Curriculum Vitae

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EDUCATION:

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1990-2013	Database Engineer National Study Center for Trauma and EMS University of Maryland – Baltimore
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CONTRIBUTOR

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Abstract

Title of Dissertation: Effectiveness of an ignition interlock device in reducing alcohol-impaired driving recidivism and alcohol-impaired motor vehicle crashes in Maryland

Timothy Kerns, Doctor of Philosophy, 2017

Dissertation directed by: Gordon Smith, M.B., Ch.B., M.P.H., Professor, Department of Epidemiology and Public Health

Background:

A. Abstract

Background: Multiple studies have shown that ignition interlock devices reduce alcohol impaired driving recidivism while the device is installed on the vehicle. However, many of these studies rely on convictions and have limited follow-up after the device has been removed from the vehicle.

Objectives: The aims of this study were to compare the characteristics of drivers who installed an ignition interlock device after receiving an alcohol impaired driving citation and a control group that did not install the device and to determine their risk of receiving a subsequent alcohol related citation or being involved in an alcohol related crash.

Methods: A Cox proportional hazard test was used to compare the risk of a subsequent citation or motor vehicle crash between the study groups.

Results: The interlock group had a lower proportion of females (22.2% interlock vs 24.2% control, $p<0.05$), and a higher mean age (36.5 years vs 34.3 years, $p<0.05$). Forty-six percent of those installing an ignition interlock device had a BAC above 0.15 g/dL

as compared with 25% in the control group ($p<0.05$). The BAC test refusal rate was higher among interlock installers (41.4% vs 33.0%, $p<0.05$). While the device was installed on the subject's vehicle, drivers were 22% less likely to receive an impaired driving citation as compared to the time when the device was not installed (HR=0.78; 95% CI: 0.73-0.84). After removal, the interlock group was 32% more likely to receive an impaired driving citation versus controls (HR=1.32; 95% CI: 1.22-1.42). Similar patterns were observed with respect to motor vehicle crashes.

Conclusion: Drivers who have installed an ignition device on their vehicle have a lower risk of receiving a subsequent alcohol involved driving citation and of being involved in an alcohol related motor vehicle crash while the device is on the vehicle as compared to the control group. Upon removal, the risk of both citations and crashes is higher for those who had an interlock device installed. Ignition interlock devices are effective for the time they are used but should not be the only tool to prevent future events of alcohol involved driving among those previously arrested for impaired driving.

The Effectiveness of an Ignition Interlock Device in Reducing Alcohol-Impaired Driving Recidivism and Alcohol-Impaired Motor Vehicle Crashes in Maryland

by
Timothy James Kerns

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, Baltimore in partial fulfillment
of the requirements for the degree of
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DEDICATION

To my family, Dale, Katy, and Alex, that endured not only this last year of dissertation writing, but also the homework, studying, and online quizzes that occasionally interrupted weekends and vacations over the last nine years. You encouraged me to achieve a goal thirty years in the making.

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List of Abbreviations

ACRS	Automated Crash Reporting System
AID	Alcohol Impaired Driving
BAC	Blood Alcohol Concentration
CDC	Centers for Disease Control and Prevention
DUI	Driving under the influence
FARS	Fatality Analysis Reporting System
g/dL	Grams per deciliter
IPTW	Inverse probability of treatment weights
MAARS	Maryland Automated Accident Reporting System
MAB	Medical Advisory Board
MVA	Motor Vehicle Administration
NHTSA	National Highway Traffic Safety Administration
OS	Order of Suspension
PBJ	Probation before judgement
PS	Propensity score

Chapter I: Introduction and Background

A. Introduction

Alcohol impaired driving (AID) is an all too common occurrence in the United States with an estimated 80 million trips made annually by drivers with a blood alcohol concentration (BAC) of 0.08 g/dL or higher (Hedlund and McCartt, 2002). According to the 2013 National Roadside Survey, 8.3% of drivers on weekend nights had a BAC level above 0.02 g/dL (Compton and Berning, 2015). The most current prevalence estimates of AID from the Centers for Disease Control and Prevention (CDC) Behavioral Risk Factor Surveillance Survey (BRFSS) indicate an estimated 4.2 million U.S. adults reported driving while impaired by alcohol at least once in the preceding 30 days resulting in an estimated 121 million alcohol impaired driving episodes annually (Jewett, 2015). After showing a steady decline in the early 1980's, the proportion of fatal motor vehicle collisions that involve at least one alcohol impaired driver has not changed in recent years and remains steady at about 33 percent. Several reports have noted that effective strategies to reduce AID are underutilized in the United States which may have contributed to the lack of further decline in alcohol-impaired collisions (Bergen et al., 2011, Williams 2006).

Alcohol impaired driving crashes accounted for 30 percent of all motor vehicle fatalities in the United States in 2014, killing 9,967 people (NHTSA, 2015). Elevated BAC among motor vehicle drivers is a well-known risk factor for crashes and resultant injuries and/or deaths; those risks increase with increasing BAC level (Zador et al, 2000). An earlier study estimated that if all drivers had a BAC of zero, as many as 13,452 traffic deaths in the United States would have been prevented in 2005 (Lund et al, 2007). All 50

states and the District of Columbia have alcohol per se laws that define driving with a BAC at or above a certain level, usually 0.08 percent, as a crime. The National Highway Traffic Safety Administration (NHTSA) focuses its research, evaluation and countermeasure efforts at that level of BAC.

While prevention activities in the 1980s and early 1990s resulted in substantial declines in the number of alcohol-related crashes, injuries and fatalities, recent years have shown less significant improvement both nationally and, to a lesser extent, in Maryland. In fact, the decline of fatalities in 2008, 2009 and 2010 has been largely attributed to the reduction in vehicle miles travelled in the United States during the same period (due to economic recession) and also to improved vehicle crashworthiness (NHTSA, 2011). Despite increases in prevention activities, the proportion of traffic fatalities in Maryland that are alcohol-related has remained relatively steady at 35% over the past few years.

However, injuries and fatalities are only part of the problem as law enforcement agencies report approximately 1.4 million annual arrests nationally for driving under the influence (CDC, 2014). The Behavioral Risk Factor Surveillance System found an estimated 112 million episodes of AID in 2010(Bergen et al, 2011). Maryland alone averages approximately 25,000 alcohol-impaired driving arrests annually. Additionally, drivers with previous AID convictions are at increased risk of being involved in a subsequent AID crash (Elder et al., 2011).

Individual states typically address AID through legislative and programmatic activities such as the imposition of strict laws with substantial penalties and the implementation of high-visibility law enforcement initiatives (e.g., sobriety checkpoints and saturation patrols), among other countermeasures (NHTSA, 2011). As with any highway safety

problem, a critical element is the ability to determine the exact nature and extent of the problem and to measure the effect these activities have on reducing AID. Timely, consistent, complete, accurate, accessible, and integrated data are essential to the conduct and evaluation of any successful highway safety program (NHTSA, 2012).

The application of sanctions on drivers arrested for AID is a key component of all state impaired driving programs but the types of sanctions vary widely both across and within states. Historically, the main sanction for impaired driving has been license suspension or revocation. This penalty has limited success as it has been shown that more than half of those drivers convicted of AID continue to drive during the suspension period (Beck, 1999; Voas, 1997; McCartt, 2003). A notable, more recent intervention used to prevent AID is through the use of an ignition interlock. An ignition interlock is a breath test device connected to a vehicle's ignition that will prevent the vehicle from starting if the driver's breath sample indicates a BAC of greater than 0.02 g/dL.

Research conducted by the Traffic Injury Research Foundation (TIRF, 2009, updated 2012), with particular reference to ignition interlocks, showed that, for maximum effectiveness of court-based programs, an agency "must be designated to actively monitor the offender to ensure that the device is being used properly and to take action on any violations (e.g., high-BAC tests)". Further, it is important for the court to "impose meaningful graduated sanctions for non-compliance in cases of offenders that fail to comply with installation or who demonstrate repeated violations". Finally, courts should partner with treatment agencies to mandate treatment services that simultaneously address any drinking problem that is the basis for the problem driving behavior. It is noted that "information captured by the alcohol interlock data recording device can assist

treatment professionals and probation officers to work effectively with offenders to overcome denial and move toward readiness for change". The need for long-term behavioral change is particularly well demonstrated by the fact that interlock devices have the effect of decreasing recidivism (i.e. repeat AID arrests) substantially while they are installed. Once they are removed however, there are indications that recidivism rates begin to rise (Marques,2001; DeYoung, 2002; Raub, 2003).

Also, without monitoring, "valuable opportunities to respond to persistent attempts to drink and drive or to reinforce compliance with the device are lost" (TIRF, 2009). It must be recognized that failure to monitor the interlock driver's behavior beginning with the installation of the interlock will tend to negate the treatment effect of the device. Once interlock-mandated drivers realize that monitoring is lax or non-existent, the deterrent effect will likely be degraded or lost as well (TIRF 2009).

B. Study Aims

The objective of the proposed study is to determine the difference in the risk of a subsequent impaired driving citation between drivers with an Order of Suspension (OS) for AID who installed an ignition interlock device on their vehicle (interlock group) and drivers with an OS for AID who did not install an ignition interlock device (control group). Additionally, the two groups will be compared with respect to their risk of experiencing a subsequent police-reported motor vehicle crash.

Aim 1. To compare the interlock group and the control group with respect to age, gender, race, blood alcohol content at time of arrest, prior citation history, median income in the driver's zip code of residence, and county of offense.

Hypothesis 1. Participants in the interlock group are younger, have a higher blood alcohol level, have a history of receiving multiple citations, reside in counties with a higher median income, and were more likely to have received their OS in a rural area of the State than those in the control group.

Aim 2. To compare the interlock group and the control group with respect to risk of receiving a subsequent AID citation while controlling for potential confounding variables (age, gender, race, blood alcohol content at time of arrest, prior citation history, median income in the driver's zip code of residence, and county of offense).

Hypothesis 2. The risk of a subsequent AID citation is lower in the interlock group as compared to the control group.

Aim 2a. To compare the risk of a subsequent AID citation among the interlock group in the time during which the device was installed on the vehicle to the risk of a subsequent AID citation among the control group while controlling for the study group and the potential confounding variables described above.

Hypothesis 2a. The risk of a subsequent AID citation is lower while the device is installed on the vehicle than when there is no device installed.

Aim 2b. To estimate the risk of a subsequent AID citation in the interlock group in the time after the device had been removed from the vehicle and to compare this risk to the risk in the matched control group for a comparable time and while controlling for the same set of variables.

Hypothesis 2b. The risk of a subsequent AID citation is higher in the interlock group after the device has been removed than in the control group.

Aim 3. To compare the interlock group and the control group with respect to the risk of a subsequent AID-related motor vehicle crash while controlling for potential confounding variables (age, gender, race, blood alcohol content at time of arrest, prior citation history, median income in the driver's zip code of residence, and county of offense).

Hypothesis 3. The risk of a subsequent AID-related motor vehicle crash is lower in the interlock group than the control group.

Aim 3a. To compare the risk of a subsequent AID-related crash among the interlock group in the time during which the device was installed on the vehicle to the risk of a subsequent AID-related crash among the control group while controlling for the study group and the potential confounding variables described above.

Hypothesis 3a. The risk of a subsequent AID-related crash is lower while the device is installed on the vehicle than when there is no device installed.

Aim3b. To estimate the risk of a subsequent AID-related crash in the interlock group in the time after the device had been removed from the vehicle and to compare this risk to

the risk in the matched control group for a comparable time and while controlling for the same set of variables.

Hypothesis 3b. The risk of a subsequent AID citation is higher in the interlock group after the device has been removed than in the control group.

