34)	5.80 (1.54)
	Partial TDSS	5.68 (1.41)	5.70 (1.48)	5.84 (1.31)
	Full TDSS	5.60 (1.30)	5.97 (1.23)	5.96 (1.28)
Comfort rules set by parents about driving	Control	5.91 (1.33)	6.03 (1.36)	6.03 (1.37)
	Partial TDSS	5.56 (1.44)	5.82 (1.41)	5.90 (1.39)
	Full TDSS	5.08 (1.47)	5.69 (1.40)	5.95 (1.22)

Parents reported that they more often used driving resources (e.g., materials intended to guide discussion about safe driving) with their teenagers early in independent driving compared to later in the study (see Table 30). Common sources reported included showing their teenagers news articles about traffic crashes in which people were injured or killed (most common), discussing insurance costs as they relate to accidents (with or without the insurance agent), and creating parent-teenager driving contracts. Very few parents reported using contracts, but for those who did, there was one parent in the control group, three parents in the TDSS group, and two parents in the full TDSS group who reported using parent-teenager driving contracts.

Table 30. Percentage of parents who reported using additional resources to discuss driving with their teens at each survey period.

	Month 1	Month 6	Month 12
Control	11%	2%	2%
Partial TDSS	11%	7%	8%
Full TDSS	15%	6%	2%

Full TDSS Group Parent-Teenager Interactions

Teenagers in the full TDSS group reported that their parents used the system feedback most frequently to remove or increase driving privileges and other privileges during Month 1 and Month 6 compared with Month 12 (see Table 31). Parents reported how frequently they used the TDSS feedback to generate incentives or consequences for their teens (i.e., "If you used incentives/consequences in the past month of driving, was it directly related to seeing positive/negative information about your teen's driving in the weekly reports?"). Thirty percent of parents in the feedback group indicated that they used the system information to determine whether an incentive was required in the first month of independent driving, and this decreased to 17% at Month 6 and 12% at Month 12. Parents reported similar rates of using the system for consequences at Month 1 (12%), Month 6 (13%) and Month 12 (10%). Speeding notifications or combinations of notifications were most frequently cited as influencing decisions about incentives and consequences (see Table 32).

Table 31. Teenagers' reported frequency of parents' use of TDSS notifications to change privileges.

	Month 1	Month 6	Month 12
Used TDSS notifications to remove driving privileges	12%	8%	2%
Used TDSS notifications to increase driving privileges	14%	15%	9%
Used TDSS notifications to remove non-driving privileges	7%	7%	0%
Used TDSS notifications to increase non-driving privileges	11%	8%	2%

Table 32. Number of times parents reported using specific notifications from the TDSS to implement incentives or consequences.

	Month 1	Month 6	Month 12
Speeding violations	12	15	11
Excessive maneuvers	8	7	6
Stop sign violations	5	9	8
Seat belt violations	9	9	10
Graduated driver licensing curfew violations	3	6	4
GDL passenger restrictions	6	4	3
All of the above	14	7	12

Note: Individual parents could indicate more than one notification.

Teenage participants in the full TDSS group reported whether the system was somewhat beneficial in learning how to drive and/or in improving their parental expectations of their driving behavior. Teenagers were mostly neutral across the study period about how the system affected their learning and their interactions with their parents (see Table 33; 1 = strongly disagree; 7 = strongly agree).

Table 33. Teenagers' reported ratings of how the TDSS with parental feedback influenced their driving and interactions with their parents.

	Month 1 M (SD)	Month 6 M (SD)	Month 12 M (SD)
Driving with the teenage driver support system was beneficial in helping me learn to drive	4.20 (1.64)	4.48 (1.64)	4.44 (1.77)
Using the teenage driver support system has had a positive effect on how I interact with my parents/guardians when discussing my driving	4.27 (1.49)	4.21 (1.46)	4.31 (1.52)
Using the teenage driver support system has had a positive effect on my parents'/guardians' expectations of my driving behavior	4.94 (1.36)	4.63 (1.46)	4.86 (1.42)
My parents/guardians used the information the system provided to them as a tool for discussing safe driving habits	4.74 (1.67)	4.25 (1.74)	4.22 (1.80)

<u>Summary of Parent-Teenager interaction Results</u>

- Parents were more likely to increase driving privileges early in the study (i.e., first month) in all study groups than they were to remove them.
- Parents in the full TDSS group reported that they used the system on occasion when deciding on incentives or consequences related to driving. Speeding notifications were cited most frequently as influencing decisions about incentives or consequences.
- The majority of parents in all three groups reported having discussions about driving safety and habits with their teenager "sometimes" or "often" throughout the study. The frequency with which parents reported discussing driving with their teenager "very often" dropped significantly between Month 1 and Month 6 of the study and remained lower in the last month.

- Very few parents reported using outside resources to help discuss safe driving with their teenagers. When they did report using resources, news stories about traffic crashes were the most commonly cited resource. Other resources included discussing insurance information or using parent-teenager driving contracts.
- In the full TDSS group, teenagers were neutral about the system's influence on learning to drive or on their interactions with their parents about driving.

TDSS Usability Results

Perceptions of the system were collected for the partial and full TDSS groups at Month 1, Month 6 and Month 12 of the study.

Teenagers

Overall, system usability was rated slightly more highly at the beginning of the study than the end of the study. Questions are discussed by content related to safety and driver performance, trust and reliability, and message comprehension and distraction. Questions are rated based on how strongly the responder disagrees (1 = strongly disagree) or agrees (7 = strongly agrees) with the statement (see Table 34).

Table 34. Mean scores for trust scale questions related to TDSS use by teenagers

		Month 1		Month 6		Month 12	
		Partial TDSS	Full TDSS	Partial TDSS	Full TDSS	Partial TDSS	Full TDSS
1	The performance of the system enhances my driving safety	5.06	4.78	4.59	4.38	4.58	4.30
2	I am familiar with the operation of the system	5.90	5.75	5.71	5.63	5.88	5.77
3	I trust the system	4.97	4.51	4.52	4.04	4.73	3.88
4	The system is reliable	4.66	4.15	4.10	3.61	4.30	3.71
5	I am confident in my ability to drive without the system active	6.38	6.42	6.26	6.17	6.16	6.19
6	The visual messages I receive from the system are easy to understand	6.34	6.04	5.91	5.89	5.97	5.81
7	The auditory messages I receive from the system are easy to understand	6.18	6.07	5.83	5.82	5.93	5.66
8	The driving feedback I receive from the system is useful and helpful	4.91	4.40	4.32	3.92	4.73	4.15
9	The driving feedback I receive from the system can be distracting at times	5.24	5.75	5.23	5.57	5.23	5.54
10	The system messages are accurate most of the time	4.87	4.21	4.35	3.44	4.53	3.86

Note: A rating of 1 = strongly disagree; 7 = strongly agree.

<u>Safety and Driver Performance</u>

Three questions (1, 5, and 8) covered driver safety and performance with and without the system. Participants in both the partial and full TDSS groups agreed, on average, that the system enhanced driving safety across the study period (question 1). The partial TDSS group responded with a higher rating than the full TDSS group across time.

For both groups, the ratings were highest in Month 1 and decreased slightly at Months 6 and 12 of the study after being exposed to the system. Participants were also surveyed about their confidence in driving without the system (question 5). Participants agreed they were confident driving without the system at all time periods, rating their confidence high overall but with a slight decrease toward the end of the study. Participants in both groups were most confident in Month 1 compared to Month 12, but the changes were not significant. Question 8 asked to what extent drivers felt the information provided by the TDSS helpful or useful. The ratings were fairly neutral, with the average ratings just above neutral and in agreement with the question.

Trust and Reliability

Questions 2, 3, 4 and 10 cover issues associated with trust and reliability in the system. Overall, participants in both groups agreed that they were familiar with the operation of the system (Question 2). Familiarity with the system was high initially (Month 1) and remained constant for both the partial and full TDSS groups throughout the study period. This indicates the system was relatively easy for novice drivers to learn, which supports the usability effort to design an easy-to-use and learn system. Trust (question 3) and reliability (questions 4 and 10) in the system were moderately high early in the study, but decreased for the full TDSS group in Month 6 and remained lower in Month 12. Average ratings dropped more for the full TDSS group than the partial TDSS group. Based on comments from teens about the system, trust and reliability were influenced mainly by problems with the study equipment, such as mounts that would not stay on the dash and problems with power cables. Some of the perceived trust and reliability issues, however, were due to the system's database map for speed limits and stop signs. For example, the commercial map deployed with the system had been updated the year previously and was not updated during the study by the vendor. This meant that drivers occasionally encountered situations in which the speed presented on the TDSS did not match the posted speed limit. In cases where the posted speed limit was higher than the system limit, teens selected to speed and receive the alert rather than drive too slowly for roadway conditions. Based on feedback, most parents and teens understood why this occurred and reported it did not occur frequently enough to be generally problematic. The stop sign database for the teen drivers in the Twin Cities was not sufficient in our study communities. For example, in one study community, there were several stop signs in the map that had been converted to traffic signals since the map was purchased for use. This meant teens in both the partial and full TDSS groups and parents in the full TDSS group sometimes received stop sign alerts when their teen drove through a green light.

Message Comprehension and Distraction

Participants in both groups mostly agreed or strongly agreed that the visual and auditory messages were easy to understand (questions 6 and 7). Because the messages were refined several times based on user feedback, this finding indicated that the previous work was successful in identifying easy-to-comprehend messages. Similar to previous studies (Creaser et al., 2009; Creaser et al., 2011), participants also agreed across the study periods that the feedback was distracting at times, with no change from early in the study to the end. What is not known is specifically what about the feedback was a distraction. For example, in previous studies, the teenagers preferred visual messages over the auditory messages, and there were some reports of the auditory messages being distracting (Creaser et al., 2011).

Parents

Parents were surveyed about the usability of both feedback content and the way that the content was delivered (texts, weekly email summary, and website). Parents also reported on their overall perceptions of the TDSS.

Website Use

The full TDSS group was given summary feedback about their teens' driving via a website and weekly emails. This was in addition to the immediate text messages received for each detected event. The number of website visits per week for each parent in this group ranged from 0 to 6. Parents most often visited the website in the first four weeks of the study, with 15-38% never visiting the site, approximately 50% visiting the site once a week, and 11-41% visiting the site multiple times per week. The total website traffic in the first week was 162 visits. By week 18, over half of parents (58%) did not log on at all during a single week, while 31% visited the site only once, and 22% visited the site multiple times during the week. Parents collectively had a total of 2,865 visits over the course of the study. The Weekly Driving Summary (website landing page) was viewed most in the first four weeks of the study compared with the other pages on the website (Driving Results List, Driving Results Map, Driving Results History).

Weekly Email Views

Parents opened their weekly email summary most often in the first week of the study; however, the number of views in the following weeks remained consistent. There were a total of 5,797 email views over the course of the study. Viewing of the email summary appeared to be more frequent and consistent than logging into the website for a session.

Information Format Ratings

Parents rated the website, weekly email summary, and text message notifications with respect to each item's presentation, usefulness of information, understandability, utility, and timeliness of information. The text messages were rated most highly, with an average of 82% of parents rating the text message format as "very good" or "excellent" for the surveyed questions. The weekly email was the next highest rated, with an average of 77% of parents rating it "very good" or "excellent." The website had the lowest rating with an average of only 60% of parents rating it as "very good" or "excellent" (see Table 35, Table 36, Table 37).

Table 35. Percentage of parents who rated each category for website questions

	Poor	Fair	Good	V. Good	Excellent
The way the information was presented	2%	5%	37%	27%	28%
The usefulness of the information	3%	4%	34%	33%	28%
How easy it was to understand the information	2%	5%	32%	31%	30%
Ability to use the information to start a discussion with your teen about the driving behavior for which you were notified	2%	5%	31%	30%	32%
The timeliness of the information	2%	1%	35%	30%	32%

Table 36. Percentage of parents who rated each category for email questions

	Poor	Fair	Good	V. Good	Excellent
The way the information was presented	0%	4%	24%	39%	33%
The usefulness of the information	1%	9%	18%	39%	33%
How easy it was to understand the information	1%	2%	16%	39%	42%
Ability to use the information to start a discussion with your teen about the driving behavior for which you were notified	1%	5%	10%	40%	44%
The timeliness of the information	1%	3%	17%	37%	42%

Table 37. Percentage of parents who rated each category for text message questions

	Poor	Fair	Good	V. Good	Excellent
The way the information was presented	0%	6%	23%	36%	35%
The usefulness of the information	0%	2%	15%	43%	40%
How easy it was to understand the information	0%	1%	7%	42%	50%
Ability to use the information to start a discussion with your teen about the driving behavior for which you were notified	0%	2%	9%	35%	53%
The timeliness of the information	0%	4%	24%	39%	33%

Teenager and Parent Perceptions of the TDSS

Teenage participants in both the partial and full TDSS groups were less likely to rate the system as “very good” or “very useful” compared to their parents; however, a majority of teenagers rated the system as “good” or “very good” (70% for partial TDSS; 62% for full TDSS) and “useful” or “very useful” (62% for partial TDSS; 58% for full TDSS). Finally, parents and teenagers were asked whether they would recommend the system (if it were a finished product) to other parents and teenagers for the first year of a teen’s driving. Ninety-six percent of parents in both the partial (32% likely; 64% very likely) and the full TDSS groups (20% likely; 76% very likely) said they would recommend the system to other parents and teenagers (1= very unlikely; 5 = very likely). Teenagers were less likely to recommend the system to other parents and teenagers, but a majority in the partial TDSS group (55% of which 38% said likely and 17% said very likely) and a majority in the full TDSS group (50% of which 30% said likely and 20% said very likely) said they would recommend it.

Summary of Usability Results

- Teenagers in both the partial and full TDSS groups reported that they somewhat agreed that the system improved their safety and performance while driving.
- Teenagers in both the partial and full TDSS groups rated their confidence in their driving abilities without the system as high throughout the study. Confidence was highest in Month 1 and lowest in Month 12, but the changes were not statistically significant.
- Trust and reliability in the system was moderately high earlier in the study for both groups, but dropped for the full TDSS group in Month 6 and stayed lower in Month 12 for this group.
- Teenagers in both groups mostly agreed or strongly agreed that the visual and auditory message were easy to understand.
- Parents in the full TDSS group most preferred the text messages and weekly email summary information when compared to the website information. Parents rarely visited the website after the first four weeks of the study.
- Parents viewed the weekly email summary more frequently than the website.

- Parents rated the text messages and weekly summary emails highest with respect to presentation, usefulness of information, understandability, utility, and timeliness of information. The website was rated lowest on these factors.
- General opinions about the system, not considering experimental issues, were positive, with a majority of parents rating the TDSS with and without feedback as good or very good.
- A majority of parents also found the TDSS with and without feedback useful or very useful.
- Teenagers were less likely to say the system was very good or very useful but generally rated it well, with a majority of teenagers in the partial and full TDSS groups having an overall good opinion of the system.
- A majority of parents said they would recommend the TDSS, both with and without parental feedback, to other parents and teenagers during the first year of a teen's driving.
- Teenagers were less likely than their parents to say they would recommend the system to other teenagers and parents.

DISCUSSION

The TDSS deployed in this study used in-vehicle feedback, reporting to parents, and forcing functions as mechanisms to support and encourage behavior change among novice teenage drivers. The TDSS included near real-time feedback using text messages about events to parents as the primary reporting function. Feedback to parents about monitored events is considered critical to reduce risky driving events in teenagers using this type of system (McGehee et al., 2007; Simons-Morton et al., 2013) because parents are responsible for managing their teenagers' driving and mentoring safety behaviors (Simons-Morton, 2007). The TDSS differed from previous teenage driver systems in that it incorporated real-time, in-vehicle feedback about risky events as well forcing functions to prevent certain behaviors that are restricted by law for teenage drivers (i.e., cellular phone use while driving was blocked). Contextual feedback to the driver from the TDSS was a feedback mechanism intended to help drivers identify risky behaviors (i.e., errors) and encourage them to think about error causes and potential solutions in order to perform better in the future (Ivancic & Hesketh, 2000). The study compared two treatment groups in which one group received in-vehicle feedback (partial TDSS) and the other received in-vehicle and parent feedback (full TDSS) with a control group to determine the effectiveness of each feedback type.

Based on previous research investigating teenage driver monitoring systems, it was expected that the TDSS deployed in this study would be most effective at reducing risky driving behaviors among the group that received parent feedback. Parents who received feedback about teenage drivers' risky behaviors in previous research were more likely to have teenagers who demonstrated fewer risky behaviors over time (McGehee et al., 2007; Prato et al., 2010; Simons-Morton et al., 2013). However, the partial TDSS group was included because previous research has identified difficulties in getting parents to respond to system feedback (Farmer et al., 2010) and has also suggested a beneficial effect for in-vehicle feedback that is persistent (e.g., Spyropolou et al., 2014; Freedmon et al., 2014). Conclusions about the full TDSS effectiveness were based on demonstrating consistency in behavioral trends across the range of dependent variables, beginning with the earliest driving when factors expected to also influence behavior (e.g., subject variability, geographic location, vehicle status) were controlled for in the analyses. The full TDSS group was expected to have *lower rates and more stable patterns of monitored behaviors* throughout the study compared to the control and partial TDSS groups because of the potential for parents to be notified of risky behaviors. The partial TDSS group was expected to have lower rates of speeding than the control group due to the persistent speeding feedback, but the effect of the post-event feedback was not expected to be effective due to previous research indicating a lack of success for post-event feedback (e.g., Simons-Morton et al., 2013). Overall, the results of the study indicated that the full TDSS implementation with parental feedback reduced the frequency of certain risky driving behaviors that are associated with novice teenage driver crashes.

The results of this study supported the expected outcomes that were based on previous research. First, the results supported the need for parental feedback in the first year of driving. Second, this study supported that graded feedback that allowed the teenager to cancel an alert was an effective method for speed reduction. Third, the study supported the need for immediate feedback to reach parents without requiring the parent to expend additional time and resources to monitor their teenage driver’s recorded behaviors as a mechanism to potential increase acceptance and utility of the system. Fourth, the results supported the potential effectiveness of forcing functions in limiting impulsive or normative behaviors while driving, such as the desire to use a cell phone while driving. Finally, parents and teenagers had different opinions of the system, but, overall, both groups agreed it supported the mutual goals of the parent to better monitor driving behavior while allowing the teenager needed independent driving experiences.

Impact of the Full TDSS on Risky Driving Behaviors

An examination of the mileage, reported supervised driving, speeding, and excessive maneuver events all supported the effectiveness of the parent feedback on minimizing the rate of observed risky behaviors. Although teenagers in both TDSS groups drove, on average, fewer miles across the study than did the control group, this effect did not exist for teenagers with their own vehicle. Teenage participants in the control and partial TDSS groups who reported they did not share a vehicle with another family member had similar rates of mileage across the study, with the unshared vehicle driving in the partial TDSS group having the highest mileage across the entire study. In contrast, the full TDSS group participants who did not share a vehicle with another family member had slightly higher mileage rates than full TDSS participants who shared a vehicle. The participants who drove unshared vehicles drove more mileage in each study group, on average, than the shared vehicles, but the difference between shared and unshared was less pronounced in the control and full TDSS groups. The teenage participants who shared a vehicle in the control group had, on average, higher mileages earlier in the study compared to the partial and TDSS participants who shared a vehicle, but drove similar mileage in the last half of the study. Although the overall average mileage was highest for participants with unshared vehicles regardless of study group, the mileage driven appeared to be attenuated for participants who drove unshared vehicles in the full TDSS group. To understand the potential reasons while mileage varied between the groups, the self-reported frequency of supervised driving was investigated.

Overall, parents who shared a vehicle with their teenage driver, regardless of study group, also reported engaging in higher levels of supervised driving over the course of the study compared to parents who did not share a vehicle with their teenager. Sharing a vehicle with a family member—in particular, a parent or guardian—lends itself to more supervised driving as the parent is more likely to offer the teenager opportunities to drive while they ride as a passenger. For unshared vehicles, parents in the full TDSS group reported more frequent supervision of their teenagers' driving across the study period compared to parents in the control and partial TDSS groups. When this finding is considered in conjunction with the mileage outcomes for unshared vehicles, it suggests that parents in the full TDSS group not only supervised teenage drivers with unshared vehicles more often but might have also limited how frequently they drove. Of interest is that parents in the full TDSS group engaged in slightly less frequent supervised driving early in the study for teenagers with whom they shared a vehicle in comparison to the control and partial TDSS groups. The lower rate of supervised driving early in the study for the full TDSS group potentially indicates that parents might have relied (to some extent) on the system to monitor and report on risky behaviors. In essence, the parents might have felt their teenager *was* being supervised because they knew they would receive information about risky driving events. Parents in the full TDSS group might have felt that this allowed them more latitude to allow unsupervised driving more frequently than parents in the control and partial TDSS groups did early in the study period. This same issue might have also applied to parents of teenagers with unshared vehicles in the partial TDSS group such that they might have assumed their teenager was adhering to the alerts and, thus, allowed them to drive more often. Less supervised driving in the full TDSS group is less likely to influence teenage driving risk because of the parent feedback, however, more mileage and less supervised driving could be problematic because there is no guarantee the teenager is adhering to the alerts.

The conclusions that can be drawn from the mileage data are limited because of the wide variability between groups that could also be due to factors other than the study condition. Mileage varied greatly across teenagers as indicated by the large standard deviations in each group, and it is possible that other factors, such as the community from which the teenager came from, influenced overall mileage. The combined results of the unshared vehicle mileage and reported supervised driving suggest parents will engage in supervised driving when motivated by information about their teenager's driving. Sharing a vehicle also affords more opportunities to supervise a teenager's driving and receiving feedback from a monitoring system might have prompted more supervision and/or management of how frequently the teenager drove, which would explain the lower vehicle mileages in all three groups for shared vehicles. Ultimately, it is difficult to know the full influence of the TDSS on miles driven, but the mileage and supervised driving outcomes are in alignment with previous research indicating parents involved in monitoring their teenage driver are likely to impose more restrictions on their driving (Beck et al., 2001; Simons-Morton, 2007).

Speeding Behaviors with Parental Monitoring

Although the ISA implemented for the TDSS was technically a passive ISA, the speeding behavior results demonstrated the influence of parental monitoring and feedback on teenagers' driving behavior. Speeding behaviors increased across all three, which is an effect found in previous research (Simons-Morton, Ouimet, et al., 2012). As expected, however, the teenage participants in the full TDSS group drove the fewest miles over the excessive speeding threshold in comparison to the control group. They also triggered the threshold warning less frequently than the partial TDSS and control groups. Finally, the overall rate of speeding text messages sent to parents was similar across the study period for the full TDSS group but increased in the other two groups in conjunction with their increased rates of speeding. The full TDSS group's consistently low rate of speeding text messages to parents occurred even though the frequency of excessive speeding warnings increased throughout the study for the group. This finding lends support to the functional design of the ISA employed in this study, which allowed teenage drivers to cancel the alert to their parents after receiving the initial in-vehicle notifications.

The increase in speeding behaviors over time provided a good example of how the full TDSS with parent feedback influenced speeding behaviors. The full TDSS group had significantly lower rates of speeding behaviors very early in the study compared to the control group. The practical differences in percentages for speeding behaviors is significant with the full TDSS group having rates around 1-2% across the study and the control group starting at about 7% and increasing to about 12% by the end of the study, on average. The partial TDSS group fell in between with a range of approximately 2%

early in the study and 5% towards the end of the study. This demonstrated that early monitoring and reporting was an effective tool to minimize speeding behaviors early after licensure. The results of the control group also indicated that teenage drivers adopted a higher rate of risky behaviors early after licensure and that the observed behaviors continued to increase over time. These results support the use of such a system over a longer time period, such as the first year of driving that was considered for this study. The full TDSS with parent feedback minimized speeding across the first year of licensure.

