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16. Abstract

In 2020 drivers 15 to 20 years old—many of whom were novices—represented 8.5% of drivers involved in fatal crashes but only 5.1% of all licensed drivers. Graduated driver licensing (GDL) laws are the most effective behavioral countermeasure for young drivers. However, although an increasing proportion of young people are delaying licensure until age 18 or older, few States currently apply the full GDL program to novices 18 to 20 years old, and little is known about the safety and driving habits of novices 18 to 20. In the current project the research team developed a hypothetical naturalistic driving study to investigate research questions about the safety and driving exposure of younger (15.5 to 16.5 years old) and older (18 to 20 years old) novice drivers in the first year of unsupervised (independent) driving. This report contains some of the material developed for the hypothetical study, including the literature review, the hypothetical study design and data analysis approach, draft questionnaires, and an assessment of potential challenges if the hypothetical study were to be conducted.

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Executive Summary

In 2020 drivers 15 to 20 years old—many of whom were novices—represented 8.5% of drivers involved in fatal crashes but only 5.1% of all licensed drivers (National Center for Statistics and Analysis, 2022). As a group, novice drivers' crash rates are highest during the initial months of licensure and decline over time (e.g., Mayhew et al., 2003), but, at an individual level, some novices drive safely throughout this period while others remain at consistently high risk (Missikpode et al., 2019).

One factor that may influence novice drivers' level of risk is the age at which they begin unsupervised driving. Although 46 States' graduated driver licensing (GDL) provisions allow unsupervised driving beginning at 15.5 to 16.5 years old, an increasing proportion of young people are delaying licensure until 18 or older (Tefft et al., 2014). Licensure delays are more likely among Latino, Black, and lower socioeconomic status (SES) young people (Vaca et al., 2021a, 2021b). Per *Countermeasures That Work* (Venkatraman et al., 2021), GDL laws are the most effective behavioral countermeasure for young drivers (e.g., McCartt et al., 2010) as they reduce novice drivers' exposure to the riskiest situations as they are gaining more experience. However, only 6 States currently require novices 18 and older to comply with at least one GDL provision, and even fewer apply their State's full GDL program (for example, a three-phase licensing system that includes nighttime and passenger restrictions in the intermediate phase) to all novices younger than 21 (Curry et al., 2017; IIHS, 2022). Because little is known about the safety and driving habits of novices 18 to 20, questions remain about whether and how to extend GDL to older novices.

In this project the research team developed a hypothetical naturalistic driving study (NDS) to investigate key research questions about the safety and driving exposure of younger (15.5 – 16.5) and older (18 – 20) novice drivers in their first year of unsupervised (independent) driving. The research team first conducted a literature review to inform the hypothetical study design. Next, the research team developed a study design and data analysis approach. The research team also prepared all material required to conduct the hypothetical study, like an Institutional Review Board (IRB) package, Information Collection Request (ICR), a Data Management Plan (DMP), questionnaires to be administered to participants, consent forms, and a draft of the Introduction and Methods sections for a report describing the hypothetical study and its results. Finally, the research team identified potential challenges for conducting the hypothetical study, along with solutions. This report contains some of the material developed for the hypothetical study, including the literature review, the study design and data analysis approach, the draft questionnaires, and an assessment of potential challenges for conducting the study.

Overall, the research team found that most existing NDSs of novice drivers have not included novices 18 and older. Additionally, most prior NDSs have used convenience samples that overrepresented White and higher SES novice drivers. When designing the hypothetical study, the research team determined that an alternative approach was necessary to obtain more representative samples of novice drivers. Specifically, the research team devised a recruitment approach in which, along with a partnership with a State driver licensing agency, researchers could increase the likelihood of reaching a diverse group of potential participants. Additionally, the research team suggested a "hybrid" approach to data collection, in which most participants would have NDS data collected via an app on their personal smartphones, while a smaller subgroup would additionally be outfitted with the kinds of in-vehicle data acquisition systems (DASs) traditionally used in NDSs. This approach removes barriers to participation associated with the installation of in-vehicle equipment, permits the recruitment of a larger number of participants, and allows researchers to examine the relationship between NDS data obtained with smartphones versus in-vehicle equipment.

Introduction

In 2020 drivers 15 to 20 years old—many of whom were novices—represented 8.5% of drivers involved in fatal crashes but only 5.1% of all licensed drivers (NCSA, 2022). While young novice drivers' crash rates have declined since States began implementing GDL programs in the 1990s (McCartt & Teoh, 2015), motor vehicle crashes remain a leading cause of death among young people 16 to 20 years old (Webb, 2015). As a group, novice driver crash rates are highest during the initial months of licensure and decline over time (e.g., Mayhew et al., 2003). However, individual novices may not follow this pattern of incrementally declining risk (Mirman et al., 2019). For example, when novices were grouped by longitudinal profiles ("trajectories") of risky driving over the first 20 weeks of independent driving, some novices drove safely throughout this period while others remained at consistently high-risk (Missikpode et al., 2019; see also Guo et al., 2013; Simons-Morton et al., 2013).

One factor that may influence heterogeneity of risk among novice drivers is the age at which they receive licensure and begin driving independently. While crash rates are generally highest for novice drivers at first licensure and decline with experience (e.g., Mayhew et al., 2003), the declines among older novices appear to be slower than for those licensed at younger ages (Curry et al., 2015a). Some evidence also suggests that drivers first licensed at 18 have higher crash rates during their first several months of driving than do new drivers first licensed at 16 or 17 (Chapman et al., 2014; Walshe et al., 2022; but see Curry et al., 2015a).

While an increasing proportion of young people are delaying licensure until 18 or older (Tefft et al., 2014; Twenge & Park, 2019), few States currently require novices 18 and older to comply with at least one GDL provision. Even fewer apply their State's full three-phase GDL program to all novices younger than 21 (Curry et al., 2017; IIHS, 2022), including nighttime and passenger restrictions currently rated with five stars for effectiveness in *Countermeasures That Work* (Venkatraman et al., 2021). Licensure delays are more likely among Latino, Black, and lower-SES young people (Vaca et al., 2021a, 2021b), raising the possibility of inequities in which novices receive the benefits of GDL. However, because few studies have examined the safety and driving habits of newly licensed drivers 18 and older, questions remain about whether and how to extend GDL. For example, it is unknown whether most older novices follow a pattern of declining risk during this period or whether some are at consistently higher (or lower) risk. It is also unknown whether the amount, type, or patterns of driving in the first months of independent driving differ, or evolve differently over time, for older and younger novices. Research in this domain may inform the development of GDL provisions for older novices that reduce exposure to risk while still ensuring mobility.

The heterogeneity of risk among young novice drivers has also led to a call to "move beyond" population-level interventions towards interventions tailored for novices with higher levels of risk or who have already exhibited unsafe driving behaviors (Winston et al., 2016). Therefore, it is critical to understand which novice drivers are likely to begin at greatest risk during the first months of independent driving, and to remain so. Conversely, understanding which novices are likely to have persistently low risk—and whether their early independent driving experiences differ in ways that promote learning but preserve safety—can be useful for those developing recommendations and education for newly-licensed drivers. Yet, few demographic or psychological factors have emerged as significant and consistent predictors of whether novices follow high- or low-risk trajectories of unsafe driving after the transition to independent driving (Missikpode et al., 2019; Roman et al., 2015). Similarly, it is unknown whether the amount, type, or patterns of driving in the first months of independent driving differ, or evolve differently over time, for high- and low-risk novice drivers.

Research Questions

The objective of this project was to develop, design, and determine the potential challenges for conducting a hypothetical NDS with younger (15.5 to 16.5) and older (18 to 20) novice drivers in the first period of independent driving to address the following research questions.

1. Do older novices exhibit different trajectories of risky driving in the first period of independent driving than younger novices?
2. Do older novice drivers differ from younger novices in the amount, type, or patterns of driving they do during the first period of independent driving? Do they differ with respect to demographic, psychological, or other individual characteristics associated with risky driving?
3. After beginning to drive independently, do most novice drivers exhibit the pattern of initially high but decreasing rates of risky driving? Or, do some groups of novice drivers follow different trajectories — e.g., consistently high or low rates of risky driving?
4. Do novice drivers who consistently engage in, or consistently refrain from, risky driving during the first period of independent driving differ in the amount, type, or patterns of driving they do during this period? Do they differ with respect to demographic, psychological, or other characteristics associated with risky driving?

Approach

To design a hypothetical study to address these research questions, the research team developed the following material:

- A literature review of existing research relevant to the research questions and potential methodological approaches for the hypothetical study;
- A study design and data analysis plan;
- Questionnaires to be administered at various timepoints during the hypothetical study;
- Material required for submission to an IRB;
- A DMP;
- Forms required to obtain participant consent;
- ICR material describing the study for submission to the OMB to comply with the Paperwork Reduction Act (PRA);
- Draft Introduction and Methods sections for a final report describing the hypothetical study; and
- An assessment of potential challenges to conducting the hypothetical study, along with solutions.

The research team did not develop material related to assessing how personally identifiable information (PII) would be collected, used, shared, and maintained (e.g., a Privacy Threshold

Analysis and/or Privacy Impact Assessment); these would be developed prior to conducting the hypothetical study using more detailed information available at that time. This report contains some of the material developed for the hypothetical study, including the literature review, the hypothetical study design and data analysis approach, and an assessment of potential challenges for conducting the hypothetical study.

Literature Review

The research team conducted a focused literature review of studies published in peer-reviewed journal articles, Government reports, and reports from private research organizations on the following topics:

- Changes in novice drivers' rates of fatalities, injuries, crashes, or risky driving performance (e.g., kinematic risky driving) or in non-performance aspects of driving (e.g., exposure, passenger presence) over the first months or years of independent driving;
- Identifying novice drivers at high risk (or low risk) of unsafe driving during the first months or years of independent driving;
- Factors associated with increased or decreased risk of unsafe independent driving among novices, including demographic, psychological, or attitudinal predictors;
- Changes in rates of fatalities, injuries, crashes, risky driving performance, or non- performance aspects of independent driving, among novices 18 or older; and
- Other studies relevant to the research questions based on studies' findings or the similarity of research methods to those planned for the current study.

Methods

To identify relevant studies, the research team first derived a search strategy that considered each of the pending hypothetical study design decisions and then enumerated keywords that would identify studies to inform these decisions. For example, to identify studies that might inform decisions regarding data reduction and analysis, "group-based trajectory modeling"—a possible approach for data analysis in the hypothetical study—was included as a keyword. For site selection, variations of "graduated driver licensing laws" were used. Finally, keywords such as "novice drivers," "new drivers," "inexperienced drivers," and "older novice drivers" were used in combination with terms such as "crash" and "safety" to identify studies that would inform decisions about screening, recruitment, and the selection of the DAS.

Once the keywords were enumerated, the research team queried numerous sources for research documents that were likely to contain most relevant studies. The research team searched the following databases.

- TRID (https://trid.trb.org/)
- PsycInfo
- PubMed (https://pubmed.ncbi.nlm.nih.gov/)
- Academic Search Premier
- NHTSA's ROSA-P Behavioral Safety Research Collection (https://rosap.ntl.bts.gov/cbrowse?pid=dot%3A242&parentId=dot%3A242)
- Google Scholar (https://scholar.google.com/)

After an initial search of the databases, a researcher reviewed the abstracts of identified documents and read in full those documents deemed most relevant to the hypothetical study. The research team combined this information with their knowledge from involvement in many studies identified in the review.

Results

Before addressing the topics of crash risk and driving performance, the research team considered how prior studies approached sampling and addressed the issue of generalizability in NDSs with novice drivers. For example, to what extent are the novice drivers in previous NDSs representative of the novice driver population? Among those participants who enroll in NDSs, are there differences between participants who drop out early compared to those who complete the study? If there are differences, how might those affect the hypothetical study? Could the sociodemographic or other characteristics of older novice drivers exacerbate the sampling and self-selection biases that may be present in studies of younger novices? Consideration of these questions informed the subsequent approach for conducting the hypothetical NDS.

What are the characteristics of novice drivers in NDS?

Table 1 describes the characteristics of driver samples in previous NDSs of novice drivers that were identified in the literature review. As evident in the table, NDSs of novice drivers in the United States to date have included volunteer samples less than 20 years old recruited in regional areas, e.g., southwestern Virginia (Ehsani et al., 2015; Lee et al., 2011) and central Iowa (Missikpode et al., 2019; Peek-Asa et al., 2019). These samples have been largely socio-demographically homogenous, mostly including White teens from higher-income households. An ongoing study in Maryland (Ehsani et al., 2021) has a more racially diverse sample, but the sample remains comprised of 75% White participants. The Second Strategic Highway Research Program (SHRP2) study (Antin et al., 2015), whose overall driver sample was 87% White, included a sample of 553 16- to 19-year-old participants with lower household income than other NDSs, but almost two-thirds (62.9%) of these reported household incomes of over $50,000, which was the median household income in the United States at the time (DeNavas-Walt et al., 2011). While the SHRP2 study protocol did not require participants to be enrolled beginning at first licensure, a sizeable proportion of the young participants could still be considered novices as they were in their initial year of driving independently.