C. Background and Significance

Maryland Driving Under the Influence Program for Offenders

The State of Maryland uses a multi-tiered approach to sanction offenders who are arrested for AID. An alcohol-related traffic violation may result in a wide variety of possible sanctions including administrative penalties such as license suspension or criminal penalties such as jail time. For those arrested for alcohol impaired driving in the State, only 29% are found guilty. Many of those arrested receive probation before judgement where they may be entered into a diversion program in which they do not receive a formal conviction provided they comply with certain conditions stipulated by the court. In addition, some may be found to be not guilty or may not be prosecuted due to poor evidence or other factors such as plea bargains. On average, 23,000 alcohol impaired driving arrests have been made annually in Maryland over the past five years.

Administrative sanctions are determined by the Motor Vehicle Administration (MVA) Office of Administrative Hearings. Administrative per se (automatic license suspension) for offenders recording a BAC level of 0.08 percent became law on October 1, 2001. Since that time, drivers who fail or refuse a breath test at the time of their arrest have their licenses immediately suspended for a period of 45 days (1st offense), 90 days (2nd offense), 120 days (1st refusal), or one year (2nd refusal). After an order of suspension has been received, drivers may request an administrative hearing. At this hearing, the

Administrative Law Judge may dismiss the license suspension if the person enrolls in the ignition interlock program for at least one year. In addition, the MVA's Administrative Adjudication Division may require drivers to participate in the ignition interlock program if they have accumulated sufficient points against their driver's license. In Maryland, if one is convicted of a vehicle-related offense, the MVA assesses points to the driver license in accordance with district court guidelines. Depending on the number of points accumulated, the MVA will take various actions. For example, if a driver accumulates 5 to 7 points, they will be required to enroll in a Driver Improvement Program. At 12 or more points, the MVA will issue a notice of license revocation. Other reasons for referral to the ignition interlock program include being a repeat offender, or having been found to violate a previously imposed alcohol-related driving restriction.

Criminal sanctions are determined by the judiciary. Drivers receiving an impaired driving violation may be charged with driving under the influence, driving under the influence per se, or driving while impaired. In Maryland, those found guilty of a criminal violation, such as impaired driving, may receive fines, jail time and/or community service hours. Further administrative sanctions, as described above, may also be imposed. The administrative and criminal sanctions are independent, meaning one arrest could follow both processes. For example, a driver arrested for alcohol impaired driving will be issued an OS by the Motor Vehicle Administration. At the same time, the citation(s) will be sent to the district court of the jurisdiction in which the citation was issued for possible additional sanctions.

A 2011 publication by Ahlin et al. (2011), using driver license history files in Maryland for 1999-2004, showed that drivers with a prior DUI offense were at a

relatively high risk of recidivating regardless of which type of sanctions were used. Another study of Maryland drivers by Rauch et al. (2010) revealed that recidivism rates among first offenders were more similar to those of second offenders than of non-offenders and indicated that any AID violation is a marker for future recidivism. However, as these studies relied upon the driver history files, which capture convictions but may not include offenses that were dismissed or otherwise adjudicated by the court, they may not provide a complete picture of all drivers cited for AID in the State.

Maryland's Ignition Interlock Program

Enacted by State statute in 1989, the Maryland Ignition Interlock Program initially targeted drivers applying for license reinstatements who had two or more alcohol-related traffic violations in their lifetime and who had been approved by the Medical Advisory Board (MAB) to apply for the reinstatement. The MAB of the MVA is a group of physicians who evaluate drivers (applicants, renewing drivers, suspended drivers, those seeking re-instatement) with medical problems, including alcohol use disorder, for their medical fitness to drive. Drivers whose license had been suspended for alcohol violations would apply to the MAB for reinstatement of their license. As a condition of the return of the license, the driver may have been required to install an ignition interlock device for a defined period of time. As of October 2011, the use of an ignition interlock became required for those persons convicted of alcohol-impaired driving who had a BAC level of 0.15g/dL or higher. A more recent change to the law (October 2016) requires the use of an interlock device by any driver who is convicted of an AID violation.

In Maryland, drivers are notified by letter that they are eligible for license reinstatement pending enrollment in the ignition interlock program. Participants have 30

days to install the device in their vehicle or face license suspension for failure to comply. Before the offender can start the car, the individual must breathe into the device, which is calibrated to "lock" the ignition if the breath–alcohol level exceeds a preprogrammed level, usually set to 0.025 g/dL. The devices are also programmed for "rolling retests" at intervals while the car is in operation. A "datalogger" device electronically captures vehicle usage and records instances of non-compliance.

Drivers in the ignition interlock program receive a restricted license that bars them from operating a vehicle that does not have an ignition interlock installed. All drivers in the program are barred from operating any motor vehicle if they have any alcohol in their system.

Currently, Maryland requires participants to return to the installing vendor every 30 days for the duration of the time that the interlock device is installed on their vehicle. The vendor checks the equipment and forwards the information captured by the device to the MVA. The report includes information on:

1. the driver, vehicle, and start and stop dates of device installation;
2. any instances where the driver had a blood alcohol concentration of 0.025 g/dL or higher when trying to start the vehicle;
3. any instances where the driver failed the rolling retest or refused to take it;
4. any tampering or bypass of the device;
5. the number of times the vehicle was started and stopped

A driver's sentence to drive with an ignition interlock may be extended if one or more violations are identified during the 30-day monitoring period. If a violation is detected, the driver is notified by letter that time in the program has been extended by one month.

If a driver has four monitoring periods in which a violation is identified, the driver may be forced to leave the program and have the original suspension imposed. Drivers are expected to start the vehicle at least 50 times within each thirty-day monitoring period; if alternative arrangements for transportation are made (e.g., carpooling or using public transportation), if they have been unable to drive due to illness, or have been out of the State, they must provide a written explanation for the low number of starts.

Participating drivers are expected to pay for all costs associated with the program, including the installation of the ignition interlock and the monthly maintenance costs. Currently, those fees range from $150 to $200 for the initial installation, and from $65 to $90 per month for monitoring. Extra fees for obtaining a restricted driver's license and the fee for obtaining a license without the restriction once the sentence has been completed are also incurred. If a driver cannot afford to pay the fees associated with the ignition interlock installation and monitoring there are several options: 1) their driving privilege will be suspended or revoked in accordance with their violation or until they are able to pay; 2) the MVA can waive the program's fee; or 3) the interlock providers may provide a reduced rate for drivers who meet the eligibility requirements for federal assistance programs.

A data recorder electronically captures and records the driver's BAC at each testing point; such information may be used by probation officers to monitor the offender's drinking and driving behavior. There has been a rapid growth in the number of drivers installing an ignition interlock device, from 7,000 enrollees in January 2008 to over 11,500 in December, 2015. In addition, the 2016 State legislature passed Noah's Law that will require ignition interlock devices for anyone convicted of AID in the State. The

proposed study will provide valuable information to the Motor Vehicle Administration and the upcoming legislative session in their efforts to reduce the impact of AID on Maryland's drivers.

Ignition Interlock Evaluation Studies

Since its introduction in the 1990s, the use of ignition interlock devices has increased steadily. In 2010 there were approximately 300,000 devices in use nationwide. While this represents a three-fold increase from 2006, these devices are still used in only about 30% of AID convictions (Elder, 2011; Roth, 2014). As described below, a number of research studies have been conducted over the years to determine the efficacy of ignition interlocks in preventing AID. While much of the evidence points to the initial effectiveness of the device, there is more that can be learned through a long-term follow up of persons who have been cited for AID and who have installed an ignition interlock device on their vehicle.

There is strong evidence that interlocks reduce recidivism among first-time and repeat offenders *while the device is installed on the vehicle*. Multiple studies have reported an average 64% reduction in the impaired driving recidivism rates while the interlock is on the vehicle (Voas and Marques, 2003; Willis, 2005). Ignition interlocks allow offenders to maintain a legal driving status while restricting their ability to drive their vehicle while impaired by alcohol. However, existing studies are limited in the length of follow-up after the device is removed and by their reliance on conviction data rather than arrest data.

Earlier evaluations of interlock programs in the United States and Canada have shown that interlocks reduced AID recidivism by at least 50 percent among offenders while the interlock device was on the vehicle, as compared to offenders without interlocks (Beirness, 2004; Dill, 2006). However, after the interlock was removed, the effects attributed to the interlock device disappeared and interlock and comparison drivers had similar recidivism rates. A Cochrane review of eleven completed and three ongoing (at the time) studies reached similar conclusions (Willis et al, 2006). A more recent systematic review of the effectiveness of ignition interlocks for preventing impaired driving and alcohol-related crashes conducted by the Preventive Services Task Force (Elder, 2011) concluded that ignition interlocks resulted in large reductions in re-arrest rates for AID when the interlock device is installed but that rates often revert back to those of comparison groups once interlocks are removed. However, many of the studies included in this review focused on repeat offenders or high BAC offenders and have as their comparison groups, persons who received significant sanctions (e.g., license suspension) in lieu of ignition interlock. A further limitation of many ignition interlock research studies is that study participants are not randomly assigned to interlock or control groups, so there may be important pre-existing differences between groups.

A recent Washington State study (McCartt, 2012) found that extending an interlock requirement to all first-time DUI convictions reduces recidivism of AID among the cohort of offenders. The study showed that offenders who installed interlocks had lower rates of recidivism than those who did not install the device. The authors suggested that states and local jurisdictions should seek ways to increase the use of ignition interlock devices and should re-consider the current policies that allow DUI charges to be reduced

to alternative traffic offenses (e.g., negligent driving) in jurisdictions that do not have an interlock requirement. An example of this policy is in effect in Maryland, which began requiring ignition interlocks for all high BAC (>0.15 g/dL)) convictions in October 2011. However, there were two significant limitations to the Washington study which were addressed in the current study. First, the drivers' license records in Washington included information only on DUI arrests that resulted in a conviction. The data available for this study include all persons who are issued a citation for AID, regardless of the subsequent adjudication. As the judicial process allows an impaired driving citation to have multiple outcomes of varying severities, including all persons charged with the offense provides a more accurate depiction of the degree of recidivism in Maryland. Second, in the Washington study, the observation that offenders who installed the ignition interlock device had a lower recidivism rate may be biased because those who choose to install an ignition interlock may have different characteristics from offenders who do not install the device. The current analysis makes use of propensity scoring to develop comparable groups for comparison, thereby controlling for confounding by driver characteristics.

In a recent review of the literature, Maryland was singled out as being the site of the only truly randomized trials in the US to evaluate the effectiveness of interlocks (Elder at al. 2011). A total of three randomized trials were conducted in Maryland (Beck 1999, Rauch 2011, Zador 2011). In the first study (Beck, 1999), the participants were drivers with two or more alcohol offenses in five years who were applying to the State's Medical Advisory Board for relicensing after an earlier suspension or revocation. Participants were randomized into an interlock or control group (monitoring program). A total of 1,387 persons were enrolled and followed for a period of two years. In the second study

using the same methodology (Rauch et al. 2011), 1,927 participants were similarly randomized into intervention (interlock) and control (monitoring program) groups with enrollment and follow-up extended to a period of four years. The findings from these two studies were similar, both showing reduced AID recidivism, in the short term, for persons assigned to the intervention group. In both studies, not all persons assigned to the intervention group followed through with the installation of the interlock device. For the third study (Zador et al. 2011), 2,168 multiple AID offenders selected from a group of drivers seeking license reinstatement from the Medical Advisory Board were assigned to an intervention (interlock with close monitoring) or control (interlock with standard monitoring) group. The groups were followed for a period of up to 24 months. The outcome variable was compliance with the interlock device (number of initial fails, disconnects, etc.). Results showed that, while compliance with the interlock device increased for both groups over time, the number of interlock violations declined at a faster rate for those in the intervention group who received close monitoring. While these randomized controlled trials demonstrate the effectiveness of the interlock device over a short-term period, these trials have limited generalizability because they are restricted to persons who were convicted of AID offenses, had their license suspended, and were in the process of applying for reinstatement from the MAB.