Participants in the full TDSS group did, however, adapt to the system thresholds by driving closer to the excessive speeding threshold (i.e., they triggered warnings more often over time). The parent monitoring kept their overall speeding behaviors lower and the teenagers clearly used the in-vehicle feedback to adjust their driving behavior to avoid alerting their parents. The TDSS excessive speeding threshold was set at 7 mph over the posted speed limit. Parents in the TDSS usability study anecdotally reported that they felt traffic typically flowed approximately 5 mph over the speed limit on many roads and perceived this to be normal for most traffic situations (Creaser et al., 2011). Because of this they also reported they would not be comfortable with the original TDSS excessive speeding threshold of 5 mph over the speed limit, and suggested a threshold ranging from 7-10 mph over the speed limit. The 7 mph threshold is, therefore, valid to parents in that that they feel comfortable enforcing the limit if they are alerted of speeding. It also provides face validity in the system to teenagers when they realize the threshold allows them to travel at similar speeds to other traffic. Overall, the excessive speeding thresholds and graded warnings used by the TDSS are representative of what happens in the real world while driving and supports users' beliefs of what constitutes speeding behaviors. Although an ideal system would have alerts set at the legal posted speed limit, this was not acceptable to users of the TDSS during the usability study and would likely not be acceptable to a wide range of potential TDSS users. The primary goal was to reduce overall speeding behaviors by teenage drivers with respect to normal driving conditions, and the TDSS achieved this in the full TDSS group by encouraging teenagers to slow down and cancel alerts. Therefore, the TDSS threshold supported safer driving by creating a ceiling for speeding that is comparable to surrounding traffic.

The self-reported crashes and violations included results that were potentially representative of the reduced speeding in the TDSS groups compared to the control group. For example, the control group reported 15 run-off-road crashes, which are a crash type that is associated with excessive speeding (Lord et al., 2011). In comparison, the partial TDSS group reported three and the full TDSS group reported five run-off-road crashes. Although there were no statistically significant differences between the groups for self-reported crash rates (based on mileage driven) the number of run-off-road crashes suggest a potential link with the increased speeding behaviors of the control group. Moreover, the control group self-reported receiving seven speeding tickets over the course of the study, while the partial TDSS group reported two and the full TDSS group reported three speeding tickets. The control group was also at an increased exposure risk because of their increased mileage. Generally, the more miles driven the higher potential for an event to occur, which is why the crash results are not statistically significant (i.e., the per mile rates are similar across groups, while the absolute numbers are higher for the control group). It does, however, support the concept that parents can better manage how frequently and/or how far their teenagers drive and under what conditions to reduce exposure risk during the riskiest period of driving (i.e., first 1-2 years). In Minnesota, most fatal crashes occur on rural roads (MnDPS, 2014), as such, parents of teenagers who live in rural areas can reduce their teenager's risk by limiting exposure to driving on two-lane, rural roads. However, this might not be feasible if the teenager is dependent on driving to get to school or work. In these cases, the TDSS could potentially be an effective tool for parents to help reduce risky driving behaviors (e.g., speeding) when their teenager must drive in known risky situations (i.e., on rural roads).

Excessive Maneuvers with Parental Monitoring

The general trend for acceleration, braking and turning events was a lower average rate for the full TDSS group early and throughout the study compared to the other groups. There were also specific effects that were aligned with the potential causes of each event type, such as inexperience and risky driving (e.g., speeding). The full TDSS group, for example, demonstrated marginally significantly lower rates of braking events early in the study compared to the other two groups, and also showed a reduction in braking event rates as the study progressed. There were no differences between the control and partial TDSS group in braking events across the study, but both groups showed a significant decline in average braking events over time with rates similar to the full TDSS group occurring at the end of the study. The acceleration and turning event rates for the full TDSS group started lower and remained lower throughout the study, despite increasing overall. The control and partial TDSS groups also showed increased average rates over time for both turning and acceleration. The key finding for all three event types was that the full TDSS group had the lowest event rates early in the study (i.e., first 1-2 months), which suggests that teenagers are capable of safer vehicle handling early independent driving.

Novice teenage drivers graduate driver's education with vehicle handling skills (e.g., steering and braking), but other factors such as inexperience with hazard perception or deliberate risk taking (e.g., speeding) influence vehicle handling (Groeger, 2000). Hard braking, for example, can be associated with inexperience, such as a poor ability to judge the distance needed to stop, or with inattention and a failure to leave enough room to stop without requiring significant braking force. Teenage drivers develop better hazard perception skills throughout the first several months, and years, of driving (Chapman et al., 2002; Groeger, 2000). If many instances of hard braking observed in this study were associated with inexperience, then it is likely the observed reductions over time were due to learning. The full TDSS group, however, started the study with rates that were about half that of the other two groups in which there was no parental notification for behaviors, and then showed a decreased rate in the last few months of the study. This difference in event rates early in the study appears to be directly related to the presence of the parent notification function. The potential for parent feedback in the full TDSS group likely encouraged the teenage drivers to adopt behaviors supporting better vehicle handling that mitigated event rates. For example, attending more to the driving task (i.e., not distracted) would facilitate lower event rates even when the driver is inexperienced by allowing them more time to plan their braking maneuvers. In contrast, the control group and partial TDSS group appeared to learn braking skills across the entire first year of driving. Overall, the braking results support the use of early monitoring to encourage more careful driving in teenage drivers who already possess reasonable vehicle handling skills from driver's education.

The lower rate of acceleration and turning events early in the study for the full TDSS also supported the need for parent reporting. However, both event types are also associated with speeding behaviors, and the increased acceleration and turning event rates over time in all groups is potentially linked to the observed increases in speeding. The increases, however, were again minimized in the full TDSS group. The acceleration and turning event rates were also associated with vehicle status, with unshared vehicle drivers having significantly higher rates of events compared to those who shared a vehicle. Previous research indicated that teenage drivers with easier access to a vehicle are more likely to report risky driving behaviors, such as talking on a cell phone while driving (e.g., Ehsani et al., 2013). However, it is not possible to compare the excessive maneuver findings for this study's shared vehicle drivers directly to previous U.S. studies that used accelerometer data because those studies only accepted teenage drivers who were the primary driver of a vehicle (e.g., did not share with another family member; Carney et al., 2010; McGehee et al., 2007).

However, a study in Israel that used an in-vehicle data recorder that reported g-force events to provide feedback to families with teenage drivers (mean age = 17.5 years) only examined teenagers who shared the family vehicle (Farah, Musicant, Shimshoni, et al., 2013). In this study, everyone in the family who drove received feedback, except for participants in the control condition who received no feedback. In one condition, the individuals received only their driving feedback. In the other two conditions, family members were able to see all scores for each family member, and in one of these groups, parents received coaching throughout the 12-month study to assist them in using the system information. The group in which parents received coaching on how to use the information had the lowest event rate overall compared to all other groups, while the control group had the highest rate of events. This finding suggests that excessive maneuver event rates of teenage drivers who share a family vehicle can be influenced similarly to those who drive their own vehicles when parents receive reports from the system. Therefore, the results for the acceleration and turning events with TDSS feedback support the use of monitoring and reporting early in independent driving to discourage behaviors or driving styles that lead to excessive maneuvers, regardless of vehicle type.

Overall, parents have a significant ability to act as a motivator and to mentor safer driving habits when they have information available to them on which to base decisions about when and where their teenager should drive (Simons-Morton et al., 2013). By providing parents with objectively collected data regarding risky driving, the TDSS potentially increased parents' understanding of risks associated with their teenager's driving, and provides increased control in understanding and managing their teenager's driving. This is important because previous research identified that parents' often underestimated or were unaware of the driving risks associated with inexperience, age-related behavioral regulation, and peer influences for their teenager (Fischer, 2013). Objective feedback provided by the TDSS or other teenage driver monitoring systems has the potential to calibrate parents' knowledge of their teenager's ability to engage in safe driving. This knowledge can then be incorporated into the parents' belief system about the risks associated with teenage driving to encourage them to be responsive and intentional in providing management and coaching of driving-related risks to their teenagers. Knowledgeable, active management of teenage driving risks is a known problem for parents, which is why educational campaigns for parents are a proposed countermeasure to reduce teenage driving risks (Fischer, 2013). Parents, however, must receive the information, understand it and act on it. Previous research identified certain difficulties in encouraging parents to visit a website to evaluate recorded events (Farmer et al., 2010). This study sought to include near real-time feedback in the form of text messages to make it easier for parents to access and act on information from the system.

Parents' Acceptance and Use of the TDSS Feedback

The TDSS differed from previous systems that were evaluated (e.g., DriveCam Carney et al., 2010; McGehee et al., 2007; Simons-Morton et al., 2013) by providing salient in-vehicle feedback about events immediately after they occurred, as well as by providing immediate feedback to parents via text message. The results of the behavioral data suggested the text message feedback and/or other feedback mechanisms influenced the teenage drivers' behavior. Fifty percent of parents rated the text message information as excellent and 42% rated it very good for ease of understanding. Additionally, 53% of parents rated the text message information as excellent and 35% rated it very good for starting a discussion with their teenage about the driving behavior that was alert. Overall, parents in the full TDSS group rated the text message and email feedback formats better than the website. The weekly email was viewed more frequently than the website. This feedback from parents about the information content suggests that it was useful to parents. Parents in the full TDSS group also reported that speeding and other events influenced their selections of consequences, and parents and teenagers both reported that feedback from the system was used to increase or decrease driving privileges.

However, a similar percentage of parents in all three groups reported that they managed their teenagers' driving by implementing consequences and incentives related directly to driving. The primary finding for incentives and consequences was that parents in all three groups reported that they more often incentivized safer driving behaviors than they applied consequences for poor or risky driving behaviors. Of particular interest is that approximately one-third of parents in each group reported increasing driving privileges during the first month after licensure "because of demonstrated safe driving behaviors." The survey results did not indicate that parents in the full TDSS group engaged in more or different types of management of their teenage driver. However, they might have been able to target behaviors more specifically using the in-vehicle feedback based on their reported use of specific information (e.g., speeding), although this cannot be specifically identified from the survey data.

Finally, the survey data indicated that parents in all three groups believed they had a comfortable relationship with their teenager when it came to discussing driving safety and when setting and enforcing driving rules. Teenagers were slightly less comfortable discussing their driving with their parents but still rated their comfort levels high overall. Teenagers also had reasonably high ratings for their comfort with how their parents set and enforced driving rules. These results suggested parents and teenagers in this study were reasonably aligned in their expectations for driving and the types of rules that would be enforced. The ratings were not significantly different between the study groups for parents or teenagers, also suggesting that the TDSS feedback to parents was not a hindrance to communication between teenagers and parents when it came to driving safety and rules.

The first month of independent driving is the riskiest for novice teenage drivers (Mayhew et al., 2003), and this willingness to increase privileges in the first month is indicative of the trust parents have in their teenagers to drive safely. However, it could increase risk if parents do not manage driving risks and/or enforce set rules. Parents in the full TDSS group also had to rely on their own judgment and perceptions of safety in order to act on the information that was presented by the system. This was one potential limitation of the TDSS feedback in comparison to other systems that provided event-specific coaching reports, such as the DriveCam system (McGehee et al., 2007; Simons-Morton et al., 2013). Parents using the TDSS feedback had to assess the severity of the situation and determine whether they would act on the information. Alternatively, they also received positive information that influenced decisions related to driving. In general, this study indicated that parents want to increase driving privileges for their teenagers, but it is possible they increase privileges too early.

Farah et al. (2013) found that when parents were provided with coaching via phone conversations periodically through the study on how to use an in-vehicle device’s feedback the novice drivers in that group had the lowest event rates even when compared to another group of teenagers’ who parents received reports about the teenager’s driving. Moreover, Farah et al. (2013) provided coaching for different conditions of the system. For example, parents were encouraged to minimize intervention and provide positive feedback when the system reported safe driving behaviors, and to increase limits when the teenager was assessed as aggressive. This coaching included suggestions to parents on how to limit driving when the teenager was aggressive to protect the teenager from the risk of a crash, such as by restricting driving privileges. This coaching offered parents a way to maintain an effective and positive relationship with their teenager while effectively using the system feedback to manage driving risk. Although the full TDSS group parents did not receive any coaching or training, their teenagers rated communication and comfort with their parents to be very good and suggests the system was not a source of conflict for the parents and teenagers. It is likely that including coaching on the TDSS, however, could further the benefits of behavioral monitoring and, in particular, mentoring of safer driving habits by improving parents attitudes and intentions towards interactions with their teenager about driving. An examination of the partial TDSS group results further identified why parent feedback is critical for this type of system.

Impact of In-vehicle Feedback and Forcing Functions without Parent Involvement

The rationale for including the partial TDSS group was based on previous research indicating a desire to bypass parents if possible because they are not always consistent in reviewing and acting on feedback from this type of system. Previous research suggested that teenagers are more likely to adhere to an in-vehicle feedback device without parent feedback if another source of motivation was provided (i.e., rewards; Lotan et al., 2014) or if the feedback was persistent enough to encourage the teenager to change their behavior (Manser et al., 2013). Overall, the partial TDSS group demonstrated certain behavioral trends that were significantly lower than those of the control group. For example, the percentage differences between the partial TDSS group (approximately 2-5% across the study) and control group (approximately 6-12% across the study) were not as large as those between the full TDSS (approximately 1-2% across the study) and the control group, but they were one-third to one-half the percentage of the control group. Previous research on passive ISA systems, which was the type of system deployed in the partial TDSS group, also found reduced rates of speeding behaviors for young drivers (Spyropoulou et al., 2014) without other feedback sources. Teenagers in the partial TDSS group likely found the persistent nature of the auditory speeding alerts annoying, and reported that they agreed the auditory alerts were distracting at times across the study period. Persistent and graded warnings for speeding were found to reduce speeding behavior among teenagers in two previous studies as well (Farmer et al., 2010; Manser et al., 2013) without parental notification. The difficulty with assessing passive ISA systems without parental feedback for teenage drivers in experimental studies is that the outcomes are potentially associated with an experimental effect. Teenagers in this group volunteered to drive with the system and were reminded whenever it was on that they were participating in a research experiment, which might have motivated them to behave in accordance with what they believed the study goals were (i.e., to adhere to the feedback).

For excessive maneuver behaviors, previous research also found a need for either parent feedback (Simons-Morton et al., 2013) or an external reward (Lotan et al., 2014). The rationale for requiring parent feedback and/or external rewards for excessive maneuver events is because they cannot be designed to be as persistent and frequent as the speeding alerts. The lack of significant differences between the partial TDSS and control groups indicated that in-vehicle feedback alone without parental monitoring was not sufficient for reducing the rates of excessive maneuver events. The finding is consistent with that of Simons-Morton et al. (2013) who found that the blinking light associated with a triggered excessive maneuver event was not sufficient to reduce event rates without parental feedback and coaching. The in-vehicle feedback given in the partial TDSS group had more context (i.e., visual icon with auditory message) than the blinking light in the Simons-Morton et al. study, but it was still a “one-and-done” notification. There is little associated annoyance with a post-event alert compared to the graded and persistent in-vehicle speed warnings the teenagers received, particularly given that overall event rates per mile driven are low.

The lack of significant effects overall for in-vehicle feedback alone could be because the teenager did not perceive the alerted event as risky and was not motivated to change behavior. Alternatively, a teenage driver with limited experience in independent driving might not be sufficiently capable of assessing why an event was triggered and how to modify behavior in the future to avoid it. The full TDSS outcomes, however, contradict this hypothesis somewhat because the teenagers who knew their parents would receive an excessive maneuver alert were able to maintain a significantly lower rate of events early in the study (i.e., when least experienced with driving) compared to the other two groups. Previous research on training teenage drivers with error-based feedback during driving, such as inducing a crash during simulated driving, has found limited effects of error-based training (Creaser, Lees & White, 2004; Ivancic & Hesketh, 2000), which further supports the need to have the parent involved in the feedback loop. Without the parent in the feedback loop, there is less motivation to attempt to avoid this type of one-time alert. This is similar to findings of Farah et al. (2013) in which the teenager’s driving behaviors were only shared with the teenager in conjunction with in-vehicle alerting (i.e., green, yellow or red light after an event detected). This group had slightly lower event rates than the control group, but had rates higher than the two groups in which parents had access to the teenager's driving behavior profile.

The primary conclusion from the results of the partial TDSS group is that feedback that is not persistent or annoying is unlikely to alter behavior significantly, unless parents are also informed of the event when it occurs. In particular, when results were examined for excessive maneuvers the outcomes for the partial TDSS and control groups were the same, with only the full TDSS group demonstrating significantly lower event rates. Overall, the results of this study and previous studies examining in-vehicle alerting systems on novice teenage drivers' behavior suggest a limited role for in-vehicle alerts without parental feedback. More significant reductions in risky behaviors were achieved by including parental notifications.

Forcing Functions

Given the limited outcomes associated with in-vehicle alerting, and the number of potential behaviors that can be alerted to parents, this study also examined the integration of forcing functions with in-vehicle and parental feedback. The partial and full TDSS implementations employed a software design that prevented incoming calls, text messages, and other social media alerts (e.g., email) from being notified to the driver while the system was active. The driver was also prevented from interacting with any other phone applications while the TDSS was running. The results associated with both TDSS groups provided evidence for the utility of forcing functions for teenage drivers. The rates of calling and texting per mile driven were significantly lower in both the partial and full TDSS groups compared to the control group. The self-reported data also indicated lower rates of cell phone use while driving in the partial and full TDSS groups.

Of particular interest was that upon entry into the study all teenagers and parents were fully informed of the GDL restrictions on cellular phone use by teenage drivers in Minnesota. Additionally, Minnesota has mandatory driver's education during which teenagers are informed of the laws and restrictions that they will be subjected to while driving in the first one to two years after obtaining their license. Despite this knowledge, many teenagers in the control group engaged in calling and texting while driving throughout the study period. Teenagers in the partial and full TDSS groups attempted, and occasionally succeeded, in bypassing the blocking system or borrowed a phone to make calls or send texts while driving, suggesting a desire by teenagers to engage in cellular phone use while driving.

The teenage drivers in the control group began calling and texting while driving early in independent driving (i.e., Month 1) and the frequency of both calling and texting behaviors increased over the 12-month study period. These results are in alignment with studies showing that knowledge of bans on texting and/or calling or the perceived risks of cell phone use are not associated with preventing or reducing calling and texting among young drivers (Atchley et al., 2011; Ehsani et al., 2014; Nelson et al., 2009). As novice drivers become more experienced, their confidence increases, and they likely believe they can handle more distractions while driving, such as multi-tasking by calling and texting. Teenagers are particularly at risk when engaging in cellular phone use while driving (Klauer et al., 2014). Moreover, the self-regulation issues identified by Steinberg (2008) and Keating (2007) suggest teenagers are less able to resist the temptation to use their phone for social connections while driving. The fact that several teenagers in each TDSS group sought to bypass the system during the study was indicative that they are motivated to use their phones while driving.

The data from this study suggest blocking technologies are a valid solution for preventing cellular phone use in novice teenage drivers who might not be able to adequately resist picking up their phone while driving. Parents in the two TDSS groups self-reported higher frequencies of phone use while driving than their teenagers and, thus, were potentially modeling to their teenagers that calling and/or texting is normal while driving. Because parents in this study were only subjected to the texting ban, and not the calling ban, there was also a conflict in the laws governing phone use for all drivers in this study that could have lowered perceptions of the behavior as problematic. For example, Atchley at al. (2012) found that a sample of young drivers perceived cellular phone use as a normative behavior, and it is possible that the teenagers in this study perceived calling and texting while driving as a normal behavior in which many other drivers, including their parents, engaged. Based on the rates of self-reported calling and texting in the TDSS groups by Month 12, it was likely that drivers in the treatment groups were engaging in calling and texting while driving to some extent when it was possible to do so. The primary conclusion associated with the cellular phone blocking function is that it had an effect on cellular phone use while it was active and available when driving. At a minimum, it potentially reduced distraction associated with phone use during the riskiest period of driving (i.e., first year in this study), but is unlikely to result in long-term behavior changes associated with cell phone use given the prevalence of cellular phone use in the driving population.

Teenagers' Perceptions of System Usability and Reliability

The teenagers in both TDSS groups somewhat agreed that the system improved their safety and performance while driving. However, they rated their perceived confidence in their driving abilities while not using the system higher than their perceptions of the system as helpful. Previous research examining driver confidence indicates that teenage drivers are often very confident in their driving abilities (Creaser et al., 2011; Creaser et al., 2004; Groeger & Brown, 1989), and driver confidence can be a contributor to risky behaviors and crash risk (Groeger, 2000). Previous research on driver support systems has also found that drivers who are unaware of potential limitations in their driving abilities rate the usefulness of support systems low, even though there is a potential benefit to using the system (e.g., Creaser, Rakauskas, Ward, Laberge, Donath, 2007). The teenagers in this study felt highly confident in their ability to drive without the system, yet over 20 crashes were reported in each of the TDSS groups across the study indicating that the teenagers were not necessarily good judges of their own driving abilities.

Perceived trust and reliability also could have influenced the teenagers' perceptions of system utility. For example, teenagers' perception that the system improved their safety and driving performance decreased from Month 1 to Month 12. At the same time, both perceived trust and reliability in the system also declined. Appropriate trust in the system is crucial to acceptance and use of this type of technology. The limitations with the experimental technology and the commercial database used for certain notifications (e.g., stop signs; passenger detection) likely influenced the ratings of trust and reliability. The overall reliability of the TDSS from location to location was not known, although the speeding database was considered to have greater than 80% coverage in most areas. To counter known gaps in the map, the system presented a message to indicate when speed limits were not available in a location ("No speed limit available. Look for signs."). However, changes to roadways resulted in some reliability issues, such as when the posted speed limit on a road had changed and, thus, did not match what was in the system's database, or, in several cases, where a stop sign had been replaced by a traffic signal. Reliability levels below 70% are considered too low to engender enough trust in a user to adhere to alerts or warnings (Fox, 1996; Lee & See, 2004), and it is possible that in some areas, the TDSS might have been close to this threshold.

Implications of the Results for Teenage Driver Systems

The study outcomes supported previous research as well as evaluated new functions that could be useful for teenage drivers and their parents (e.g., cellular phone blocking; text message feedback). As deployed in this study, the TDSS encouraged teenagers' driving behavior towards expected goals (i.e., reduced frequency of risky behaviors) early on and throughout the first year of driving for those who received the full TDSS with parental feedback. Employing this system in the first year of driving, when risks are greatest for teenage drivers, demonstrated that reductions in risky driving could be achieved in comparison to a control group that was also subjected to GDL restrictions. In particular, the parental feedback, as well as the speed alerting (ISA), and cellular phone blocking functions worked together and independently, to some extent, to reduce risky driving in the full and partial TDSS groups. For example, speeding was significantly reduced in both TDSS groups in comparison to the control group. All teenagers were also aware that cellular phone use was illegal upon entry into the study, but the control group drivers engaged in increasingly more frequent rates of calling and texting throughout the study. In comparison, the TDSS groups with cellular phone blocking were unable to engage in cellular phone use while driving (except under limited circumstances). The desire of teenagers in this study to bypass the phone blocking suggested that they are motivated to engage in cellular phone use while driving and that this function is likely an appropriate countermeasure for teenage drivers who might not be able to exercise self-regulation over phone use.

The potential for parental notification appeared to minimize risky driving behaviors even in the earliest phase of independent driving (i.e., first month). Teenagers in the full TDSS group appeared to be highly motivated to avoid triggering an alert to parents and seemingly were able to anticipate the driving behaviors needed to prevent an alert. For example, excessive maneuver rates early on were almost half in the full TDSS group compared to the other two groups. In particular, this suggests that teenagers were motivated to intentionally engage in control over their driving behaviors in order to avoid triggering the system. However, their increased speeding near the excessive speeding threshold as well as their desire to bypass the cellular phone blocking indicates an effect of other influencing factors on traffic safety, such as norms associated with speeding and cellular phone use. This suggests that the long-term role of the system in changing behavior will be limited until such time as traffic safety culture changes such that all drivers minimize these behaviors by holding stronger attitudes and beliefs that support safety. The TDSS is a tool that, when deployed in the first year of driving, works to change the attitudes and beliefs of parents and teenagers about teenage driving, as well as encourages increased control of parents and teenagers over driving while the system is deployed, but long-term behavioral changes associated with using the system remain unknown.