Table 1. Characteristics of driver samples in novice driver NDS studies

NDS	Region	N	Sampling	Age at Recruit-ment	Race	Household Income	Study Vehicles
NIH 1 (Simons-Morton et al., 2015)	Roanoke/ Blacksburg, Virginia	42	Convenience	16.4	>90% White	42% >$100,000	Partici-pant-owned
NIH 2 (Ehsani et al., 2017b)	Roanoke/ Blacksburg, Virginia	90	Convenience	15.5	90% White	47% >$100,000	Partici-pant-owned
University of Iowa (Missik-pode et al., 2019; Peek-Asa et al., 2019)	Des Moines/Iowa City, Iowa	51	Convenience	15-17	89% White	Not re-ported	Partici-pant-owned
Johns Hopkins (Ehsani et al., 2021)	Maryland	157	Convenience	15.8	75% White	87% >$80,000	Partici-pant-owned
SHRP2 (Antin et al., 2015)	Florida, Indiana, New York, North Carolina, Pennsylvania, and Washington	553	Convenience	16-19	87% White (overall sample)	63% >$50,000	Partici-pant-owned

Additionally, analyses of the SHRP2 data have identified a tendency toward a "good driver" bias among younger participants in NDSs. For example, Simons-Morton and colleagues (2020) found that as the study progressed, participation of the riskiest younger drivers decreased (i.e., they withdrew from the study sooner than the safer drivers). Specifically, crash rates were significantly higher among those in the study for less than 12 months compared with those in the study for 12 months or more (odds ratio = 1.5). This bias further limits the generalizability of novice driver samples in previous NDSs.

What are the characteristics of younger versus older novices?

In the United States, the age when young people begin to drive once they have reached the minimum age in their State appears to be heavily influenced by economic factors. Surveys have found that at ages 16 and 17 approximately half the population (54%) have driver licenses, and this group is predominantly White and from higher income households (Tefft et al., 2013). By contrast, in a longitudinal study (2009 – 2016) of a nationally-representative cohort of 10th graders, approximately 31% of teens did not delay obtaining a license, 39% delayed by 1 to 2 years, and 30% delayed for more than 2 years (Vaca et al., 2021a). Drivers who are licensed at 18 and 19 are more likely to be Black or Latino and to come from lower income or single-parent households (Vaca et al., 2021a, 2021b), even when accounting for whether a novice lives in an urban, suburban, or rural area. A study of licensing records and Census tract data in New Jersey found that 87% of young people residing in the highest-income areas were licensed before 18 whereas in the lowest-income areas, only 36% were licensed before 18 (Curry et al., 2015b).

The most common reasons older novices (18 to 20) cite for not being licensed sooner are not having a car, the costs associated with driving, and being able to get around without driving (Tefft et al., 2014). In a recent survey, young people who were not licensed before 18 were more likely to come from lower affluence families, to report that their families could not afford cars for them to drive, and to report that there was nobody in their families who had time to help them obtain licenses (Tefft & Foss, 2019). The literature review did not identify any studies that reported estimates of vehicle access for novices 18 and older.

Implications

Any study that relies on volunteers is at risk of suffering a sampling bias. This bias can occur both during recruitment and in retention. While volunteer bias in the social sciences has been widely documented (e.g., Brassey et al., 2017), the extent to which this sampling bias might bias general population estimates or limit the generalizability of NDS research to other subpopulations of novice drivers has not been critically examined. To date, participants who are White and from higher income households have been overrepresented in NDS of novice drivers. Moreover, older novices are more likely to be Black, Latino, and from lower income households (e.g., Vaca et al., 2021a). Therefore, to recruit a sample of older novice drivers that is reflective of the driving population, study participants for the hypothetical NDS would need to be intentionally sampled—in cooperation with study sites that have information about the population of novices in that area (e.g., State licensing agencies)—rather than relying on convenience sampling.

One reason why NDS samples may skew towards higher income and White participants may be the requirement to own and have access to a vehicle that can be instrumented for the duration of the study. This literature review could not identify any studies that specifically examined vehicle access among older novice drivers. To design an NDS with results for older novices, there is a need to understand vehicle access patterns in that population and to accommodate these patterns in the NDS sample design. For example, to adequately represent subpopulations of older novices that may not have stable access to a single vehicle and may be driving various non-household vehicles, NDS instrumentation may need to be associated with the person rather the vehicle (e.g., a smartphone). Alternatively, a primary vehicle could be highly instrumented while driving behavior in other vehicles could be measured using smartphones. A third and far more expensive approach would be to provide participants with study-supplied vehicles. Although this approach is far more costly, it has the advantage of supporting virtually any type of instrumentation that needs to be installed by the research team. On the other hand, while providing novice drivers with study-supplied vehicles may overcome issues related to instrumentation, it may introduce a confounding factor of increased vehicle access (which, discussed later, is independently associated with increased crash risk).

What do we know about novice drivers' risky driving and crash risk?

Younger Novices

Early research on novice drivers using self-report (McCartt et al., 2007; Twisk & Stacey, 2007) and cross-sectional crash data (Mayhew et al., 2003) indicated that crash rates were initially high among younger novices and gradually declined over time. However, individual novices may not follow this population-level pattern of incrementally declining risk (Mirman et al., 2019). More recent cohort studies using State-level crash data have found that age of licensure influences the rate of decline of crashes. Analyses of California data revealed crash rates for those licensed at 16 declined significantly after 25 to 36 months, while rates of those licensed at 17 declined after 13 to 24 months, and those licensed at 18 declined after 7 to 12 months (Chapman et al., 2014). Notably, Chapman and colleagues also found that 70% of 16 to 17-year-old novices were crash-free for their first 3 years of licensure. Curry and colleagues (2017) linked licensing and crash data and found that crash rates among 17-year-old novices in New Jersey were higher the first month after licensure than rates among novices licensed at 18, 19, or 20. Crash rates declined for about 6 months among novices of each age but more steeply for the youngest.

Population-level crash data lack exposure information about the drivers who crashed. Driving exposure is known to vary widely within the population and by economic cycles and seasonality (Brown & Baass, 1997; Edwards, 2008). The ability of NDSs to record performance measures such as kinematic risky driving (KRD) (elevated gravitational force events that exceed predefined thresholds) and crash near-crash (CNC) (events that require last minute maneuvers to avoid crashes) rates, along with driving exposure, allows for more precise estimates of risky driving incidents per miles driven.

This detailed measurement of driving performance also highlights the complexity of the relationship between driving skill and crash risk. Unlike population-level data, measures of driving performance such as KRD and CNC rates do not appear to consistently show decline over the first 12 to 24 months of independent driving (Guo et al., 2013; Simons-Morton et al., 2013, 2020). For example, in one study, CNC rates appeared to decrease over time, even as KRD rates increased (Simons-Morton et al., 2015). An analysis of driving behaviors by Pradhan and colleagues (2013) using the same data compared safety behaviors (e.g., checking a blind spot, signaling prior to changing lanes) between novice teens and their parents. They found that teens consistently engaged in more safety behaviors than their parents but also experienced a higher rate of crashes and near-crashes.

One reason for these discrepancies between population-level crash data and KRS and CNC rates may be the substantial variation in measures such as KRD and CNC rates within the samples (Guo et al., 2013; Simons-Morton et al., 2013). A concrete example is the wide variability in driving exposure within a sample, where a few high-mileage drivers can skew the overall mileage rates dramatically. In the first NIH-sponsored NDS of young novices, the average miles driven was 6,384 miles with a standard deviation (SD) of 3,246, but one relatively safe participant drove 14,865 miles (Simons-Morton et al., 2011a). In the same study, one participant was involved in six crashes, which skewed the data to such an extent that this person was excluded from subsequent analysis. Excluding this participant limited one bias but may have added another. Obviously, larger samples are less susceptible to the effects of outliers.

Older Novices

Population crash data indicate that, similar to younger novices, older novices as a group experience high initial crash rates that decline rapidly over the first year of driving (Twisk & Stacey, 2007). However, declines among older novices appear to be slower than for those licensed at younger ages (Curry et al., 2015). Additionally, some evidence suggests that drivers first licensed at 18 have higher crash rates during their first several months of driving than do new drivers first licensed at 16 or 17 (Chapman et al., 2014; Walshe et al., 2022; but see Curry et al., 2015). Indirect evidence suggests that older (18 to 20) novice drivers' risk profiles may vary as a function of the trip characteristics: for example, rates of crashes at night and with several passengers show a more rapid decrease than overall crashes among older novices during the first year of licensure (Curry, Metzger, Williams, et al., 2017).

Implications

Prior NDSs have shown that within samples that are not representative of the sociodemographic characteristics of novice drivers, different risk groups can be identified, but the extent to which the driving behaviors of these groups generalize to the novice driver population is unknown. Accurate measurement of the variability in novice drivers' crash risk using naturalistic methods (i.e., when novices drive as they typically would) requires: (1) a sample that is representative of the novice driver population; (2) a sample size that is sufficiently powerful to detect within- and between-group differences; and (3) a sufficiently long study duration to accommodate seasonal influences and the variability in driving exposure and risky driving that is observed in an NDS. Refinements to typical recruitment and inclusion criteria may help ensure that samples of novice drivers in NDSs are more representative of the population, that findings are more generalizable, and that the study samples include drivers across the entire risk continuum. Regarding the number of participants in NDSs, a formal power analysis calculation is necessary based on the hypothesized differences in the outcomes of interest between groups (e.g., property-damage crashes between younger and older novices).

From an analytic perspective, the sample size also has implications for the methods and techniques that can be used in an NDS. Group-based trajectory modeling (Nagin, 2005) is a statistical approach that provides a method to map changes in behavior (e.g., speeding) and the course of an outcome (e.g., crash rates) over time (e.g., Felt et al., 2017; Missikpode et al., 2019; Nagin & Odgers, 2010). In this kind of approach, the number of subgroups/latent longitudinal strata that best represent the individual-level heterogeneity of risk trajectories needs to be determined based on the variability in the sample. Ideally, this decision incorporates domain experts' knowledge and statistical criteria to evaluate model fit. Previous NDSs identified two or three subgroups in the young novice driver population with different CNC rates and risky driving behaviors; these subgroups differed in their psychosocial and demographic characteristics and were unequal in size, with the high-risk group being the smallest (Gershon et al., 2020).

Regarding the study period, NDSs with novice drivers should have sufficient duration to allow for the annual variation in driving exposure and crash risk to be adequately captured (i.e., a minimum of 12 months). The fact that older novices' overall crash rates may decline at a slower rate than younger novices (Curry et al., 2015) also supports the need for a longer study duration. Once the initial investment in recruitment and vehicle instrumentation has been made, the incremental costs of extending the follow-up period in a study are marginal. The longer the study period, however, the more dropouts can be expected, thereby necessitating a careful analysis of any biases created by a differential departure by some groups (e.g., less affluent, older).

The expected variability in subgroup sizes, and the zero-inflated nature of crash and near-crash count data, also suggest that a follow-up period of 12 months (e.g., versus 6 months) is more likely to satisfy the requirements for group-based trajectory modeling (i.e., at least 3 time points). This study duration also allows the calculation of event rates over time intervals of 1 to 3 months, providing more stable measures and limiting the short-term impact of the zero-inflated outcomes (Simons-Morton et al., 2013). A Bayesian estimation framework can be incorporated with group-based trajectory modeling to accommodate the case of relatively small n subgroups (Zhang et al., 2007).

In NDSs, one way to reduce the costs associated with a larger sample and/or longer study duration may be to use a hybrid approach that combines both higher- and lower-resolution data collection methods. Under this type of approach, a smaller number of participants' vehicles could be equipped with high-resolution data collection equipment, while a larger sample could use a simplified continuous data collection method (e.g., a smartphone). The findings of these two groups would be combined to generate a more generalizable set of findings (Ehsani et.al., 2021) and to validate the accuracy of the lower-resolution data.

What do we know about predictors of novice driver risk?

As a group, young drivers are at a higher risk of crashing than any other age group (NCSA, 2022). However, within this population, there is wide variability in crash risk. Studies using self-report data, crash databases, and naturalistic driving measures all suggest that approximately one-third of young drivers account for most crashes (Chapman et al., 2014; Ehsani et al., 2020; McCartt et al., 2007). Recent research suggests that risky driving behavior is best understood within the framework of the social-ecological model, where behavior is nested within individual, social, and environmental contexts (Cassarino & Murphy, 2018). For this review, the research team compiled a brief overview of the factors, often revealed through the combination of self-report and NDSs, that are relevant for the design of an NDS of older and higher-risk novices.

At an individual level, biological sex, personality, and physiological factors have been found to be associated with higher likelihood of crashing in novices. Epidemiological data indicate that males are more likely to be involved in fatal crashes (NCSA, 2022), particularly crashes involving speed and loss of vehicle control (Bingham & Ehsani, 2012). Previous NDS research on novice teen drivers have found that sensation-seeking personality (the tendency to pursue new and different sensations, feelings, and experiences) was associated with a higher incidence of speeding and crashes (Ehsani et al., 2020; Simons-Morton et al., 2015). In contrast, conscientious personality (the tendency to be responsible, goal-directed, and to adhere to norms and rules) was associated with fewer crashes than other personality types (Ehsani et al., 2015).