Few studies have evaluated the impact of ignition interlocks on motor vehicle crashes as most evaluated the impact on AID convictions. An exception is a recent study (Kaufman, 2016) which compared the frequency of alcohol-involved crash deaths between states with universal ignition interlock requirements and those without. This

study found that states with regulations requiring interlocks for all AID convictions had 15% fewer fatalities as compared to states with lesser restrictions. Prior to this report, only a few published studies have assessed the impact of ignition interlocks on crashes, and the results of these studies were mixed (Carter, 2015; Elder, 2011). The Kaufman study (2016) is limited by its reliance on crashes involving a fatality and, more importantly, by the fact that it used state-level data, not individual data. Since the majority of alcohol involved crashes do not result in a fatality, this study adds to the existing research by identifying all police-reported crashes for individuals in both the interlock and control groups.

Limitations of existing studies

Most studies of penalties resulting from AID have focused on analyses of the driver license history file, which only captures information on persons who receive sanctions as a result of an AID-related arrest. However, these represent only a subset of the persons who receive an impaired driving citation and are charged with AID. Many studies do not include drivers who are not prosecuted or those who have their charges reduced and therefore may not have an AID-related conviction on their driving record. For example, in Maryland there have been several analyses using only those with an AID conviction recorded on the driving record for evaluation of AID behavior (Ahlin, 2011; Rauch, 2010; Zador, 2011). This approach may have excluded up to 60% of persons arrested for AID, including those with a first or second offense and those who may receive a reduced (or no) penalty through the judicial process. Few studies are able to use individual

crashes as an outcome measure, instead other studies often rely on a surrogate measure such as late-night, single vehicle crashes to approximate impaired driving crashes. (McCartt, 2013).

Chapter II. Study Design and Methods

Study Design and Population

This retrospective cohort study compares the risk of receiving a subsequent alcohol impaired driving (AID) citation or being involved in an AID-related crash between Maryland licensed drivers who have been arrested for AID and have installed an ignition interlock device in their vehicle with those who were arrested for AID but did not have an ignition interlock device installed. Data on all Maryland licensed drivers receiving an Order of Suspension (OS) as the result of AID between January 1, 2008 and December 31, 2015 were obtained from the Maryland Motor Vehicle Administration (MVA). Subjects were divided into two study groups. One cohort included all persons who received an OS and subsequently installed an ignition interlock device on their vehicle between January 1, 2008 and December 31, 2015. The second cohort comprised those persons with an OS who did not install an ignition interlock device on their vehicle.

Setting

With a population of just over 6.0 million people, Maryland is the 19th most populous state in the nation. The State is divided into 24 jurisdictions - 23 counties and Baltimore City. Maryland's population is largely clustered around the suburbs of Washington, DC, and Baltimore, and along the I-95 corridor. There are over 55,000 miles of roadway maintained by both State and local agencies. Approximately 58 percent of the population is Caucasian and 29 percent is African-American. Asians, Hispanics and Latinos of any race make up the remaining 13 percent of the population. Over the past five years, there was a yearly average of 502 deaths and 3,702 serious injuries in Maryland, nearly one-third of which were attributed to AID.

This study involves Maryland-licensed drivers who were arrested for AID in the State. Under Maryland law, drivers whose blood alcohol concentration (BAC) is 0.08 grams of alcohol per deciliter of blood (g/dL) or higher are considered impaired. An impaired driving arrest is the starting point for the MVA's process of sanctioning and monitoring impaired drivers. From 2008 to 2015, more than 174,000 impaired driving arrests were made in Maryland. For each AID arrest, multiple citations may be issued by the arresting officer in order to encompass all applicable sections of the law.

If the driver refuses to submit to an alcohol test, or tests above the legal limit, the arresting officer issues, along with the relevant citations, an OS to the driver with a copy provided to the MVA.

As part of a unified court system, all traffic citations issued in the State are initially disposed of through Maryland's district court system. In contrast to many previous ignition interlock studies that include only AID convictions, the use of the statewide citation data allowed for the identification of all subsequent AID events.

Study Groups

As shown in Figure 2.1, there were 113,573 Maryland licensed drivers who were issued an OS for AID in Maryland between January 1, 2008 and December 31, 2015. Of those, 107,426 (94.6%) were linked to the licensing, citation, and crash data to provide additional demographic and behavioral characteristics. Thirty percent (32,509) subsequently installed an ignition interlock device on their vehicle between January 1, 2008 and December 31, 2015. The remaining 74,618 drivers did not install an interlock on their vehicle subsequent to their OS (control group). The majority of drivers who installed an interlock device did so within one year of their OS date (Appendix 1).

Drivers who have a greater than one year lag time from OS to installation may have received additional judicial or administrative sanctions based on the severity of their infraction. Thus, subjects who installed the interlock device more than 365 days after they received their OS (n=4,386) were excluded. This left the final interlock group with 28,123 subjects.

Data Sources:

Licensing Records

The MVA maintains a database of all licensed drivers in the State. This database includes basic demographic information, zip code of residence, and the driver license number. Maryland's driver license number is a unique 13-digit alpha-numeric code and was the key linkage variable used to combine the datasets for this analysis. In 2016, there were more than four million licensed drivers in the State.

OS Data

The MVA also maintains information on all drivers who are issued an administrative OS as the result of an AID citation. This dataset provided the driver license number, the date the OS was issued, and the BAC test result associated with the AID citation.

Ignition Interlock Device Data

Ignition interlock device data are collected by vendors who manage the day-to-day aspects of the program. These data are compiled and submitted to the MVA. For this study, data were provided by the MVA for all persons who had an interlock device installed in their vehicle between January 1, 2008 and December 31, 2015. Data

elements included the driver license number, date of installation, date of removal, reason for entry into the interlock program and total number of violations recorded by the ignition interlock device itself (e.g. breath test fails).

Citation Data

Citation data are maintained by the Maryland District Court. As part of a unified court system, the district courts are the primary method of adjudication for impaired driving arrests and collect data on all traffic citations issued by Maryland law enforcement agencies. Data elements include driver license number, date of citation, and county of citation.

Crash Data

All crashes in the State of Maryland resulting in a personal injury or tow-away of the disabled vehicle generate a police crash report. By statute, the Maryland State Police are responsible for collecting and maintaining crash report data. From 1993-2014, data were maintained in the Maryland Automated Accident Reporting System (MAARS). Beginning in 2014, the State began transition to the Automated Crash Reporting System (ACRS). Data from both systems were provided for the period January 1, 2008 to December 31, 2015 to allow the identification of drivers who were involved in a crash during that time.

Alcohol involved crashes were identified using the following four data elements on the police crash report.

- Driver condition – 'had been drinking'

- Substance use detected – ‘alcohol’
- BAC test result – greater than 0
- Contributing circumstances – ‘under the influence of alcohol’

If one or more of these characteristics were indicated on the crash report by the investigating officer, the crash was identified as alcohol involved.

Census Data

The United States Census Bureau collects information related to median household income of the nation’s population as part of the decennial census. This value is available by geographic area, including zip code.

Data Linkage

To compile the dataset for analysis, OS data were linked to the licensing records provided by the MVA. This combined data set was then linked to the ignition interlock device data to identify drivers who had installed an ignition interlock device on their vehicle within 365 days of the OS date. The resultant database was then linked to the citation data to identify the AID citation that was issued in association with the OS, any previous citations that may have been issued to the driver between January 2000 and the OS date, and subsequent citations that were issued to the driver. Finally, this database was linked to the decennial census data to provide the median income in the driver’s zip code of residence. Zip code of residence was used to link the study database with the census information. All other linkages were made using the individual’s driver license number.

Outcome Measures

The outcome measure for the first manuscript, a subsequent AID citation, was identified through the use of citation data. The outcome measure for the second manuscript, a subsequent AID-related motor vehicle crash, was identified through the crash data.

Subsequent AID events were identified through a linkage of the citation data and crash data to the study groups. The driver license number is specific to each individual and was used as the key identifier to link the databases. If a driver in the interlock or control group matched to more than one AID citation or crash, the first event that occurred after the initial OS was selected.

Covariables

Based on evidence indicating a potential association with AID events or with their likelihood of installing an interlock device, several independent variables were identified and included in the statistical analysis (Table 2.1). Previous research has shown that males are more likely to be repeat AID offenders than females and older drivers are at greater risk (Caviaola, 2003; Lapham, 2000). There also appears to be a relationship between race and subsequent AID, however, this relationship varies by region in the United States (Chang, 1996 and Nochajski, 2006). Nationwide, 35% of all impaired driving convictions are for drivers with at least one previous impaired driving conviction in the preceding 7 years (Schell, 2006). Other studies have found that while impaired driving offenders represent a wide range of income levels, repeat offenders tend to have lower incomes than first offenders (Nochajski 2006; Beirness 1997).

Table 2.1: Description and source of covariables

Variables	Description	Source
Age	Driver age as of OS issue date	MVA
Blood alcohol content 0.00-0.07 g/dL 0.08-0.14 g/dL 0.15 g/dL or greater Refused test	The most commonly used metric of alcohol intoxication. Maryland's legal limit is 0.08 g/dL. Test refusals were also included as an additional category	MVA – order of suspension
County of initial AID offense Urban Rural	Urban/rural status of Maryland county in which the AID offense occurred Urban – Greater than 80% of county population lives in an urban center as defined by Maryland Department of Planning	Maryland District Court
Race White Black Other	Race as categorized on the driver license	MVA
Sex Male Female	Sex as categorized on the driver license	MVA
Priors 0 1-2 3 or more	Number of citations issued to drivers prior to the order of suspension for speeding, impaired driving, failure to wear seat belt, driving while suspended or revoked	Maryland District Court
Median Income Less than $50,000 $50,000-$99,999 $100,000-$149,999 $150,000 or greater	Median income in driver's zip code of residence	U.S. Census Bureau

Missing values

An examination of the missing data patterns showed that 94.6% of the observations had complete data. Fewer than 1% of the drivers did not have a BAC test result recorded or did not have an indication that the test was refused. Observations with missing BAC