For teenage driver safety, the full TDSS might be best used to help parents identify and address issues with teenagers who are resistant to intervention (i.e., have the highest rates of risky events). For example, previous research found subsets of aggressive young drivers (e.g., Deery & Fildes, 1999) who were seemingly immune to intervention. McGehee et al. (2007) and Carney et al. (2010) identified a small subset of their drivers who had significantly higher rates of events and for whom the intervention was successful at reducing those event rates. For these “hard cases”, a reliable monitoring system is a potentially effective countermeasure when used by a parent or parents who are willing to take away driving access for teenagers who refuse to adhere to the system’s feedback. Indeed, the goal of the coaching protocol for parents in the Israeli study was to restrict driving only when the risk profile was aggressive in order to protect the teenager (Farah et al., 2013). Another option is to also include external stakeholders in the deployment of such a system, such as insurance companies. If teenagers do not wish to adhere to their parents, they might be willing to drive more safely for a significant reduction in insurance, particularly if they are required to pay for it themselves. Forcing functions are also ideal solutions for problem drivers as it allows the teenager to drive but not engage in risky driving. The latter two conditions could reduce potential friction between parents and teenagers who already have difficulty communicating because forcing functions or an external stakeholder do not necessarily require interaction of the parent and teenager to work. However, parents and teenagers in this study reported the system did not negatively impact their communication about the teenager's driving.

The significantly lower rates of risky behaviors observed in the full TDSS group also demonstrated the specific capabilities of smartphones to serve as platforms for a teenage driver application or "app." The purpose of locating most of the system on the phones was to ensure that key functions could be made widely available to parents and teenagers without any specialized equipment. The smartphone contained all the needed sensors and functions necessary to run a smartphone-only application that included monitoring and/or blocking of a subset of the known risky behaviors associated with teenage crashes. The smartphone also contained the necessary features to provide near real-time feedback to parents about events to facilitate easy access to information. Although the TDSS in this study was deployed with additional in-vehicle components, the speeding, excessive maneuver, and cellular phone blocking functions can all be deployed without any additional in-vehicle components. The seat belt and passenger detection sensors were included primarily as a demonstration of those functions but this study and previous research identified the difficulty of incorporating after-market sensors into vehicles long-term. The stop sign violation function was also tested in the usability study (Creaser et al., 2011) but was not feasible in this large-scale, real-world deployment. However, this type of function is likely to improve as digital maps become more comprehensive and are updated more frequently. The push for increasingly connected vehicles, such as vehicle-to-vehicle and vehicle-to-infrastructure communication, will provide affordances for teenage driver safety systems in the future by also enhancing the availability of digital map information or location-specific information (e.g., traffic signs; Rephlo, 2013).

The recent demonstrations of safety systems for teenager drivers, such as those deployed in this study and previous research (e.g., Manser et al., 2013), have pushed the market towards supporting individual functions or incorporated functions into vehicles. For example, Chevrolet recently announced a Teen Driver system for its 2016 Malibu that includes an enhanced visual and auditory safety belt warning, provides tracking information about teenage driving behavior to parents, enables the teenage driver vehicle features using a special key fob, and has an option to select a single maximum vehicle speed between 40 and 75 mph that will chime and provide a visual warning when the speed is reached. These features likely stem from the body of research on teenage driver safety systems, including that of the Safer Teen Car project that was specifically conducted for NHTSA by Manser et al. (2013) to identify functions that could be built into vehicles by manufacturers. The advent of a teenage driver specific vehicle system suggests that stakeholders in vehicle design and safety are taking notice of the significant crash rate of teenagers and are seeking creative solutions to manage those risks above and beyond existing countermeasures.

A recent report from the Traffic Injury Research Foundation (TIRF; Mayhew, Williams & Pashley, 2014) also specifically highlighted technology interventions as complementary to GDL laws. The TIRF report specifically identified the research on in-vehicle devices with parental monitoring and noted the lack of research on other functions, such as technology blockers (e.g., phone blocking), geofencing, and passenger sensing technologies. The results of this study provide new research-based support for the potential effectiveness of cellular phone blocking and highlighted the difficulty in implementing aftermarket passenger detection systems. Geofencing is when geographical boundaries are set and parents are alerted when the teenager drives outside the specified areas. Geofencing is feasible in a smartphone application and was evaluated in the TDSS usability study, but parents surveyed in the usability study were less accepting of this feature (Creaser et al., 2011). However, if geofencing is acceptable to parents, a smartphone-based teenage driver system like the TDSS can easily incorporate a geofencing function. The sensing and detecting of passengers and seat belt use, however, are more the purview of vehicle manufacturers because they are easier to incorporate into the vehicle design at the time a vehicle is built. The TDSS study highlighted the difficulties of incorporating such after-market sensors into a vehicle long term. For example, the seat belt sensors were difficult to affix to the wide range of seat belt types and frequently became dislodged with continuous use in the current study.

The desire to integrate mobile technologies, such as smartphones, with the vehicle, however, is likely to support smartphone-based teenage driver applications that wish to include seat belt and passenger detection alerts and reporting. For example, seat belt and passenger information could be sent from the vehicle to a smartphone application via Bluetooth or while the phone is docked in the vehicle. Bluetooth pairing and phone docking are already features in certain vehicles and it is expected such connectivity between mobile devices will increase in the future. For example, the TDSS engineering team demonstrated the feasibility of obtaining such information from a vehicle via the OBD-II port for use with the smartphone application. The smartphone can then be used to interpret the information and provide it to relevant interfaces (e.g., phone or in-vehicle) as well as send feedback to parents. This type of implementation would reduce costs for vehicle manufacturers while allowing individuals to manage the software application and associated parental feedback privately. It would also capitalize on and integrate the full capabilities of vehicle sensors and smartphone technology.

Theoretically, wide-scale adoption of monitoring and feedback systems for teenagers could influence societal beliefs among parents about the need to effectively manage and mentor teenage drivers. This study demonstrated that parents are open to using system feedback to manage driving and it seemed to increase their management of driving in the full TDSS group. Changing teenagers' beliefs about driving might require the adoption of other behavior-change constructs that are better aligned with teenagers' personalities and goals. For example, social learning theory (Bandura, 1977; 1986) indicates that modeling behavior for learners is an effective way to help learners develop desired behaviors. Prato et al. (2010) found that parents' driving behaviors were highly correlated with their teenagers' driving behaviors (i.e., riskier parents had riskier teenage drivers), which supports the need for parents to role model safer driving habits. One way technology could be used to support role modeling would be for parents and teenagers both to agree to being monitored. Although teenagers reported the system did not adversely affect their relationship with their parents, allowing teenagers to simultaneously monitor their parents' driving could provide additional buy-in to the system and its goals to engage in safer driving. Alternatively, the distribution described by McGehee et al. (2007) that demonstrated where a teenager fell in terms of number of events among their peers with respect to safe driving could be adopted into a gaming strategy where friends compete to learn and demonstrate safer driving habits. Applying such unique alternatives in the use of technology could have a significant influence on how families and teenagers approach independent driving, and potentially influence attitudes towards driving safety over the long-term for families who engage in these strategies.

Ultimately, the goal of countermeasures for driving safety, including the adoption of technological solutions is to improve long-term safety among teenage drivers, and, in particular, reduce crash rates for this at-risk group of drivers. However, the limited number of short-term studies conducted to date does not adequately demonstrate long-term effectiveness, as identified in the report by Mayhew et al. (2014). Because the rates of reported crashes per mile driven in this study were not significantly different between the groups, it is difficult to conclude that the system significantly improved safety overall in the full TDSS group based on increased parent involvement. Ideally, a reduction in risky driving behaviors should be correlated with a reduction in crash rates. Although this study did not demonstrate a significantly reduced crash rate for the full TDSS group, a potential protective effect on the total number of crashes was observed in relation to the reduced mileage driven in the TDSS groups in comparison to the control group. The control group drove significantly more miles and reported a larger number of crashes compared to both TDSS groups. Therefore, although the comparison of crash rates between groups was not statistically significant, the group with the highest mileage (i.e., control) had more crashes, indicating a risk of exposure due to more driving. Reducing exposure to risky situations is one the tenets of GDL programs and this study demonstrated that exposure risk was potentially reduced in the full TDSS group with parent feedback due to lower mileages driven. This highlights a limitation of this type of research to determine the effectiveness of technology interventions.

Limitations and Future Research

The lack of a follow-up period to determine if teenage driver behaviors in the full TDSS group remained similarly low after the system was removed from the vehicle. Previous research has identified continued reductions in observed risky driving behaviors shortly after the removal of the system (Carney et al., 2010; McGehee et al., 2007), but no study has fully assessed the potential long-term benefits of such systems on the adoption of safe driving habits and crash rates. The collection of data to support the long-term effectiveness of road safety countermeasures is inherently difficult and often associated with funding limitations and the difficulty in following a sample longitudinally (Manser, Creaser & Boyle, 2013). In particular, reductions in crash rates are difficult to observe in short-term studies of driving interventions, and, in particular, fatal crashes—although highest for the youngest drivers—remain a rare occurrence. The most recent data for Minnesota indicated that, for drivers aged 16-17, 16 drivers were killed while approximately 6,000 were involved in crashes of all types in 2012 (MN DPS, 2013). The long-term effect of teenage driver support systems for reducing crashes has not been established in the literature, instead self-reported or observed reductions in risky behaviors serve as surrogate measures to indicate whether the intervention is potentially successful. The overhead associated with long-term research to determine reductions in crash rates is a limitation of this type of research, but it should be considered an important part of future research as these types of technologies mature.

This study was also subjected to similar constraints faced by previous research, such as the inability to employ a pre-test/post-test study design due to funding and logistical constraints in managing such a large sample. However, now that the functional utility of the TDSS has been identified and the smartphone platform has been validated as a useful tool, it increases the feasibility of future research to employ more robust quasi-experimental designs or even randomized controlled trials with pre and post-treatment baseline periods. Additionally, although the study was conducted in Minnesota, the behaviors associated with teenage driver fatal crashes are similar across the U.S. (NHTSA, 2014a) and are also a concern worldwide, as demonstrated by the Israeli research with an in-vehicle teenage driver system (Farah et al., 2013; Lotan et al., 2014). It is expected that deployment of the TDSS to other areas of the U.S. would yield similar reductions in the monitored risky driving events. For example, DriveCam has seen similar results in Minnesota, Iowa, and Maryland teenage drivers, as well as across rural and suburban teenage samples.

Another limitation in this study was associated with the aftermarket sensors employed for passenger detection and seat belt use. Although there was a workable solution to detect sensor problems for the seat belt data and account for that during analysis, this was not the case for passenger detection. The NFC key fob used to disable the TDSS and data collection software when the teenager was not driving proved to be more difficult to implement than expected. Some parents reported difficulty in understanding the instructions for use across the three groups, necessitating periodic updates to instructions for participants. This likely explains some of the discrepancy in usage between the control and TDSS groups. Farah et al. (2013) used Dallas keys with their in-vehicle system to identify the driver and also found that approximately one-third of drives during the 12-month study period did not have an identified driver. Tools such as the TDSS NFC fob require the participant to be carrying them at the time they are driving. It is likely that in this study, parents might have forgotten the fob at times and, as such, some of the driving in each group was assumed not to be that of the teenage driver. Fortunately, the unshared vehicle dataset was substantial enough to provide a verification of outcomes for the study. Future system designs should carefully consider easy yet secure ways to identify the teenage driver and ensure the data collected are associated with the intended teenage driver.

Finally, the instructional materials provided to parents and teenagers in this study were system specific and did not provide any information on how to effectively interpret the feedback or coach the teenage driver. Parents were left to determine the best course of action on their own and the survey data was not able to accurately determine whether the detailed feedback influenced parents' decision-making significantly differently than parents in the other groups. To gain the full benefit of a TDSS or similar system, parents might need additional training or educational materials on how to effectively use the driving behavior feedback. Research shows that parents are not always good at describing how to generalize behavior to multiple situations or at providing information on how to mitigate risky behaviors (Goodwin et al., 2014) and that specific parental coaching on how to use the positive and negative information results in reduced event rates using a monitoring system (Farah et al., 2013). Many parents in the current study, for example, were not aware of certain novice teenage driver laws or risks when they joined the study. In general, this matches previous research that has identified parents are often not well equipped with knowledge about the risks teenage drivers face (Simons-Morton, 2007). Receiving feedback is the first step in reducing driving risks for novice teenage drivers, but parents must also be prepared to effectively discuss safety and driving strategies with their teens. This also means there is a role for continued research and development in parent education programs that incorporate information on how to effectively use teenage driver technologies.

Conclusions

The results of the study indicated that full TDSS implementation *with parental feedback* reduced the frequency of risky driving behaviors that are associated with novice teenage driver crashes. There was less experimental evidence to support aspects of the system when partial TDSS functionality was deployed, such as providing teenagers with speeding notifications without also alerting their parents. The most consistent results observed across both functions and outcomes were seen with full TDSS implementation, which indicates, as expected, that providing parents with feedback about their teenager's driving is a necessary component of such systems. The usability results associated with the TDSS in this study indicated that parents and teenagers are willing to adopt such technologies if there is a perceived benefit for both parties. Moreover, despite the some of the technological issues they experienced due to the experimental equipment (i.e., sensor issues), most parents and a majority of teenagers said they would recommend the system to other parents and teenagers. For parents, the TDSS affords them an opportunity to allow their teenager to drive independently while retaining the ability to monitor and supervise their driving. For teenagers, the reported acceptance of the system was likely associated with increased driving privileges that were obtained by demonstrating safer driving behaviors to their parents. Creaser et al. (2011) found that teenagers said they would use the TDSS if it meant they would be allowed to drive more often, and parents in the current study were forthcoming with increased privileges starting early in independent driving. Further research could examine incorporating parent education with using teenage driver technologies to ensure parents increase privileges appropriately. Main conclusions of the study are summarized below:

- As deployed in this study, the TDSS altered behaviors toward expected goals (i.e., reduced frequency of risky behaviors) early on and throughout the first year of driving for novice teenage drivers who received the full system with parental feedback.
- The in-vehicle monitoring with parental feedback deployed in this study is a potentially useful intervention to minimize increases in risky driving behaviors that naturally occur during a teenager's first year of driving. In this study, rates of certain monitored behaviors (e.g., speeding, cellular phone use) became more frequent across all groups, but the full TDSS group of teenagers had the lowest rates of change over time.
- The TDSS could potentially provide a significant benefit to teenagers who do not share a vehicle with another family member. Because the TDSS can be implemented for a long period of time (i.e., one year in this study), it could encourage parents to better monitor teenage drivers who are primary vehicle drivers (i.e., do not share with another family member).
- The TDSS as deployed for this study was well received by parents and teenagers in both TDSS groups.

- To make system feedback salient, information on monitored events must be pushed to parents shortly after an event occurs, such as through text messaging and in a weekly summary report. Although a website provides a good base for data archiving, this research and previous research indicated that parents were not willing to regularly login to a website to review their teen's driving behaviors.
- A smaller set of TDSS functions with parental feedback, such as speeding alerts and phone blocking, can be deployed on a mobile device without special in-vehicle equipment. Both speeding alerts and phone blocking can be triggered based on estimated vehicle speed and would not require the phone to be custom mounted.
- The TDSS is a tool to support parents and does not replace the need for parents to coach their teens in how to drive more safely. Training integrated into education programs for parents on teenage driving risks could help parents effectively use TDSS technologies as they become available on the market, avoiding a situation in which parents assume their teens are safe simply because they have the system.

REFERENCES

Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes*, *50*(2), 179-211.

Arnett, J. (1996). Sensation seeking, aggressiveness, and adolescent reckless behavior. Personality and Individual Differences, 20(6), 693-702.

Arnett, J. (1994). Sensation seeking: A new conceptualization and a new scale. *Personality and Individual Differences*, *16*(2), 289-296.

Atchley, P., Atwood, S., & Boulton, A. (2011). The choice to text and drive in young drivers: Behavior may shape attitude. *Accident Analysis and Prevention, 43*, 134-142.

Atchley, P., Hadlock, C., & Lane, S. (2012). Stuck in the 70s: The role of social norms in distracted driving. *Accident Analysis and Prevention, 48*, 279-284.

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological Review*, *84*(2), 191.

Bandura, A. (1986). The explanatory and predictive scope of self-efficacy theory. *Journal of Social and Clinical Psychology*, *4*(3), 359-373.

Beck, K. H., Shattuck, T., & Raleigh, R. (2001). Parental predictors of teen driving risk. *American journal of health behavior*, *25*(1), 10-20.

Berk, R., & MacDonald, J. (2008). Overdispersion and Poisson regression. *Journal of Quantitative Criminology*, *24*, 269-284.

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

Brovold, S., Ward, N., Donath, M., Simon, S., Shankwitz, C., & Creaser, J. (2007). The use of technology to address patterns of risk among teenage drivers. *Journal of Safety Research, 38*, 413-422.

Cameron, A., & Trivedi, P. (1990). Regression-based test for overdispersion in the Poisson model. *Journal of Econometrics, 46,* 347-364.

Carney, C., McGehee, D., Lee, J., Reyes, M., & Raby, M. (2010). Using an event-triggered video intervention system to expand the supervised learning of newly licensed adolescent drivers. *American Journal of Public Health, 100*(6), 1101-1106.

Carter, P., Bingham, C., Zakrajsek, J., Shope, J., & Sayer, T. (2014). Social norms and risk perception: predictors of distracted driving behavior among novice adolescent drivers. *Journal of Adolescent Health*, *54*(5), S32-S41.

Centers for Disease Control. (2012). *Injury Prevention & Control: Motor Vehicles -- Teen Drivers.* http://www.cdc.gov/Motorvehiclesafety/Teen_Drivers/index.html, retrieved on November 15, 2014.

Chapman, P., Underwood, G., & Roberts, K. (2002). Visual search patterns in trained and untrained novice drivers. *Transportation Research Part F, 5,* 157-167.

Chen, L., Baker, S., & Li, G. (2006). Graduated driver licensing programs and fatal crashes of 16-year-old drivers: a national evaluation. *Pediatrics*, *118*(1), 56-62.

Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: Design and analysis for field settings*. Rand McNally.

Cooper, P. J., Pinili, M., & Chen, W. (1995). An examination of the crash involvement rates of novice drivers aged 16 to 55. *Accident Analysis & Prevention*, *27*(1), 89-104.

Creaser, J., Gorjestani, A., Manser, M., & Donath, M. (2011). *Usability evaluation of a smartphone-based Teen Driver Support System (TDSS)* (Report. No. MnDOT 2011-13). St. Paul, MN: Minnesota Department of Transportation.

Creaser, J., Hoglund, R., Manser, M., & Donath, M. (2009). *Development and Evaluation of a Cellular Phone Based Teen Driving Support System* (Report No. CTS 09-22). Minneapolis, MN: Center for Transportation Studies.

Creaser, J. I., Rakauskas, M. E., Ward, N. J., Laberge, J. C., & Donath, M. (2007). Concept evaluation of intersection decision support (IDS) system interfaces to support drivers' gap acceptance decisions at rural stop-controlled intersections. *Transportation Research Part F: Traffic Psychology and Behaviour*, *10*(3), 208-228.

Creaser, J., Lees, M., & White, C. (2004). The effect of insight and error-based feedback on young drivers' following behavior and confidence. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 48, No. 19, pp. 2261-2265). Santa Monica, CA: Human Factors and Ergonomics Society.

Deery, H., & Fildes, B. (1999). Young novice driver subtypes: Relationship to high-risk behavior, traffic accident record, and simulator driving performance. *Human Factors*, *41*(4), 628-643.

Ehsani, J., Bingham, C., Ionides, E., & Childers, D. (2014). The impact of Michigan's text messaging restriction on motor vehicle crashes. *Journal of Adolescent Health, 54*, S68-S74.

Ehsani, J., Brooks-Russell, A., Li, K., Perlus, J., Pradhan, A., & Simons-Morton, B. (2013). Prevalence of Novice Teenage Driver Cell Phone Use. *7th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.* New York, June 18-20.

Engström, I., Gregersen, N., Hernetkoski, K., Keskinen, E., & Nyberg, A. (2003). *Young novice drivers, driver education and training: Literature Review* (VTI Report A 491). Linkoping, Sweden.

Farah, H., Musicant, O., Shimshoni, Y., Toledo, T., Grimberg, E., Omer, H., & Lotan, T. (2013). The first year of driving–can IVDR and parental involvement make it safer (Paper No. 13-1531). *Proceedings of the 92nd Annual Meeting of the Transportation Research Board*. Washington, DC: Transportation Research Board.

Farmer, C., Kirley, B., & McCartt, A. (2010). Effects of in-vehicle monitoring on the driving behavior of teenagers. *Journal of safety research*, *41*(1), 39-45.

Ferguson, S., Teoh, E., & McCartt, A. (2007). Progress in teenage crash risk during the last decade. *Journal of safety research*, *38*(2), 137-145.

Fischer, P. (2013). Parent Involvement in Teen Driving: An In-Depth Look at the Importance and Initiatives. Retrieved September 5, 2013 from http://ghsa.org/html/files/pubs/sfteens13.pdf.

Foss, R.D., Goodwin, A.H., McCartt, A.T., & Hellinga, L.A. (2009). Short-term effects of a teenage driver cell phone restriction. *Accident Analysis and Prevention, 41*, 419-424.

Fox, J. M. (1996). *Effects of information accuracy on user trust and compliance*. In CHI 1996 Conference on Human Factors in Computing Systems (pp. 35-36). New York: Association for Computing Machinery.

Freedmon, M., Lerner, N., Zador, P., Signer, J., & Levi, S. (2007). *Effectiveness and Acceptance of Enhanced Seat Belt Reminder Systems: Characteristics of Optimal Reminder Systems* (Report No. DOT HS 811 097). Washington, D.C.: National Highway Traffic Safety Administration.

Goodwin, A. H., O'Brien, N. P., & Foss, R. D. (2012). Effect of North Carolina's restriction on teenage driver cell phone use two years after implementation. *Accident Analysis & Prevention*, *48*, 363-367.

Goodwin, A.H., Foss, R.D., Margolis, L.H. & Harrell, S. (2014). Parent comments and instruction during the first four months of supervised driving: An opportunity missed? *Accident Analysis and Prevention, 69*, 15-22.

Groeger, J. (2000). *Understanding driving: Applying cognitive psychology to a complex everyday task.* Philadelphia, P.A.: Taylor and Francis, Inc.

Groeger, J., & Brown, I. (1989). Assessing one's own and others' driving ability: Influences of sex, age, and experience. *Accident Analysis & Prevention*, *21*(2), 155-168.

Hedlund, J., & Compton, R. (2005). Graduated driver licensing research in 2004 and 2005. *Journal of Safety Research, 36*(2), 109-119.

Hedlund, J., Shults, R., & Compton, R. (2003). What we know, what we don't know, and what we need to know about graduated driver licensing. *Journal of Safety Research*, *34*(1), 107-115.

Insurance Institute for Highway Safety. (2014). Cellphones and texting. http://www.iihs.org/iihs/topics/laws/cellphonelaws?topicName=distracted-driving Retrieved on November 18, 2014.

Ivancic, K., & Hesketh, B. (2000). Learning from errors in a driving simulation: Effects on driving skill and self-confidence. *Ergonomics, 43*(12), 1966-1984.

Jonah, B.A., Thiessen, R., & & Au-Yeung, E. (2001). Sensation seeking, risky driving and behavioural adaptation. *Accident Analysis and Prevention, 33*, 679-684.

Jonah, B.A., 1990. Age differences in risky driving. *Health Education Research 5*(2), 9–149.

Karaca-Mandic, P., & Ridgeway, G. (2010). Behavior impact of graduated driver licensing on teenage driving risk and exposure. *Journal of Health Economics, 29*, 48-61.

Kerr, D. (October 29, 2013). Smartphones commandeer 70 percent of teen market. Retrieved from http://www.cnet.com/news/smartphones-commandeer-70-percent-of-teen-market/ November 15, 2014.

Klauer, S., Guo, F., Simons-Morton, B., Ouimet, M., Lee, S., & Dingus, T. (2014). “Distracted driving and risk of road crashes among novice and experienced drivers.” *New England Journal of Medicine,* 370(1), 54-59.

Klauer, S., Dingus, T., Neale, V., Sudweeks, J., & Ramsey, D. (2006). *The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data.* (DOT HS 810 594). Washington, D.C.: U.S. Department of Transportation.

Keating, D.P. (2007). Understanding adolescent development: Implications for driving safety. *Journal of Safety Research, 38*, 47-157.

Laapotti, S., Keskinen, E., Hatakka, M., & Katila, A. (2001). Novice drivers' accidents and violations – a failure on higher or lower hierarchical levels of driving behaviour. *Accident Analysis and Prevention, 33*, 759-769.