There is also an emerging literature on the role of psychopathology and risky driving behavior. In a carefully designed study that was nested within the first NIH-sponsored NDS, Ouimet and colleagues found that people with a blunted cortisol response to a stress test[1] were significantly more likely to have higher crash and near-crash rates (Ouimet et al., 2014). Blunted cortisol response has been associated with a range of psychopathologies and aggressive behaviors (Stadler et al., 2011). Surveys and NDSs have also found an association between mental health conditions such as anxiety and depression, risky driving behavior, and crash risk (Sita et al., 2018; Williams et al., 2015). Cohort studies using State-level crash data by Curry and colleagues have established higher rates of crashes among teen drivers with a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD) (Curry et al., 2019; Curry, Metzger, Pfeiffer, et al., 2017).

At the household level, the parent-child relationship and teens' access to a vehicle have also been found to be predictors of crash risk. An authoritative parenting style and parental involvement and knowledge of their child's life are associated with a lower likelihood of crashing (Ginsburg et al., 2009; Hartos et al., 2002). Parent-child communication has also been found to be associated with different attitudes towards risky driving behavior among teenagers (Yang et al., 2013). Arguably, the single most important role that parents play in the learning to drive process is facilitating access to a vehicle (Simons-Morton et al., 2008). Surveys and NDSs have both found

[1] Cortisol is a hormone that is typically secreted as an adaptation to stress. If lower than typical secretion of this hormone is observed in a presence of a stressor, it is classified as a "blunted cortisol response."

that risky driving behavior and crash rates are significantly higher when newly licensed teens have independent access to a vehicle (García-España et al., 2009; Gershon et al., 2018; 2021).

The social and environmental correlates of risky driving behavior have been studied extensively using a range of approaches. Over twenty years ago, Chen and colleagues described the elevated likelihood of fatal crashes among teen drivers when peer passengers were present in the vehicle (Chen et al., 2000). While the presence of peer passengers has been found to be associated with risky driving in an experimental context using a driving simulator (Simons-Morton et al., 2014, 2019), this finding has not always been replicated in NDSs (e.g., Gershon et al., 2018; Simons-Morton et al., 2011b). Instead, analyses of NDS data suggest the negative influence of peer passengers is limited to teen novices driving their own vehicle versus a shared vehicle (Gershon et al., 2018), or to no negative influence at all (Simons-Morton et al., 2011b). A critical factor, revealed through the combination of survey and NDS data, may be the extent to which a teen novice's friends are risky, as teen novices who reported having risky friends, and friends who engaged in risky driving specifically, also had higher rates of speeding, KRD and CNCs (Simon-Morton et al., 2011; Simons-Morton et al., 2015). Despite the inconclusive findings using NDS data, however, the presence of passengers increases crash risk for young drivers (see Ouimet et al., 2015, for a review), and GDL provisions that restrict the number of passengers are associated with lower crash rates (e.g., McCartt et al., 2010).

Implications

As described previously, participants in NDSs of novice drivers have not typically been representative of the general population of novice drivers. Studies that rely on a convenience sample of volunteers may be more likely to recruit participants who are lower-risk drivers. Therefore, the results of those studies will tend to highlight the kinds of predictors that are relevant for lower-risk drivers and for which there is sufficient variation among the study sample to detect an effect. By contrast, predictors of risky driving for which there is little or no variation among lower-risk drivers may be missed using a convenience sample. Similarly, levels of predictors of risky driving that do not occur, or occur infrequently, among lower-risk drivers will also go undetected if a convenience sample is used. NDSs involving novice drivers that take deliberate steps to screen participants through survey questions or to develop a recruitment strategy to obtain a sample that is more representative of the population may be more likely to include novice drivers across the entire risk continuum. This approach, however, may increase the complexity and cost of a study and, if not implemented with care, could increase the burden of participation and may deter some potential participants from underrepresented subpopulations.

Another implication of the work reviewed is that the ability to combine naturalistic driving methods with survey research has the potential to improve understanding of risk factors associated with crash risk and risky driving behaviors, as well as factors influencing licensure timing. Based on the reviewed studies, NDS studies aiming to investigate sociodemographic and psychosocial predictors of crashes and driving performance may consider including:

- Demographics (e.g., sex, race, ethnicity)
- Household income and family affluence
- Personality inventories (e.g., NEO Five Factor Inventory, McCrae & Costa, 2004)
- Prior driving experience and driving training or education

- A measure of life stage to identify lifestyle and environmental factors
- Driving behavior questionnaires
- Risk taking behavior (not while driving)
- Presence of risky friends
- Vehicle access
- Parent-child relationship and communication.

What do we know about GDL provisions that apply to older novices?

One of the goals of the current project is to design a hypothetical NDS to investigate differences between younger and older novice drivers with respect to risky driving, amount and patterns of exposure, and predictors of risky driving as they relate to State GDL laws. To identify potential States in which to conduct the hypothetical study, the research team consulted the database maintained by the Insurance Institute for Highway Safety (IIHS, 2022) and corresponded with a Senior Legislative Analyst at IIHS. When this review was conducted, 46 States had a minimum age for unsupervised driving (intermediate license) between 15.5 and 16.5 years old. Of these 46 States, six—the District of Columbia, Connecticut, Maryland, Minnesota, New Jersey, and Maine—had GDL provisions that applied to novices 18 years old or older.

Implications

The results of the hypothetical study would generalize to most State contexts if the study was conducted in a State with GDL laws that include a minimum driving age between 15.5 and 16.5 *and* that do not apply to drivers 18 and older.

Discussion: Summary of Implications for the Current Study Design

Sampling

- NDSs are prone to sampling bias, and bias can occur during both recruitment and in retention.
- Novice drivers who are White and from higher income households have been over-represented in NDSs. By contrast, older novice drivers are more likely to be Black, Latino, and from lower income households.
- For an NDS to recruit a sample of older novices that is reflective of the novice driver population, study participants need to be purposely sampled rather than relying on convenience sampling.
- Partnership with a State licensing agency may be necessary to identify and recruit eligible novice drivers who are early in the licensure process.
- The requirement for NDS participants to have vehicles that can be instrumented with data collection systems may be a barrier to participation for novices with older vehicles and/or shared vehicle access.

Sample Size

- NDSs of novice drivers should include formal power analysis calculations[2] based on the hypothesized differences in the outcomes of interest between groups.

Study Period

- The study period for an NDS of novice drivers should have sufficient duration to allow for the annual variation in driving exposure and crash risk among teenage drivers to be adequately captured (i.e., a minimum of 12 months).
- The fact that older novices' overall crash rates may decline at a slower rate than younger novices also suggests a longer study duration.
- From an analytic perspective, the expected variability in subgroup sizes and the zero-inflated nature of crash and near-crash count data also indicate that a study duration of 12 months is more likely to satisfy the requirements for approaches to analyzing longitudinal data, like group-based trajectory modeling.

Study Location

- In order to improve generalizability, the hypothetical NDS should be conducted in a State that does not include GDL requirements for novices 18 years old and older *and* has a minimum driving age between 15.5 and 16.5 years old.

Vehicle Instrumentation

- For a study to adequately represent subpopulations of older novices that may not have stable access to a single vehicle, NDS instrumentation may need to be associated with the person rather the vehicle (e.g., a smartphone).
- A way to contain the costs associated with a larger sample and/or longer study duration could be to use a hybrid approach, combining a smaller number of participants' vehicles equipped with high-resolution data collection equipment with a larger sample using a simplified continuous data collection method.

Surveys

- To investigate predictors of crashes and risky driving, NDSs with novice drivers may include surveys of sociodemographic and psychosocial factors like personality traits, presence of risky friends, vehicle access, and aspects of parent-child relationships.

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[2] A power analysis is used to estimate the smallest sample size needed for a study at the desired significance level, statistical power, and effect size.

Study Design and Data Analysis

Study Overview

The research team designed the hypothetical NDS to address research questions related to older versus younger and higher- versus lower-risk novice drivers (see Research Questions). This NDS includes investigating novice driver risk trajectories for a period of 12 months after initial independent driving licensure, with or without other restrictions (e.g., limits on nighttime driving or passengers). This duration of data collection was selected not only to ensure sufficient statistical power to detect differences in trajectories between the novice driver groups but also to avoid the possibility of seasonal influences on the study's findings.

While prospective crash-based analyses using reports to State driver licensing agencies can be used to assess risk, a study approach employing only crash reports does not include the driver exposure information that an NDS inherently provides. Also, the relative rarity of crash events limits the statistical power to differentiate among subgroups of novices that follow different risk trajectories. An NDS not only permits the examination of directly measured crash events but also collects a much larger set of surrogate crash measures such as near-crashes and KRD events that support more fine-grained comparisons among the groups of interest. An NDS approach also provides objective measures of exposure that are more accurate and easier to collect than subjective measures, like drivers' self-reports using logs.

However, typical methods of sample selection used in most prior NDSs may not be compatible with a study designed to focus on older novices and those novices at highest risk. Typically, NDS approaches (e.g., Antin et al., 2015) use convenience samples of drivers who volunteer to have instrumentation installed in their vehicles. Some of these studies have even required participants to have late-model vehicles equipped with digital data buses to support the study instrumentation. These inclusion criteria appear to yield participant pools in which White novice drivers from higher income households are overrepresented. Older novice drivers, on the other hand, are more likely to be Black, Latino, and from lower income households (Vaca et al., 2021). To represent adequately the subpopulations of novice drivers of interest, the hypothetical study will require large samples of younger and older novices that are more reflective of the actual novice driver population. Obtaining such samples will necessitate a more purposeful quota sampling approach rather than relying on a convenience sample.

Another limitation of previous NDS efforts is that the data collection instrumentation is installed in a single vehicle for each participant. This approach restricts the sample to drivers who have a dedicated vehicle that they drive all or almost all the time. Many novices, however, drive several vehicles (e.g., a parent's car, a friend's car, a work vehicle), which either limits their ability to participate in an NDS or reduces (and biases) the amount of data they produce as participants. In the hypothetical study, this issue will be avoided by associating the instrumentation with the person rather than the vehicle by making use of participants' smartphones. This approach makes use of the inherent capabilities of a smartphone resulting from its manufacturer-installed suite of hardware and software, especially GPS receivers and programs that determine the location of the smartphone at a high sampling rate. Associated computational routines can calculate measures of interest for the study, such as velocity, from these fine-grained position determinations. In addition, modern smartphones contain a three-axis accelerometer, which delivers acceleration values in each of the three standard orthogonal axes (X, Y, Z). Smartphones also have accurate time values from several sources, including the GPS satellites, and using applications ("apps") and internet connections can determine variables of interest such as the weather at a driver's present location. Finally, using smartphones for data collection has the potential to reduce the cost associated with collecting comprehensive driving data and to enable data collection from difficult to measure populations (Ehsani et al., 2021).

Existing smartphone apps are capable of capturing data that can be used to characterize much of the driving behavior of interest, like crashes, kinematic risky driving (KRD), speed, cellphone use, and information about driving exposure (see Table 7 for more details). In the commercial setting, these apps are used with millions of drivers primarily in the fleet management and insurance markets. For the research setting, apps have been developed to measure driving behavior in vulnerable populations with hundreds of drivers (e.g., Teen Driver Support System: Creaser et al., 2015; DrivingApp: Ehsani et al., 2021). A variation on the smartphone-only data collection method is the combination of a Bluetooth-paired device that connects with the vehicle directly (possibly through the OBD II port) and operates in combination with a smartphone. The LongROAD study used a similar hybrid approach with older adult drivers (Li et al., 2017). While this approach provides more information, such as advanced driving assistance system (ADAS) activations, and more resolution on measures such as vehicle speed and seat belt use, the added hardware and installation steps may be too complex for novices, who often use several vehicles.

Each of these data collection approaches can automatically begin data collection when a participant drives a vehicle and continuously collect acceleration, braking, and GPS data. These data are typically stored in a cloud-based server and can be analyzed for risky driving behaviors such as rapid acceleration and braking, hand-held smartphone use, and speeding. When this approach is used in the fleet and insurance markets, drivers are assigned a risk score and stratified according to risk profiles. These categorizations form the basis for behavior-based insurance premiums and fleet management driver feedback and incentive systems.

The state-of-the-art of NDS smartphone applications continues to be advanced by organizations such as independent software developers and insurance companies. Also, smartphones themselves are becoming more capable, with additional storage, computing power, and more sophisticated sensors. However, an NDS using smartphones for data collection need not rely on commercially available apps; an alternative approach could involve developing a new application for the needs of the hypothetical study.

While use of people's personal smartphones as data collection devices may overcome many of the recruiting and sampling problems characteristic of past NDSs that used vehicle-based DASs, they are limited in the types of data they can collect (see Grimberg et al., 2020, for a review). For example, smartphones cannot acquire video of the roadway setting or vehicle interior, and they are not attached to the vehicle's data bus, so they do not have direct access to information such as seat belt, headlight, and windshield wiper use. Additionally, there is currently little research on whether and how data collected from participants' smartphones can distinguish between instances when the participant is a driver versus a passenger (Wahlström et al., 2017). Therefore, the hypothetical study design includes a subsample of participants whose vehicles *will* be equipped with a full in-vehicle DAS, in addition to these participants carrying smartphones configured to record driving data. This hybrid approach will support the examination of correlations between measures collected/derived from both systems, and some prior research suggests "substantial overlap" between the two (Friedlin et al., 2018).