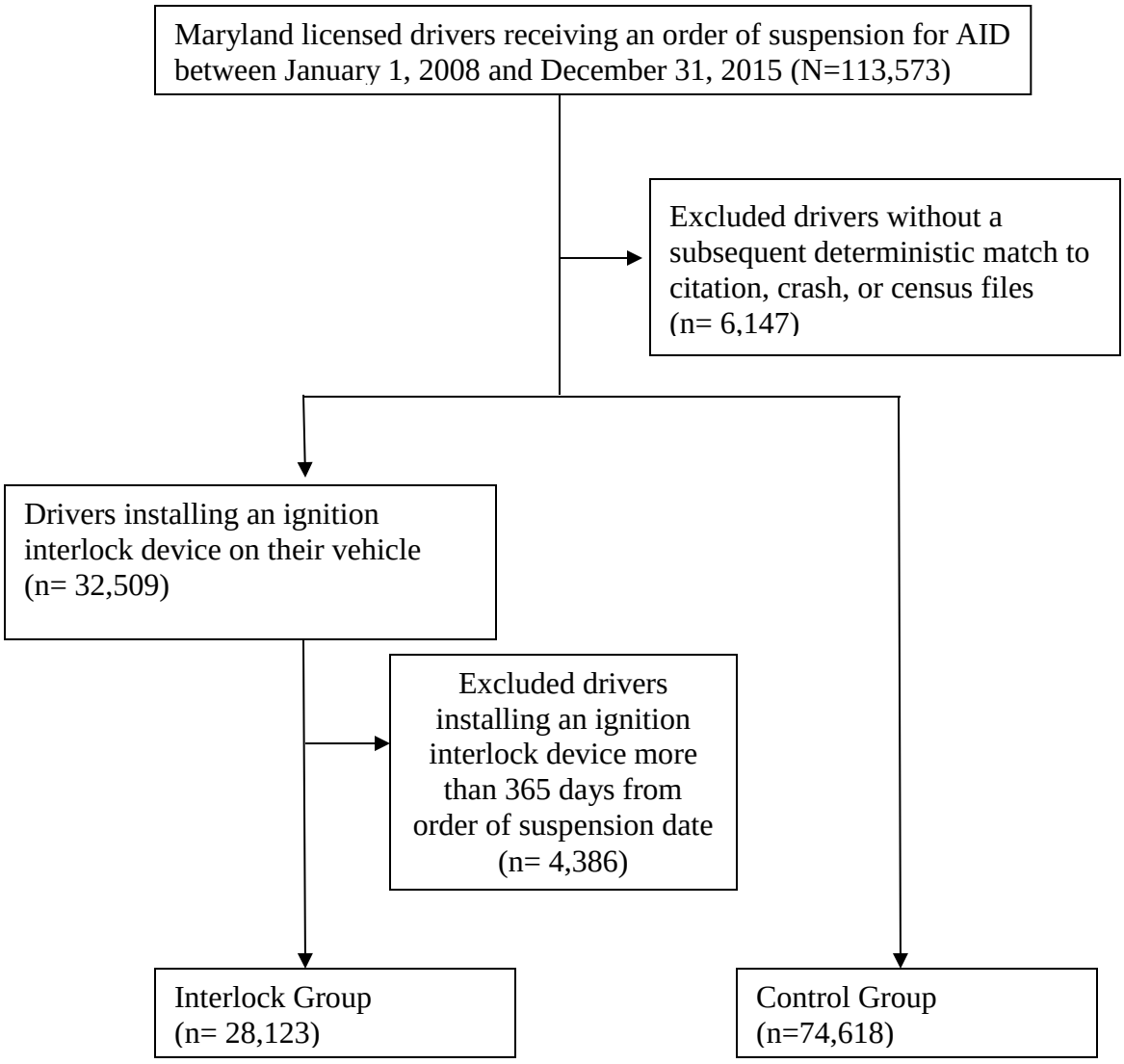
test results were not included in the regression analysis. The majority of remaining missing values were the data elements (specifically urban/rural designation) provided by the linkage between the OS data and the citation data to determine the county in which the citation was issued. This information was missing due to no matches being found between the driver license numbers in the citation and the OS databases. The driver license number is essential to MVA data tracking and regular quality control measures are used to ensure accurate information is recorded. The electronic citation data provided by the District Court reflects the information collected in the field and may include errors or omissions in the driver license number that will prevent a successful match to the OS file. Observations with missing urban/rural designations were also excluded from the analysis.

Data Analysis

Propensity Scores

Propensity scores are used to account for the lack of the randomization found in observation studies and can approximate a similar distribution of potential confounders in the study groups (Rosenbaum and Rubin, 1983). The propensity score is defined as the predicted probability of being in the interlock group, and can be calculated from a logistic regression model using identified covariates. In this study, the objective was to balance the interlock and control groups in order to reduce confounding and, therefore, to better estimate the effect of the interlock on the outcome measures.

Figure 2.1 Flow diagram showing creation of study groups



For this study, propensity scores were calculated through the use of a logistic regression model in which ignition interlock status, was the outcome variable and the co-variables listed in Table 2.1 were included as explanatory variables. Once calculated, propensity scores may be used in covariate adjusted, stratified, matched analyses, or as a basis for weighted analysis.

A commonly-used method for applying propensity scores is to use inverse probability of treatment weights (IPTW). This method uses the propensity scores to weight each observation to create a study population where the confounding variables are balanced between the interlock and control groups. For these manuscripts, I used the IPTW methodology.

In time-to-event analyses, the application of propensity scores using IPTW has been shown to minimize bias as compared to the other methods (Austin, 2013). IPTW are used in a fashion similar to survey sampling weights which help to make survey samples representative of specific target populations (Morgan, 2008). The weight for a subject in the interlock group is defined as the inverse of the subject's propensity score (1/PS) while the weight for the control subjects is defined as the inverse of one minus the subject's propensity score (1/(1-PS)). Note that the PS can be interpreted as the probability of being in the interlock group and (1-PS) is the probability of being in the control group, based on the covariates. Analysis with IPTW allows for the inclusion of all study subjects.

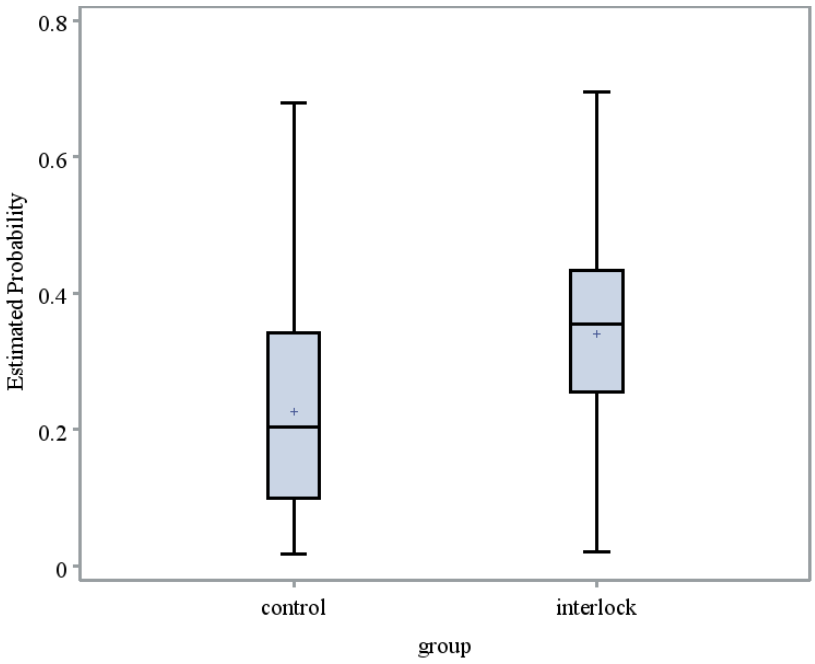
To make comparisons between the groups for the time period after the interlock device was removed from the vehicle in the interlock group, a matched data set was created. Drivers in the control group were matched to drivers from the interlock group

two or three to one, based on their individual propensity scores. For drivers in the interlock group, the number of days from their initial OS until removal of the device was calculated. This number was then added to the initial OS date for each of their matched controls. By doing so, I was able to compare similar time frames between the groups, so that time intervals from OS to the new index dates were equivalent.

Propensity Score Diagnostics

The groups were compared with respect to the distribution of propensity scores using a box plot. The region of the distributions that overlap is known as the region of common support. Ideally the distributions overlap entirely, indicating that subjects with a certain set of identified characteristics have the opportunity to be included in either the interlock or the control group. The presence of confounding in an observational study usually results in markedly different distributions of propensity scores and small areas of overlap between the two groups. The box plots displaying the range of distribution of the propensity scores for the two study groups are displayed in Figure 2.2. The box indicates the interquartile range that incorporates 50% of the values. The median value is indicated by a horizontal line within the box and the mean is indicated by the '+' sign. The lines (whiskers) extending above and below the box indicate the minimum and maximum values. There is significant overlap between the interlock and control group indicating common support between the two groups.

Figure 2.2. Estimated probability (propensity score) distribution between study groups



Two additional tests were performed on the logistic model used to calculate the propensity scores (Schmitz, 2015). These tests measured the correlation and the multicollinearity among the covariables. If correlation between two of the variables is 0.55 or higher, one or more of the explanatory variables may need to be removed and the model retested. For the analysis conducted for these manuscripts, no significant correlation was detected among the covariables (Appendix 2).

Similarly, multicollinearity testing was performed to determine if pairs of predictor variables were highly collinear. The REG procedure in SAS was used to calculate the Condition Index for the explanatory variables used in the analysis. The Condition Index is the square root of the ratio of the largest eigenvalue (5.69) to each individual eigenvalue. A value greater than 30 indicates that there are one or more dependencies or near dependencies among the variables, i.e. the possible presence of collinearity. Results

of the test are shown in Table 2.2. No evidence of collinearity was observed among the covariates.

Table 2.2. Collinearity Diagnostics

Collinearity Diagnostics									
			Proportion of variation						
Eigen-value	Condition Index	Intercept	Sex	Age	Priors	BAC	Median Income	Race	County
5.69	1.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01
0.62	3.01	0.00	0.00	0.18	0.73	0.00	0.00	0.00	0.00
0.50	3.35	0.00	0.00	0.58	0.14	0.17	0.00	0.02	0.01
0.47	3.45	0.00	0.01	0.01	0.00	0.00	0.00	0.53	0.15
0.29	4.38	0.01	0.01	0.12	0.05	0.66	0.01	0.08	0.20
0.23	4.88	0.00	0.69	0.03	0.05	0.03	0.00	0.02	0.21
0.11	6.97	0.03	0.14	0.02	0.01	0.06	0.45	0.24	0.38
0.03	12.43	0.96	0.14	0.05	0.02	0.06	0.53	0.07	0.04

Statistical Analysis

Comparative Analysis (Aim 1)

Comparisons between the interlock and control groups were made with respect to sex, age, race, BAC level at time of initial arrest, median income of zip code of residence, prior violations, and county of arrest. Differences between the groups on continuous variables were identified through the t-test. The chi-square test was used for categorical variables.

Survival Analysis to compare the risk of a subsequent AID citation (Aims 2, 2a, and 2b)

The Cox proportional hazards model was used for three analyses: 1) an overall comparison to determine the rate of a subsequent AID citation in the interlock group as compared to the control group; 2) a comparison of the rates of a subsequent AID citation

for drivers in the study population during the time the interlock was installed on the vehicle compared to the time when it was not; and 3) a comparison of the rates of a subsequent AID citation for drivers in the interlock group for the period of time after the device had been removed from the vehicle as compared to a comparable period of time for drivers in the control group.

For the first analysis, a weighted model, based on propensity scores, was estimated to balance the study groups with respect to the identified covariables. For the second analysis, a time-dependent variable was created through the use of programming statements in the PHREG procedure (Allison, 2010). This variable is set to 1 while a driver has the interlock device installed in their vehicle and to 0 when it is not installed. A weighted model, controlling for the identified covariables and study group, was used to estimate the hazard of receiving a subsequent AID citation while the device was installed. For the third analysis, controls were matched to cases by propensity score to identify a time interval in the controls that was similar to the time interval between citation and device removal among drivers in the interlock group. A comparison was made between the interlock and control groups based on removal time as the new index date.

For each of the three comparisons, one model was estimated using only the outcome of interest and a second to estimate the outcome of interest while controlling for the contribution of the identified covariates.

Survival Analysis to compare the risk of a subsequent AID-related crash (Aims 3, 3a, and 3b)

As described above, the Cox proportional hazards model was used for three analyses: 1) an overall comparison of the rate of a subsequent AID-related crash in the interlock

group as compared to the control group; 2) a comparison of the rates of a subsequent AID-related crash for drivers in the study population during the time the interlock was installed on the vehicle compared to the time when it was not; and 3) a comparison of the rates of a subsequent AID-related crash for drivers in the interlock group for the period of time after the device had been removed from the vehicle as compared to a comparable period of time for drivers in the control group. Statistical significance in the Cox models was defined as a 95% confidence interval for the hazard ratio that excludes 1.0.

Approval was obtained from the University of Maryland's Institutional Review Board for this analysis and the use of these databases. SAS software (version 9.3; SAS Institute Inc., Cary, NC) was used for all data analyses.

Chapter III: Impaired driving recidivism in Maryland. The effectiveness of an ignition interlock device in preventing repeat alcohol impaired driving offenses.

A. Abstract

Objective: To compare the characteristics of Maryland drivers who install an ignition interlock device on their vehicle after being issued an Order of Suspension (OS) for alcohol impaired driving (interlock group) to those who did not (control group) and to compare the rates of receiving a subsequent AID citation between the two groups.