Lajunen, T., Karola, J., & Summala, H. (1997). Speed and acceleration as measures of driving style in young male drivers. *Perceptual and motor skills*, *85*(1), 3-16.

Lee, J.D. (2007). Technology and teen drivers. *Journal of Safety Research, 38,* 2, 203-213.

Lee, J., & See, K. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *46*(1), 50-80.

Lee, J. D., & Moray, N. (1994). Trust, self-confidence, and operators' adaptation to automation. *International journal of human-computer studies*, *40*(1), 153-184.

Lerner, N., Jenness, J., Singer, J., Klauer, S., Lee, S., Donath, M., Manser, M., & Ward, N. (2010). *An Exploration of Vehicle-Based Monitoring of Novice Teen Drivers: Final Report.* (DOT HS 811 333). Washington, D.C.: National Highway Traffic Safety Administration.

Liu, C., & Subramanian, R. (2009). *Factors related to fatal single-vehicle run-off-road crashes*. Washington, D.C.: National Highway Traffic Safety Administration.

Lord, D., Brewer, M.A., Fitzpatrick, K., Geedipally, S.R., & Peng, Y. (2011). *Analysis of roadway departure crashes on two-lane rural roads in Texas* (FHWA/TX-11/0-

603101). Texas Transportation Institute, The Texas A&M University System, College Station, Texas.

Lotan, T., Musicant, O., & Grimberg, E. (2014). Can young drivers be motivated to use smartphone based driving feedback?–A pilot study 2. (No. 14-2594). *Proceedings of the 93rd Annual Meeting of the Transportation Research Board*. Washington, D.C.: Transportation Research Board.

Manser, M.P., Creaser, J.I., & Boyle, L.N. (2013). Methodological and measurement issues in behavioural adaptation. In M. Rudin-Brown, & S. Jamson. (Eds.), *Behavioural Adaptation and Road Safety: Theory, Evidence, and Action*. CRC Press: London.

Manser, M., Edwards, C., Lerner, N., Jenness, J. & Huey, R. (2013). *Evaluation of a prototype Safer Teen Car: Final Report* (DOT HS 811784). Washington, D.C.: National Highway Traffic Safety Administration.

Masten, S.V, Foss, R.D., & Marshall, S.W. (2011). Graduated driver licensing and fatal crashes involving 16- to 19-year-old drivers. *Journal of the American Medical Association, 306*, *10*, 1098-1103.

Masten, S., & Foss, R. (2010). Long-term effect of the North Carolina graduated driver licensing system on licensed driver crash incidence: a 5-year survival analysis. *Accident Analysis & Prevention*, *42*(6), 1647-1652.

Mayhew, D., Williams, A.F., & Pashley, C. (2014). *A New Framework: Evidence Base to Integrate Novice Driver Strategies.* Ottawa, ON: Traffic Injury Research Foundation.

Mayhew, D., Simpson, H., & Pak, A. (2003). Changes in collision rates among novice drivers during the first months of driving. *Accident Analysis & Prevention, 35*, 638−691.

McCartt, A., Teoh, E., Fields, M., Braitman, K., & Hellinga, L. (2010). Graduated licensing laws and fatal crashes of teenage drivers: a national study. *Traffic injury prevention*, *11*(3), 240-248.

McCartt, A. T., Shabanova, V. I., & Leaf., W. A. (2003). Driving experience, crashes and traffic citations of teenage beginning drivers. *Accident Analysis and Prevention, 35*, 311−320.

McGehee, D., Carney, C. Raby, M. Reyes, M., Lee, J. (2007). Extending parental mentoring using an event-triggered video intervention in rural teen drivers. *Journal of Safety Research*, *38*(2), 215-227.

McKnight, A., & McKnight, A. (2003). Young novice drivers: careless or clueless? *Accident Analysis and Prevention, 35*, 921−925.

Michon, J. A. (1989). Explanatory pitfalls and rule-based driver models.*Accident Analysis & Prevention*, *21*(4), 341-353.

Minnesota Department of Public Safety. (2014). *Minnesota Motor Vehicle Crash Facts 2013*. https://dps.mn.gov/divisions/ots/reports-statistics/Documents/2013-crash-facts.pdf Retrieved on November 15, 2014.

Mourant, R., Rockwell, T. (1972). Strategies of visual search by novice and experienced drivers. *Human Factors, 14*, 325−335.

National Highway Traffic Safety Administration. (2013). Traffic Safety Facts: Distracted Driving 2011 (DOT HS 811 737). Washington, D.C.: NHTSA

National Highway Traffic Safety Administration. (2014a). Traffic Safety Facts: Young Drivers, 2012 data (DOT HS 812 019). Washington, D.C.: NHTSA

National Highway Traffic Safety Administration. (2014b) Traffic Safety Facts: Overview 2012 (HS 812 016). Washington, D.C.: NHTSA

National Highway Traffic Safety Administration. (2014c) Traffic Safety Facts: Speeding 2012 (HS 812 021). Washington, D.C.: NHTSA

National Highway Traffic Safety Administration. (2014d). Traffic Safety Facts: Occupant Protection 2012 Data (DOT HS 811 892). Washington, D.C.: NHTSA

Nelson, E., Atchley, P., & Little, T. (2009). The effects of perception of risk and importance of answering and initiating a cellular phone call while driving. *Accident Analysis and Prevention, 41*, 438-444.

Neyens, D., Donmez, B., & Boyle, L. (2008). The Iowa graduated driver licensing program: Effectiveness in reducing crashes of teenage drivers. *Journal of safety research*, *39*(4), 383-390.

Norman, D.A. (2002). *The Design of Everyday Things*. New York, NR: Basic Books.

Norman, D.A. (1988). *The Psychology of Everyday Things*. New York, NY: Basic Books.

Parasuraman, R., Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, *39*(2), 230-253.

Prato, C., Toledo, T., Lotan, T., & Taubman-Ben-Ari, O. (2010). Modeling the behavior of novice young drivers during the first year after licensure. *Accident Analysis & Prevention, 42*, 480-486.

Preusser, D. F., Ferguson, S. A., & Williams, A. F. (1998). The effect of teenage passengers on the fatal crash risk of teenage drivers. *Accident Analysis & Prevention*, 30(2), 217-222

Reason, J., Manstead, A., Stradling, S., Baxter, J., & Campbell, K. (1990). Errors and violations on the roads: a real distinction? *Ergonomics*, *31*, 1315-1332.

Regan, M., Triggs, T., Young, K., Tomasevic, N., Mitsopoulos, E., Stephan, K., & Tingvall, C. (2006). *On-road evaluation of Intelligent Speed Adaptation, Following Distance Warning and Seatbelt Reminder Systems: Final results of the TAG SafeCar project.* Monash, Australia: *Monash University Accident Research Centre Reports*.

Renner, W., & Anderle, F.G. (2000). Venturesomeness and extraversion as correlates of juvenile drivers' traffic violations, *Accident Analysis and Prevention, 32*, 673–678.

Rephlo, J. (2013). Connected Vehicles for Safety, Mobility, and User Fees: Evaluation of the Minnesota Road Fee Test. St. Paul, MN: Minnesota Department of Transportation.

Shadish, W.R., Cook, T.D., Campbell, D.T. (2002). *Experimental and Quasi-Experimental Designs for Generalized Causal Inferen*ce. Boston, MA: Houghton Mifflin Co.

Shope, J.T. & Bingham, C.R. (2008). Teen driving: Motor-vehicle crashes and factors that contribute. *American Journal of Preventive Medicine, 35*(3S), S261-S271.

Shope, J.T. (2007). Graduated driver licensing: review of evaluation results since 2002. *Journal of Safety Research, 38*, 165–175.

Simons-Morton, B. G., Bingham, C. R., Ouimet, M. C., Pradhan, A., Falk, E., Li, K., Green, P., Almani, F., & Shope, J. (2014). Experimental effects of injunctive norms on simulated risky driving among teenage males. *Health Psychology,* 33(7), 616-627.

Simons-Morton, B., Guo, F., Klauer, S., Ehsani, J., & Pradhan, A. (2014). Keep your eyes on the road: Young driver crash risk increases according to duration of distraction. *Journal of Adolescent Health, 54*(5), S61-S67.

Simons-Morton, B., Bingham, R., Ouimet, M., Pradhan, A., Chen, R., Baretto, A., & Shope, J. (2013). The effect of teenage risky driving feedback from a safety monitoring system: A randomized controlled trial. *Journal of Adolescent Health, 53*, 21-26.

Simons-Morton, B.G., Ouimet, M.C., Chen, R., Klauer, S.G., Lee, S.E., Wang, J., & Dingus, T.A. (2012). Peer influence predicts speeding prevalence among teenage drivers. *Journal of Safety Research, 43*, 397-403.

Simons-Morton, B., Zhang, Z., Jackson, J., &Albert, P. (2012). Do elevated gravitational-force events while driving predict crashes and near crashes? *American Journal of Epidemiology, 175*(12), 1075-1079.

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

Simons-Morton, B.G. (2007). Parent involvement in novice teen driving: Rationale, evidence of effects, and potential for enhancing graduated driver licensing effectiveness. *Journal of Safety Research*, *38*(2), 193-202.

Simons-Morton, B., Hartos, J., Leaf, W., & Preusser, D. (2006). “The effect on teen driving outcomes of the Checkpoints Program in a state-wide trial.” *Accident Analysis & Prevention*, *38*(5), 907-912.

Simons-Morton, B., & Ouimet, M. C. (2006). Parent involvement in novice teen driving: a review of the literature. *Injury Prevention*, *12*(S1), i30-i37.

Simons-Morton, B., Lerner, N., & Singer, J. (2005). The observed effects of teenage passengers on the risky driving behavior of teenage drivers. *Accident Analysis & Prevention*, *37*(6), 973-982.

Spyropoulou, I., Karlaftis, M., & Reed, N. (2014). Intelligent Speed Adaptation and driving speed: Effects of different system HMI functionalities. *Transportation Research Part F: Traffic Psychology and Behaviour*, *24*, 39-49.

Stanton, N.A., & Baber, C. Speed-based alarm displays. In N.A. Stanton & J. Edworthy (Eds.), *Human Factors in Auditory Warnings* (pp. 243-261). Brookfield, VT: Ashgate Publishing Company.

Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental Review*, *28*, 78-106.

Stoklosa, A. (March 20, 2015). 2016 Chevrolet Malibu to Debut New Spyware Targeting Teen Drivers. Retrieved March 23, 2015 from http://blog.caranddriver.com/2016-chevrolet-malibu-to-debut-new-spyware-targeting-teen-drivers/

af Wåhlberg, A. (2004). The stability of driver acceleration behavior, and a replication of its relation to bus accidents. *Accident Analysis & Prevention,36*(1), 83-92.

af Wåhlberg, A. (2006). Speed choice versus celeration behavior as traffic accident predictor. *Journal of Safety Research*, *37*(1), 43-51.

af Wåhlberg A. (2007). Aggregation of driver celebration behavior data: effects on stability and accident prediction. *Journal of Safety Science, 45*(4), 487-500.

Ward, N. J., Otto, J., & Linkenbach, J. (2014). A Primer for Traffic Safety Culture. *ITE Journal-Institute of Transportation Engineers*, *84*(5), 41-47.

Williams, A. F. (2006). Young driver risk factors: successful and unsuccessful approaches for dealing with them and an agenda for the future. *Injury Prevention, 12*, 4−9.

Williams, A., Ferguson, S., & Wells, J. (2005). Sixteen-year-old drivers in fatal crashes, United States, 2003. *Traffic Injury Prevention*, *6*(3), 202-206.

Williams, A., & Shults, R. (2010). Graduated Driver Licensing research, 2007–present: A review and commentary. *Journal of Safety Research, 41*, 77–84

Williams, A., Tefft, B., Grabowski, J. (2012). Graduated Driver Licensing research, 2010-present. *Journal of Safety Research, 43*(3), 195-203.

APPENDIX A: TDSS BETA TESTING

The TDSS was beta tested prior to study deployment. The purpose of the beta test was to remove software bugs and address hardware issues, validate that the phone and the in-vehicle software met design specifications, and validate that the dependent variables were collected according to specifications. Six university researchers agreed to have their cars equipped with the TDSS hardware and drive with the TDSS software on a study smartphone for two months. A beta version of the software was installed on six Galaxy S3 smartphones with the same specifications as the intended study phones that would be used by the participants. The researchers each drove for two to three weeks with the data collection application (i.e., control), the TDSS partial system, or the TDSS full system application and reported any issues or discrepancies that occurred between their driving and the system. A pre-trip and post-trip application was created so that researchers could input trip data relevant to behaviors monitored by the TDSS (e.g., mileage, trip time) and then input comments and information about crashes or problems at the end of each drive. An automated phone and text query program was developed so that each beta test phone received a call and text every time the software was running in the vehicle to ensure the blocking features worked correctly. Data from the beta test were sent to the TDSS server, and the dependent variables were calculated using that data to ensure they were all correct.

The results from the beta test identified a small subset of issues that were easily corrected early in the testing regimen. Following these minor corrections, the TDSS system correctly and consistently provided feedback to the driver based on the Navteq map (i.e., speed and mapping database) and sensor inputs. The dependent variables were verified, and a data validation website was created in conjunction with the variables collected to allow researchers to monitor for potential software and hardware problems in the equipment used by the participants for the duration of the study.

In addition to the beta testing, the accelerometer algorithm for detecting excessive maneuvers was tested and compared to a mounted, high-quality in-vehicle accelerometer. Excessive maneuvers are those related to turning, braking, and accelerating that create considerable g-forces on the vehicle. As described earlier, these types of events are most commonly used by various teen support systems and are considered to be predictive of crash risk. A robust classification algorithm was created that counteracts the challenges presented by the non-rigid smartphone mount to the vehicle, possible orientation changes of the smartphone while in operation, and varying road conditions and environments inherent in naturalistic driving.

The algorithm uses both the GPS measurements and accelerometer measurements to calculate two separate measures of lateral and longitudinal acceleration in an effort to mitigate false positives. In particular, the excessive maneuver algorithm did not run unless the algorithm detected that the phone was mounted firmly and in the correct orientation. This approach is responsive enough to detect high dynamic vehicle trajectories of interest (i.e., hard turning, braking, accelerations).

The classification success rates of the TDSS smartphone algorithm were 91.6% for right turns, 91.6% for left turns, 100% for braking, but only 16.6% for acceleration maneuvers, compared to 100% performance for all maneuver types in the vehicle-mounted sensor suite. The acceleration maneuvers highlighted an issue with the longitudinal acceleration calculation method. At low speeds, longitudinal acceleration cannot be calculated as detailed earlier. The test vehicle achieves peak acceleration at these low speeds, which cannot be observed by the smartphone's acceleration calculations. Based on the results, it is expected that acceleration events will be under-detected during the study. Acceleration events (i.e., fast acceleration from a stop) represent driving style and are less likely to be associated with a risky event when compared to taking curves too fast (e.g., run-off-road crashes in curves often occur at excessive speed) or braking too hard (e.g., an emergency event, or failure to detect the rate of deceleration in traffic ahead, which could lead to a rear-end collision).

APPENDIX B: IRB AND NIH CERTIFICATE OF CONFIDENTIALITY

UNIVERSITY OF MINNESOTA

Twin Cities Campus

Human Research Protection Program
Office of the Vice President for Research

D528 Mayo Memorial Building
420 Delaware Street S.E.
MMC 820
Minneapolis, MN 55455

Office: 612-626-5654
Fax: 612-626-6061
E-mail: irb@umn.edu or ibc@umn.edu
Website: http://research.umn.edu/subjects/

May 15, 2012

Christopher J Edwards
Mechanical Engineering 0691A
Room 1101 MechE
111 Church St SE
Minneapolis, MN 55455

RE: "Teen Driver Support System (TDSS) Field Operational Test (Award Title: Teen Driver Support System (TDSS) Field Operational Test, Mn/DOT Contract No. 99008, Work Order No. 17)"
IRB Code Number: **1204S12942**

Dear Dr. Edwards

The Institutional Review Board (IRB) received your response to its stipulations. Since this information satisfies the federal criteria for approval at 45CFR46.111 and the requirements set by the IRB, final approval for the project is noted in our files. Upon receipt of this letter, you may begin your research.

IRB approval of this study includes the parent control consent form, parent system consent form, teen control assent form and teen system assent form received May 10, 2012. Recruitment materials received May 10, 2012 are also approved.

The IRB committee notes that approval is granted upon the condition that the researcher submits letters of approval from the schools and the school district where the proposed research will be conducted. The committee notes that no recruitment of study subjects or collection of research data can begin until these letters are obtained and submitted for committee review.

The IRB determined that children could be included in this research under 45CFR46.404; research not involving greater than minimal risk.

The IRB would like to stress that subjects who go through the consent process are considered enrolled participants and are counted toward the total number of subjects, even if they have no further participation in the study. Please keep this in mind when calculating the number of subjects you request. This study is currently approved for 300 subjects. If you desire an increase in the number of approved subjects, you will need to make a formal request to the IRB.

For your records and for grant certification purposes, the approval date for the referenced project is May 4, 2012 and the Assurance of Compliance number is FWA00000312 (Fairview Health Systems Research FWA00000325, Gillette Children's Specialty Healthcare FWA00004003). Research projects are subject

Driven to Discover℠

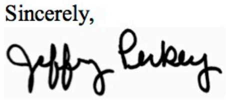
to continuing review and renewal; approval will expire one year from that date. You will receive a report form two months before the expiration date. If you would like us to send certification of approval to a funding agency, please tell us the name and address of your contact person at the agency.

As Principal Investigator of this project, you are required by federal regulations to:
*Inform the IRB of any proposed changes in your research that will affect human subjects, changes should not be initiated until written IRB approval is received.
*Report to the IRB subject complaints and unanticipated problems involving risks to subjects or others as they occur.
*Inform the IRB immediately of results of inspections by any external regulatory agency (i.e. FDA).
*Respond to notices for continuing review prior to the study's expiration date.
*Cooperate with post-approval monitoring activities.

Information on the IRB process is available in the form of a guide for researchers entitled, What Every Researcher Needs to Know, found at http://www.research.umn.edu/irb/WERNK/index.cfm

The IRB wishes you success with this research. If you have questions, please call the IRB office at 612-626-5654.

Sincerely,



Jeffery Perkey, MLS, CIP
Research Compliance Supervisor
JP/bw

CC: Ensar Becic, Janet Creaser, Alec Gorjestani, Michael Manser, Arvind Menon, Nichole Morris, Samantha Sandgren

DEPARTMENT OF HEALTH AND HUMAN SERVICES

The UMN IRB has reviewed and acknowledged this submission.

6.12.12 Jeffery Perkey

6/1/2012

University of Minnesota
Dr. Michael Manser
Mechanical Engineering
111 Church Street SouthEast
Minneapolis, MN 55455

Dear Dr. Manser,

Enclosed is the Confidentiality Certificate protecting the identity of research subjects in your project entitled, '"Teen Driver Support System (TDSS) Field Operational Test (Award Title: Teen Driver Support System (TDSS) Field Operational Test, Mn/DOT Contract No. 99008, Work Order No. 17)"'. Please note that the Certificate expires on 02/28/2015.

Please be sure that the consent form given to research participants accurately states the intended uses of personally identifiable information (including matters subject to reporting) and the confidentiality protections, including the protection provided by the Certificate of Confidentiality with its limits and exceptions.

If you determine that the research project will not be completed by the expiration date, 02/28/2015, you must submit a written request for an extension of the Certificate three months prior to the expiration date. If you make any changes to the protocol for this study, you should contact me regarding modification of this Certificate. Any requests for modifications of this Certificate must include the reason for the request, documentation of the most recent IRB approval, and the expected date for completion of the research project.

Please advise me of any situation in which the Certificate is employed to resist disclosure of information in legal proceedings. Should attorneys for the project wish to discuss the use of the Certificate, they may contact the Office of the NIH Legal Advisor, National Institutes of Health, at (301) 496-6043.

Correspondence should be sent to:

Steven Hirschfeld, MD PhD
Associate Director for Clinical Research
Eunice Kennedy Shriver National Institute of Child Health and Human Development
31 Center Drive, Room 2A03, MSC 2425
Bethesda, MD 20892-2425
Telephone: (301) 496-0044
Fax: (301) 480-1104

Sincerely,

Steven Hirschfeld, MD PhD

CERTIFICATE OF CONFIDENTIALITY
CC-HD-12-41
issued to
University of Minnesota
conducting research known as
"Teen Driver Support System (TDSS) Field Operational Test (Award Title: Teen Driver Support System (TDSS) Field Operational Test, Mn/DOT Contract No. 99008, Work Order No. 17)"

In accordance with the provisions of section 301(d) of the Public Health Service Act 42 U.S.C. 241(d), this Certificate is issued in response to the request of the Principal Investigator, Dr. Michael Manser, to protect the privacy of research subjects by withholding their identities from all persons not connected with this research. Dr. Manser is primarily responsible for the conduct of this research, which is supported by The primary source of funding is the Minnesota Department of Transportation. The Contract and work order number are: Mn/DOT Contract No. 99008, Work Order No. 17..

Under the authority vested in the Secretary of Health and Human Services by section 301(d), all persons who:

1. are enrolled in, employed by, or associated with the University of Minnesota and their contractors or cooperating agencies and

2. have in the course of their employment or association access to information that would identify individuals who are the subjects of the research pertaining to the project known as "Teen Driver Support System (TDSS) Field Operational Test (Award Title: Teen Driver Support System (TDSS) Field Operational Test, Mn/DOT Contract No. 99008, Work Order No. 17)"

are hereby authorized to protect the privacy of the individuals who are the subjects of that research by withholding their names and other identifying characteristics from all persons not connected with the conduct of that research.

The University of Minnesota is conducting a Field Operational Test to evaluate the efficacy of a Teen Driver Support System (TDSS). Approximately 300 teen and parent pairs will be recruited as participants for the teen driver research. The system will use cellular telephones and other hardware to collect vehicle data and display alerts to drivers. Participants will be divided into three groups, two of which will get TDSS driver feedback and one group will be a control group (no feedback). Participation and data collection will last for 12 months.

A Certificate of Confidentiality is needed because sensitive information will be collected during the course of the study. The certificate will help researchers avoid involuntary disclosure that could expose subjects or their families to adverse economic, legal, psychological and social consequences.

All subjects will be assigned a code number and identifying information and records will be kept in locked files at the Institution.

This research is currently underway and is expected to end on 02/28/2015.

As provided in section 301 (d) of the Public Health Service Act 42 U.S.C. 241(d):

'Persons so authorized to protect the privacy of such individuals may not be compelled in any Federal, State, or local civil, criminal, administrative, legislative, or other proceedings to identify such individuals.'

This Certificate does not protect you from being compelled to make disclosures that: (1) have been consented to in writing by the research subject or the subject's legally authorized representative; (2) are required by the Federal Food, Drug, and Cosmetic Act (21 U.S.C. 301 et seq.) or regulations issued under that Act; or (3) have been requested from a research project funded by the National Institutes of Health (NIH) or the Department of Health and Human Services (DHHS) by authorized representatives of those agencies for the purpose of audit or program review.

CERTIFICATE OF CONFIDENTIALITY
CC-HD-12-41
issued to
University of Minnesota
conducting research known as
"Teen Driver Support System (TDSS) Field Operational Test (Award Title: Teen Driver Support System (TDSS) Field Operational Test, Mn/DOT Contract No. 99008, Work Order No. 17)"

This Certificate does not represent an endorsement of the research project by the DHHS. This Certificate is now in effect and will expire on 02/28/2015. The protection afforded by this Confidentiality Certificate is permanent with respect to subjects who participate in the research during the time the Certificate is in effect.

Date: 6/1/2012

Steven Hirschfeld, MD PhD
Associate Director for Clinical Research
Eunice Kennedy Shriver National Institute of Child Health and Human Development

Page 2 of 2

APPENDIX C: GENERAL SURVEYS

TEENAGERS

DEMOGRAPHICS
This questionnaire will collect information such as your age, gender and how often you expect to drive. Your answers are confidential. If you feel uncomfortable answering a particular question, you may leave it blank. Please tick one box for each question that has multiple options.

1. Your date of birth: MM: ________ / DD: ________ / YYYY ________

2. Your current age: _____ years

3. Your sex:
   ☐ Male
   ☐ Female

4. What is your cumulative GPA this academic year? _____________________________

5. Please state the month, day and year when you obtained your provisional driving license OR state the date of your scheduled test.