In addition to recruiting a more representative sample of novices, it will be beneficial for the hypothetical study to enroll the entire sample at a similar time in their driving history. To answer the hypothetical study's research questions (see Research Questions), the optimal timing for enrollment would be prior to the beginning of a novice's first independent driving experience. A sample that is more representative of novices and as homogenous as possible with respect to the amount of driving experience may increase the validity of the hypothetical NDS relative to studies with a convenience sample. Enrolling participants prior to the beginning of independent driving can be accomplished using the driver license files for the State where the study will be conducted. While novices will still likely vary in the extent and type of their pre-licensure driving experience (Ehsani et al., 2017a), this variation can be assessed as part of the baseline participant survey. Alternatively, a survey could be used as part of recruiting and screening to try to determine potential participant stages in their driving careers and their demographic characteristics. Self-reported information about any prior licensing may be less accurate than the information in a State's official driver license file, while other self-reported information (like race and ethnicity) will be more accurate. However, recruiting based on license file data may be easier, faster, and less expensive than administering a survey and certainly places less burden on potential novice driver participants. Using State license data for recruiting would not involve approaching anyone who is not eligible for the study based on the basic demographic and driving history included in the license file data.

Recruiting samples of both younger and older novices that are more representative of the U.S. novice driver population would be facilitated by a partnership with a State driver licensing agency. From driver record files, the involved licensing agency could provide all or most of the information needed to initially select and stratify potential participants. Novice drivers would then be recruited and screened when they scheduled their on-road driving tests—typically the final step before obtaining licensure that allows unsupervised driving. If the participant is in the subgroup of participants whose vehicles will also be outfitted with DAS, the vehicle-based equipment can be installed on the day of the on-road test. In this way, younger and older novices can be recruited at similar points in their driving careers. This enrollment strategy will also allow time and flexibility prior to the day of the on-road test for the research team to screen prospective participants who expressed interest in the study but were unable to complete screening at the time of scheduling the road test and may therefore require follow-up (e.g., the younger novice's legal guardian was not present to give assent and a follow-up visit is necessary). Moreover, this strategy minimizes both the burden on prospective study participants and the risk to DAS equipment, as equipment will only be installed once a novice is fully eligible for the study. The strategy also allows for capturing data on novices' earliest independent driving experience. While there may be some novices in the in-vehicle instrumentation group that require follow-up appointments to install the in-vehicle DAS, such as those who bring an alternate vehicle other than their primary one to the on-road test, the smartphone DAS can be installed immediately on the day of the road test and the in-vehicle one within days thereafter. In the unlikely event that the on-road test is scheduled and administered the same day, all study recruitment, screening, and enrollment activities can still proceed if all study conditions are met on that day.

Joining with a State licensing agency for the study purposes has at least two advantages beyond facilitating the recruiting process. First, it would reduce the burden on participants in the number of questionnaires the study requires: some classification variables of interest may be available in the State's licensing data. Second, it would preclude the need to ask a detailed series of questions concerning crash and violation history (during the learner permit phase or unlicensed driving) that might not be accurately or truthfully answered by participants. The driver record information held by licensing authorities within a State has objective information about these events measured equivalently for each participant.

Study Methods

The suggested approach for a study is a classic research design for an NDS with two groups of drivers/participants—younger and older novices—to contrast their driving behavior and safety-critical events. The plan described below includes the basic methodological steps generic to similar studies—site selection, participant recruitment and intake, material development, data collection, specification of tasks and procedures, data management and security, data quality control, processing, and analysis. It also contains some techniques that are novel and some that will be a modification from general uses. The next sections describe each of these steps in more detail.

Site selection

The selection of a site for a study is an essential early step. To answer the study research questions (see Research Questions), researchers will need to identify and select one State that has a GDL law with a minimum unsupervised driving age from 15.5 to 16.5 years old but that does not apply GDL provisions to novices 18 and older. To identify a study site with applicable GDL provisions, researchers can consult the database maintained by IIHS (2022) or the laws and regulations of individual States. Researchers should verify the accuracy of the information for the selected candidate States before finalizing their site selections.

In States with applicable GDL laws, researchers should establish liaison with the State driver licensing agencies to look for the following.

- The essential variables of interest in their driver license files:
    - Date of learner permit issuance
    - Date of first licensure for independent driving
    - Date of birth
    - Sex
    - Race
    - Other demographic data of possible interest
- Experience conducting research of this type of project, including the ability and willingness to retrieve the needed data without extensive new programming
- High-volume licensing offices where participant recruitment could be conducted efficiently
- Interest in participating
- Location convenient to the research team

In addition to these criteria, a State or area within a State with racial and ethnic diversity is desirable so that a sample with demographic characteristics similar those of novice drivers in the United States can be readily recruited.

Table 2 shows some of these necessary study site characteristics that can be determined without contacting all 50 States and the District of Columbia. The research team compiled the data in the table from State licensing agency websites and/or relevant secondary source information when the information of interest was not available online. A dash (-) is displayed in the table when the availability of a driver record variable could not be determined from the available data.

Table 2. Necessary State characteristics to serve as potential study sites

State	Minimum Unsupervised Driving Age 15.5 - 16.5	No GDL 18+	Driver Record: Date of Learner	Driver Record: Date of Licensure	Driver Record: DOB	Driver Record: Sex	Driver Record: Race
AL	X	X	X	X	X	X	
AK	X	X	X	X	X	X	
AZ	X	X	X	X	X	X	
AR	X	X	X	X	X	X	
CA	X		X	X	X	X	
CO	X	X	X	X	X	X	
CT	X		X	X	X	X	
DE	X	X	-	-	-	-	-
DC	X		X	X	X	X	
FL	X	X	X	X	X	X	X
GA	X	X	X	X			
HI	X	X	X	X	X		
ID		X	X	X	X	X	
IL	X	X	X	X	X	X	
IN	X	X	X	X	X	X	
IA	X	X	X	X	X	X	
KS	X	X	X	X	X	X	
KY	X	X	X	X	X	X	
LA	X	X	-	-	-	-	-
ME	X		X	X	X	X	
MD	X		X	X	X	X	X
MA	X	X	X	X	X	X	
MI	X	X	X	X	X	X	
MN	X		-	-	-	-	-
MS	X	X	-	-	-	-	-
MO	X	X	X	X	X	X	
MT		X	X	X	X		
NE	X	X	X	X	X	X	X
NV	X	X	X	X	X	X	
NH	X	X	X	X	X	X	
NJ			X	X			
NM	X	X	X	X	X	X	
NY	X	X	X	X	X	X	
NC	X	X	X	X	X	X	X
ND		X	X	X	X	X	
OH	X	X	-	-	-	-	-
OK	X	X	-	-	-	-	-
OR	X	X	X	X	X		
PA	X	X	X	X	X	X	
RI	X	X	X	X	X	X	
SC	X	X	-	-	-	-	-
SD		X	-	-	-	-	-

State	Minimum Unsupervised Driving Age 15.5 - 16.5	No GDL 18+	Driver Record: Date of Learner	Driver Record: Date of Licensure	Driver Record: DOB	Driver Record: Sex	Driver Record: Race
TN	X	X	X	X	X	X	
TX	X	X	X	X	X	X	
UT	X	X	-	-	-	-	-
VT	X	X	X	X	X		
VA	X	X	X	X	X	X	
WA	X	X	X	X	X	X	
WV	X	X	X	X	X	X	
WI	X	X	X	X	X	X	
WY	X	X	X	X	X	X	

A State with an "X" in both of the first two columns is likely to have an appropriate GDL law to support a study. As can be seen in Table 2, there are 46 States with minimum ages for unsupervised driving between 15.5 and 16.5 years old. Among these, the current review found that 7 jurisdictions—the District of Columbia, Connecticut, Maryland, Minnesota, New Jersey, Maine, and California—will likely *not* be suitable for this study because they apply one or more GDL provisions to drivers 18 and older. Among the remaining 40 States, only three—Florida, Nebraska, and North Carolina—appear to have the necessary data on their driver record files based on the State licensing agency websites and secondary source data reviewed.

However, note that the number of States holding the desired data in their State licensing files may actually be larger than described in the table. The additional States may not report the information in the readily available sources that were searched for this plan. An inquiry to States with conducive GDL laws may uncover additional candidates for study. Also, as State licensing agencies update their data processing systems, more States may become candidates.

Finally, since the goal for the hypothetical study is to have a novice driver sample that approximates the United States as a whole and not a particular State or region, the study should be conducted in a location with sufficient racial and ethnic diversity to facilitate recruiting a sample with demographics similar to the novice driver population in the United States The racial and ethnic diversity of the study site will affect the length of time required to recruit sufficient numbers of participants with different sociodemographic characteristics.

Participant recruitment and intake

Sample Size Calculation

The hypothetical study will require sampling two groups: (1) younger novice drivers 15.5 to 16.5 years old from the outset of their independent driving (i.e., without the supervision of another licensed adult), with or without GDL restrictions; and (2) older novice drivers 18 to 20 years old who are not subject to GDL and also from the beginning of their independent driving. These groups of participants will also be divided into two data collection modes: (1) those using only a DAS application on their smartphone; and (2) those using both the smartphone DAS and more extensive vehicle-based DAS instrumentation. To determine the sample size of those using only the smartphone DAS, the research team assumed a mixed effect model with three covariates (e.g., sex: male/female; race-ethnicity: Latino, Black/not Latino, White/not Latino, Other race/not Latino; and household income/family affluence: 3 levels) and four repeated measures per participant (i.e., 12 months of data collection equivalent to 4 quarters), together with an expected intraclass correlation coefficient of 0.5.

Assuming the differences in outcome measures between sampling groups of younger and older novice drivers will be small (e.g., an effect size of 0.1), and that there will be equal numbers in each group, the minimum total number of participants needed per group would be 357 (Table 3), for a total of 714 participants. There are, however, factors inherent in this study that suggest the need to augment this sample size, particularly the "good driver" bias among teen participants who complete NDSs (i.e., the riskiest participants tend to withdraw from the study at faster and higher rates, Simons-Morton et al., 2020). Thus, the researchers who ultimately conduct this study should be conservative and assume a 40% attrition in the study after initial recruitment and secure 500 participants per group (a total of 1,000 participants) to help ensure a sufficient sample for analysis.

Table 3. Estimated samples sizes per group by effect size

	Effect Size (*d*)									
Power (1- β) = 0.80	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
*n**	357	187	130	102	85	74	66	60	56	52

*Table reflects the size of a single age group (*n*). Thus, the total number of participants in the study (*N*) is 2 times *n*.

The research team also conducted an additional analysis to determine the size of the subsample that uses both a smartphone and in-vehicle DAS. This analysis indicated that a subsample size of $n = 60$ participants in each age group (younger versus older novices) would be sufficient to detect two or three latent subgroups with effect sizes *d* of 0.36 and 0.23, respectively. Assuming a 40% attrition, a final sample of 84 participants out of the 500 in each age group (168 total) would be required for the subgroup with both smartphone and vehicle-based DASs.

Basic Sampling Criteria

To satisfy the needs of the hypothetical study, prospective participants must meet certain basic criteria, as follows.

- Possess a current, valid learner permit or the equivalent from the State where the study will be conducted
- Drive regularly (or plan to drive regularly after licensure)
- Scheduled to take their driving tests for licenses permitting independent driving
- Have access to one or more vehicles that have current automotive liability insurance with the legally mandated limits for the study State
- Possess, regularly carry, and intend to keep and use an Android or iOS smartphone Reside within a 2-hour drive of the study's research center or satellite location to facilitate periodic visits if needed and to support the in-vehicle DAS subsample

Ultimately, entry into the study will also require participants to pass the on-road driving test and thereby convert their learner permits or the equivalent to licenses that allow independent (unsupervised) driving. Immediately upon passing the on-road driving test, the research team for the hypothetical study can verify a match with the basic sampling criteria and a fit with one of the study quotas (see below), and the prospective participant can be offered enrollment in the study. Thus, novices will be recruited and screened as prospective study members contingent upon passing their on-road driving test and fulfilling a requirement of the remaining demographic sampling needs at the time they pass their driving test.

Data Collection Period

Potential participants who meet the basic sampling criteria will be invited to participate in the study at the partner State licensing agency offices at the time they schedule their on-road tests. While the period of independent driving is of primary interest to the current study, contact prior to this period is necessary to ensure data collection will include participants' first independent driving experiences. The study period will span the first 12 months of independent driving. As mentioned earlier, 12 months of independent driving is included not only to provide sufficient crash and violation experience but also to control for any possible seasonal effects on novice risk trajectory, such as those observed in prior studies showing increased teen driver crashes in summer relative to other seasons (e.g., Neyens et al., 2008).