Methods: Using records of the Maryland Motor Vehicle Administration, drivers were identified who had received an OS that was issued in conjunction with an AID citation between January 1, 2008 and December 31, 2015. Those who installed an ignition interlock device on their vehicle within a year of receiving the OS (interlock group) were compared to the control group (drivers who received an OS but did not install an ignition interlock device on their vehicle) with respect to the risk of receiving a subsequent AID citation.

Results: There were 28,123 drivers in the interlock group and 74,618 in the control group. Forty-six percent of those installing an ignition interlock device had a blood alcohol concentration (BAC) above 0.15 g/dL as compared with 25% in the control group ($p<0.05$). Additionally, the BAC test refusal rate was higher among interlock installers (41.4% vs 33.0%, $p<0.05$). While the device was installed on the driver's vehicle, drivers were 22% less likely to receive an impaired driving citation as compared to the time when the device was not installed (HR=0.78; 95% CI:0.73-0.84). However, an

examination of the time period after the interlock device had been removed from the vehicle, revealed that those in the interlock group were 32% more likely to receive an impaired driving citation than those in the control group (HR=1.32; 95% CI: 1.22-1.42).

Conclusion: Drivers who install an ignition interlock device on their vehicle have a lower risk of receiving a subsequent AID citation while the device is on the vehicle as compared to the control group. Upon removal, however, the risk of a subsequent AID citation is higher for those who had an interlock device as compared to those who did not. This suggests that ignition interlock devices are effective only for the relatively short time they are actively used. Ignition interlock devices should not be the only tool used to prevent repeat AID behavior that may lead to a subsequent citation. Additional treatment options or sanctions should be considered to help maintain safe driving behavior among persons who have a history of AID.

B. Background

Alcohol reduces brain function and results in impaired thinking and loss of muscle coordination, both important components of successfully operating a motor vehicle (NIAAA, 2016)

As alcohol levels in a person's system increase, the effects on the central nervous system correspondingly increase. When alcohol is consumed, it is absorbed directly through the walls of the stomach, passing into the bloodstream before being metabolized by the liver. A person's blood alcohol concentration (BAC) is measured by the weight of alcohol in a certain volume of blood. According to the National Highway Traffic Safety

Administration (NHTSA), having a BAC of 0.08 grams of alcohol per deciliter of blood significantly increases a person's crash risk and is currently the legal limit in all states for persons age 21 and over (NHTSA, 2017). However, even a small amount of alcohol can affect driving ability.

Significant progress has been made over the past 30 years in reducing the number of alcohol impaired driving (AID) related crashes and fatalities in the United States. The implementation of strong impaired driving laws in states across the nation has played a critical role in this reduction (Voas and Tippetts, 1999 and Zador, 1989). The enactment of these laws was accompanied by high visibility law enforcement campaigns strengthening the perception that drivers will be arrested if they are found to be operating a motor vehicle while under the influence of alcohol or drugs (Lacey, 1990 and Wells, 1992). These enforcement campaigns included the use of sobriety checkpoints and saturation patrols, both of which have been shown to reduce impaired driving at the local level (Bergen, 2014; Fell, 2008).

Another tool that is increasingly being used to reduce impaired driving is the ignition interlock. The interlock device is designed to prevent drivers from starting their vehicles if they have been drinking. A driver is required to blow into a breath testing device prior to starting his or her vehicle and again while the vehicle is operating to ensure that the driver is still sober. A review of ignition interlock studies compiled by the Centers for Disease Control and Prevention found that the re-arrest rate for offenders decreased by 67% while the device was installed on the vehicle when compared to drivers who did not have the device installed (Elder, 2011). A more recent study (Kaufman, 2016) examined the impact of state ignition interlock laws on alcohol-related crash deaths in the United

States using the Fatality Analysis Reporting System (FARS) data. States requiring interlocks for all impaired driving convictions had 15% fewer alcohol-related crash fatalities as compared to states without this requirement. While there is sufficient evidence to demonstrate the effectiveness of the device while it is installed on the vehicle, less is known about any lasting effects after its removal. As states pass additional legislation to require the use of ignition interlocks for first time convictions, additional research is needed to determine whether there is a lasting effect of ignition interlock devices on AID.

The objective of this study was to evaluate the effectiveness of the ignition interlock device in reducing subsequent AID citations in Maryland, both while the device is on the vehicle and after it has been removed.

C. Methods

Study Population

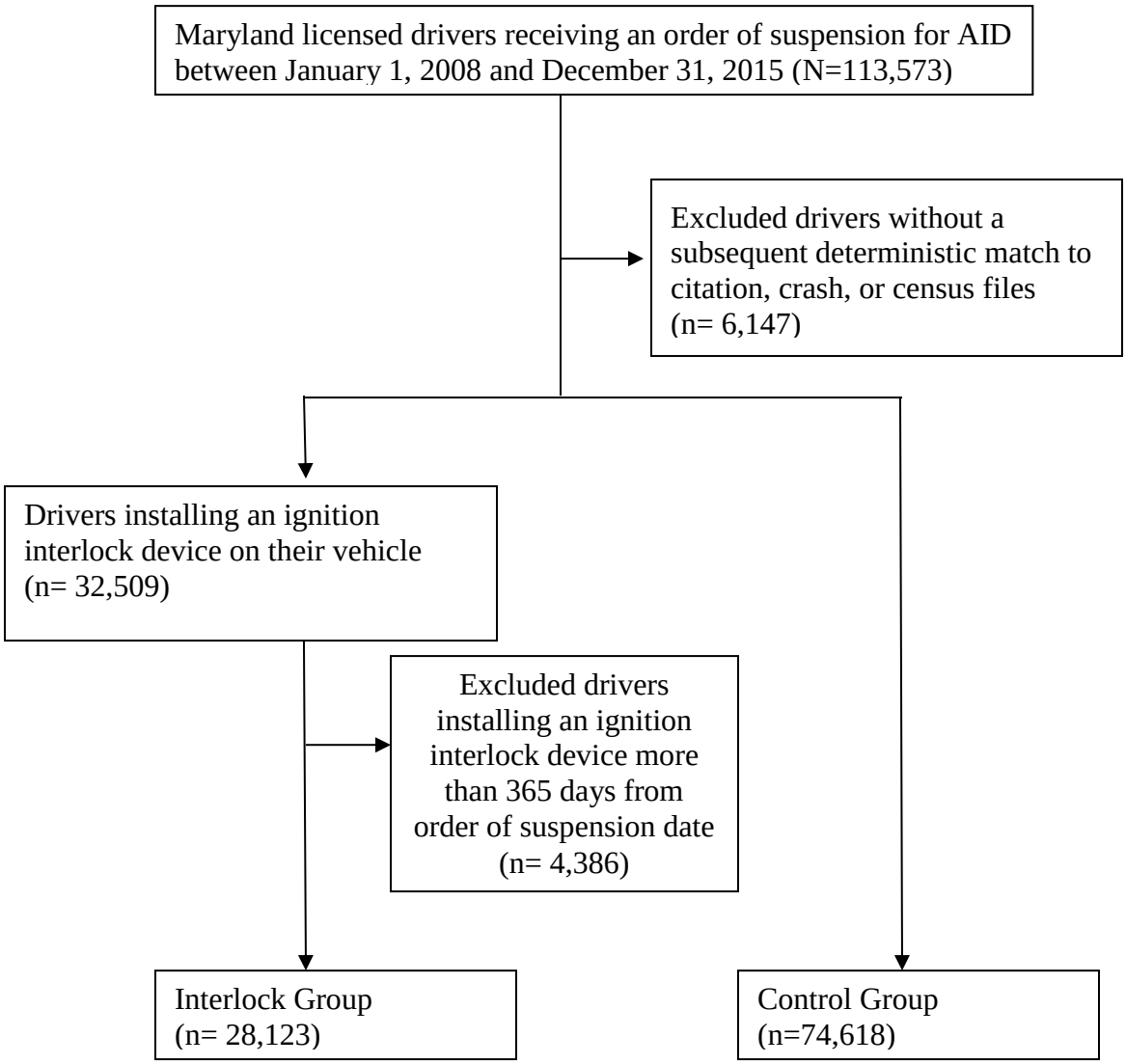
Study subjects were identified through the Maryland Motor Vehicle Administration (MVA) by identifying motor vehicle operators who had received an order of suspension (OS) that was issued in conjunction with an AID citation between January 1, 2008 and December 31, 2015. Persons who did not have a driver license or whose driver license was issued by another state were excluded as follow-up for subsequent citations would not be feasible using the available data sources. The interlock group comprised drivers who received an OS and who installed an ignition interlock device in their vehicle on or after January 1, 2008 and within one year of the date the OS was issued. The control

group comprised drivers who received an OS but did not install an ignition interlock device on their vehicle.

Study Design

This retrospective cohort study used data provided by several state agencies in Maryland to identify and compare the interlock and control groups.

Figure 3.1 Flow diagram showing creation of study groups



Data Sources:

Licensing Records

The MVA maintains a database of all licensed drivers in the State. This database includes basic demographic information, zip code of residence, and the driver license number. Maryland's driver license number is a unique 13-digit alpha-numeric code and was the key linkage variable used to combine the datasets for this analysis. In 2016, there were more than four million licensed drivers in the State.

OS Data

The MVA also maintains information on all drivers who are issued an administrative OS as the result of an AID citation. This dataset provided the driver license number, the date the OS was issued, and the BAC test result associated with the AID citation. In the event that a driver had more than one OS issued for AID, the earliest one was selected for the study.

Ignition Interlock Device Data

Ignition interlock device data are collected by vendors who manage the day-to-day aspects of the program. These data are compiled and submitted to the MVA. For this study, data were provided by the MVA for all persons who had an interlock device installed in their vehicle between January 1, 2008 and December 31, 2015. Data elements included the driver license number, date of installation, date of removal, reason for entry into the interlock program and total number of violations recorded by the ignition interlock device itself (e.g. breath test fails).

Citation Data

Citation data are maintained by the Maryland District Court. As part of a unified court system, the district courts are the primary method of adjudication for impaired driving arrests and collect data on all traffic citations issued by Maryland law enforcement agencies. Data elements include driver license number, date of citation, and county of citation.

Census Data

The United States Census Bureau collects information related to median household income of the nation's population as part of the decennial census. This value is available by geographic area, including zip code.

Data Linkage

To compile the dataset for analysis, OS data were linked to the licensing records provided by the MVA. This combined data set was then linked to the ignition interlock device data to identify drivers who had installed an ignition interlock device on their vehicle within 365 days of the OS date. The resultant database was then linked to the citation data to identify the AID citation that was issued in association with the OS, any previous citations that may have been issued to the driver between January 2000 and the OS date, and subsequent citations that were issued to the driver. Finally, this database was linked to the decennial census data to provide the median income in the driver's zip code of residence. Zip code of residence was used to link the study database with the

census information. All other linkages were made using the individual's driver license number.

Outcome Variable

For each driver, the citation data was searched to identify citations issued for a violation of Maryland's impaired driving statute that occurred subsequent to the OS date. Time to a subsequent AID citation was the time from the driver's OS date through the end of the study period (December 31, 2015). Follow-up was censored at the time of a subsequent AID citation or the end of the follow-up period, whichever occurred first.

Covariables

Based on literature that indicates a potential association with AID events or with their likelihood of installing an interlock device, several independent variables were identified and included in the statistical analysis (Table 3.1). Previous research has shown that males are more likely to be repeat AID offenders than females and older drivers are at greater risk (Caviaola, 2003; Lapham, 2000). There also appears to be a relationship between race and subsequent AID, however, this relationship varies by region in the United States (Chang, 1996 and Nochajski, 2006). Nationwide, 35% of all impaired driving convictions are for drivers with at least one previous impaired driving conviction in the preceding 7 years (Schell, 2006). Other studies have found that while impaired driving offenders represent a wide range of income levels, repeat offenders tend to have lower incomes than first offenders (Nochajski 2006; Beirness 1997).