MM: ________ / DD: ________ / YYYY ________

6. In addition to Driver's Education, who else spent the most time teaching you how to drive?
   Mother
   Father
   Female Guardian
   Male Guardian
   Other Adult (over 21) – Please specify________
   Other: Please explain

7. Think of the last three months you had your learner's permit, before you got your driver's license. At that time, about how many hours of driving practice did you get each week?

   __hours

8. How often (days per week) do you expect to drive once you have your license?
   ☐ Every Day
   ☐ 5 or 6 days per week
   ☐ 3 to 4 days per week
   ☐ 2 days per week

9. What type of vehicle will you be driving during this study (vehicle in which the study's data collection equipment will be installed)?

   ☐ Passenger Car

☐ Pick-Up Truck
☐ Sport utility vehicle
☐ Van or Minivan

10. Will you be driving a shared vehicle? Yes/No
    If yes, who do you share with:
    Parent/Guardian
    Sibling
    Other, please explain:

MONTH 1

Welcome to the Month 1 Survey of the Teen Driver Study! This set of questions is to be completed by the TEEN participant approximately one month after you entered the Study. This survey asks you about your first month of driving and also inquires about interactions with your parents about driving. Please answer based on your experiences since you received your license. Please complete this set of questions by yourself (i.e., without your parent or guardian present). We ask that you answer as honestly and accurately as possible. Please remember that your responses are confidential and are not stored with any identifying information, such as your name. The responses to the study surveys are collected and stored on a secure server and are only accessible by the researchers on this project. This survey provides a unique link that appends your Study ID Code to the data automatically. This means you do not need to enter your Study ID code for this survey.

Your Driving

This section asks you about your driving behaviors and experiences. Your responses are confidential and you are free not to answer a question you are do not wish to.

Please indicate, on average, how many days per week you drive.
- ❍ Less than one day per week (1)
- ❍ One or two days per week (2)
- ❍ Three or four days per week (3)
- ❍ Five or six days per week (4)
- ❍ Every Day (5)

Please indicate how many times you had to take your driver's test (including the time you passed) before receiving your license.
- ❍ Took test once, passed the first time (1)
- ❍ Took test twice, passed the second time (2)
- ❍ Took test 3 times, passed third time (3)
- ❍ Took test 4 times, passed fourth time (4)
- ❍ Took test 5 or more times (5)

If more than 5 times, how many times did you take your driver's test before you passed?

How frequently has one of your parents/guardians supervised your driving since you received your license (i.e., how frequently or what percentage of time do they spend in the car while you are driving)?

- Never (0%) (1)
- Hardly Ever (1-10%) (2)
- Sometimes (11-50%) (3)
- Often (51-75%) (4)
- Very Often (76-90%) (5)
- Always (91-100%) (6)

How frequently has another adult age 21 or over (not your parent/guardian) supervised your driving since you received your license (i.e., how frequently or what percentage of time do they spend in the car while you are driving)?

- Never (0%) (1)
- Hardly Ever (1-10%) (2)
- Sometimes (11-50%) (3)
- Often (51-75%) (4)
- Very Often (76-90%) (5)
- Always (91-100%) (6)

In general, tell us how often you do the following behaviors while driving.

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Always (5)
You wear your seat belt as a driver (1)	❍	❍	❍	❍	❍
Your passengers wear their seat belts (2)	❍	❍	❍	❍	❍
You talk on your cell phone while driving (3)	❍	❍	❍	❍	❍
You send text messages while driving (including when stopped at a light or in traffic) (4)	❍	❍	❍	❍	❍
You drive between midnight and 5 a.m. (5)	❍	❍	❍	❍	❍
You drive between 9 p.m. and midnight (6)	❍	❍	❍	❍	❍
You drive too fast for the conditions (bad weather) (7)	❍	❍	❍	❍	❍

Driving History

This section asks you questions about your driving history. Your responses are confidential and you are free not to answer a question you are do not wish to.

Since you received your driver's license, have you been stopped and/or cited by the police for any traffic offenses (excluding parking tickets)?

❍ Yes, I have received a traffic ticket since I got my license. (1)

❍ Yes, I have received a warning (not a ticket) since I got my license. (2)

❍ No, I have not received a traffic ticket or warning since I got my license. (3)

If you answered "yes" to the previous question, please enter the number of citations (tickets) you received related to the traffic offenses below.

	Indicate Yes/No		Enter Number of Tickets
	Yes (1)	No (2)	Number (1)
Speeding (1)	❍	❍	
Stop sign violation (2)	❍	❍	
Traffic light violation (such as ran red light) (3)	❍	❍	
Not wearing a seat belt (4)	❍	❍	
Impaired driving due to alcohol or drugs (5)	❍	❍	
Careless/dangerous driving (6)	❍	❍	
Graduated Driver Licensing violation (teen passengers, talking on phone, curfew violation midnight-5 a.m.) (7)	❍	❍	
Texting while driving (8)	❍	❍	
Received a warning for one of the above offences (but not a ticket) (9)	❍	❍	
Other (10)	❍	❍	

Since you have had your driver's license (not including permit time), have you have any accidents/crashes while driving?

❍ Yes (1)

❍ No (2)

If you answered "YES" to having an accident/crash, please indicate the type and number of crashes by entering a number in the appropriate box below (if no accidents/crashes for a category, leave blank or enter 0).

	Yes/No		How Many Crashes?
	Yes (1)	No (2)	If Yes (1)
I rear ended another vehicle (1)	❍	❍	
I hit another vehicle but it was not a rear end collision (2)	❍	❍	
I hit a stationary object, such as a parked car, lamp post, parking lot object (3)	❍	❍	
I hit another road user that was not a vehicle, such as a pedestrian, bicycle (4)	❍	❍	
Another vehicle hit me--any crash type (5)	❍	❍	
I ran off the road but did not hit another vehicle or object (6)	❍	❍	
Other (7)	❍	❍	

What type of vehicle are you driving during the study (vehicle that has study equipment in it)?

- ❍ Passenger car (1)
- ❍ Pick-up Truck (2)
- ❍ Sport Utility Vehicle (SUV) (3)
- ❍ Minivan or Van (4)
- ❍ Other (5)

Driving Interactions
This part of the survey asks you about interactions with your parents/guardians with respect to your driving.

How strongly do you agree or disagree with the following statements?

	Strongly Disagree (1)	(2)	(3)	(4)	(5)	(6)	Strongly Agree (7)
I am very comfortable discussing my driving skills or habits with my parents when it comes up in conversation. (1)	❍	❍	❍	❍	❍	❍	❍
I am very comfortable with the rules my parents have set and enforced about driving, such as when, where and with whom I can drive. (2)	❍	❍	❍	❍	❍	❍	❍

Please indicate how often you have discussed your driving habits and/or skills or talked about safe driving tips with your parent(s)/guardian(s) since you received your license.
❍ Not at all (1)
❍ Seldom (2)
❍ Sometimes (3)
❍ Often (4)
❍ Very often (5)

Driving Privileges
This section of the survey asks you about driving privileges. Driving privileges are any privileges related to driving that you receive from your parents/guardians, such as being allowed to use the car on certain days or to drive to certain events or locations. It does not pertain to non-driving privileges (e.g., allowances, being allowed to attend an event, etc).

Since you received your license, have your parents/guardians reduced or taken away any of your driving privileges because you violated an agreed-upon rule about when, where or with whom you are allowed to drive (e.g., took car without permission, drove somewhere not allowed to go, etc)?

- Yes (1)
- No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, not allowed to go certain places, etc) and why.

Since you received your license, have your parents/guardians reduced or taken away any of your driving privileges because you demonstrated risky or unsafe driving behaviors?

- Yes (1)
- No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, not allowed to go certain places, etc) and why.

Since you received your license, have your parents/guardians increased any of your driving privileges because you demonstrated safe driving behaviors?

- Yes (1)
- No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

Since you received your license, have your parents/guardians reduced or taken away any of your driving privileges for a non-driving related reason (e.g., violating curfew, not completing chores on time, trouble at school, etc)?

- Yes (1)
- No (2)

IF YES, please indicate in the space provided what driving privileges were removed or taken away (e.g., reduced days of driving, etc) and why.

Since you received your license, have your parents/guardians increased any of your driving privileges for a non-driving related reason (e.g., good grades, doing work around the house, etc)?

- Yes (1)
- No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc).

Non-Driving Privileges

This section of the survey asks you about how your parents relate non-driving privileges to driving habits and behaviors. A non-driving privilege would be such things as allowances or being allowed to go to friends' houses or special events (regardless of whether you drive there or not).

Since you received your license a month ago, have your parents/guardians reduced or taken away non-driving privileges (e.g., allowance, grounded you from visiting friend’s houses, etc) because of risky or unsafe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate what non-driving privileges were reduced or took away and why.

Since you received your license a month ago, have your parents/guardians reduced or taken away non-driving privileges (e.g., allowance, grounded you from visiting friends' houses, etc) because you violated an agreed-upon rule about when or where or with whom you are allowed to drive (e.g., took care without permission, drove somewhere not allowed to drive)?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate what non-driving privileges were reduced or took away and why.

If you have any other comments you would like to make about your driving experiences since receiving your license, please use the space provided.

MONTH 6

Welcome to the Month 6 Survey of the Teen Driver Study! This set of questions is to be completed by the TEEN participant approximately 6 months after you entered the Study. This survey asks you about your recent driving behaviors and experiences. It also inquires about interactions with your parents about driving. Please answer based on your experiences since you received your license. Please complete this set of questions by yourself (i.e., without your parent or guardian present). We ask that you answer as honestly and accurately as possible. Please remember that your responses are confidential and are not stored with any identifying information, such as your name. The responses to the study surveys are collected and stored on a secure server and are only accessible by the researchers on this project. This survey provides a unique link that appends your Study ID Code to the data automatically. This means you do not need to enter your Study ID code for this survey.

Your Driving

This section asks you about your driving behaviors and experiences over the past month.

Please indicate, on average, how many days per week you drove in the past month.

- ❍ Less than one day per week (1)
- ❍ One or two days per week (2)
- ❍ Three or four days per week (3)
- ❍ Five or six days per week (4)
- ❍ Every Day (5)

How frequently has one of your parents/guardians supervised your driving in the past month (i.e., how frequently or what percentage of time do they spend in the car while you are driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

How frequently has another adult age 21 or over (not your parent/guardian) supervised your driving in the past month (i.e., how frequently or what percentage of time do they spend in the car while you are driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

In general, tell us how often you did the following behaviors while driving over the past month.

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Always (5)
You wear your seat belt as a driver (1)	❍	❍	❍	❍	❍
Your passengers wear their seat belts (2)	❍	❍	❍	❍	❍
You talk on your cell phone while driving (3)	❍	❍	❍	❍	❍
You send text messages while driving (including when stopped at a light or in traffic) (4)	❍	❍	❍	❍	❍
You drive between midnight and 5 a.m. (5)	❍	❍	❍	❍	❍
You drive between 9 p.m. and midnight (6)	❍	❍	❍	❍	❍
You drive too fast for the conditions (bad weather) (7)	❍	❍	❍	❍	❍

Driving History
This section asks you questions about your driving history.

Since you received your driver's license, have you been stopped and/or cited by the police for any traffic offenses (excluding parking tickets)?
- ❍ Yes, I have received a traffic ticket since I got my license. (1)
- ❍ Yes, I have received a warning (not a ticket) since I got my license. (2)
- ❍ No, I have not received a traffic ticket or warning since I got my license. (3)

If you answered "yes" to the previous question, please enter the number of citations (tickets) you received related to the traffic offenses below.

	Indicate Yes/No		Enter Number of Tickets
	Yes (1)	No (2)	Number (1)
Speeding (1)	❍	❍	
Stop sign violation (2)	❍	❍	
Traffic light violation (such as ran red light) (3)	❍	❍	
Not wearing a seat belt (4)	❍	❍	
Impaired driving due to alcohol or drugs (5)	❍	❍	
Careless/dangerous driving (6)	❍	❍	
Graduated Driver Licensing violation (teen passengers, talking on phone, curfew violation midnight-5 a.m.) (7)	❍	❍	
Texting while driving (8)	❍	❍	
Received a warning for one of the above offences (but not a ticket) (9)	❍	❍	
Other (10)	❍	❍	

Since you received your driver's license (not including permit time), have you have any accidents/crashes while driving?
- ❍ Yes (1)
- ❍ No (2)

If you answered "YES" to having an accident/crash, please indicate the type and number of crashes by entering a number in the appropriate box below (if no accidents/crashes for a category, leave blank or enter 0).

	Yes/No		How Many Crashes?
	Yes (1)	No (2)	If Yes (1)
I rear ended another vehicle (1)	❍	❍	
I hit another vehicle but it was not a rear end collision (2)	❍	❍	
I hit a stationary object, such as a parked car, lamp post, parking lot object (3)	❍	❍	
I hit another road user that was not a vehicle, such as a pedestrian, bicycle (4)	❍	❍	
Another vehicle hit me--any crash type (5)	❍	❍	
I ran off the road but did not hit another vehicle or object (6)	❍	❍	
Other (7)	❍	❍	

Driving Interactions
This part of the survey asks you about interactions with your parents/guardians with respect to your driving.

How strongly do you agree or disagree with the following statements?

	Strongly Disagree (1)	(2)	(3)	(4)	(5)	(6)	Strongly Agree (7)
I am very comfortable discussing my driving skills or habits with my parents when it comes up in conversation. (1)	❍	❍	❍	❍	❍	❍	❍
I am very comfortable with the rules my parents have set and enforced about driving, such as when, where and with whom I can drive. (2)	❍	❍	❍	❍	❍	❍	❍

Please indicate how often you have discussed your driving habits and/or skills or talked about safe driving tips with your parent(s)/guardian(s) in the past month.
❍ Not at all (1)
❍ Seldom (2)
❍ Sometimes (3)
❍ Often (4)
❍ Very often (5)

Driving Privileges
This section of the survey asks you about driving privileges. Driving privileges are any privileges related to driving that you receive from your parents/guardians, such as being allowed to use the car on certain days or to drive to certain events or locations. It does not pertain to non-driving privileges (e.g., allowances, being allowed to attend an event, etc).

In the past month, have your parents/guardians reduced or taken away any of your driving privileges because you violated an agreed-upon rule about when, where or with whom you are allowed to drive (e.g., took car without permission, drove somewhere not allowed to go, etc)?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, not allowed to go certain places, etc) and why.

In the past month, have your parents/guardians reduced or taken away any of your driving privileges because you demonstrated risky or unsafe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, not allowed to go certain places, etc) and why.

In the past month, have your parents/guardians increased any of your driving privileges because you demonstrated safe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

In the past month, have your parents/guardians reduced or taken away any of your driving privileges for a non-driving related reason (e.g., violating curfew, not completing chores on time, trouble at school, etc)?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, etc) and why.

In the past month, have your parents/guardians increased any of your driving privileges for a non-driving related reason (e.g., good grades, doing work around the house, etc)?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

Non-Driving Privileges

This section of the survey asks you about how your parents relate non-driving privileges to driving habits and behaviors. A non-driving privilege would be such things as allowances or being allowed to go to friends' houses or special events (regardless of whether you drive there or not).

In the past month, have your parents/guardians reduced or taken away non-driving privileges (e.g., allowance, grounded you from visiting friends' houses, etc) because of risky or unsafe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate what non-driving privileges were reduced or taken away and why.

In the past month, have your parents/guardians reduced or taken away non-driving privileges (e.g., allowance, grounded you from visiting friends' houses, etc) because you violated an agreed-upon rule about when or where or with whom you are allowed to drive (e.g., took care without permission, drove somewhere not allowed to drive)?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate what non-driving privileges were reduced or taken away and why.

If you have any other comments you would like to make about your driving experiences since receiving your license, please use the space provided.

PARENTS

DEMOGRPAHICS SURVEY

This questionnaire will collect information regarding your driving history, your teen's driving history, your current driving behaviors, and driving records such as tickets and crashes. Your answers will be completely confidential. If you feel uncomfortable answering a particular question, you may leave it blank.

1. What is your current age: _____ years

2. Your sex: ☐ Male

   ☐ Female

3. What is the highest level of education you have completed (select one)?

   ☐ Some high school – no diploma
   ☐ High school graduate or equivalent
   ☐ Some college or Associate's degree
   ☐ Bachelor's degree
   ☐ Advanced degree (MBA, PhD, etc.)
   ☐ Other, please specify
   ____

4. How many years have you had a full driver's license? _______years

5. What is your total annual household income (select one)?

   ☐ Under $20,000

   ☐ $20,000 to 29,999

   ☐ $30,000 to 39,999

   ☐ $40,000 to 49,999

   ☐ $50,000 to 69,999

   ☐ $70,000 to 99,999

   ☐ $100,000 to 149,999

   ☐ $150,000 or over

6. What is your relationship to the teen driver who is taking part in this study (select one)?

☐ Mother
☐ Father
☐ Step-mother
☐ Step-father
☐ Legal Guardian
☐ Other, please specify
____

7. How many people including yourself, live in your household? ____ people

8. Of all the people in your household, including yourself, how many are licensed drivers?

____licensed drivers

9. How many vehicles are there in your household? ____ vehicles

10. Will the teen participating in this study share the vehicle with another member of the household? Yes / No

If yes, with who (select more than one box if applicable, such as “mother” and “father”):

☐ 1 Sibling
☐ More than 1 sibling
☐ Mother
☐ Father
☐ Step-mother
☐ Step-father
☐ Legal Guardian
☐ Other, please explain:

11. How often (days per week) do you typically drive?

☐ Every Day
☐ 5 or 6 days per week
☐ 3 to 5 days per week
☐ 1 or 2 days per week
☐ Less than 1 day per week

12. On average, how many miles do you currently drive every week? ______________________

13. In general, tell us how often:

	Never	Seldom	Often	Very Often	Always

You wear your seat belt as a driver.	☐	☐	☐	☐	☐
Your passengers wear their seatbelts.	☐	☐	☐	☐	☐
You talk on your cell phone while driving.	☐	☐	☐	☐	☐
You send text messages while driving.	☐	☐	☐	☐	☐

MONTH 1 SURVEY

Welcome to the Month 1 Survey of the Teen Driver Study! This set of questions is to be completed by the PARENT or GUARDIAN participant one month after their teen driver entered the Study. This survey asks primarily about your interactions with your teen during the first month or so of the study. Please answer based on your experiences with your teen since they received their license. Please complete this set of questions by yourself (i.e., without your teen present). We ask that you answer as honestly and accurately as possible. We also ask that only the parent who has agreed to participate (i.e., signed the consent form to participate themselves) complete the questionnaires throughout the study to ensure consistency in responses. Please remember that your responses are confidential and are not stored with any identifying information, such as your name. The responses to the study surveys are collected and stored on a secure server and are only accessible by the researchers on this project. This survey provides a unique link that appends your Study ID Code to the data automatically. This means you do not need to enter your Study ID code for this survey.

This section asks you about you teen's driving since they were licensed.

How frequently have you supervised your teen's total driving time since they received their license (i.e., how frequently or what percentage of time are you a passenger in the car while they are driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

How frequently has someone else (e.g., your spouse or another adult) supervised your teen's total driving time since they received their license (i.e., how frequently or what percentage of time does your teen have another adult passenger in the car with them while driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

Driving Interactions

This part of the survey asks you about interactions with your teen about his or her driving experiences or habits.

Please indicate how strongly you agree or disagree with the following statements.

	Strongly Disagree (1)	(2)	(3)	(4)	(5)	(6)	Strongly Agree (7)
I am very comfortable discussing my teen's driving skills or habits with them with comes up in conversation. (1)	❍	❍	❍	❍	❍	❍	❍
I am very comfortable setting and enforcing rules about driving, such as when, where and with whom my teen can drive. (2)	❍	❍	❍	❍	❍	❍	❍

Please indicate how often you have discussed you teen's driving habits, skills or talked about safe driving tips with your teen over the past month.

- Not at all (1)
- Seldom (2)
- Sometimes (3)
- Often (4)
- Very often (5)

Driving Privileges

This section of the survey asks you how you handle driving privileges. Driving privileges are any privileges related to driving that you extend to your teen, such as being allowed to use the car on certain days or to go to certain events or locations. It does not pertain to other non-driving privileges (e.g., allowances, being able to attend a special event, etc).

Since your teen received their license, have you reduced or taken away any of their driving privileges because they violated an agreed-upon rule about when, where or with whom they are allowed to drive (e.g., took car without permission, drove somewhere not allowed to go, etc)?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate in the space provided what driving privileges were reduced (e.g.,no longer allowed to drive to school or extracurricular events, etc) and why.

Since your teen received their license, have you reduced or taken away any of their driving privileges because they demonstrated risky or unsafe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate in the space provided what driving privileges were reduced (e.g., no longer allowed to drive to school or extracurricular events, reduced days of driving, etc) and why.

Since your teen received their license, have you increased any of their driving privileges because they demonstrated safe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

Since your teen received their license, have you reduced or taken away any of their driving privileges for a non-driving related reason (e.g., violating curfew, not completing chores on time, trouble at school, etc)?

- ❍ Yes (1)
- ❍ No (2)
- ❍ If YES, please indicate in the space provided what driving privileges were removed or taken away (e.g., no longer allowed to drive to school or extracurricular events, reduced days of driving, etc) and why.

Since your teen received their license, have you increased any of their driving privileges for a non-driving related reason (e.g., good grades, doing work around the house, etc)?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

Non-Driving Privileges

This section of the survey asks you about how you relate non-driving privileges to driving habits and behaviors. A non-driving privilege would be such things as allowances or being allowed to go to friends' houses or special events (regardless of whether your teen drives there or not).

Since your teen received their license a month ago, have you reduced or taken away non-driving privileges (e.g., allowance, grounded your teen from visiting friends' houses, etc) because of risky or unsafe driving behaviors you have witnessed?

- Yes (1)
- No (2)

If YES, please indicate what non-driving privileges (e.g., allowance, etc) you reduced or took away and why.

Since your teen received their license a month ago, have you reduced or taken away non-driving privileges (e.g., allowance, grounded your teen from visiting friends' houses, etc) because your teen violated an agreed-upon rule about when or where or with whom they are allowed to drive (e.g., took car without permission, drove somewhere not allowed to drive)?

- Yes (1)
- No (2)
- If YES, please indicate what non-driving privileges (e.g., allowance) you reduced or took away and why.

Since your teen received their license, have you used any resources about teen driving to help you decide which consequences or incentives might be useful for your teen during this phase of driving (e.g., parent-teen driving contracts, prepared discussions about safe driving, etc)?

- Yes (1)
- No (2)

If YES, please explain or provide examples in the comments box.

MONTH 6 SURVEY

Welcome to the Month 6 Survey of the Teen Driver Study! This set of questions is to be completed by the PARENT or GUARDIAN participant approximately 6 months after their teen driver entered the Study. This survey asks primarily about your interactions with your teen over the past month of driving. Please complete this set of questions by yourself (i.e., without your teen present). We ask that you answer as honestly and accurately as possible. We also ask that only the parent who has agreed to participate (i.e., signed the consent form to participate themselves) complete the questionnaires throughout the study to ensure consistency in responses. Please remember that your responses are confidential and are not stored with any identifying information, such as your name. The responses to the study surveys are collected and stored on a secure server and are only accessible by the researchers on this project. This survey provides a unique link that appends your Study ID Code to the data automatically. This means you do not need to enter your Study ID code for this survey.

This section asks you about you teen's driving in the past month.

How frequently have you supervised your teen's total driving time in the past month (i.e., how frequently or what percentage of time are you a passenger in the car while they are driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

How frequently has someone else (e.g., your spouse or another adult) supervised your teen's total driving time in the past month (i.e., how frequently or what percentage of time does your teen have another adult passenger in the car with them while driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

Driving Interactions

This part of the survey asks you about interactions with your teen about his or her driving experiences or habits.

Please indicate how strongly you agree or disagree with the following statements.

	Strongly Disagree (1)	(2)	(3)	(4)	(5)	(6)	Strongly Agree (7)
I am very comfortable discussing my teen's driving skills or habits with them with comes up in conversation. (1)	❍	❍	❍	❍	❍	❍	❍
I am very comfortable setting and enforcing rules about driving, such as when, where and with whom my teen can drive. (2)	❍	❍	❍	❍	❍	❍	❍

Please indicate how often you have discussed your teen's driving habits, skills or talked about safe driving tips with your teen over the past month.