Compensation

The compensation schedule presented in Table 4 (in 2022 dollars) should be considered for those drivers who apply for or qualify for the study and complete all study activities. The compensation amounts are similar to prior NDSs of young novice drivers (e.g., Ehsani et al., 2017; Simons-Morton et al., 2015), but scaled to adjust for a shorter duration of data collection and less intensive participant involvement relative to these studies.

Table 4. Hypothetical study compensation schedule by group

Installment	**Study Task**	**Smartphone Only**	**Smartphone + in-vehicle instrumentation**
1	Consent and screening	$25	$25
2	DAS installation and baseline questionnaire	$100.00	$200.00
3	6 months of independent driving	$100.00	$100.00
4	Final study questionnaire and other activities	$250.00	$350.00
TOTAL		**$475.00**	**$675.00**

As presented in the table, the subsample with both data collection systems will receive higher compensation due to the greater burden associated with instrumenting their vehicles and retrieving the equipment at the end of the study. All prospective participants will be paid a small stipend for completing the consent form and screening questionnaire. Since basic eligibility will be predetermined from the driver license records, almost everyone solicited should meet fundamental qualifications. Attrition, however, will come from refusals, road test failures, and sampling quota limits.

Once invited and accepted for either the smartphone only or smartphone plus in-vehicle DAS group, the total stipend will be divided so that participants receive part of the stipend after completing each study step (baseline questionnaire and DAS installation, each follow-up questionnaire/activity). This reinforces continuing participation. The level of compensation also considers the cost of extra smartphone data usage from trip data uploads when Wi-Fi is not available to a participant. The form of payment (e.g., check, electronic transfer, gift card) and the need to complete required tax forms would be determined at the time the study is conducted.

Demographic Sampling Criteria

In addition to the basic criteria for a participant to enter the study, the design includes matching the study sample as closely as possible to the novice driver population of the United States. The study design must therefore include a plan to quota sample participants to approximate the sex, race, and socioeconomic characteristics (e.g., family affluence) of U.S. novice drivers in the two sampling groups. To achieve this design, researchers should aim to set the sampling quotas based on nationally representative data on novice driver characteristics in a manner similar to what has been done previously (e.g., Tefft & Foss, 2019; Vaca et al., 2021a) but based upon the most recent available data. To illustrate such a process, Table 5 presents the target sample size for each demographic stratum based on the most recent and applicable available data (Vaca et al., 2021a).[3]

Table 5. Target sample sizes for hypothetical study by demographic stratum

	Smartphone only		Smartphone + in-vehicle instrumentation	
Demographic Stratum	**Younger novice *n* (%)**	**Older novice *n* (%)**	**Younger novice *n* (%)**	**Older novice *n* (%)**
Sex				
Male	241 (48%)	191 (38%)	40 (48%)	32 (38%)
Female	259 (52%)	309 (62%)	44 (52%)	52 (62%)
Race-ethnicity				
Latino	84 (17%)	169 (34%)	14 (17%)	28 (34%)
Black, not Latino	96 (19%)	159 (32%)	16 (19%)	27 (32%)
White, not Latino	300 (60%)	153 (31%)	50 (60%)	26 (31%)
Other race, not Latino	20 (4%)	19 (4%)	4 (4%)	3 (4%)
Family Affluence				
Low	100 (20%)	192 (38%)	17 (20%)	32 (38%)
Moderate	263 (53%)	225 (45%)	44 (53%)	38 (45%)
High	137 (27%)	83(17%)	23 (27%)	14 (17%)

The novice driver demographic characteristics presented in Table 5 appear to have been relatively stable since they were last examined (Tefft et al., 2013; Tefft & Foss, 2019). Ongoing work (e.g., Ehsani et al., 2021) can also be used to determine if stability continued through the time of initial drafting of this plan (July 2021) and beyond, and any possible influence of the COVID-19 pandemic on the demographic characteristics of novice drivers.

Sample Recruitment Locations

One design goal of the study should be to enroll all participants at essentially the same point in their driving careers. This goal can be accomplished by soliciting prospective participants at State licensing agency offices immediately after they have passed the on-road driving test (e.g., Thomas et al., 2016). For reasons of efficiency and cost-effectiveness, a study should target State licensing agency testing locations with high flow rates of younger and older novices applying for first-time driver licenses. In addition, the availability of sufficient space in the licensing agency

[3] The Vaca et al. (2021a) study presents the best data available on characteristics of the novice driver population in the United States, even though it only reports sample weights by sex, race-ethnicity, and family affluence for intermediate (1-2 year) and long (2+ year) delayed licensure groups. Still, based on the weights by these same variables for the total sample, the no-delay group appears to approximate the intermediate delayed group at least with respect to sex, race-ethnicity, and family affluence. Thus, the information for the intermediate delay group from Vaca et al. is a reasonable target for a study's younger novice group.

office to set up a study room or "booth" may be essential, and proximity to other high-flow-rate offices to allow for easier project management is also desirable. Per Thomas et al. (2016), the higher flow rate licensing agency offices in California achieved amounted to conducting licensing examinations for 10 to 50 novice drivers a day depending on the time of year. Offices of equivalent size in other States may be expected to have similar test rates. Approximately a third of those tested (e.g., 3 to 17 in the California example) would be expected to be older novices (Vaca et al., 2021). When contemplating sampling at State licensing agency test locations, the fact that some percentage of new drivers fail the on-road test must also be considered. Taking all factors into consideration, by selecting State licensing agency offices with the highest testing rates, researchers can plan for a range from 5 to 25 fully eligible potential participants per recruiting day, with 1 to 8 of these potential participants being older novices and the balance being younger novices.

When estimating the time it will take to recruit a total sample of approximately 1,000 participants, it is also necessary to consider the participation rate of those solicited. Thomas et al. (2016) achieved a participation rate of 78% in State licensing agency offices with a novice driver population but for a study commitment of only 20 to 30 minutes at the licensing office immediately after passing the on-road driving test. Moreover, the Thomas et al. (2016) study did not quota sample, which will slow recruiting because it lowers the eligibility rate of novice drivers who pass their on-road driving test as various sampling strata become filled.

Based on the above considerations, it is estimated that a high-volume State licensing agency office would likely yield 3 to 18 participants (1 to 6 older novices) per day if the project started during the summer, when the highest numbers of novices tend to apply for first-time licenses. Given the target sample size of 500 younger and 500 older novices, researchers should plan for 83 to 500 office days to complete the recruitment of the sample for the hypothetical study. The actual calendar days to achieve the 83 to 500 office days could be reduced if participants were recruited at several field offices simultaneously. For example, Thomas et al. (2016) recruited teen novice drivers at six field offices. With the participation of an equivalent number of field offices and the maximum estimate of 500 office days, total time for recruitment for the hypothetical study would span 83 calendar days. While this may seem like many days, the data collection period for each participant is independent and begins immediately upon acceptance into the study. Thus, the participants recruited on the first day will already have completed a large percentage of the total data collection period by the time the last participants are recruited.

Material development and data collection

Conducting the study requires developing various forms and data collection aids. Researchers must also identify and establish mechanisms for acquiring existing data from the State licensing agency's driver license file. The driver license file of the partner State licensing agency will be an important cornerstone of the project. It will provide the research team access to the necessary driver information (i.e., license status, sex, race, and ethnicity) to screen prospective participants. It will then be used at the end of the data collection period for each driver to determine the incidence of crash and violation events during the entire study period, particularly during the first year of licensure after passing the driving test (in addition to the data collected via naturalistic methods).

If the State licensing agency offices used for recruitment have a significant number of prospective participants who have primary languages other than English, the research team may need to include translations of the various forms and data collections aids, including the study questionnaire, in one or more alternative languages to avoid biasing the sample by excluding prospective participants who cannot complete the screening questionnaire in English. Study staff on site at the licensing agency offices would also need to speak the alternative language.

To date, no study has examined national estimates of U.S. non-English-speaking novice drivers. However, a prior study estimated that about 34% of novices who delayed obtaining licenses (i.e., waited more than 2 years after the State minimum licensing age) reported Latino ethnicity (Vaca et al., 2021a), and a proportion of U.S. residents of Hispanic/Latino ethnicity report that English is spoken "less than very well" at their homes (Flores et al., 2015). Thus, in the hypothetical study, the development of Spanish study material and presence of Spanish-speaking study staff may be critical for recruiting a study sample that is representative of the older novice driver population. Additionally, if a potential participant speaks a language other than English or Spanish, the research team should take steps to ensure meaningful access to participate in the study, e.g., providing a language interpreter and translating study material into that language.

Screening Questionnaire

In the study, prospective participants will be interviewed by study recruiting staff (which might include people from the partner State licensing agency) to confirm eligibility for both the smartphone and in-vehicle DAS groups, determine willingness to volunteer, and to collect screening data not maintained in the driver license file. Screening items for socioeconomic factors and, possibly, some additional demographics that are required to quota sample participants to match the U.S. novice driver population may be needed because these items are typically not available in State driver license files. The screening questionnaire will be administered once to novice drivers scheduling their on-road tests who meet the initial study criteria based on the data available in the State license agency file. (See Draft Questionnaires for more information about screening questions.)

Study Questionnaires

The study's questionnaires are intended to be web-based, using a secure survey platform, and self-administered using the participant's smartphone, since having and using a smartphone will be a requirement of participation. The study questionnaire will be administered three times during the data collection period: upon acceptance into the study and participant consent to take part, at the midpoint of the 12-month study period (i.e., at 6 months), and at its end. While the driver record will likely provide access to information about driving behavior such as police-reported crashes and violations, also including these topics in the questionnaire can provide more timely access to this information for interim results compared to waiting for the information to become available on the driver's record. The study questionnaire should be available in whatever languages were necessary to collect the full set of screening questionnaires. The language choice of each participant for every administration of both questionnaires should be recorded. (See Draft Questionnaires for more information about the study questionnaires.)

It should also be noted that additional research may be published by the time this study is implemented that could suggest adding or deleting questions from the questionnaire. Also, the cooperating State licensing agency may wish to include a few questions of interest to its operations as part of its agreement to participate. Even so, study staff should aim to keep the time it takes to complete the study questionnaire to 30 minutes or less. Pilot testing by study staff will confirm precise timing. Pending results of pilot testing, abbreviated versions of scales could be used or created to shorten the questionnaire.

Informed Assent/Consent Form

The study will include detailed assent and consent forms. Assent by a parent or guardian will be necessary for all participants who are less than the legal age of consent in the study State. All participants will have an opportunity to review these forms prior to the assent/consent session. All participants will be required to sign the forms physically or electronically upon scheduling the on-road test. This session can be accomplished remotely via a web-conference software or entirely over phone/email. In the rare instance that a parent/guardian of a prospective participant younger than the legal age of consent is not available, contact information for the parent/guardian will be obtained from the prospective participant, and an attempt will be made to schedule a follow-up session to obtain assent from the parent/guardian. All copies of assent and consent forms will be held in a secure location at the research team offices. A copy of the signed form will be made available to the participant and legal guardian (as appropriate).

Participant Identification System

Each novice driver will be assigned a study-unique participant ID code. All participant data will only be associated with this code. At time of assent/consent, a picture of each participant in the in-vehicle DAS-equipped subsample will be collected for comparison with video of each trip to make sure the enrolled driver is the person driving for a given trip. For all participants regardless of DAS type, all PII will be stored on the research team's secure servers with role-based access.

Vehicle-Based DAS

A subset of participants will have the DAS installed in their vehicles. An attempt should be made to limit this subset to those that have stable access to a vehicle expected to survive mechanically for at least 12 months and residing within a 2-hour drive of the research center or satellite location.[4] Additionally, some drivers with disabilities have adaptive technologies or equipment installed in their personal vehicles. If any participants in the hypothetical study have such equipment, the research team will need to determine whether the equipment is compatible with the vehicle-based DAS before the participants can be assigned to the vehicle-based DAS subgroup. Overall, researchers should make sure that the participant subset with vehicle-based DAS is as similar to the balance of participants as possible. However, since access to the same vehicle and residence location may be correlated with socioeconomic or demographic variables, the subgroup criteria may have to be altered in order to recruit a sufficient number of participants. Ultimately, ensuring the subgroup closely matches the full sample on demographic characteristics is of utmost importance. One criterion to consider relaxing is increasing the distance criteria beyond a 2-hour drive from the research or satellite location.

The DAS will be installed and removed at the research center or a satellite location where researchers have access to any needed installation resources. At the time of this plan design, the

[4] It can be expected that across the subsample of participants, one or more of the participant vehicles will be taken out of service during the data collection period due to crashes, mechanical problem, or voluntary replacement. The study should develop a specific protocol for either expeditiously transferring the equipment to an alternate vehicle to be used by the participant or for removing the participant from the study while making whatever use is possible of the data collected up to the point the participant and vehicle were no longer available.

concept for the vehicle-based DAS includes at least three cameras, an accelerometer, a gyroscope, and a GPS system. Table 6 contains a brief description of the principal DAS components. The main unit of the DAS, which houses the data storage drive and data processing components, is installed using automotive grade fixtures and material to ensure that it remains securely in place. At a minimum, cameras should be placed to allow for views of activities inside the vehicle cabin, activities outside the vehicle, and the instrument cluster. If additional cameras are possible, views of the rear roadway, driver's eyes, and pedal area can also be added. At the completion of the study, the vehicle instrumentation is removed from a participant's vehicle at the research center or satellite location. Note that vehicle-based DAS designs are continually evolving, and storage capacity and the ability to upload data cost effectively in real time may improve. Also, it may be possible to package the entire DAS in a plug that fits in the OBD II port and acquires both data and power from it.