Table 3.1: Description and source of covariables

Variables	Description	Source
Age	Driver age as of OS issue date	MVA
Blood alcohol content 0.00-0.07 g/dL 0.08-0.14 g/dL 0.15 g/dL or greater Refused test	The most commonly used metric of alcohol intoxication. Maryland's legal limit is 0.08 g/dL. Test refusals were also included as an additional category	MVA – order of suspension
County of initial AID offense Urban Rural	Urban/rural status of Maryland county in which the AID offense occurred Urban – Greater than 80% of county population lives in an urban center as defined by Maryland Department of Planning	Maryland District Court
Race White Black Other	Race as categorized on the driver license	MVA
Sex Male Female	Sex as categorized on the driver license	MVA
Priors 0 1-2 3 or more	Number of citations issued to drivers prior to the order of suspension for speeding, impaired driving, failure to wear seat belt, driving while suspended or revoked	Maryland District Court
Median Income Less than $50,000 $50,000-$99,999 $100,000-$149,999 $150,000 or greater	Median income in driver's zip code of residence	U.S. Census Bureau

For this study, prior citations were defined as- the total number of citations received by the study drivers between January 1, 2000 and the OS date. Four violation types were included: impaired driving, failure to wear a seatbelt, speeding, and driving while

suspended or revoked. These violations have been shown to contribute to motor vehicle fatalities in the United States (IIHS, 2015).

Approval was obtained from the University of Maryland's Institutional Review Board for this analysis and the use of these databases. SAS software (version 9.3; SAS Institute Inc., Cary, NC) was used for all data analyses.

Statistical Analysis

To identify differences in the characteristics of drivers in the interlock and control groups, unweighted comparisons were made with respect to sex, age, race, BAC level at time of initial OS, prior violations, median income of zip code of residence, and county of citation. Differences between continuous variables were identified through the t-test; the chi-square test was used for categorical variables.

Propensity scores were used to account for differences between the groups. As defined by Rosenbaum (1985), propensity scores are predicted values that reflect the probability that a subject was included in the treated (interlock) group. For this study, age, median income in the driver's zip code of residence, prior citations, BAC level associated with the OS, sex, race, and county of citation were included in a logistic regression model that calculated the propensity scores for drivers in both study groups. The inverse of the propensity score was used to calculate weights that were applied to each subject. In time-to-event analyses, this method has been shown to be more effective in reducing bias than other applications of the propensity score (Austin, 2013).

A Cox proportional hazards model was used to compare the rate of a subsequent AID citation among those in the interlock group to those in the control group for a period of

up to 7 years after the OS date while controlling for age, sex, race, median income in the zip code of residence, county of arrest, prior citations, and BAC level. An inverse probability of treatment weights (IPTW) was used where the weight for subjects in the interlock group is defined as the inverse of the subject's propensity score (1/PS), while the weight of the control subjects is defined as the inverse of one minus the propensity score (1/(1-PS)). Follow-up was conducted from the index date through the date of a subsequent AID citation or the end of the study period (December 31, 2015).

The Cox proportional hazards model was used for two additional analyses based on the use of the ignition interlock device. First, for a comparison of the rates of a subsequent AID citation for drivers in the study population during the time the interlock was installed on the vehicle compared to the time when it was not. Second, for a comparison of the rates of a subsequent AID citation for drivers in the interlock group for the period of time after the device had been removed from the vehicle as compared to a comparable period of time for drivers in the control group.

To determine the effectiveness of the ignition interlock device while installed on the vehicle, a time-dependent variable was created through the use of programming statements in the PHREG procedure (Allison, 2010). This variable is set to 1 while the driver has the interlock device installed in their vehicle and to 0 when it is not installed.

To make comparisons between the study groups for the time period after the interlock device was removed from the vehicle in the interlock group, a matched data set was created. Drivers in the control group were matched to drivers from the interlock group two or three to one, based on their individual propensity scores. For drivers in the interlock group, the number of days from their initial OS until removal of the device was

calculated. This number was then added to the initial OS date for each of their matched controls. By doing so, a comparable time interval was established for the drivers in the control group time that was similar to the time period from the OS to removal of the ignition interlock device for those in the interlock group.

D. Results

As shown in Figure 3.1, there were 113,573 Maryland licensed drivers who were issued an OS for AID in Maryland between January 1, 2008 and December 31, 2015. Of those, 107,426 (94.6%) were linked to the licensing, citation, and crash data to provide additional demographic and behavioral characteristics. Thirty percent (32,509) subsequently installed an ignition interlock device on their vehicle between January 1, 2008 and December 31, 2015. The remaining 74,618 drivers did not install an interlock on their vehicle subsequent to their OS (control group). The majority of drivers who installed an interlock device did so within one year of their OS date. To maintain proximity with the OS date, subjects who installed the interlock device more than 365 days after they received their OS (n=4,386) were excluded. This left the final interlock group with 28,123 subjects. The median length of ignition interlock device installation for the interlock group was 425 days. The median follow-up period for both the interlock group (1,424 days) and control group (1,489 days) was approximately four years with ranges from 12 to 2,920 days.

The distribution of the propensity scores for the interlock and control groups were compared using a box plot. The box plots indicated significant overlap of propensity

scores between the two groups which indicated that individual observations from both the interlock and control were available across the range of the PS scores.

Demographic characteristics

There were 28,123 drivers in the interlock group and 74,618 in the control group (Figure 3.1). The interlock group had a lower proportion of females (22.2%) than the control group (24.2%), and a higher mean age than the control group (36.5 years vs 34.3 years, respectively) (Table 3.2). Interlock participants were also more likely to have a higher BAC level at the time of their initial OS than the control group. More than 46% of those in the interlock group had a BAC of 0.15 g/dL or above as compared with 24.7% in the control group. Additionally, the BAC test refusal rate was higher in the interlock group than in the control group (41.4% vs 33.0%, respectively). A higher proportion of those with three or more prior citations installed an interlock device (43.8%) as compared to the control group (36.6%).

Table 3.2. Characteristics of study subjects, by study group

Characteristic	Overall (n=102,741)		Interlock (n=28,123)		Control (n=74,618)	
	n	%	n	%	n	%
Sex						
Male	78,411	76.3	21,869	77.8	56,542	75.8
Female	24,330	23.7	6,254	22.2	18,076	24.2
Age Groups						
<21 years	6,043	5.9	1,360	4.8	4,683	6.3
21-34 years	52,109	50.7	12,846	45.7	39,263	52.6
35-49 years	29,412	28.6	9,095	32.3	20,317	27.2
50-64 years	13,522	13.2	4,365	15.5	9,157	12.3
≥65 years	1,655	1.6	457	1.6	1,198	1.6
Race						
Black	26,546	25.8	4,735	16.8	21,811	29.2
White	59,421	57.8	19,234	68.4	40,187	53.9
Other	16,774	16.3	4,154	14.8	12,620	16.9
Median income in zip code of residence						
Less than $50,000	11,443	11.1	2,576	9.2	8,867	11.9
$50,000-$99,999	74,368	72.4	20,393	72.5	53,975	72.3
$100,000-$149,999	15,700	15.3	4,800	17.1	10,900	14.6
$150,000 or more	1,230	1.2	354	1.3	876	1.2
County of arrest						
Rural	31,044	30.2	8,325	29.6	22,719	30.4
Urban	71,697	69.8	19,798	70.4	51,899	69.6
Prior citations						
0	28,019	27.3	6,397	22.8	21,622	29.0
1-2	35,060	34.1	9,397	33.4	25,663	34.4
3 or more	39,662	38.6	12,329	43.8	27,333	36.6
BAC level						
0.15 g/dL or greater	31,390	30.6	12,976	46.1	18,414	24.7
0.08-0.14 g/dL	35,017	34.1	3,490	12.4	31,527	42.3
0.00-0.07 g/dL	57	0.1	6	<0.1	51	0.1
Refused BAC test	36,277	35.3	11,651	41.4	24,626	33.0
Mean age (years ± SD)	34.9±12.3		36.5±12.2		34.3±12.3	

During follow-up, 12,473 study drivers received an AID citation subsequent to their OS date, 12.0% of those in the interlock group and 12.1% of those in the control group (p=0.96) (Table 3.3).

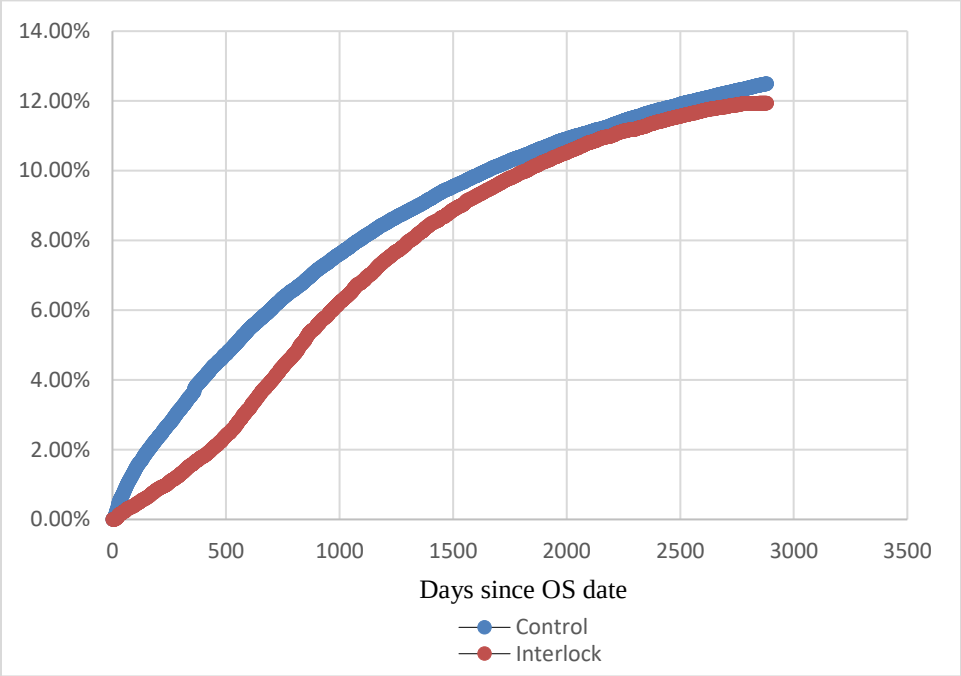
Table 3.3. Characteristics of drivers with a subsequent AID citation

		Subsequent AID citation		
Characteristics	N	n	%	p-value
Study group				
Interlock	28,123	3,412	12.0	0.96
Control	74,618	9,061	12.1	
Sex				
Male	78,411	10,114	12.9	<0.01
Female	24,330	2,359	9.7	
Age groups				
Less than 21 years	6,043	925	15.3	<0.01
21-34 years	52,109	6,514	12.5	
35-49 years	29,412	3,596	12.2	
50-64 years	13,522	1,302	9.6	
65+ years	1,655	135	8.2	
Race				
Black	26,546	3,633	13.7	<0.01
White	59,421	6,593	11.1	
Other	16,774	2,247	13.4	
Median income in zip code of residence				
Less than $50,000	11,443	1,330	11.4	<0.01
$50,000-$99,999	74,368	9,274	12.5	
$100,000-$149,999	15,700	1,782	11.4	
$150,000 or more	1,230	117	9.5	
County of arrest				
Rural	31,044	4,000	12.9	<0.01
Urban	71,697	8,473	11.8	
Prior citations				
0	28,019	3,114	11.1	<0.01
1-2	35,060	3,885	11.1	
3 or more	39,662	5,474	13.8	
BAC level				
≥0.15g/dL	31,390	3,994	12.7	<0.01
0.08-0.14g/dL	35,017	3,483	10.0	
0.00-0.07 g/dL	57	11	19.3	
Refused BAC test	36,277	4,985	13.7	

Survival Analysis

Toward the start of the follow-up period, drivers in the interlock group have a lower frequency of subsequent AID citations than in the control group (Figure 3.2). As follow-up progresses, the frequency of subsequent AID citations rises to the level of the controls.