❍ Not at all (1)
❍ Seldom (2)
❍ Sometimes (3)
❍ Often (4)
❍ Very often (5)

Driving Privileges

This section of the survey asks you how you handle driving privileges. Driving privileges are any privileges related to driving that you extend to your teen, such as being allowed to use the car on certain days or to go to certain events or locations. It does not pertain to other non-driving privileges (e.g., allowances, being able to attend a special event, etc).

In the past month, have you reduced or taken away any of their driving privileges because they violated an agreed-upon rule about when, where or with whom they are allowed to drive (e.g., took car without permission, drove somewhere not allowed to go, etc)?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., no longer allowed to drive to school or extracurricular events, etc) and why.

In the past month, have you reduced or taken away any of their driving privileges because they demonstrated risky or unsafe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., no longer allowed to drive to school or extracurricular events, reduced days of driving, etc) and why.

In the past month, have you increased any of their driving privileges because they demonstrated safe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

In the past month, have you reduced or taken away any of their driving privileges for a non-driving related reason (e.g., violating curfew, not completing chores on time, trouble at school, etc)?

❍ Yes (1)
❍ No (2)

If YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., no longer allowed to drive to school or extracurricular events, reduced days of driving, etc) and why.

In the past month, have you increased any of their driving privileges for a non-driving related reason (e.g., good grades, doing work around the house, etc)?

❍ Yes (1)
❍ No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

Non-Driving Privileges

This section of the survey asks you about how you relate non-driving privileges to driving habits and behaviors. A non-driving privilege would be such things as allowances or being allowed to go to friends' houses or special events (regardless of whether your teen drives there or not).

In the past month, have you reduced or taken away non-driving privileges (e.g., allowance, grounded your teen from visiting friends' houses, etc) because of risky or unsafe driving behaviors you have witnessed?

❍ Yes (1)
❍ No (2)

If YES, please indicate what non-driving privileges (e.g., allowance, etc) were reduced or taken away and why.

In the past month, have you reduced or taken away non-driving privileges (e.g., allowance, grounded your teen from visiting friends' houses, etc) because your teen violated an agreed-upon rule about when or where or with whom they are allowed to drive (e.g., took car without permission, drove somewhere not allowed to drive)?

❍ Yes (1)
❍ No (2)

If YES, please indicate what non-driving privileges (e.g., allowance) were reduced or taken away and why.

In the past month, have you used any resources about teen driving to help you decide which consequences or incentives might be useful for your teen during this phase of driving (e.g., parent-teen driving contracts, prepared discussions about safe driving, etc)?

- ❍ Yes (1)
- ❍ No (2)

If YES, please explain or provide examples in the comments box.

Arnett Inventory of Sensation Seeking (Arnett, 1994)

For each item, indicate which response best applies to you:

A) describes me very well
B) describes me somewhat
C) does not describe me very well
D) does not describe me at all

1. I can see how it would be interesting to marry someone from a foreign country.

2. When the water is very cold, I prefer not to swim even if it is a hot day. (-)

3. If I have to wait in a long line, I'm usually patient about it. (-)

4. When I listen to music, I like it to be loud.

5. When taking a trip, I think it is best to make as few plans as possible and just take it as it comes.

6. I stay away from movies that are said to be frightening or highly suspenseful. (-)

7. I think it's fun and exciting to perform or speak before a group.

8. If I were to go to an amusement park, I would prefer to ride the rollercoaster or other fast rides.

9. I would like to travel to places that are strange and far away.

10. I would never like to gamble with money, even if I could afford it.(-)

11. I would have enjoyed being one of the first explorers of an unknown land.

12. I like a movie where there are a lot of explosions and car chases.

13. I don't like extremely hot and spicy foods. (-)

14. In general, I work better when I'm under pressure.

15. I often like to have the radio or TV on while I'm doing something else, such as reading or cleaning up.

16. It would be interesting to see a car accident happen.

17. I think it's best to order something familiar when eating in a restaurant. (-)

18. I like the feeling of standing next to the edge on a high place and looking down.

19. If it were possible to visit another planet or the moon for free, I would be among the first in line to sign up.

20. I can see how it must be exciting to be in a battle during a war.

<u>Novelty subscale</u>

1. I can see how it would be interesting to marry someone from a foreign country.

3. If I have to wait in a long line, I'm usually patient about it.(-)

5. When taking a trip, I think it is best to make as few plans as possible and just take it as it comes.

7. I think it's fun and exciting to perform or speak before a group.

9. I would like to travel to places that are strange and far away.

11. I would have enjoyed being one of the first explorers of an unknown land.

13. I don't like extremely hot and spicy foods. (-)

15. I often like to have the radio or TV on while I'm doing something else, such as reading or cleaning up.

17. I think it's best to order something familiar when eating in a restaurant. (-)

19. If it were possible to visit another planet or the moon for free, I would be among the first in line to sign up.

Intensity subscale

2. When the water is very cold, I prefer not to swim even if it is a hot day. (-)

4. When I listen to music, I like it to be loud.

6. I stay away from movies that are said to be frightening or highly suspenseful. (-)

8. If I were to go to an amusement park, I would prefer to ride the rollercoaster or other fast rides.

10. I would never like to gamble with money, even if I could afford it.(-)

12. I like a movie where there are a lot of explosions and car chases.

14. In general, I work better when I'm under pressure.

16. It would be interesting to see a car accident happen.

18. I like the feeling of standing next to the edge on a high place and looking down.

20. I can see how it must be exciting to be in a battle during a war.

Scoring: Combine responses to items, with A = 4, B = 3, C = 2, D = 1, so that higher score = higher sensation seeking. For items followed by (-), scoring should be reversed.

APPENDIX D: PARTIAL AND FULL TDSS GROUP QUESTIONS

TEENAGERS

PARTIAL AND FULL TDSS:
MONTH 1 AND MONTH 6 ADDITIONAL QUESTIONS

My parents/guardians used the negative information the system provided to them (e.g., speeding notifications) as a reason for reducing or taking away some of my driving privileges over the past month.

- ❍ Yes (1)
- ❍ No (2)

My parents/guardians used the positive information the system provided to them (e.g., always wearing my seat belt, no violations) as a reason for increasing my driving privileges past month.

- ❍ Yes (1)
- ❍ No (2)

My parents/guardians used the negative information the system provided to them (e.g., speeding notifications) as a reason for reducing or taking away non-driving privileges (e.g., no allowance, grounded, etc) past month.

- ❍ Yes (1)
- ❍ No (2)

My parents/guardians used the positive information the system provided to them (e.g., always wearing my seat belt, no violations) as a reason for increasing non-driving privileges (e.g., increased allowance, access to other activities) past month.

- ❍ Yes (1)
- ❍ No (2)

If you have any other comments you would like to make about driving with the system or the feedback it provides to your parents, please use the space provided here.

PARTIAL TDSS: MONTH 12 SURVEY

Welcome to the Month 12 Survey of the Teen Driver Support System Study!
This set of questions is to be completed by the TEEN participant approximately 12 months after you entered the Study. This survey asks you about your recent driving behaviors and experiences. It also inquires about interactions with your parents about driving. Please answer based on your experiences since you received your license. Please complete this set of questions by yourself (i.e., without your parent or guardian present). We ask that you answer as honestly and accurately as possible. Please remember that your responses are confidential and are not stored with any identifying information, such as your name. The responses to the study surveys are collected and stored on a secure server and are only accessible by the researchers on this project. This survey link is UNIQUE for each participant. If you share an email with your parents or guardians, please ensure you are completing the correct survey.

Your Driving
This section asks you about your driving behaviors and experiences over the past month.

Q2 Please indicate, on average, how many days per week you drove in the past month.
- ❍ Less than one day per week (1)
- ❍ One or two days per week (2)
- ❍ Three or four days per week (3)
- ❍ Five or six days per week (4)
- ❍ Every Day (5)

How frequently has one of your parents/guardians supervised your driving in the past month (i.e., how frequently or what percentage of time do they spend in the car while you are driving)?
- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

How frequently has another adult age 21 or over (not your parent/guardian) supervised your driving in the past month (i.e., how frequently or what percentage of time do they spend in the car while you are driving)?
- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

In general, tell us how often you did the following behaviors while driving over the past month.

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Always (5)
You wear your seat belt as a driver (1)	❍	❍	❍	❍	❍
Your passengers wear their seat belts (2)	❍	❍	❍	❍	❍
You talk on your cell phone while driving (3)	❍	❍	❍	❍	❍
You send text messages while driving (including when stopped at a light or in traffic) (4)	❍	❍	❍	❍	❍
You drive between midnight and 5 a.m. (5)	❍	❍	❍	❍	❍
You drive between 9 p.m. and midnight (6)	❍	❍	❍	❍	❍
You drive too fast for the conditions (bad weather) (7)	❍	❍	❍	❍	❍

Driving History

This section asks you questions about your driving history.

Since you received your driver's license, have you been stopped and/or cited by the police for any traffic offenses (excluding parking tickets)?

- ❍ Yes, I have received a traffic ticket since I got my license. (1)
- ❍ Yes, I have received a warning (not a ticket) since I got my license. (2)
- ❍ No, I have not received a traffic ticket or warning since I got my license. (3)

IF you answered "yes" to the previous question, please enter the number of citations (tickets) you received related to the traffic offenses below.

	Indicate Yes/No		Enter Number of Tickets
	Yes (1)	No (2)	Number (1)
Speeding (1)	❍	❍	
Stop sign violation (2)	❍	❍	
Traffic light violation (such as ran red light) (3)	❍	❍	
Not wearing a seat belt (4)	❍	❍	
Impaired driving due to alcohol or drugs (5)	❍	❍	
Careless/dangerous driving (6)	❍	❍	
Graduated Driver Licensing violation (teen passengers, talking on phone, curfew violation midnight-5 a.m.) (7)	❍	❍	
Texting while driving (8)	❍	❍	
Received a warning for one of the above offences (but not a ticket) (9)	❍	❍	
Other (10)	❍	❍	

Since you received your driver's license (not including permit time), have you have any accidents/crashes while driving?

- ❍ Yes (1)
- ❍ No (2)

If you answered "YES" to having an accident/crash, please indicate the type and number of crashes by entering a number in the appropriate box below (if no accidents/crashes for a category, leave blank or enter 0).

	Yes/No		How Many Crashes?
	Yes (1)	No (2)	If Yes (1)
I rear ended another vehicle (1)	❍	❍	
I hit another vehicle but it was not a rear end collision (2)	❍	❍	
I hit a stationary object, such as a parked car, lamp post, parking lot object (3)	❍	❍	
I hit another road user that was not a vehicle, such as a pedestrian, bicycle (4)	❍	❍	
Another vehicle hit me--any crash type (5)	❍	❍	
I ran off the road but did not hit another vehicle or object (6)	❍	❍	
Other (7)	❍	❍	

Driving Interactions

This part of the survey asks you about interactions with your parents/guardians with respect to your driving.

How strongly do you agree or disagree with the following statements?

	Strongly Disagree (1)	(2)	(3)	(4)	(5)	(6)	Strongly Agree (7)
I am very comfortable discussing my driving skills or habits with my parents when it comes up in conversation. (1)	❍	❍	❍	❍	❍	❍	❍
I am very comfortable with the rules my parents have set and enforced about driving, such as when, where and with whom I can drive. (2)	❍	❍	❍	❍	❍	❍	❍

Please indicate how often you have discussed your driving habits and/or skills or talked about safe driving tips with your parent(s)/guardian(s) over the past month.

❍ Not at all (1)
❍ Seldom (2)
❍ Sometimes (3)
❍ Often (4)
❍ Very often (5)

Driving Privileges

This section of the survey asks you about driving privileges. Driving privileges are any privileges related to driving that you receive from your parents/guardians, such as being allowed to use the car on certain days or to drive to certain events or locations. It does not pertain to non-driving privileges (e.g., allowances, being allowed to attend an event, etc).

In the past month, have your parents reduced or taken away any of your driving privileges because you violated a rule about when, where or with whom you are allowed to drive (e.g., took car without permission, drove somewhere not allowed to go, etc)?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, not allowed to go certain places, etc) and why.

In the past month, have your parents/guardians reduced or taken away any of your driving privileges because you demonstrated risky or unsafe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, not allowed to go certain places, etc) and why.

In the past month, have your parents/guardians increased any of your driving privileges because you demonstrated safe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

In the past month, have your parents/guardians reduced or taken away any of your driving privileges for a non-driving related reason (e.g., violating curfew, not completing chores on time, trouble at school, etc)?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, etc) and why.

In the past month, have your parents/guardians increased any of your driving privileges for a non-driving related reason (e.g., good grades, doing work around the house, etc)?

❍ Yes (1)
❍ No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

Non-Driving Privileges

This section of the survey asks you about how your parents relate non-driving privileges to driving habits and behaviors. A non-driving privilege would be such things as allowances or being allowed to go to friends' houses or special events (regardless of whether you drive there or not).

In the past month, have your parents/guardians reduced or taken away non-driving privileges (e.g., allowance, grounded you from visiting friends' houses, etc) because of risky or unsafe driving behaviors?

❍ Yes (1)
❍ No (2)

If YES, please indicate what non-driving privileges were reduced or taken away and why.

In the past month, have your parents/guardians reduced or taken away non-driving privileges (e.g., allowance, grounded you from visiting friends' houses, etc) because you violated an agreed-upon rule about when or where or with whom you are allowed to drive (e.g., took care without permission, drove somewhere not allowed to drive)?

❍ Yes (1)
❍ No (2)

If YES, please indicate what non-driving privileges were reduced or taken away and why.

If you have any other comments you would like to make about your driving experiences since receiving your license, please use the space provided.

Teen Driver Support System Questions

Think about how you felt while driving with the in-vehicle system over the past month. Please read the statements below and indicate how strongly you agree or disagree with each statement.

	Strongly Disagree (1)	Disagree (2)	Somewhat Disagree (3)	Neither Agree nor Disagree (4)	Somewhat Agree (5)	Agree (6)	Strongly Agree (7)
The performance of the system enhances my driving safety. (1)	❍	❍	❍	❍	❍	❍	❍
I am familiar with the operation of the system. (2)	❍	❍	❍	❍	❍	❍	❍
I trust the system. (3)	❍	❍	❍	❍	❍	❍	❍
The system is reliable. (4)	❍	❍	❍	❍	❍	❍	❍
I am confident in my ability to drive without the system active. (5)	❍	❍	❍	❍	❍	❍	❍
The visual messages I receive from the system are easy to understand. (6)	❍	❍	❍	❍	❍	❍	❍
The	❍	❍	❍	❍	❍	❍	❍

auditory messages I receive from the system are easy to understand. (7)							
The driving feedback I receive from the system is useful and helpful. (8)	❍	❍	❍	❍	❍	❍	❍
The driving feedback I receive from the system can be distracting at times. (9)	❍	❍	❍	❍	❍	❍	❍
The system messages are accurate most of the time. (10)	❍	❍	❍	❍	❍	❍	❍

Please indicate how strongly you agree or disagree with the following statements about using the TDSS:

	Strongly Disagree (1)	Disagree (2)	Somewhat Disagree (3)	Neither Agree nor Disagree (4)	Somewhat Agree (5)	Agree (6)	Strongly Agree (7)
Driving with the teen driver support system has been beneficial in helping me learn to drive since I received my license. (1)	❍	❍	❍	❍	❍	❍	❍

Did you ever succeed in making calls using your study phone while the TDSS software was running?

❍ Yes (9)
❍ No (10)

If you answered YES that you succeeded in making calls while driving using the study phone even though the software was running, please explain (e.g., used a voice-to-call app, software did not prevent this, etc):

Did you ever succeed in sending texts using your study phone while the TDSS software was running?

❍ Yes (9)
❍ No (10)

If you answered YES that you succeeded in sending texts while driving using the study phone even though the software was running, please explain (e.g., used a voice-to-text app, software did not prevent this, etc):

Ignoring any issues that might have occurred during the study because of the nature of experimental equipment, what is your overall opinion of the TDSS?

- Very Poor (11)
- Poor (12)
- Fair (13)
- Good (14)
- Very Good (15)

Ignoring any issues that might have occurred during the study because of the experimental nature of the software and equipment, what is your overall opinion of the usefulness of the TDSS?

- Very Useless (24)
- Useless (25)
- Neutral (26)
- Useful (27)
- Very Useful (28)

If any problems or issues you had with the system were fixed, how likely would you be to recommend the TDSS to other teens for use in the first year of driving?

- Very Unlikely (24)
- Unlikely (25)
- Undecided (26)
- Likely (27)
- Very Likely (28)

If you have any other comments you would like to make about driving with the system, please use the space provided here.

FULL TDSS GROUP

Welcome to the Month 12 Survey of the Teen Driver Support System with Parental Feedack Study! This set of questions is to be completed by the TEEN participant approximately 6 months after you entered the Study. This survey asks you about your recent driving behaviors and experiences. It also inquires about interactions with your parents about driving. Please answer based on your experiences since you received your license. Please complete this set of questions by yourself (i.e., without your parent or guardian present). We ask that you answer as honestly and accurately as possible. Please remember that your responses are confidential and are not stored with any identifying information, such as your name. The responses to the study surveys are collected and stored on a secure server and are only accessible by the researchers on this project. This survey link is UNIQUE for each participant. If you share an email with your parents or guardians, please ensure you are completing the correct survey.

Your Driving: This section asks you about your driving behaviors and experiences over the past month.

Please indicate, on average, how many days per week you drove in the past month.

- ❍ Less than one day per week (1)
- ❍ One or two days per week (2)
- ❍ Three or four days per week (3)
- ❍ Five or six days per week (4)
- ❍ Every Day (5)

How frequently has one of your parents/guardians supervised your driving in the past month (i.e., how frequently or what percentage of time do they spend in the car while you are driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

How frequently has another adult age 21 or over (not your parent/guardian) supervised your driving in the past month (i.e., how frequently or what percentage of time do they spend in the car while you are driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

In general, tell us how often you did the following behaviors while driving over the past month.

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Always (5)
You wear your seat belt as a driver (1)	❍	❍	❍	❍	❍
Your passengers wear their seat belts (2)	❍	❍	❍	❍	❍
You talk on your cell phone while driving (3)	❍	❍	❍	❍	❍
You send text messages while driving (including when stopped at a light or in traffic) (4)	❍	❍	❍	❍	❍
You drive between midnight and 5 a.m. (5)	❍	❍	❍	❍	❍
You drive between 9 p.m. and midnight (6)	❍	❍	❍	❍	❍
You drive too fast for the conditions	❍	❍	❍	❍	❍

(bad weather) (7)					

Driving History: This section asks you questions about your driving history.

Since you received your driver's license, have you been stopped and/or cited by the police for any traffic offenses (excluding parking tickets)?

- ❍ Yes, I have received a traffic ticket since I got my license. (1)
- ❍ Yes, I have received a warning (not a ticket) since I got my license. (2)
- ❍ No, I have not received a traffic ticket or warning since I got my license. (3)

If you answered "Yes, I have received a traffic ticket since I got my license" to the previous question, please enter the number of citations (tickets) you received related to the traffic offenses below.

	Indicate Yes/No		Enter Number of Tickets
	Yes (1)	No (2)	Number (1)
Speeding (1)	❍	❍	
Stop sign violation (2)	❍	❍	
Traffic light violation (such as ran red light) (3)	❍	❍	
Not wearing a seat belt (4)	❍	❍	
Impaired driving due to alcohol or drugs (5)	❍	❍	
Careless/dangerous driving (6)	❍	❍	
Graduated Driver Licensing violation (teen passengers, talking on phone, curfew violation midnight-5 a.m.) (7)	❍	❍	
Texting while driving (8)	❍	❍	
Received a warning for one of the above offences (but not a ticket) (9)	❍	❍	
Other (10)	❍	❍	

Since you received your driver's license (not including permit time), have you have any accidents/crashes while driving?

❍ Yes (1)

❍ No (2)

If you answered "YES" to having an accident/crash, please indicate the type and number of crashes by entering a number in the appropriate box below (if no accidents/crashes for a category, leave blank or enter 0).

	Yes/No		How Many Crashes?
	Yes (1)	No (2)	If Yes (1)
I rear ended another vehicle (1)	❍	❍	
I hit another vehicle but it was not a rear end collision (2)	❍	❍	
I hit a stationary object, such as a parked car, lamp post, parking lot object (3)	❍	❍	
I hit another road user that was not a vehicle, such as a pedestrian, bicycle (4)	❍	❍	
Another vehicle hit me--any crash type (5)	❍	❍	
I ran off the road but did not hit another vehicle or object (6)	❍	❍	
Other (7)	❍	❍	

Driving Interactions:
This part of the survey asks you about interactions with your parents/guardians with respect to your driving.

How strongly do you agree or disagree with the following statements?

	Strongly Disagree (1)	(2)	(3)	(4)	(5)	(6)	Strongly Agree (7)
I am very comfortable discussing my driving skills or habits with my parents when it comes up in conversation. (1)	❍	❍	❍	❍	❍	❍	❍
I am very comfortable with the rules my parents have set and enforced about driving, such as when, where and with whom I can drive. (2)	❍	❍	❍	❍	❍	❍	❍

Please indicate how often you have discussed your driving habits and/or skills or talked about safe driving tips with your parent(s)/guardian(s) over the past month.

❍ Not at all (1)
❍ Seldom (2)
❍ Sometimes (3)
❍ Often (4)
❍ Very often (5)

Driving Privileges:
This section of the survey asks you about driving privileges. Driving privileges are any privileges related to driving that you receive from your parents/guardians, such as being allowed to use the car on certain days or to drive to certain events or locations. It does not pertain to non-driving privileges (e.g., allowances, being allowed to attend an event, etc).

In the past month, have your parents reduced or taken away any of your driving privileges because you violated a rule about when, where or with whom you are allowed to drive (e.g., took car without permission, drove somewhere not allowed to go, etc)?
❍ Yes (1)
❍ No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, not allowed to go certain places, etc) and why.

Q23 In the past month, have your parents/guardians reduced or taken away any of your driving privileges because you demonstrated risky or unsafe driving behaviors?
❍ Yes (1)
❍ No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, not allowed to go certain places, etc) and why.

In the past month, have your parents/guardians increased any of your driving privileges because you demonstrated safe driving behaviors?
❍ Yes (1)
❍ No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

In the past month, have your parents/guardians reduced or taken away any of your driving privileges for a non-driving related reason (e.g., violating curfew, not completing chores on time, trouble at school, etc)?
❍ Yes (1)
❍ No (2)

IF YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., reduced days of driving, etc) and why.

In the past month, have your parents/guardians increased any of your driving privileges for a non-driving related reason (e.g., good grades, doing work around the house, etc)?

- ❍ Yes (1)
- ❍ No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

Non-Driving Privileges:
This section of the survey asks you about how your parents relate non-driving privileges to driving habits and behaviors. A non-driving privilege would be such things as allowances or being allowed to go to friends' houses or special events (regardless of whether you drive there or not).

In the past month, have your parents/guardians reduced or taken away non-driving privileges (e.g., allowance, grounded you from visiting friends' houses, etc) because of risky or unsafe driving behaviors?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate what non-driving privileges were reduced or taken away and why.

In the past month, have your parents/guardians reduced or taken away non-driving privileges (e.g., allowance, grounded you from visiting friends' houses, etc) because you violated an agreed-upon rule (e.g., took car without permission, drove somewhere not allowed to drive)?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate what non-driving privileges were reduced or taken away and why
If you have any other comments you would like to make about your driving experiences since receiving your license, please use the space provided.

Teen Driver Support System Questions:

Think about how you felt while driving with the in-vehicle system over the past month. Please read the statements below and indicate how strongly you agree or disagree with each statement.