Table 6. Potential components for DAS used in hypothetical study

Components	In-Vehicle DAS	Smartphone DAS
Cameras	Forward roadway Instrument cluster Driver/cabin (rearward view of the entire cabin)	Not available
Global Positioning System (GPS)	Recording position at 10 Hz	Recording position at 10 Hz
Inertial Measurement Unit (IMU)	Acceleration in 6D (x, y, & z; and yaw, pitch, and roll) at 10Hz	Acceleration in 6D (x, y, & z; and yaw, pitch, and roll) at 10Hz
Data storage	2.5" Solid-state drive (typically 1 TB)	Varies according to participant's device
Data encryption	Drive level	Drive level

Smartphone DAS Software Application

The DAS used by all participants (including the subgroup that will also use the vehicle-based DAS) will be smartphone-based. At present, two versions (iOS and Android) would be needed to accommodate the two operating systems that cover virtually the entire installed base of smartphones. If a third operating system emerges and gains traction, it will have to be considered for inclusion to avoid introducing a potential bias into the study population.

Participants in the study will download software onto their personal smartphones that will serve as a DAS and measure driving behavior. A study team member will provide the participants with detailed instructions on downloading and using the software. To restrict the use of the app to those eligible to participate in the study, a team member will provide the participants with a unique username and password generated at the time of enrollment. Signing into the software will link the phone to the participant's study profile so the participant's progress can be tracked over the duration of the study. Once logged in, the user will remain logged into the software to streamline access and improve study retention. If possible, the application could be written to prevent the user from logging out or "force closing" it and to restart it automatically on a smartphone reboot or operating system update. Additionally, if possible, the research team will check at regular intervals during the data collection period to ensure that the smartphone is still actively collecting data. A code can be provided to the researcher to remove the app at the request of the participant at the end of the study or in the event of withdrawal.

Participants will be instructed to contact research staff when they switch phones. When phones of the same manufacturer are upgraded, all apps typically transfer to the new phone. Research staff will also continually monitor incoming data to identify participants who are no longer providing data to identify those who stop using the app, are no longer driving, or have switched phones without transferring the app. These participants will be contacted to determine their status. If they have not dropped out of the study, they will be instructed to redownload the software and log-in to the app as necessary. Data is likely to be comparable across phone types and models as well as operating systems.

Smartphone software can operate in the background of the participant's phone and will measure driving performance on every trip. If possible, the smartphone software will automatically begin recording at the beginning of a trip, and stop recording at the end of the trip, without needing to be turned on or off. Algorithms applied to the data later by the research team may be able to distinguish between travel mode (e.g., Servizi et al., 2021) and whether the participant is a driver or passenger (see Wahlström et al., 2017, for a review). At the end of the trip or when connected to Wi-Fi, data will automatically be uploaded to a study server by the application. The research team will need to consider and address whether data uploads that use cellular data (e.g., if Wi-Fi is not available) will affect the burden on participants and/or study attrition rates.

DAS Measures

Table 7 contains the classes of relevant outcome measures and their output forms produced by the vehicle-based and smartphone instrumentation approaches.

Table 7. DAS outcome measures for hypothetical study

	DAS Type	
Outcome Measures	**Smartphone software**	**In-vehicle DAS**
Safety events	Crash, KRD	Crash, near-crash, KRD
Geolocation	Road type during trip, trip duration, trip time of day	Road type during trip, trip duration, trip time of day
Driving performance	Speed	Speed, headway, lane deviations
Behaviors	Cellphone (handheld versus fixed) use	Passenger presence, secondary tasks engagement, seatbelt use
Driving exposure	Weather during trip, posted speed during trip, familiarity of current route, complexity of driving environment	Weather during trip, posted speed during trip, familiarity of current route, complexity of driving environment

Geolocation variables, such as road type, could be estimated or determined via the smartphone software using two sources of information. As an estimation, data such as the average vehicle speed and number of stops could be used as a proxy measure for road type. For a more precise determination, the GPS data collected from the smartphone and vehicle instrumentation can be merged with a roadway information database (e.g., OpenStreetMaps) to determine the road type for each road segment. The latter approach, although implementable totally by software, involves additional effort but is likely to be more accurate. The in-vehicle DAS subgroup will collect video that can also define road type and the like and support validation of road type measures from the smartphone calculations.

As shown in Table 7, the use of handheld devices will be detectable using the smartphone software. Smartphone operating systems (Android and iOS) deny access to information about which apps are running in the background (i.e., passive use). However, the gyroscope and accelerometer of a smartphone can determine whether the device is being held in a hand or if it is fixed (i.e., in a cellphone holder or cup holder). Algorithms have been developed using the accelerometer data that can reliably distinguish handheld smartphone use from when a device is fixed (Susi et al., 2013).

Driving exposure information, such as the driver's familiarity with the current route, can also be determined by the smartphone software. If a participant has (or has not) made two or more trips that begin and end in the same location, have the same trip length, and have a similar GPS footprint (e.g., within 0.1 mi to allow for different lane and parking options at destinations), a route can be considered as being a familiar or unfamiliar to the driver. Familiarity is relevant because trips on unfamiliar roadways are associated with an elevated crash risk (Ehsani and Tefft, 2021).

Other exposure information, such as the complexity of the driving environment, can be characterized by a combination of different aspects, including daylight conditions, weather or visibility conditions, and the roadway environment conditions that the drivers may experience during a single trip. In terms of daylight conditions, a trip can be classified based on the time of day and sunrise/sunset times on the date of the trip. Weather conditions or visibility can be calculated using hourly visibility data from the National Oceanic and Atmospheric Administration or from a weather app on the smartphone. The visibility data can account for various weather conditions, such as rain, fog, and snow. Distances from the origin/end point of routes to local weather stations can be identified and visibility data from the nearest station can be linked to the individual trip. The light and visibility data can be combined to form a complexity variable for a trip. If the trip is occurring on an unfamiliar route (defined earlier) this can be added as an additional factor (e.g., by multiplying the complexity score by 2).

Tasks and Procedures

After participants have completed the assent/consent process and have been enrolled, they will be assigned a study ID number. The participant will then be randomly assigned to either the smartphone-only group or the in-vehicle DAS plus smartphone subgroup on a proportional basis so that the relative group membership (e.g., 10% in the DAS subgroup) remains approximately constant throughout the data collection period. Participants in the in-vehicle DAS subsample will have a full-face photograph taken.

One critical piece of information that will be collected for all participants is their driver license numbers as assigned by the State licensing agency. Each number will be the link between the study and the licensing agency records. It will permit the licensing agency to notify the research team when an enrolled participant schedules their road test, which, if passed, will permit the person to begin independent driving. It will also permit the licensing agency to identify the volunteers as participants when they pass their road tests and to retrieve driver records on them at a fixed time after they have completed a year of independent driving. The timing of the record access will depend on the State licensing agency data update rate. It is important to allow sufficient time for the driver record files to "mature" before data are accessed to avoid bias from records, particularly of more serious offenses, that are delayed in the adjudication system.

If there is a concern about the researchers having access to participant driver license numbers because they are PII, all interchange between the project and the State licensing agency can be accomplished using only the study number. The licensing agency would maintain a correspondence list between driver license number and study ID and thereby retain all PII in its files.

Volunteer Enrollment and DAS Installation and Initiation

Volunteers will be identified as prospective participants upon scheduling the on-road tests. Upon passing the on-road tests, participants will be eligible to be enrolled in the study if they consent and receive the data collection equipment (smartphone or smartphone plus in-vehicle DAS) appropriate to their group assignment. These participants will also be given other study-related instructions such as a request to notify the project immediately if they plan to sell or replace their car or drop out of the study so that the DAS can be removed and transferred as warranted.

When the research project is notified of an on-road test appointment of a prospective participant, a researcher will be assigned to monitor the test outcome. Upon passing the on-road tests, the researcher should notify the interested people that they are officially fully qualified, obtain consent, assign them to a data collection group, install the smartphone app (or arrange for it to be installed if their smartphones are not present). The researcher will also guide them on how to take the baseline questionnaires on their smartphones as soon as possible. If a prospective participant fails the on-road test, the person will be returned to the pool of possible participants and tracked to determine if the person reschedules the road test. Since these participants have already completed the screening questionnaires, they do not have to be contacted again until they pass the on-road tests and then only if their demographic strata still have openings.

Data Offload

All data from the in-vehicle DAS will be recorded on an encrypted data drive. Since solid-state drives (SSDs) are more robust than mechanical units, have come down significantly in price, and are likely to continue to decline in price per unit of storage, SSDs are the most likely choice for on-board storage. The DAS data drives will be retrieved from vehicles and downloaded to a secure server periodically during the study depending on a schedule to be developed based on storage capacity and record size. If extremely large drives are cost-effective, it may be possible to offload data only once or twice over the course of the data collection period. If the data are retained in the vehicle for long periods, redundant drives should be considered to avoid losing participant data due to disk failure. It may also be possible to offload DAS data via Wi-Fi as is currently done by the telematic systems in many cars.

Data from the smartphone DAS will be stored on the participant’s device and will be offloaded at least daily to a remote encrypted data drive either as soon as the participant has a Wi-Fi connection or overnight via cellular data service if no Wi-Fi connection is available. Individual trip files are expected to be approximately several hundred kilobytes each. All DAS data will be processed, coded, and stored by study ID.

Unusual Events

Each participant will be instructed to contact the research team in the event the person is involved in a crash, encounters any difficulties with the vehicle, changes smartphones, or if the person notices any maintenance issues with either DAS system (e.g., a wire comes loose and dangles). Participants should also be instructed to seek emergency help the way they normally would if they are involved in crashes or have medical events while driving. They must be cautioned that the study and its data collection are secondary to safe driving and the normal duties of drivers on the highway.

Data management and security

All data will be encrypted as they are stored on the in-vehicle DAS data drive and potentially on the smartphones as well. Upon uploading, the data will be stored with association to participant ID on secure computers/servers with role-based access. Only research staff with a need will have access to these data and be given the decryption key. Screening and other survey data will be stored separately by the same participant ID codes. Kinematic and video data will be stored on the research team's servers for access during coding efforts. All processed and coded naturalistic driving data will be stored in a separate analysis file, and in no instance will any study coders have access to any PII. Information and/or data files will be merged by participant ID as needed for analysis purposes. Government sponsors may require the ability to receive de-identified data analysis files at the end of the study.

Data quality control, processing, and analysis

Each DAS collects an array of raw data that can be translated or transformed into many variables suitable for safety and mobility-related analyses. The processing of trip files after transfer from the data drives will include checks to confirm the integrity of all video (in-vehicle DAS only) and sensor data (smartphone and in-vehicle DAS). For the subsample with the instrumented vehicle DAS, researchers will follow a driver identification protocol using the picture provided during the consent process on all trip files to confirm the driver was a consented participant since the in-vehicle DAS will collect data on any trip regardless of who is driving. Trip files collected by the in-vehicle DAS when a non-participant was driving will not be analyzed. These same trips will also be deleted from the smartphone DAS for the dual-DAS participants.

For the smartphone-only group, driver/passenger status could be estimated using participants' prior trips including the reference to locality of the previous routes that have been driven, similarity of the previous routes, variations in time of day or day of week compared to previous trips, and hand-held phone use during the trip. These passenger classification algorithms could be compared directly for the dual-DAS participants and the degree of accuracy of the classification algorithm could be determined and, if possible, improved. Clearly, if accuracy is poor when no video is available, this data screening will have to be omitted.

Variable mapping will prepare files with integrated video and time series data for further analysis. Standard algorithms based on those developed as part of prior NDSs will be applied to the resulting dataset to identify possible safety-critical events, which will be verified in the dual-DAS subsample via visual inspection of the associated video files.

A smartphone DAS user guide will be placed on a project web page and referenced in the smartphone app. The smartphone app will also contain a feature so participants can contact the research staff by phone, email, and text. This should reduce errors due to uncertainties during operation. Quality control protocols will also be put in place to ensure the data collection methods for both the questionnaires and the DASs are functioning correctly. For the smartphone app, software will be used for the following.