Figure 3.2: Cumulative recidivism rates for the study groups over 7-year follow-up



The Cox proportional hazards model was used for three analyses: 1) an overall comparison to determine the rate of a subsequent AID citation in the interlock group as compared to the control group; 2) a comparison of the rates of a subsequent AID citation for drivers in the study population during the time the interlock was installed on the vehicle compared to the time when it was not; and 3) a comparison of the rates of a subsequent AID citation for drivers in the interlock group for the period of time after the device had been removed from the vehicle as compared to a comparable period of time for drivers in the control group.

For the first analysis, a weighted model, based on propensity scores, was estimated to balance the study groups with respect to the covariables described in Table 3.1. No

differences were noted between the interlock and control group with respect to receiving a subsequent AID citation (HR=1.01; CI: 0.98-1.05, p=.49) (Table 3.4).

For the second analysis, a time-dependent variable was created through the use of programming statements in the PHREG procedure (Allison, 2010). This variable was set to 1 while a driver has the interlock device installed in their vehicle and to 0 when it is not installed. A weighted model was used to estimate the hazard of receiving a subsequent AID citation while the device was installed. While the interlock was installed on the vehicle, study subjects were 22% less likely to receive a citation for AID as compared to the time the device was not installed on the vehicle (HR=0.78; CI:0.73-0.84) (Table 3.5).

For the third analysis, controls were matched to cases by propensity score in order to identify a time interval in the controls similar to that of the interlock cases between citation and device removal. A comparison was made between the interlock and control groups based on removal time of the ignition interlock device as the new index date. After removal of the ignition interlock device, subjects in the interlock group were 32% more likely to receive a subsequent AID citation as compared to the control group (HR=1.32; CI: 1.22-1.42, p<0.01) (Table 3.6).

Table 3.4 Results of adjusted Cox proportional hazards analysis

Characteristic	Hazard Ratio	95% Confidence Interval	p value
Study Group			
Control	Reference		
Interlock	1.01	0.98-1.05	0.49
Sex			
Female	Reference	1.15-1.25	<0.01
Male	1.20		
Age (per year increase)	0.990	0.989-0.992	<0.01
Race			
Black	Reference		
White	0.70	0.67-0.73	<0.01
Other	0.99	0.94-1.04	0.64
Median income in zip code of residence			
$25,000-$49,999	Reference		
$50,000-$99,999	1.15	1.09-1.21	<0.01
$100,000-$149,999	1.08	1.01-1.15	0.03
$150,000-$199,999	0.90	0.75-1.08	0.26
County of arrest			
Rural	Reference		
Urban	0.86	0.83-0.90	<0.01
Prior citations			
0	Reference		
1-2	0.97	0.93-1.02	0.24
3 or more	1.21	1.16-1.27	<0.01
BAC level			
0.00-0.07 g/dL	1.94	1.23-3.05	<0.01
0.08-0.14g/dL	Reference		
0.15g/dL or more	1.24	1.19-1.29	<0.01
Refused	1.43	1.38-1.49	<0.01

Table 3.5. Results of adjusted* Cox proportional hazards model – interlock installed

Time	Hazard Ratio	95% Confidence Interval	p value
Interlock installed Yes No	 0.78 Reference	 0.73-0.84	 <0.01

*****Adjusted hazard ratio obtained from Cox models controlling for study group, demographic, and behavioral factors as described in Table 3.1

Table 3.6. Results of adjusted* Cox proportional hazards model – post interlock removal

Time	Hazard Ratio	95% Confidence Interval	p value
Study Group Interlock Control	 1.32 Reference	 1.22-1.42	 <0.01

*****Adjusted hazard ratio obtained from Cox models controlling for demographic and behavioral factors as described in Table 3.1

E. Discussion

Drivers in the interlock group were older, more likely to be white, and more likely to live in a zip code with a higher median income than those in the control group. Drivers in the interlock group were also more likely to have received multiple citations for a combination of illegal driving behaviors including AID, driving while unrestrained, speeding, and driving while their license was suspended or revoked. These findings are consistent with earlier findings (Marine, 2001; Bierness, 2004).

Cox proportional hazards analysis indicated no differences in the risk of a subsequent AID citation between the interlock and control groups. This finding was surprising as interlock devices are widely accepted as effective deterrents to impaired driving (Elder, 2011). However, additional analysis showed that the ignition interlock devices are an effective deterrent to subsequent AID while they are installed on the vehicle as

demonstrated by a 22% reduction in the rate of subsequent AID citations while the device was installed on the vehicle (HR=0.78; CI:0.73-0.84). While this is not as dramatic a change as has been reported in other studies, (Voas and Marques, 2003; Willis, 2005), it does represent a significant impact of the use of an ignition interlock device in this study population.

After removal of the device, however, drivers in the interlock group exhibited a higher risk for a subsequent AID citation than drivers in the control group (HR=1.32; CI: 1.22-1.42, $p<0.01$). Prior studies have also noticed a tendency for those who had installed ignition interlock devices to see an increase in their number of subsequent AID citations after removal (Willis, 2006) but many of those studies have either a limited follow-up, or relatively few subjects in the interlock group.

The strengths of this study include the use of large administrative databases providing a large sample size to evaluate the effect of using an ignition interlock device to deter future AID. Also, the ability to use impaired driving citations allows the identification of a larger number of recidivists than in previous studies by capturing all persons who are arrested for AID in Maryland, not just those who are convicted. This study also has a longer follow-up period, especially post-removal of the ignition interlock device than many previous studies. In the absence of randomization, the use of propensity scores helped to balance the preexisting characteristics of the interlock and control groups, to the extent possible, through weighting and matching techniques (Austin, 2013).

This study has several limitations. First, since this was a retrospective study, it was not possible to randomize the drivers to the treatment and control groups. Despite the use of propensity scores to balance subject characteristics between the two groups, there may

still be unmeasured confounders that affect a both the subjects' installation of an ignition interlock device and their likelihood of experiencing a second AID violation. Second, there is no good measure of exposure in terms of vehicle miles traveled. A license suspension as the result of an AID citation may result in fewer trips driven, whereas the installation of an interlock device allows a person to drive legally and to resume their normal driving patterns. Capturing odometer readings is not feasible as those who are required to have an ignition interlock device in their vehicle may drive a friend's or family member's car rather than their own. Also, drivers who died or left the state during the follow-up period are not identified in the records available for analysis. While this is likely an insignificant number, any effect they would have is unmeasured. Third, information was not available with regard to other court sanctions or to other forms of treatment (i.e. education classes) that may have been utilized by the study subjects. Some ignition interlock programs (e.g. Florida and Nova Scotia) incorporate additional alcohol treatment into their ignition interlock programs (Vanlaar, 2017; Voas, 2016). In both places, recidivism rates remained low even after removal of the interlock device.

When policy makers and legislators are developing policies and legislation related to an ignition interlock program, a further identification of the characteristics associated with AID recidivism should be considered. Additional sanctions could involve extending the device installation time or a requirement for the drivers to participate in other treatment programs that may more directly affect their misuse of alcohol.

While ignition interlock devices are an important tool for the short-term prevention of future AID driving behaviors, since their effectiveness significantly diminishes after removal, additional measures must be considered to reduce the risk of future AID events.

Chapter IV: Effect of ignition interlock devices in reducing subsequent impaired driving crashes in Maryland.

A. Abstract

Objective: To compare the rates of a subsequent alcohol impaired driving (AID) related crash between drivers with an Order of Suspension (OS) for AID who installed an ignition interlock device on their vehicle and drivers with an OS for AID who did not install an ignition interlock device.

Methods: Using data from the Maryland Motor Vehicle Administration, drivers were identified who had received an OS that was issued in conjunction with an AID citation between January 1, 2008 and December 31, 2015. The interlock group (those who installed an ignition interlock device on their vehicle) were compared to a control group who received an OS but did not install a device on their vehicle. The relative risk of involvement in a subsequent AID-related crash between the OS date and the end of the study period was determined by comparing the groups through the use of a weighted Cox proportional hazards model.

Results: There were 28,123 drivers in the interlock group and 74,618 in the control group. Of those in the interlock group, 2.5% had a subsequent AID-related crash as compared to a similar percentage in the control group (2.5%). While the interlock device was installed on the vehicle, drivers were 29% less likely to be involved in a subsequent AID-related crash as compared to when the device was not installed. After removal of the interlock device, however, no differences in the rate of subsequent AID-

related crashes was observed between the interlock and control groups (HR=1.14; CI: 0.96-1.35, p=0.14).

Conclusion: Drivers with an OS who have an ignition interlock device installed their vehicle have a lower rate of involvement in a subsequent AID-related crash during the time in which the device is installed. Ignition interlock devices are an effective tool for the reduction of AID-related crashes while they are installed on the vehicle but the effects are not sustained once they are removed from the vehicle.

B. Background

According to the Centers for Disease Control and Prevention, 28 people in the United States die each day as the result of a motor vehicle crash involving alcohol impaired driving (AID) (CDC, 2015). These crashes result in an annual cost of over $44 billion in medical care, legal fees, travel delays, and lost productivity (Blincoe, 2015). The National Highway Traffic Safety Administration reported that 10,265 people died in AID crashes in 2015, accounting for almost 30% of all motor vehicle fatalities in the country (NHTSA, 2016). This number has remained fairly steady since 2010.

Ignition interlock devices are increasingly being used as a primary intervention in the fight against AID. As of 2016, all 50 states have some form of ignition interlock law in place (McGinty, 2016). These laws range from mandatory installation of interlocks for all persons who are convicted of AID to more permissive regulations that leave the installation of an interlock up to the discretion of the judge or administrative official. While much information is available on the effectiveness of the device at reducing

subsequent AID citations while the device is on the vehicle (Beck, 1999; Roth, 2007; Casanova-Powell, 2015), much less is known about its overall effectiveness on subsequent motor vehicle crashes involving AID or its specific effectiveness while it is installed on the vehicle (Vezina, 2002).

Maryland drivers who operate a motor vehicle while impaired by alcohol and other drugs continue to cause irreparable harm to individuals, families, and communities across the State. Over the past five years, Maryland has averaged more than 7,800 AID crashes annually, resulting in over 4,000 injuries and more than 170 fatalities each year.

This loss of life as the result of AID represents approximately one-third of Maryland's traffic fatalities. To address this problem, Maryland has developed an administrative and legislative approach that combines strict laws with license sanctions, an ignition interlock program, high-visibility law enforcement, public outreach campaigns, and an increase in the alcohol tax that are all aimed at reducing AID behavior. The objective of this study was to determine the overall effectiveness of the ignition interlock device in reducing the occurrence of AID-related crashes among Maryland drivers and to determine its effectiveness in preventing AID-related crashes while it is on the vehicle.

C. Methods

Study Population

Study subjects were identified through the Maryland Motor Vehicle Administration (MVA) by identifying motor vehicle operators who had received an order of suspension (OS) that was issued in conjunction with an AID citation between January 1, 2008 and December 31, 2015. Persons who did not have a driver license or whose driver license

was issued by another state were excluded as follow-up for subsequent citations would not be feasible using the available data sources. The interlock group comprised drivers who received an OS and who installed an ignition interlock device in their vehicle on or after January 1, 2008 and within one year of the date the OS was issued. The control group comprised drivers who received an OS but did not install an ignition interlock device on their vehicle.

Study Design

This retrospective cohort study uses data provided by several state agencies in Maryland to compare the characteristics of the interlock and the control groups. These data were also used to compare the two study groups with respect to the rate of involvement in an AID-related motor vehicle crash after their OS date.