	Strongly Disagree (1)	Disagree (2)	Somewhat Disagree (3)	Neither Agree nor Disagree (4)	Somewhat Agree (5)	Agree (6)	Strongly Agree (7)
The performance of the system enhances my driving safety. (1)	❍	❍	❍	❍	❍	❍	❍
I am familiar with the operation of the system. (2)	❍	❍	❍	❍	❍	❍	❍
I trust the system. (3)	❍	❍	❍	❍	❍	❍	❍
The system is reliable. (4)	❍	❍	❍	❍	❍	❍	❍
I am confident in my ability to drive without the system active. (5)	❍	❍	❍	❍	❍	❍	❍
The visual messages I receive from the system are easy to understand. (6)	❍	❍	❍	❍	❍	❍	❍

The auditory messages I receive from the system are easy to understand. (7)	❍	❍	❍	❍	❍	❍	❍
The driving feedback I receive from the system is useful and helpful. (8)	❍	❍	❍	❍	❍	❍	❍
The driving feedback I receive from the system can be distracting at times. (9)	❍	❍	❍	❍	❍	❍	❍
The system messages are accurate most of the time. (10)	❍	❍	❍	❍	❍	❍	❍

Please indicate how strongly you agree or disagree with the following statements about using the TDSS With Parental Feedback:

	Strongly Disagree (1)	Disagree (2)	Somewhat Disagree (3)	Neither Agree nor Disagree (4)	Somewhat Agree (5)	Agree (6)	Strongly Agree (7)
Driving with the teen driver support system has been beneficial in helping me learn to drive since I received my license. (1)	❍	❍	❍	❍	❍	❍	❍
Using the teen driver support system has had a positive effect on how I interact with my parents/guardians when discussing my driving. (2)	❍	❍	❍	❍	❍	❍	❍
Using the teen driver support system has had a positive effect on my parents'/guardians' expectations of my driving behavior. (3)	❍	❍	❍	❍	❍	❍	❍
My parents/guardians used the information the system provided to them (e.g., speeding notifications) as a tool for	❍	❍	❍	❍	❍	❍	❍

discussing safe driving habits. (4)							

My parents/guardians used the negative information the system provided to them (e.g., speeding notifications) as a reason for reducing or taking away some of my driving privileges over the past month.

- Yes (1)
- No (2)

My parents/guardians used the positive information the system provided to them (e.g., always wearing my seat belt, no violations) as a reason for increasing my driving privileges past month.

- Yes (1)
- No (2)

My parents/guardians used the negative information the system provided to them (e.g., speeding notifications) as a reason for reducing or taking away non-driving privileges (e.g., no allowance, grounded, etc) past month.

- Yes (1)
- No (2)

My parents/guardians used the positive information the system provided to them (e.g., always wearing my seat belt, no violations) as a reason for increasing non-driving privileges (e.g., increased allowance, access to other activities) past month.

- Yes (1)
- No (2)

At any point during the study, did you use a cell phone not provided by the study while you were driving (e.g., make texts or calls while driving when the TDSS was active using a second phone, a friend's phone, etc)?

- Yes (9)
- No (10)

IF you answered YES to using a different phone at any point during the study, how often would you estimate you used a non-study phone to call or text while driving?

- Never (14)
- Less than Once a Month (15)
- Once a Month (16)
- 2-3 Times a Month (17)
- Once a Week (18)
- 2-3 Times a Week (19)
- Daily (20)

Did you ever succeed in making calls using your study phone while the TDSS software was running?
- ❍ Yes (9)
- ❍ No (10)

If you answered YES that you succeeded in making calls while driving using the study phone even though the software was running, please explain (e.g., used a voice-to-call app, software did not prevent this, etc):

Did you ever succeed in sending texts using your study phone while the TDSS software was running?
- ❍ Yes (9)
- ❍ No (10)

If you answered YES that you succeeded in sending texts while driving using the study phone even though the software was running, please explain (e.g., used a voice-to-text app, software did not prevent this, etc):

Ignoring any issues that might have occurred during the study because of the nature of experimental equipment, what is your overall opinion of the TDSS With Parental Feedback?
- ❍ Very Poor (11)
- ❍ Poor (12)
- ❍ Fair (13)
- ❍ Good (14)
- ❍ Very Good (15)

Ignoring any issues that might have occurred during the study because of the experimental nature of the software and equipment, what is your overall opinion of the usefulness of the TDSS With Parental Feedback?
- ❍ Very Useless (24)
- ❍ Useless (25)
- ❍ Neutral (26)
- ❍ Useful (27)
- ❍ Very Useful (28)

How likely would you be to recommend the TDSS (if it were a finished product) to other teens and parents for use in the first year of driving?
- ❍ Very Unlikely (24)
- ❍ Unlikely (25)
- ❍ Undecided (26)
- ❍ Likely (27)
- ❍ Very Likely (28)

If you have any other comments you would like to make about driving with the system or the feedback it provides to your parents, please use the space provided here.

PARENTS

PARTIAL TDSS

MONTH 12 SURVEY

Welcome to the Month 12 Survey of the Teen Driver Support System Study! This set of questions is to be completed by the PARENT or GUARDIAN participant approximately 12 months after their teen driver entered the Study. This survey asks you to update your demographic and driving history information. It also asks about your interactions with your teen during the past month of driving. Please complete this set of questions by yourself (i.e., without your teen present). We ask that you answer as honestly and accurately as possible. We also ask that only the parent who has agreed to participate (i.e., signed the consent form to participate themselves) complete the questionnaires throughout the study to ensure consistency in responses. Please remember that your responses are confidential and are not stored with any identifying information, such as your name. The responses to the study surveys are collected and stored on a secure server and are only accessible by the researchers on this project. This survey link is UNIQUE for each participant. If you share an email with your teen, please ensure you are completing the correct survey.

In general, tell us how often you did the following behaviors while driving over the past month.

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Always (5)
You wear your seat belt as a driver (1)	❍	❍	❍	❍	❍
Your passengers wear their seat belts (2)	❍	❍	❍	❍	❍
You talk on your cell phone while driving (3)	❍	❍	❍	❍	❍
You send text messages while driving (including when stopped at a light or in traffic) (4)	❍	❍	❍	❍	❍
You drive between midnight and 5 a.m. (5)	❍	❍	❍	❍	❍
You drive between 9 p.m. and midnight (6)	❍	❍	❍	❍	❍
You drive too fast for the conditions (bad weather) (7)	❍	❍	❍	❍	❍

This section asks you about your TEEN's driving over the past month.

Q3 How frequently have you supervised your teen's total driving time in the past month (i.e., how frequently or what percentage of time are you a passenger in the car while they are driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

How frequently has someone else (e.g., your spouse or another adult) supervised your teen's total driving time in the past month (i.e., how frequently or what percentage of time does your teen have another adult passenger in the car with them while driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

In the past 12 months, has your TEEN been stopped and/or cited by the police for any traffic offenses (excluding parking tickets)?

- ❍ Yes, my teen has received a traffic ticket in the past 12 months. (1)
- ❍ Yes, my teen has received a warning (not a ticket) in the past 12 months. (2)
- ❍ No, my teen has not received a traffic ticket or warning in the past 12 months. (3)

If you answered "Yes, my TEEN has received a traffic ticket in the past 12 months" to the previous question, please enter the number of citations (tickets) your teen received related to the traffic offenses below.

	Indicate Yes/No		Enter Number of Tickets
	Yes (1)	No (2)	Number (1)
Speeding (1)	❍	❍	
Stop sign violation (2)	❍	❍	
Traffic light violation (such as ran red light) (3)	❍	❍	
Not wearing a seat belt (4)	❍	❍	
Impaired driving due to alcohol or drugs (5)	❍	❍	
Careless/dangerous driving (6)	❍	❍	
Graduate driver licensing violation (e.g., too many passengers; driving after curfew--midnight to 5 a.m.; talking on a cell phone while driving) (7)	❍	❍	
Texting while driving (8)	❍	❍	
Received a warning for one of the above offences (but not a ticket) (9)	❍	❍	
Other (10)	❍	❍	

In the past 12 months, has your TEEN had any accidents/crashes while driving?

❍ Yes (1)

❍ No (2)

If you answered "YES" to your teen having had an accident/crash, please indicate the type and number of crashes by entering a number in the appropriate box below (if no accidents/crashes for a category, leave blank or enter 0).

	Yes/No		How Many Crashes?
	Yes (1)	No (2)	If Yes (1)
My teen rear ended another vehicle (1)	❍	❍	
My teen hit another vehicle(s) but it was not a rear end collision (2)	❍	❍	
My teen hit a stationary object, such as a parked car, lamp post, parking lot object (3)	❍	❍	
My teen hit another road user that was not a vehicle, such as a pedestrian, bicycle (4)	❍	❍	
Another vehicle hit my teen--any crash type (5)	❍	❍	
My ran off the road but did not hit another vehicle (include whether hit or did not hit something after running off the road, such as a tree, fence, etc) (6)	❍	❍	
Other (7)	❍	❍	

Driving Interactions
This part of the survey asks you about interactions with your teen about his or her driving experiences or habits.

Please indicate how strongly you agree or disagree with the following statements.

	Strongly Disagree (1)	(2)	(3)	(4)	(5)	(6)	Strongly Agree (7)
I am very comfortable discussing my teen's driving skills or habits with them with comes up in conversation. (1)	❍	❍	❍	❍	❍	❍	❍
I am very comfortable setting and enforcing rules about driving, such as when, where and with whom my teen can drive. (2)	❍	❍	❍	❍	❍	❍	❍

Please indicate how often you have discussed your teen’s driving habits, skills or talked about safe driving tips with your teen over the past month.

❍ Not at all (1)
❍ Seldom (2)
❍ Sometimes (3)
❍ Often (4)
❍ Very often (5)

Driving Privileges

This section of the survey asks you how you handle driving privileges. Driving privileges are any privileges related to driving that you extend to your teen, such as being allowed to use the car on certain days or to go to certain events or locations. It does not pertain to other non-driving privileges (e.g., allowances, being able to attend a special event, etc).

In the past month, have you reduced or taken away any of their driving privileges because they violated an agreed-upon rule about when, where or with whom they are allowed to drive (e.g., took car without permission, drove somewhere not allowed to go, etc)?

- Yes (1)
- No (2)

If YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., no longer allowed to drive to school or extracurricular events, etc) and why.

In the past month, have you reduced or taken away any of their driving privileges because they demonstrated risky or unsafe driving behaviors?

- Yes (1)
- No (2)

If YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., no longer allowed to drive to school or extracurricular events, reduced days of driving, etc) and why.

In the past month, have you increased any of their driving privileges because they demonstrated safe driving behaviors?

- Yes (1)
- No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

In the past month, have you reduced or taken away any of their driving privileges for a non-driving related reason (e.g., violating curfew, not completing chores on time, trouble at school, etc)?

- Yes (1)
- No (2)

If YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., no longer allowed to drive to school or extracurricular events, reduced days of driving, etc) and why.

In the past month, have you increased any of their driving privileges for a non-driving related reason (e.g., good grades, doing work around the house, etc)?

- Yes (1)
- No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

Non-Driving Privileges

This section of the survey asks you about how you relate non-driving privileges to driving habits and behaviors. A non-driving privilege would be such things as allowances or being allowed to go to friends' houses or special events (regardless of whether your teen drives there or not).

In the past month, have you reduced or taken away non-driving privileges (e.g., allowance, grounded your teen from visiting friends' houses, etc) because of risky or unsafe driving behaviors you have witnessed?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate what non-driving privileges (e.g., allowance, etc) were reduced or taken away and why.

In the past month, have you reduced or taken away non-driving privileges (e.g., allowance, grounded your teen from visiting friends' houses, etc) because your teen violated an agreed-upon rule about when or where or with whom they are allowed to drive (e.g., took car without permission, drove somewhere not allowed to drive)?

- ❍ Yes (1)
- ❍ No (2)

If YES, please indicate what non-driving privileges (e.g., allowance) were reduced or taken away and why.

In the past month, have you used any resources about teen driving to help you decide which consequences or incentives might be useful for your teen during this phase of driving (e.g., parent-teen driving contracts, prepared discussions about safe driving, etc)?

- ❍ Yes (1)
- ❍ No (2)

If YES, please explain or provide examples in the comments box.

Ignoring any issues that might have occurred during the study because of the nature of experimental equipment, what is your overall opinion of the TDSS (based on your teen's experience with the system)?

- ❍ Very Poor (11)
- ❍ Poor (12)
- ❍ Fair (13)
- ❍ Good (14)
- ❍ Very Good (15)

Ignoring any issues that might have occurred during the study because of the experimental nature of the software and equipment, what is your overall opinion of the usefulness of the TDSS (based on your teen's experience with the system)?

- ❍ Very Useless (24)
- ❍ Useless (25)
- ❍ Neutral (26)
- ❍ Useful (27)
- ❍ Very Useful (28)

How likely would you be to recommend the TDSS (if it were a finished product) to other teens (and parents) for use in the first year of driving?

- ❍ Very Unlikely (24)
- ❍ Unlikely (25)
- ❍ Undecided (26)
- ❍ Likely (27)
- ❍ Very Likely (28)

Please use this space if you wish to share any of your experiences in the study so far.

FULL TDSS GROUP

MONTH 12 PARENT SURVEY

Welcome to the Month 12 Survey of the Teen Driver Support System with Parental Feedback Study! This set of questions is to be completed by the PARENT or GUARDIAN participant approximately 12 months after their teen driver entered the Study. This survey asks you to update your demographic and driving history information. It also asks about your interactions with your teen during the past month of driving. Please complete this set of questions by yourself (i.e., without your teen present). We ask that you answer as honestly and accurately as possible. We also ask that only the parent who has agreed to participate (i.e., signed the consent form to participate themselves) complete the questionnaires throughout the study to ensure consistency in responses. Please remember that your responses are confidential and are not stored with any identifying information, such as your name. The responses to the study surveys are collected and stored on a secure server and are only accessible by the researchers on this project. This survey link is UNIQUE for each participant. If you share an email with your teen, please ensure you are completing the correct survey.

In general, tell us how often you did the following behaviors while driving over the past month.

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Always (5)
You wear your seat belt as a driver (1)	❍	❍	❍	❍	❍
Your passengers wear their seat belts (2)	❍	❍	❍	❍	❍
You talk on your cell phone while driving (3)	❍	❍	❍	❍	❍
You send text messages while driving (including when stopped at a light or in traffic) (4)	❍	❍	❍	❍	❍
You drive between midnight and 5 a.m. (5)	❍	❍	❍	❍	❍
You drive between 9 p.m. and midnight (6)	❍	❍	❍	❍	❍
You drive too fast for the conditions (bad weather) (7)	❍	❍	❍	❍	❍

This section asks you about your TEEN's driving over the past month.

Q3 How frequently have you supervised your teen's total driving time in the past month (i.e., how frequently or what percentage of time are you a passenger in the car while they are driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

How frequently has someone else (e.g., your spouse or another adult) supervised your teen's total driving time in the past month (i.e., how frequently or what percentage of time does your teen have another adult passenger in the car with them while driving)?

- ❍ Never (0%) (1)
- ❍ Hardly Ever (1-10%) (2)
- ❍ Sometimes (11-50%) (3)
- ❍ Often (51-75%) (4)
- ❍ Very Often (76-90%) (5)
- ❍ Always (91-100%) (6)

In the past 12 months, has your TEEN been stopped and/or cited by the police for any traffic offenses (excluding parking tickets)?

- ❍ Yes, my teen has received a traffic ticket in the past 12 months. (1)
- ❍ Yes, my teen has received a warning (not a ticket) in the past 12 months. (2)
- ❍ No, my teen has not received a traffic ticket or warning in the past 12 months. (3)

If you answered "Yes, my TEEN has received a traffic ticket in the past 12 months" to the previous question, please enter the number of citations (tickets) your teen received related to the traffic offenses below.

	Indicate Yes/No		Enter Number of Tickets
	Yes (1)	No (2)	Number (1)
Speeding (1)	❍	❍	
Stop sign violation (2)	❍	❍	
Traffic light violation (such as ran red light) (3)	❍	❍	
Not wearing a seat belt (4)	❍	❍	
Impaired driving due to alcohol or drugs (5)	❍	❍	
Careless/dangerous driving (6)	❍	❍	
Graduate driver licensing violation (e.g., too many passengers; driving after curfew--midnight to 5 a.m.; talking on a cell phone while driving) (7)	❍	❍	
Texting while driving (8)	❍	❍	
Received a warning for one of the above offences (but not a ticket) (9)	❍	❍	
Other (10)	❍	❍	

In the past 12 months, has your TEEN had any accidents/crashes while driving?

❍ Yes (1)

❍ No (2)

If you answered "YES" to your teen having had an accident/crash, please indicate the type and number of crashes by entering a number in the appropriate box below (if no accidents/crashes for a category, leave blank or enter 0).

	Yes/No		How Many Crashes?
	Yes (1)	No (2)	If Yes (1)
My teen rear ended another vehicle (1)	❍	❍	
My teen hit another vehicle(s) but it was not a rear end collision (2)	❍	❍	
My teen hit a stationary object, such as a parked car, lamp post, parking lot object (3)	❍	❍	
My teen hit another road user that was not a vehicle, such as a pedestrian, bicycle (4)	❍	❍	
Another vehicle hit my teen--any crash type (5)	❍	❍	
My ran off the road but did not hit another vehicle (include whether hit or did not hit something after running off the road, such as a tree, fence, etc) (6)	❍	❍	
Other (7)	❍	❍	

Driving Interactions
This part of the survey asks you about interactions with your teen about his or her driving experiences or habits.

Please indicate how strongly you agree or disagree with the following statements.

	Strongly Disagree (1)	(2)	(3)	(4)	(5)	(6)	Strongly Agree (7)
I am very comfortable discussing my teen's driving skills or habits with them with comes up in conversation. (1)	❍	❍	❍	❍	❍	❍	❍
I am very comfortable setting and enforcing rules about driving, such as when, where and with whom my teen can drive. (2)	❍	❍	❍	❍	❍	❍	❍

Please indicate how often you have discussed your teen's driving habits, skills or talked about safe driving tips with your teen over the past month.

❍ Not at all (1)
❍ Seldom (2)
❍ Sometimes (3)
❍ Often (4)
❍ Very often (5)

Driving Privileges

This section of the survey asks you how you handle driving privileges. Driving privileges are any privileges related to driving that you extend to your teen, such as being allowed to use the car on certain days or to go to certain events or locations. It does not pertain to other non-driving privileges (e.g., allowances, being able to attend a special event, etc).

In the past month, have you reduced or taken away any of their driving privileges because they violated an agreed-upon rule about when, where or with whom they are allowed to drive (e.g., took car without permission, drove somewhere not allowed to go, etc)?

- Yes (1)
- No (2)

If YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., no longer allowed to drive to school or extracurricular events, etc) and why.

In the past month, have you reduced or taken away any of their driving privileges because they demonstrated risky or unsafe driving behaviors?

- Yes (1)
- No (2)

If YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., no longer allowed to drive to school or extracurricular events, reduced days of driving, etc) and why.

In the past month, have you increased any of their driving privileges because they demonstrated safe driving behaviors?

- Yes (1)
- No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

In the past month, have you reduced or taken away any of their driving privileges for a non-driving related reason (e.g., violating curfew, not completing chores on time, trouble at school, etc)?

- Yes (1)
- No (2)

If YES, please indicate in the space provided what driving privileges were reduced or taken away (e.g., no longer allowed to drive to school or extracurricular events, reduced days of driving, etc) and why.

In the past month, have you increased any of their driving privileges for a non-driving related reason (e.g., good grades, doing work around the house, etc)?

- Yes (1)
- No (2)

IF YES, please indicate in the space provided what driving privileges were increased (e.g., allowed to drive more often, etc) and why.

Non-Driving Privileges

This section of the survey asks you about how you relate non-driving privileges to driving habits and behaviors. A non-driving privilege would be such things as allowances or being allowed to go to friends' houses or special events (regardless of whether your teen drives there or not).

In the past month, have you reduced or taken away non-driving privileges (e.g., allowance, grounded your teen from visiting friend’s houses, etc) because of risky or unsafe driving behaviors you have witnessed?

❍ Yes (1)
❍ No (2)

If YES, please indicate what non-driving privileges (e.g., allowance, etc) were reduced or taken away and why.

In the past month, have you reduced or taken away non-driving privileges (e.g., allowance, grounded your teen from visiting friends' houses, etc) because your teen violated an agreed-upon rule about when or where or with whom they are allowed to drive (e.g., took car without permission, drove somewhere not allowed to drive)?

❍ Yes (1)
❍ No (2)

If YES, please indicate what non-driving privileges (e.g., allowance) were reduced or taken away and why.

In the past month, have you used any resources about teen driving to help you decide which consequences or incentives might be useful for your teen during this phase of driving (e.g., parent-teen driving contracts, prepared discussions about safe driving, etc)?

❍ Yes (1)
❍ No (2)

If YES, please explain or provide examples in the comments box.

If you used incentives (e.g., increased driving privileges, increased allowance, etc) of any kind (driving or non-driving related) in the past month of driving with the Teen Driver Support System, was it directly related to seeing positive feedback about your teen's driving in the weekly reports?

❍ Yes (1)
❍ No (2)

If you used consequences (e.g., reduced or took away driving privileges, grounded your teen, didn’t give them their usual allowance, etc) of any kind (driving or non-driving related) in the past month of driving with the Teen Driver Support System, was it directly related to seeing negative feedback about your teen’s driving (e.g., via text message or weekly reports)?

❍ Yes (1)
❍ No (2)

If you used consequences for behaviors reported by the Teen Driver Support System in the past month, which behaviors did you think most required consequences? Please check all that apply.

❑ Speeding violations (1)
❑ Excessive maneuvers (e.g., hard braking, turning or accelertating) (2)
❑ Stop sign violations (3)
❑ Seat belt violations (4)
❑ Graduated driver licensing (GDL) curfew violations (driving between midnight-5 a.m.) (5)
❑ GDL passenger restrictions (6)
❑ All of the above (7)

Do you think using the TDSS had a positive effect on your interactions with your teen when discussing their driving habit and behaviors?

❍ No (22)
❍ Yes (23)

Please explain.

Do you think using the TDSS had a positive effect on your expectations of your teen's driving behavior?

❍ Yes (9)
❍ No (10)

Please explain.

These questions are about the TEXT MESSAGE FEEDBACK you received from the TDSS while your teen was using the system. How would you rate the text message notifications you received during the study?

	Poor (11)	Fair (12)	Good (13)	Very Good (14)	Excellent (15)
The way the information was presented. (1)	❍	❍	❍	❍	❍
The usefulness of the information. (2)	❍	❍	❍	❍	❍
How easy it was to understand the information. (3)	❍	❍	❍	❍	❍
Ability to use the information to start a discussion with your teen about the driving behavior for which you were notified. (14)	❍	❍	❍	❍	❍
The timeliness of the information. (15)	❍	❍	❍	❍	❍

These questions are about the EMAIL SUMMARY FEEDBACK you received from the TDSS while your teen was using the system. How would you rate the weekly email summary you received during the study?

	Poor (11)	Fair (12)	Good (13)	Very Good (14)	Excellent (15)
The way the information was presented. (1)	❍	❍	❍	❍	❍
The usefulness of the information. (2)	❍	❍	❍	❍	❍
How easy it was to understand the information. (3)	❍	❍	❍	❍	❍
Ability to use the information to start a discussion with your teen about the driving behavior for which you were notified. (14)	❍	❍	❍	❍	❍
The timeliness of the information. (15)	❍	❍	❍	❍	❍

These questions are about the WEBSITE INFORMATION you received on the website from the TDSS while your teen was using the system. How would you rate the information you were able to access on the TDSS website during the study?

	Poor (11)	Fair (12)	Good (13)	Very Good (14)	Excellent (15)
The way the information was presented. (1)	❍	❍	❍	❍	❍
The usefulness of the information. (2)	❍	❍	❍	❍	❍
How easy it was to understand the information. (3)	❍	❍	❍	❍	❍
Ability to use the information to start a discussion with your teen about the driving behavior for which you were notified. (14)	❍	❍	❍	❍	❍
The timeliness of the information. (15)	❍	❍	❍	❍	❍

Ignoring any issues that might have occurred during the study because of the nature of experimental equipment, what is your overall opinion of the TDSS With Parental Feedback?

- ❍ Very Poor (11)
- ❍ Poor (12)
- ❍ Fair (13)
- ❍ Good (14)
- ❍ Very Good (15)

Ignoring any issues that might have occurred during the study because of the experimental nature of the software and equipment, what is your overall opinion of the usefulness of the TDSS With Parental Feedback?