- Verify that the contact information for participants is formatted correctly (e.g., a valid email address with correct structure and characters) and simplify the process of updating the data by a participant.
- Send automatic reminders if participants do not complete the questionnaires within a certain amount of time (e.g., 45 days) using a Dillman protocol (Dillman et al., 2014) , a framework for improving the quantity and quality of survey responses. Based on the completion status, the software system will automatically initiate a follow-up email or other reminder.
- Generate automatic reminders for incomplete surveys.
- Identify participants who are at risk of being lost to the study so research assistants can follow up to decrease survey incompletion.
- Implement a communication tracking system so any authorized study staff members can see the previous contacts and concerns expressed by participants when conducting follow-up calls.
- Enable coding of participants so if their status changes to "Lost to Follow-Up" or "Withdrawn," surveys will be discontinued.
- Calculate scores for participants' responses to survey scales with predetermined scoring keys.
- Count the number of trips recorded by each participant's DAS (before any exclusion resulting from the checking described above).
- Maintain a unique login credential for the smartphone app for each participant.
- Confirm that the smartphone app is downloaded on each participant's phone and functioning correctly. This will require the user to complete a controlled test drive to verify the app is downloaded and operating on the participant's smartphone.
- Perform weekly data checks of trips to assess data quality and ensure minimal possible data loss using automated algorithms.

A combination of automated and manual data reduction will be used to create the measures shown earlier in Table 7. A first step in analyzing the resulting data will be to examine descriptive statistics for all naturalistic driving time periods of interest. After reviewing the frequencies and distributions for the measures of interest, statisticians will follow the data analysis approach in Table 8.

Table 8. Data analysis approaches for the hypothetical study

Research Question	Hypotheses	Data (Source)	Analysis
After beginning to drive independently, do most novice drivers exhibit the pattern of initially high but decreasing rates of risky driving? Or do some groups of novice drivers follow different trajectories—e.g., consistently high or low rates of risky driving?	In aggregate across all novices, these drivers will exhibit a pattern of initially high but decreasing rates of risky driving, but some subgroups will follow different trajectories.	- DV: Crash, kinematic risky driving event rates (DAS) - Covariates: Race-ethnicity, sex, age of licensure (driver record) family affluence, changes over time in characteristics/attitudes/beliefs (survey)	Latent Class Growth Analyses (LCGA) using Growth Mixture Modeling (GMM) to identify trajectories and Mixed-Effects Generalized Linear Models with nested random effects of subject and time from licensure to study the association with the covariates.
Do novice drivers who consistently engage in, or consistently refrain from, risky driving during the first 12 months of independent driving differ from each other, or from other novices, in the amount, type, or patterns of driving they do during this period?	Novice drivers who consistently engage in or refrain from risky driving will significantly differ in, geolocation, driving behavior, and exposure variables listed in Table 7.	- DV: Geolocation, driving behavior, and exposure variables (DAS) (see Table 7) - IV: Novice driver subgroups that emerge from group-based trajectory analysis above	- Mixed-Effects Generalized Linear Models with nested random effects of subject and time from licensure.
Do novice drivers who consistently engage in, or consistently refrain from, risky driving during the first 12 months of independent driving differ with respect to demographic, psychological, or other characteristics associated with risky driving?	Novice drivers who consistently engage in or refrain from risk driving will significantly differ in demographic, psychological, attitudes and beliefs, lifestyle, driving, and health status characteristics listed in Table 10 and Table 11.	- DV: Demographic, psychological, attitudes and beliefs, lifestyle, driving behavior, and health status characteristics (survey) - IV: Novice driver subgroups that emerge from group-based trajectory analysis above	Reliability analysis using Cronbach's alpha or Omega coefficient – depending on the responses, followed by ANOVA, Ordinal regression, or K-means Cluster analysis depending on the question type.

Research Question	Hypotheses	Data (Source)	Analysis
Do older novices exhibit different trajectories of risky driving in the first 12 months of independent driving than those observed among younger novices?	Both older and younger novices will experience relatively high initial crash rates or KRD events, but the declines in these events will be slower for older novices than for younger ones.	- DV: Crash, kinematic risking driving event rates (DAS) - IV: Age of licensure (driver record)	Latent Class Growth Analyses (LCGA) using Growth Mixture Modeling (GMM) to identify trajectories. Mixed-Effects Generalized Linear Models with nested random effects of subject and time from licensure as well as Spline Mixed-effect to compart the dynamics of trajectories.
Do older novice drivers differ from younger novices in the amount, type, or patterns of driving they do during the first 12 months of independent driving?	Older novices will differ from younger novices in the geolocation, driving behavior, and exposure variables listed in Table 7.	- DV: Geolocation, driving behavior, and exposure variables (DAS) - IV: Age of licensure (driver record)	Mixed-Effects Generalized Linear Models with nested random effects of subject and time from licensure.
Do older novices differ from younger novices with respect to demographic, psychological, or other individual characteristics associated with risky driving?	Older novices will significantly differ from younger novices in demographic, psychological, attitudes and beliefs, lifestyle, driving, and health status characteristics listed in Table 10 and Table 11.	- DV: Demographic, psychological, attitudes and beliefs, lifestyle, driving behavior, and health status characteristics (survey) - IV: Age of licensure (driver record)	Reliability analysis using Cronbach's alpha or Omega coefficient – depending on the responses, followed by ANOVA, Ordinal regression, or K-means Cluster analysis depending on the question type.
What is the level of agreement between the smartphone and instrumented vehicle DAS for driving exposure, risky driving behavior and crashes?	Consistent with Freidlin et al. (2018), the correlation between the driving behaviors between the smartphone app and the DAS will be high.	- DV: Crash, kinematic risking driving event rates, geolocation, driving behavior, and exposure variables (DAS) - IV: DAS type	Pearson correlations and Bland-Altman plots, depending on the level of analysis.
Note. DV = dependent variable; IV = independent variable.			

The analysis approaches detailed in Table 8 will broadly proceed in three steps. First, one or more rates of risky or unsafe driving (e.g., KRD events) at the finest-grain timescale that is feasible (e.g., daily or weekly) will be calculated for each participant for the entire study period. Second, group-based latent trajectory analysis[5] will determine the number of subgroups that best represent the individual-level heterogeneity of trajectories for each measure of risky driving behavior across all novice drivers at aggregate, as well as within each age group (younger and older novices). The third step of the analyses will examine whether the latent subgroups identified previously (all novices aggregated or by age group) differ in other driving behaviors and exposure, such as the amount of driving, trip durations, the proportion of driving done at night, and the proportion of driving on high-speed roads. The analyses will also investigate whether these subgroups differ with respect to demographic, personality characteristics, attitudes, and beliefs about traffic safety, or other self-reported information.

Additional Items

To conduct the study, some additional resources must be available before the commencement of data collection.

Questionnaires

This project developed draft questionnaires, which are described later in this report (see Draft Questionnaires). When available for relevant topics, the questionnaires use validated scales. Ultimately, the research team will not only need to finalize the draft versions of these questionnaires but also create a web-based administration format that is compatible with iOS and Android smartphones (or whatever other devices are widely in use at the time). This step requires OMB approval of an ICR package before the questions can be used. If an implementation of the study determines translations of questions into languages other than English are required, these translations would have to be accomplished prior to submitting material to IRB or ICR review and, if necessary, be adjusted to obtain approvals.

Recruitment material

Recruitment flyers and invitations to participate in the study will be necessary to recruit the desired sample. These materials will also be needed as part of the IRB and ICR material. The current project developed a draft of these material. However, modifications to the basic material will likely be needed as a function of the study site and potential changes in requirements for use of human subjects. As a cooperating State licensing agency would be involved in the hypothetical study, final flyers should likely include this State licensing agency's logo to assure potential participants of the project's authenticity.

Scripts for participant check-ins

Emails, phone, or digital check-ins with potential or actual study participants will be necessary as part of the screening and data collection process. Scripts and checklists for these encounters will

[5] A group-based latent trajectory analysis is a longitudinal analysis technique that groups people by changes in an outcome over time without assuming that participants are drawn from distinct subpopulations (Nagin, 2005). The approach can be used with the hypothetical study's data in a manner similar to that employed by Missikpode et al. (2019).

also be needed as part of the IRB and ICR material. The current project developed drafts of these scripts.

IRB material for human subjects' protections

As the hypothetical study involves the collection of human subjects' data, approval from an IRB will be needed before data collection commences to verify protection of the rights and welfare of these subjects. This project prepared an IRB protocol that describes the hypothetical study and data protections. The IRB protocol is consistent with that for a certified IRB that is currently registered and covered by an approved assurance of compliance under the Department of Health and Human Services, Office for Human Research Protections. Although the IRB material is comprehensive, it will facilitate the IRB review process if an IRB were selected that is familiar with previous NDSs, particularly those involving a smartphone DAS. All consent forms, questionnaires, scripts, and recruiting material are included in the IRB package developed in the current project. The compatibility of the package developed for this project should be verified as part of an actual study implementation.

Information collection request material for submission to OMB

The study requires OMB clearance because it meets the definition of an information collection under the Paperwork Reduction Act. The current project prepared draft ICR material describing the study for submission to OMB to comply with the PRA (https://pra.digital.gov/). Researchers should anticipate that OMB clearance may take a year or more. As with the IRB material, any PRA clearance sought for the study would need to meet and follow all OMB submission requirements.

Draft Questionnaires

In the study the researchers will ask potential and enrolled participants questions at various timepoints during the first year of independent driving. First, researchers will ask potential participants to complete screening questions (in a format that depends on the study site, e.g., by telephone, in person, or online). Researchers will append participants' responses to screening questions with information from the partner State's licensing agency files to determine eligibility. Once enrolled, participants will also complete questionnaires on various topics at the beginning of the study and at 6 and 12 months after licensure.

Screening Questionnaire

Table 9 shows the questions that will be asked of potential participants in the study to determine eligibility. Figure 1 shows the process by which the research team will determine if a potential participant is eligible and to which experimental group a participant will be assigned.

Table 9. Screening questions administered to potential participants

Topic/Scale	**Number of Questions**
Questions to determine eligibility	
Planned number of driving days per week	1
Proof of current automobile liability insurance meeting State minimums	1
Use, regularly carry, and intend to keep using a smartphone for next 12 months	1
Android or iOS operating system on phone	1
Questions to determine group assignment (smartphone only versus smartphone + vehicle DAS)	
Plan to drive in one vehicle	1
Vehicle age less than 20 years	1
Can drive to research office in < 2 hours	1
Presence of adaptive technologies or equipment in vehicle	1
Questions used for quota sampling	
Family Affluence Scale (Currie et al., 2008)	4

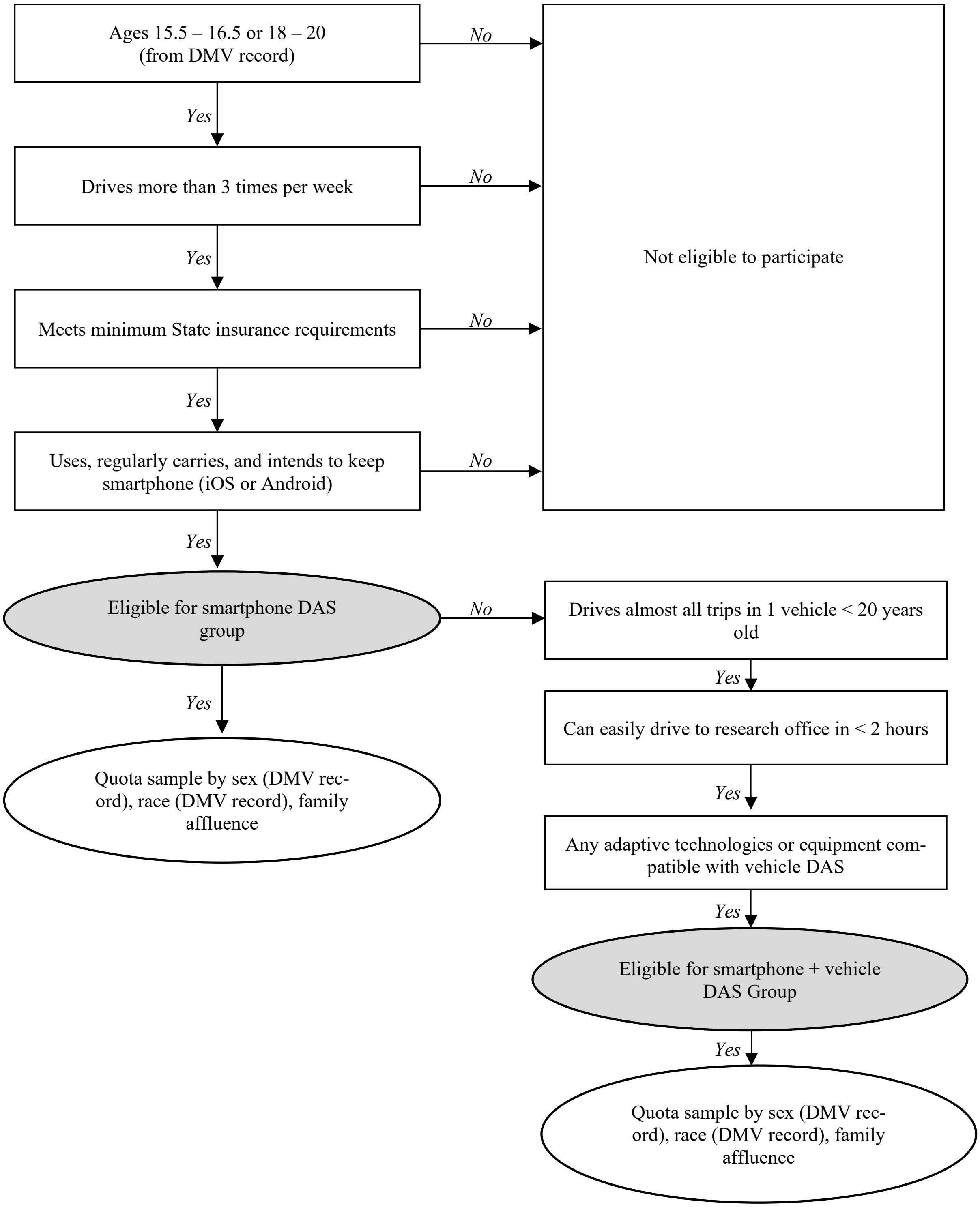

Figure 1. Process for determining participant eligibility in hypothetical study

Baseline Questionnaire

At the beginning of the study enrolled participants will complete a questionnaire on a variety of topics that prior research suggests are predictive of risky driving (see Literature Review), like personality measures, attitudes about traffic safety, and parental involvement. This survey will be electronic and delivered on a computer or smartphone. Some of the items included in this questionnaire are from previously validated measures; these measures will be scored using the validated metric (e.g., sum of item scores, average of scores) created as part of their development or prior implementation. All responses can also be analyzed by individual item. Table 10 shows an overview of the potential contents of the baseline questionnaire.