- ❍ Very Useless (24)
- ❍ Useless (25)
- ❍ Neutral (26)
- ❍ Useful (27)
- ❍ Very Useful (28)

How likely would you be to recommend the TDSS (if it were a finished product) to other teens and parents for use in the first year of driving?

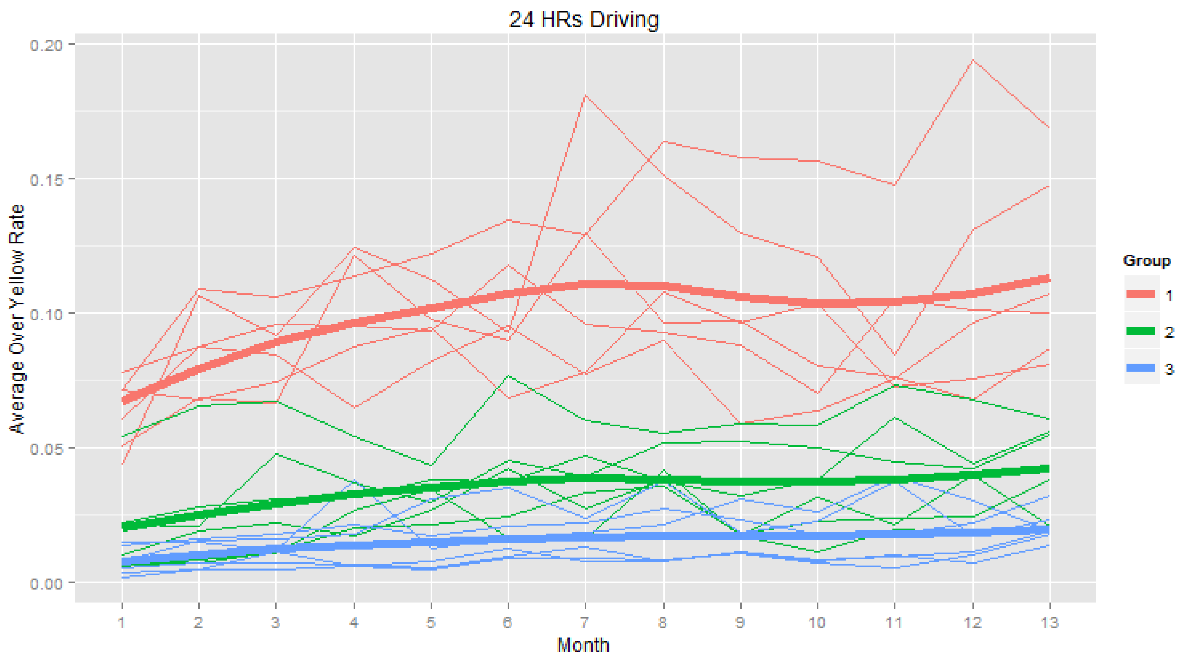
- ❍ Very Unlikely (24)
- ❍ Unlikely (25)
- ❍ Undecided (26)
- ❍ Likely (27)
- ❍ Very Likely (28)

Please use this space if you wish to share any of your experiences in the study so far.

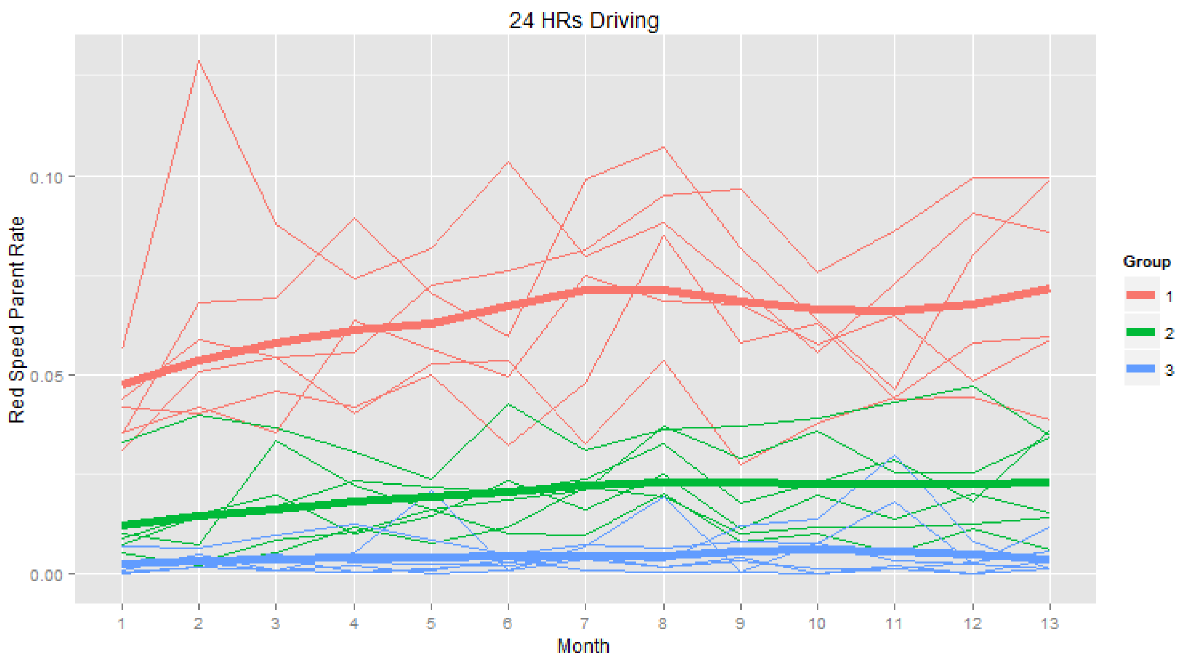
APPENDIX E: SPAGHETTI PLOTS FOR VEHICLE DEPENDENT VARIABLES

In the following graphs, the different study groups can be identified as follows:

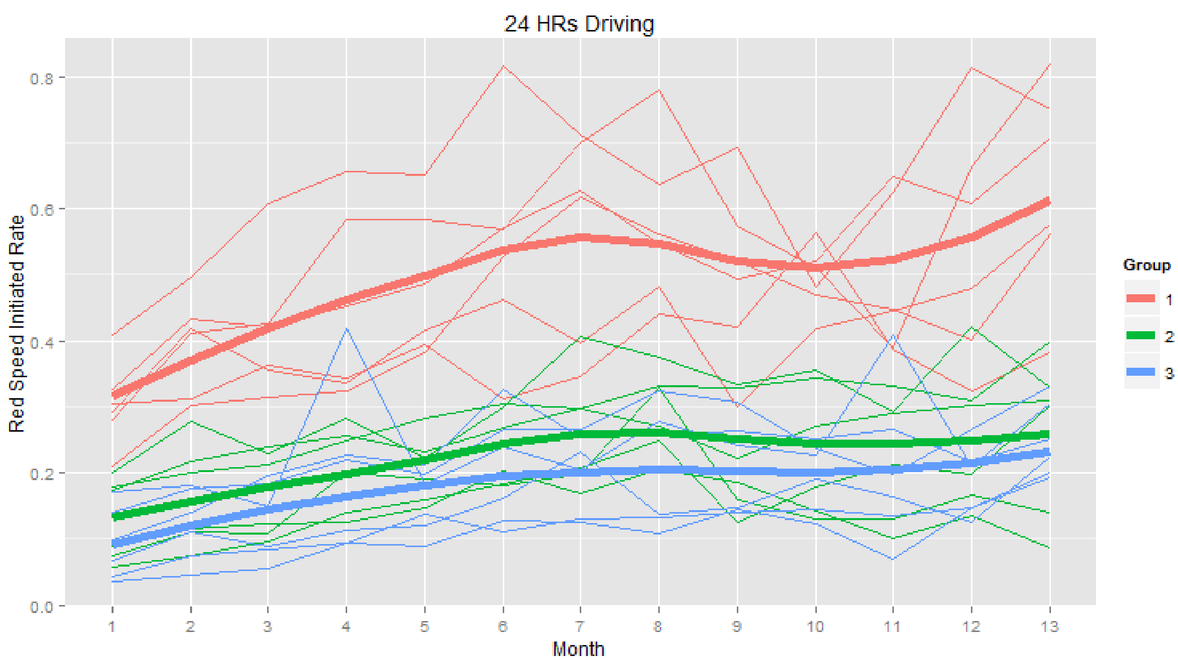
- Control: Group 1
- Partial TDSS: Group 2
- Full TDSS: Group 3



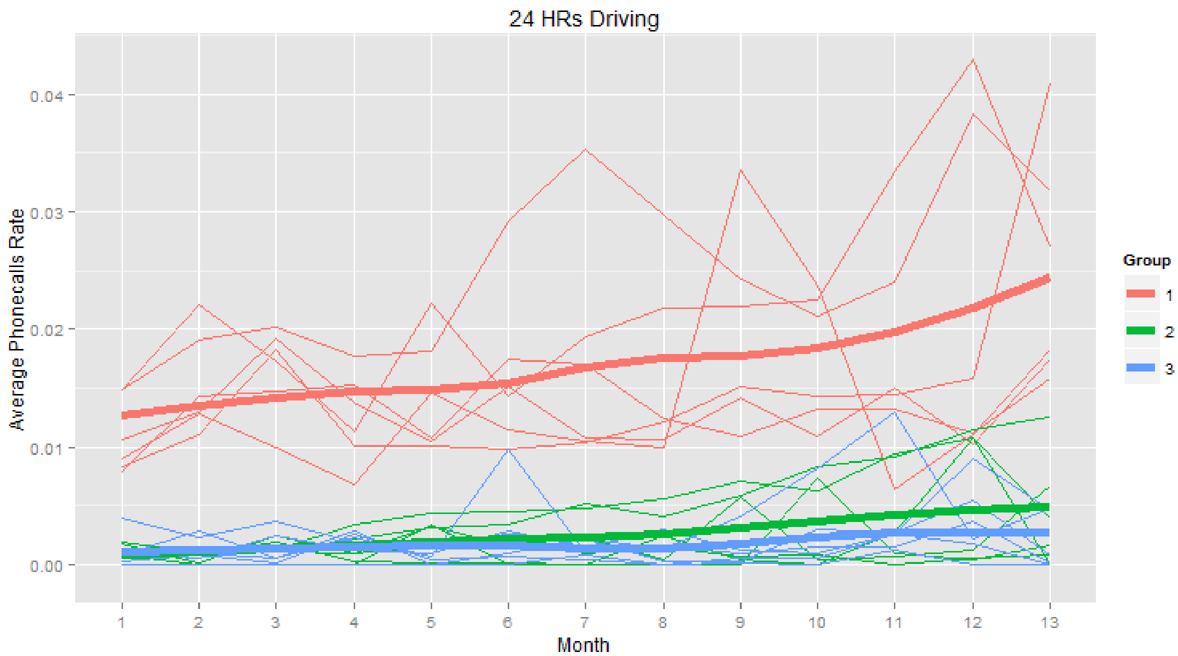
Variability plot of the percentage of speeding miles over 7 mph showing the average trend for each group (heavy lines) plus the lines associated with individual participants.



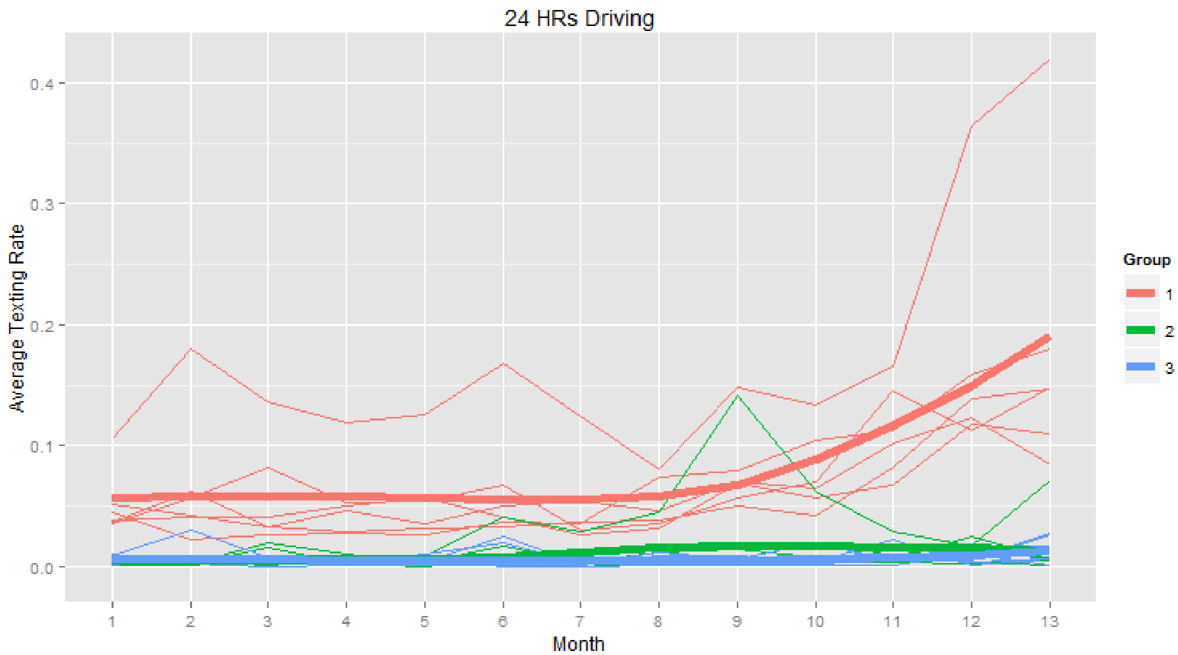
Variability plot of the rate of parent text messages sent/would be sent showing the average trend for each group (heavy lines) plus the lines associated with individual participants.



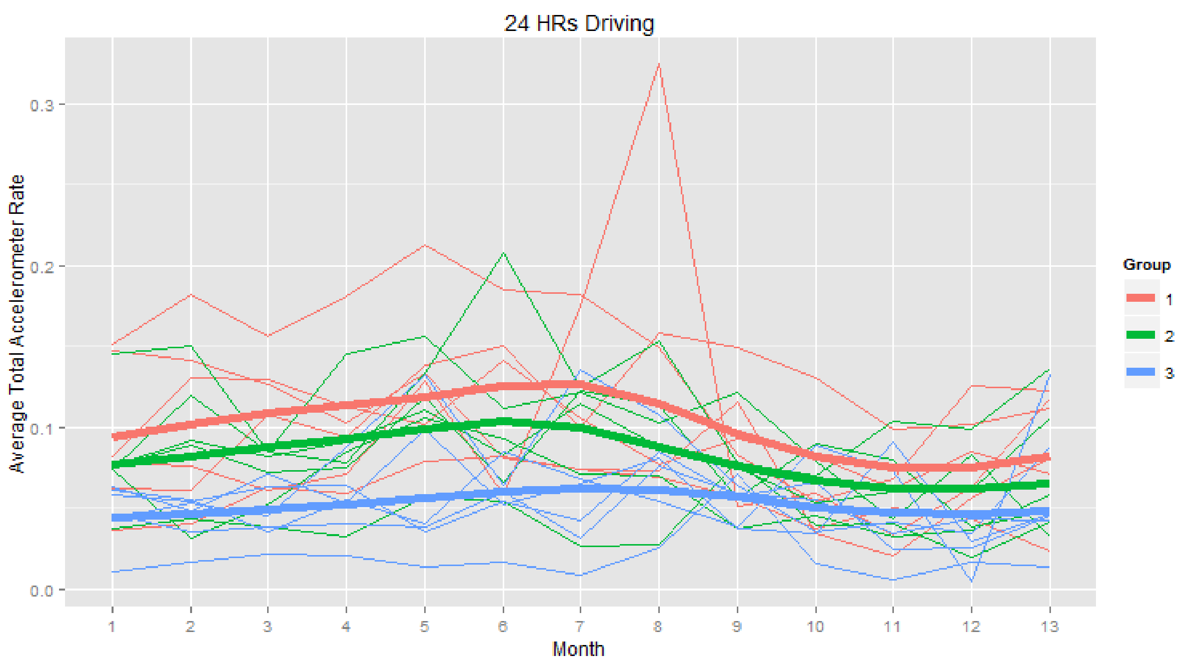
Variability plot of the rate of red speed initiations showing the average trend for each group (heavy lines) plus the lines associated with individual participants.



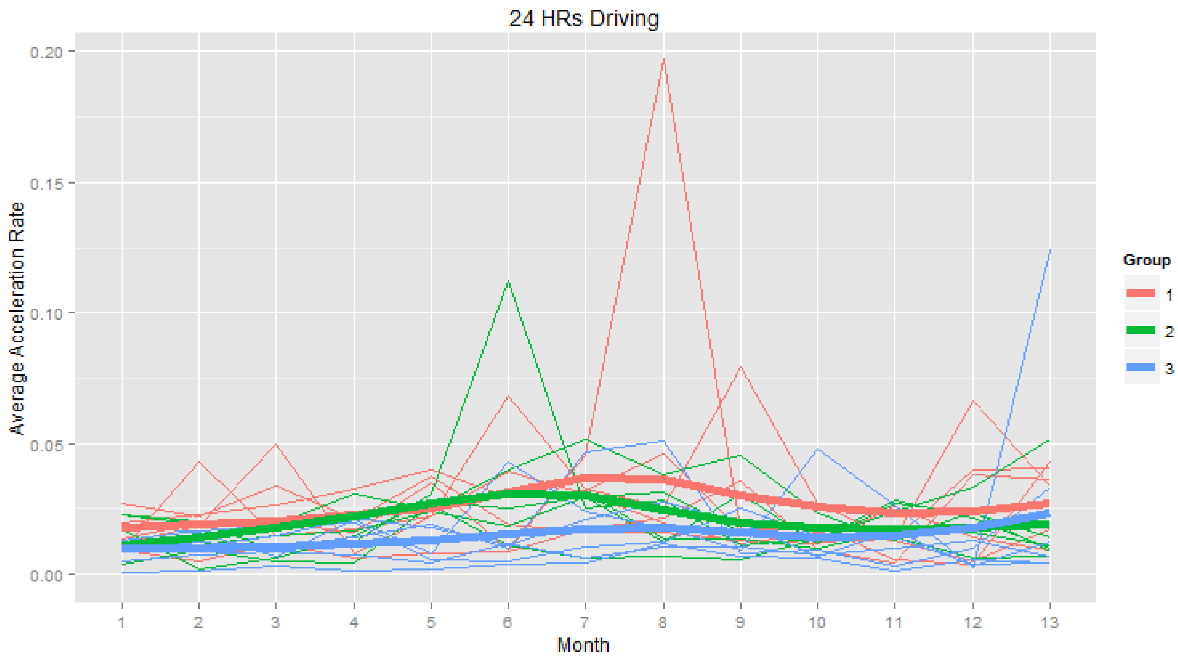
Variability plot of the rate of cell phone calls made showing the average trend for each group (heavy lines) plus the lines associated with individual participants.



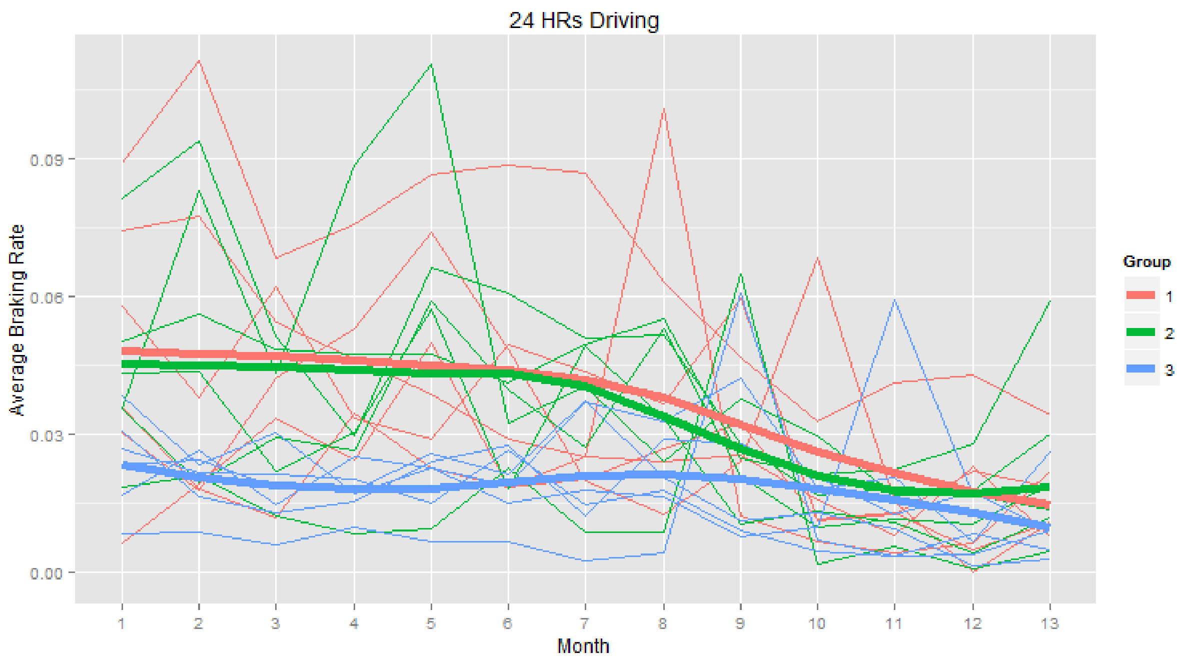
Variability plot of the rate of text messages sent showing the average trend for each group (heavy lines) plus the lines associated with individual participants.



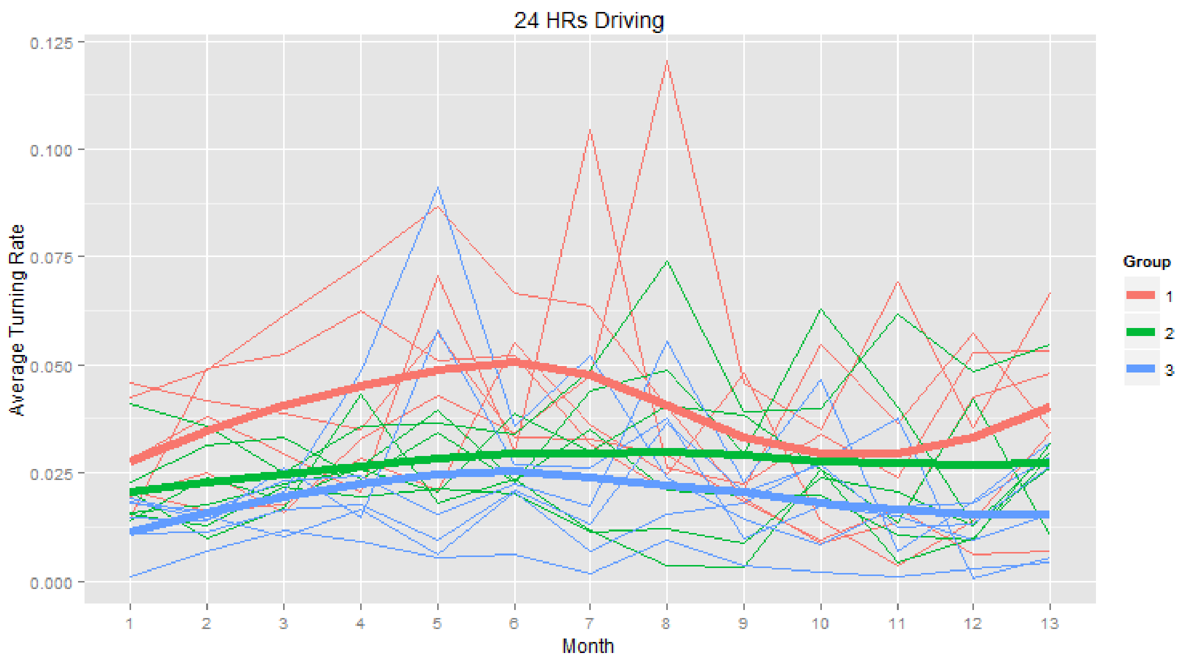
Variability plot of the rate of total accelerometer events showing the average trend for each group (heavy lines) plus the lines associated with individual participants.



Variability plot of the rate of acceleration events showing the average trend for each group (heavy lines) plus the lines associated with individual participants.



Variability plot of the rate of braking events showing the average trend for each group (heavy lines) plus the lines associated with individual participants.



Variability plot of the rate of total turning events showing the average trend for each group (heavy lines) plus the lines associated with individual participants.