Table 10. Questions administered to participants at beginning of study (baseline)

Topic/Scale	# of Questions in Scale
NEO-Five Factor Inventory (McCrae & Costa, 2004) (neuroticism, extraversion, openness, agreeableness, conscientiousness)	60
Brief Sensation Seeking [sic] Scale (Hoyle et al., 2002)	8
Revised Sense of Purpose Scale (SOPS-2; Sharma & Yukhymenko-Lescroart, 2019)	14
Parent Trust and Knowledge Scale (Kerr et al., 1999)	14
Friends' risky behaviors (Simons-Morton et al., 2006)	13
Attitudes towards traffic safety (Iversen & Rundmo, 2004)	16
Support for supervised driving requirement	2
Pre-permit/pre-license driving experience (Ehsani et al., 2017b)	8
Driver education resources	1
Number of attempts at written/driving test	2
Driving Behavior Questionnaire (DBQ; Reimer et al., 2005)	24
Number of violations/tickets during learner's/pre-license period	2
Number of crashes during learner's/pre-license period	1
Reasons for delayed licensure (only if 18 to 20 years old)	1
Vehicle ownership	1
Vehicle type	2
Vehicle access	2
Access to alternative transportation	1
Social media use (Anderson & Jiang, 2018)	1
Family structure (Conway et al., 2013)	4
Educational attainment	2
Marital status	1
Employment status	1
School enrollment status	1
Urbanicity	1

Topic/Scale	# of Questions in Scale
Sleep quality (Snyder et al., 2018)	1
Health status	2
Race	2
Ethnicity	1
Sex	1

Follow-up Questionnaires

At 6 months into the duration of the data collection for each participant, each participant will complete a follow-up questionnaire on a variety of topics that prior research suggests are predictive of risky driving (see Literature Review) and may change with increasing driving experience (e.g., attitudes about traffic safety) or time (e.g., vehicle access, sleep quality). The follow-up questionnaires also ask participants to report any crashes or violations/tickets that have occurred within the past 6 months. Participants will complete the same follow-up questionnaire again at the end of data collection at 12 months. These follow-up questionnaires will be electronic and delivered on a computer or smartphone. Some of the items included in this questionnaire are from previously validated measures; these measures will be scored using the validated metric (e.g., sum of item scores, average of scores) created as part of their development or prior implementation. All responses can also be analyzed by individual item. Table 11 shows an overview of the potential contents of the follow-up questionnaires.

Table 11. Questions administered to participants after 6 and 12 months of data collection

Topic/Scale	# of Questions in Scale
Attitudes towards traffic safety (Iversen & Rundmo, 2004)	16
Driving Behavior Questionnaire (DBQ; Reimer et al., 2005)	24
Number of violations/tickets	2
Number of crashes	1
Vehicle access	2
Sleep quality (Snyder et al., 2018)	1
Health status	2

Assessment of Potential Challenges

The research team identified potential challenges associated with executing the hypothetical NDS described in previous sections. For this assessment, the research team first enumerated the key factors affecting the success of the hypothetical study.

- Site selection
- Site cooperation
- DAS selection
- Representativeness of sample
- Availability of sample
- Retention of sample
- Verification of sample
- Validity of DAS results from smartphones
- Changes in roadway and in-vehicle environment
- External events that impact driving behavior (e.g., COVID-19 pandemic)
- Maintaining data flow and integrity

For each key factor, the research team then enumerated specific technical or cost risks that threaten successful execution. The research team also documented the likelihood of each risk manifesting and recommended solutions. The resulting assessment is presented in Table 12.

Table 12. Potential challenges for conducting the hypothetical study

Challenge	Risks	Likelihood	Solutions
Site selection	All (or most) States adopt GDL restrictions for newly licensed drivers 18+ years old.	Moderate – Legislation is pending in some States already and may be more 5 or more years from now.	Change site selection criteria.
Site participation	- No State licensing agency wants to participate - Cooperating agency does cannot deliver what is promised.	Moderate – It is possible that no State licensing agency will want to participate given the effort involved with facilitating recruitment and providing driver records data at several timepoints. It is also possible that not all planned measures from the driver record will be available.	- Use community-based recruitment approaches (e.g., advertisements/flyers) to reach novices. - Shift screening measures that were originally planned to be obtained from driver record to be obtained from the survey. - Ensure discussions with prospective study sites prior to IRB/OMB submission confirm which variables the study team can obtain from driver records versus which ones will need to be obtained via the surveys.
DAS selection	A smartphone DAS that captures all measures of interest may not be commercially available.	Low – A number of apps are already commercially available and would likely work for purposes of this hypothetical study, but pilot testing would need to confirm.	- Have an existing app manufacturer modify an existing app for study purposes. - Develop new app for study purposes.
Representativeness of sample	- A significant portion of the study novices have another language other than English as their primary language. - The novices that agree to be in the smartphone plus in-vehicle DAS sample are qualitatively different than those in the smartphone only sample.	- Low to High – Novices in households that have a primary language other than English are likely to have sufficient exposure to English that no alternative language translation will be necessary. However, it is possible that a proportion of the participants will be unable to complete the surveys and follow the study instructions provided in English. - The requirement to have stable access to a vehicle for the in-vehicle DAS group is likely to result in some qualitative difference between this subsample and the full smartphone only sample. It is likely that these differences can be identified and quantified. - The dropout rate may be high enough in the DAS group to reduce the sample size below what is desired. - DAS group participants may change vehicles during the study period.	- Translate questionnaire and study material and hire study staff proficient in the alternative prominent language. - Include protocol to expeditiously transfer the DAS equipment to an alternate vehicle to be used by the participant. - Include participant replacement protocol for the DAS group if dropouts exceed a predefined threshold. - Acknowledge potential bias of participant subsample as study limitation.

Challenge	Risks	Likelihood	Solutions
Availability of sample	Recruiting the novice driver sample of the desired characteristics takes longer than anticipated.	Moderate – Without knowing the precise operating characteristics of the partner State licensing agency, it is difficult to predict the recruitment location's flow and the participation rate, but initial estimates suggest flow could be as little as one older novice per office per day.	- Increase the number of recruitment locations to increase participant intake. - Extend the data collection period to provide sufficient time to recruit the full sample. - Increase the incentives for participation.
Retention of sample	A significant portion of the study sample does not drive regularly or fails to complete the study.	Moderate to High - A study of this magnitude that involves a sample with inherently low motivation (i.e., novices) is at risk for high dropout rates. Effective screening questions (e.g., likelihood of moving to another State, plans to drive regularly) should minimize this factor, but it still might be larger than anticipated.	- Increase study incentives to ensure participants are sufficiently motivated. - Frequent and automated data quality control measures to actively monitor participants' driving behavior. Research assistants would follow-up with participants who have not driven (i.e., no recorded trips) within a certain period. - Frequent check-ins to remind inactive participants of the importance of compliance. - Include protocol to expeditiously transfer the DAS to an alternate smartphone/vehicle to be used by the participant.
Verification of sample	No reliable method of distinguishing the enrolled drivers on specific trips can be achieved without video identification. Participant logs of driver/passenger status can be used to obtain this information but are notoriously unreliable.	Moderate – Some work (see Wahlström et al., 2017, for a review) suggests methods that do not involve video can distinguish between drivers and passengers on trips, but little research has evaluated the accuracy of these approaches in practice (Grimberg et al., 2020)	- Use alternative technological methods related to driving style or position in the vehicle. - Have novices keep a journal of their trips to assist with identification. - Use biometric or electronic ID systems (costly and still subject to participant dishonesty). - Acknowledge as limitation.
Validity of DAS results from smartphones	The measures from the smartphone DAS are inconsistent with the same measures from the in-vehicle DAS.	Low – Some prior work (Friedlin et al., 2018, 2020) suggests substantial overlap with the same measures measured by the smartphone DAS and the in-vehicle DAS. May be higher for any inferred/calculated measures.	- Acknowledge as limitation while recognizing the strengths of the use of the smartphone DAS. - Correct measures if the issue is calibration not validity.
Changes in roadway and in-vehicle environment (e.g., advancing automation)	- Novices' licensure quantitatively and qualitatively differs from current licensure. - Novices' exposure, behavior, and risk may differ from current expected levels.	Low – Changes to the roadway and in-vehicle environment will likely not occur within the timeframe that the hypothetical study may be conducted (e.g., five years), although they may change from now. In general, major highway or	- Carefully document the actual starting State of the study. It may be different than that at the time of the development of the plan. - Update the profile of novices through a survey to provide the most up-to-date characteristics relevant to recruitment and quota sampling.

Challenge	Risks	Likelihood	Solutions
		vehicle environment changes take 10+ years, which is much longer than the study would last.	- Acknowledge as limitation that comparisons to previous studies pre-automation is difficult.
External events that impact driving behavior (e.g., COVID-19 pandemic)	Data collection is significantly disrupted.	Low – Substantial changes in life circumstances (e.g., COVID-19) are rare events. It is impossible to prepare contingency plans for everything that might happen. Study will have to react as needed. Generic approach/process can be identified.	- Delay the balance of data collection until normal traffic flow resumes. - Continue the balance of data collection with an acknowledgment of the change in circumstances as a limitation when interpreting results.
Maintaining data flow and integrity	- Study design does not collect enough data. - Some of the collected data is unusable (lost or corrupt).	High – A study of this magnitude that involves a sample with inherently low motivation (i.e., novices) is at risk for data flow and integrity issues without a sufficient stipend and an experienced study team that routinely and rigorously conducts data flow and quality checks. Thus, some data loss is to be expected.	- Increase study incentives to ensure participants are sufficiently motivated. - Frequent and automated data quality control measures to actively monitor participants' driving behavior. Research assistants would follow-up with participants who have not recorded trips within a certain period. - Oversample beyond what power analyses indicate to provide a margin for loss.

Discussion

In this project, the research team developed a hypothetical NDS of younger (15.5 to 16.5 years old) and older (18 to 20) novice drivers to examine their first year of unsupervised (independent) driving. Specifically, this study would investigate differences in safety and driving exposure of younger and older novice drivers, as well as between higher- and lower-risk novices. Given the increasing proportion of young people delaying licensure (Twenge & Park, 2019), some States may be considering whether and how to extend GDL provisions to drivers over 18. The hypothetical study would provide information that could be used to develop GDL provisions for older novices that reduce exposure to risk while ensuring mobility.

The research team found that most existing NDSs of novice drivers used convenience samples that overrepresented White and higher SES novice drivers. Therefore, the hypothetical study adopted an alternative approach designed to obtain more representative samples of novice drivers—particularly older ones. Specifically, the research team devised a recruitment strategy in which, along with a State partner, driver licensing information and screener questions could be used to increase the likelihood of reaching a diverse group of potential participants. The hypothetical study also includes a "hybrid" approach to data collection, in which most participants would have NDS data collected via an app on their personal smartphones while a smaller subgroup would additionally be outfitted with the type of in-vehicle DAS traditionally used in NDSs. This approach may remove barriers to participation associated with the installation of in-vehicle equipment, permits the recruitment of a larger number of participants, and allows researchers to examine the correspondence between NDS data obtained with smartphones versus in-vehicle equipment.

There are several potential challenges for conducting the hypothetical study, including difficulty in finding a State licensing agency to participate, in recruiting and retaining a sufficient number of participants, and in ensuring the accuracy of data collected from smartphones. These challenges are potentially surmountable but may require significant effort. Despite these challenges, the results of the hypothetical study would provide rare and valuable insight into an understudied, yet growing, group: novice drivers over 18 years old. Young drivers 15 to 20 already have the highest rate of involvement in fatal crashes of any age group (NCSA, 2022), and increases in the proportion of drivers 18 to 20 who are still learning to drive may affect this pattern of risk. The hypothetical study also presents an opportunity to determine how well naturalistic driving data collected from smartphones corresponds to data collected with traditional in-vehicle systems, as well as whether using smartphones for data collection yields more representative samples of participants.

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