Data Sources:

Licensing Records

The MVA maintains a database of all licensed drivers in the State. This database includes basic demographic information, zip code of residence, and the driver license number. Maryland's driver license number is a unique 13-digit alpha-numeric code and was the key linkage variable used to combine the datasets for this analysis. In 2016, there were more than four million licensed drivers in the State.

OS Data

The MVA also maintains information on all drivers who are issued an administrative OS as the result of an AID citation. This dataset provided the driver license number, the date the OS was issued, and the BAC test result associated with the AID citation. In the event that a driver had more than one OS issued for AID, the earliest one was selected for the study.

Ignition Interlock Device Data

Ignition interlock device data are collected by vendors who manage the day-to-day aspects of the program. These data are compiled and submitted to the MVA. For this study, data were provided by the MVA for all persons who had an interlock device installed in their vehicle between January 1, 2008 and December 31, 2015. Data elements included the driver license number, date of installation, date of removal, reason for entry into the interlock program and total number of violations recorded by the ignition interlock device itself (e.g. breath test fails).

Citation Data

Citation data are maintained by the Maryland District Court. As part of a unified court system, the district courts are the primary method of adjudication for impaired driving arrests and collect data on all traffic citations issued by Maryland law enforcement agencies. Data elements include driver license number, date of citation, and county of citation.

Crash Data

All crashes in the State of Maryland resulting in a personal injury or tow-away of the disabled vehicle generate a police crash report. By statute, the Maryland State Police are responsible for collecting and maintaining crash report data. From 1993-2014, data were maintained in the Maryland Automated Accident Reporting System (MAARS). Beginning in 2014, the State began transition to the Automated Crash Reporting System (ACRS). Data from both systems were provided for the period January 1, 2008 to December 31, 2015 to allow the identification of drivers who were involved in a crash during that time.

Alcohol involved crashes were identified using the following four data elements on the police crash report.

- Driver condition – 'had been drinking'
- Substance use detected – 'alcohol'
- BAC test result – greater than 0
- Contributing circumstances – 'under the influence of alcohol'

If one or more of these characteristics were indicated on the crash report by the investigating officer, the crash was identified as alcohol involved.

Census Data

The United States Census Bureau collects information related to median household income of the nation's population as part of the decennial census. This value is available by geographic area, including zip code.

Data Linkage

To compile the dataset for analysis, OS data were linked to the licensing records provided by the MVA. This combined data set was then linked to the ignition interlock device data to identify drivers who had installed an ignition interlock device on their vehicle within 365 days of the OS date. The resultant database was then linked to the citation data to identify the AID citation that was issued in association with the OS and any previous citations that may have been issued to the driver between January 2000 and the OS date for the purposes of defining the driver's citation history. An additional linkage was made to the decennial census data to provide the median income in the driver's zip code of residence. Zip code of residence was used to link the study database with the census information. All other linkages were made using the individual's driver license number. Finally, these data were linked to the crash database to determine the time of the first subsequent AID-related crash that occurred between the OS date and the end of the study period (December 31, 2015).

Outcome Variable

The crash data was searched to identify AID-related motor vehicle crashes involving a study subject as the driver.

Covariables

Based on literature that indicates a potential association with AID events or with their likelihood of installing an interlock device, several independent variables were identified and included in the statistical analysis (Table 4.1). Previous research has shown that the

risk of being involved in an AID-related crash is greater for young people than for older people at all levels of alcohol impairment (Zador, 2000). Additionally, among drivers with BAC levels greater than 0.08 g/dL who were involved in a fatal crash in 2014, 30% were between the ages of 21 and 24 years of age and 29% were between the ages of 25 to 34 (NHTSA, 2015).

Several additional variables associated with impaired driving were also included in the statistical analysis (Table 4.1). Previous research has shown that males are more likely to be repeat AID offenders than females and older drivers are also at greater risk (Caviaola, 2003; Lapham, 2000). Additionally, there appears to be a relationship between race and subsequent AID, a relationship that varies by region in the United States (Chang, 1996 and Nochajski, 2006). Nationwide, slightly more than one-third of all impaired driving convictions (35%) are for drivers with at least one previous impaired driving conviction in the preceding 7 years (Schell, 2006). Other studies have found that while impaired driving offenders represent a wide range of income levels, repeat offenders tend to have lower incomes that first offenders (Nochajski 2006; Beirness 1997).

For this study, prior citations were defined as- the total number of citations received by the study drivers between January 1, 2000 and the OS date. Four violation types were included: impaired driving, failure to wear a seatbelt, speeding, and driving while suspended or revoked. These violations have been shown to contribute to motor vehicle fatalities in the United States (IIHS, 2015).

Approval was obtained from the University of Maryland's Institutional Review Board for this analysis and the use of these databases. SAS software (version 9.3; SAS Institute Inc., Cary, NC) was used for all data analyses.

Figure 4.1 Flow diagram showing creation of study groups

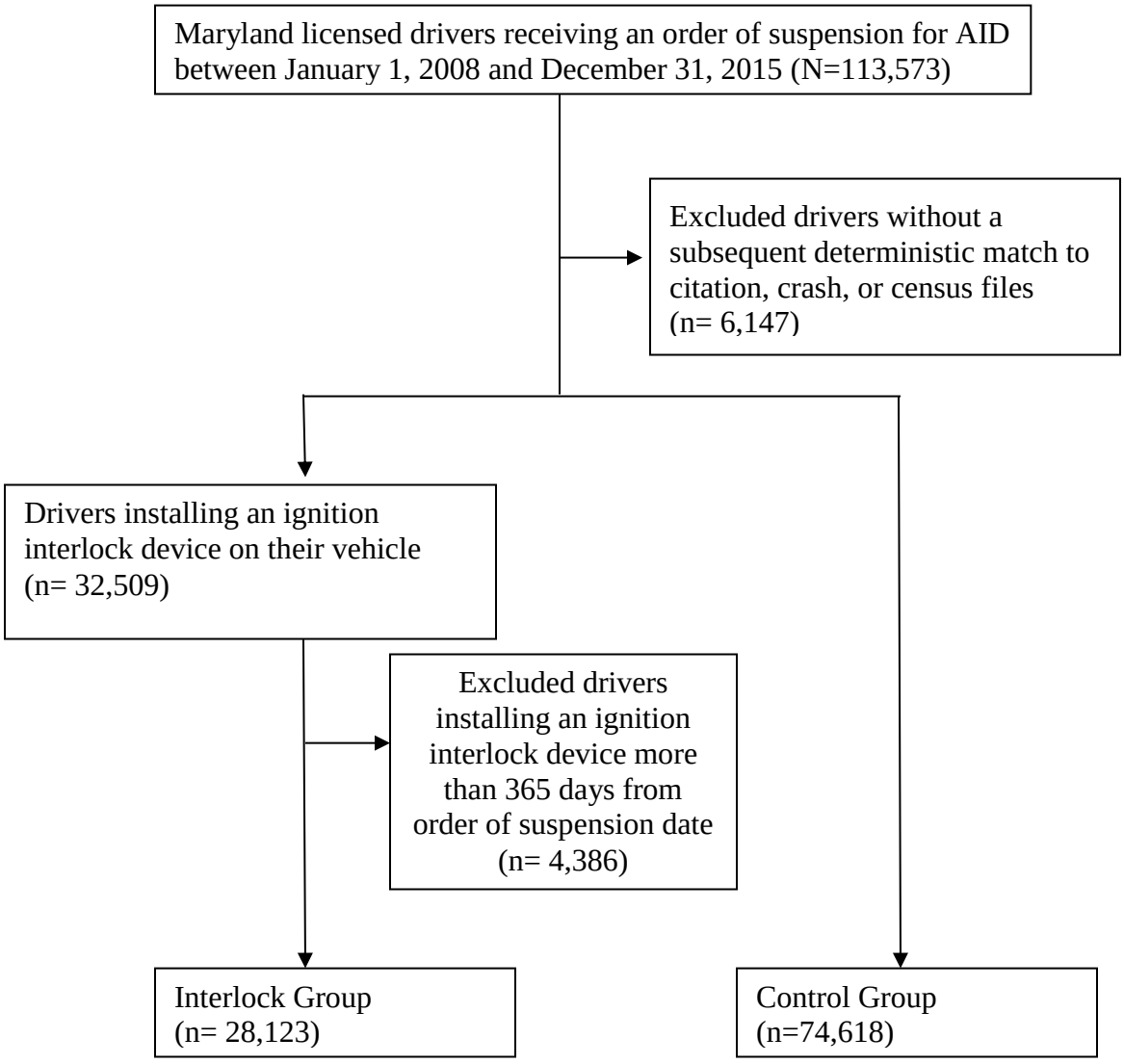


Table 4.1: Description and source of covariables

Variables	Description	Source
Age	Driver age as of OS issue date	MVA
Blood alcohol content 0.00-0.07 g/dL 0.08-0.14 g/dL 0.15 g/dL or greater Refused test	The most commonly used metric of alcohol intoxication. Maryland's legal limit is 0.08 g/dL. Test refusals were also included as an additional category	MVA – order of suspension
County of initial AID offense Urban Rural	Urban/rural status of Maryland county in which the AID offense occurred Urban – Greater than 80% of county population lives in an urban center as defined by Maryland Department of Planning	Maryland District Court
Race White Black Other	Race as categorized on the driver license	MVA
Sex Male Female	Sex as categorized on the driver license	MVA
Priors 0 1-2 3 or more	Number of citations issued to drivers prior to the order of suspension for speeding, impaired driving, failure to wear seat belt, driving while suspended or revoked	Maryland District Court
Median Income Less than $50,000 $50,000-$99,999 $100,000-$149,999 $150,000 or greater	Median income in driver's zip code of residence	U.S. Census Bureau

Statistical Analysis

To identify differences in the characteristics of drivers in the interlock and control groups, unweighted comparisons were made with respect to sex, age, race, BAC level at time of initial OS, prior violations, median income of zip code of residence, and county of citation. Differences between continuous variables were identified through the t-test; the chi-square test was used for categorical variables.

Propensity scores were used to balance the groups with respect to factors that might be related both to the use of interlock devices and to the risk of a subsequent AID-related crash. Propensity scores are predicted values that reflect the probability that a subject was included in the treated (interlock) group (Rosenbaum, 1985). For this study, each of the covariables listed above were included in a logistic regression model that calculated the propensity scores for drivers in both study groups. The inverse of the propensity score (or for control subjects, the inverse of 1-propensity score) was used to calculate weights that were applied to each subject. In time-to-event analyses, this method has been shown to be more effective in reducing bias than other applications of the propensity score (Austin, 2013).

The Cox proportional hazards model was also used for two additional analyses based on the use of the ignition interlock device. First, for a comparison of the rates of a subsequent AID-related crash involving drivers in the study population during the time the interlock device was installed on the vehicle compared to the time when it was not. Second, for a comparison of the rates of a subsequent AID-related crash for drivers in the

interlock group for the period of time after the device had been removed from the vehicle as compared to a comparable period of time for drivers in the control group.

To determine the effectiveness of the ignition interlock device while installed on the vehicle, a time-dependent variable was created through the use of programming statements in the PHREG procedure (Allison, 2010). This variable is set to 1 while the driver has the interlock device installed in their vehicle and to 0 when it is not installed.

To make comparisons between the study groups for the time period after the interlock device was removed from the vehicle in the interlock group, a matched data set was created. Drivers in the control group were matched to drivers from the interlock group up to three to one, based on their individual propensity scores. For drivers in the interlock group, the number of days from their initial OS until removal of the device was calculated. This number was then added to the initial OS date for each of their matched controls. By doing so, a comparable time interval was established for the drivers in the control group time that was similar to the time period from the OS to removal of the ignition interlock device for those in the interlock group.

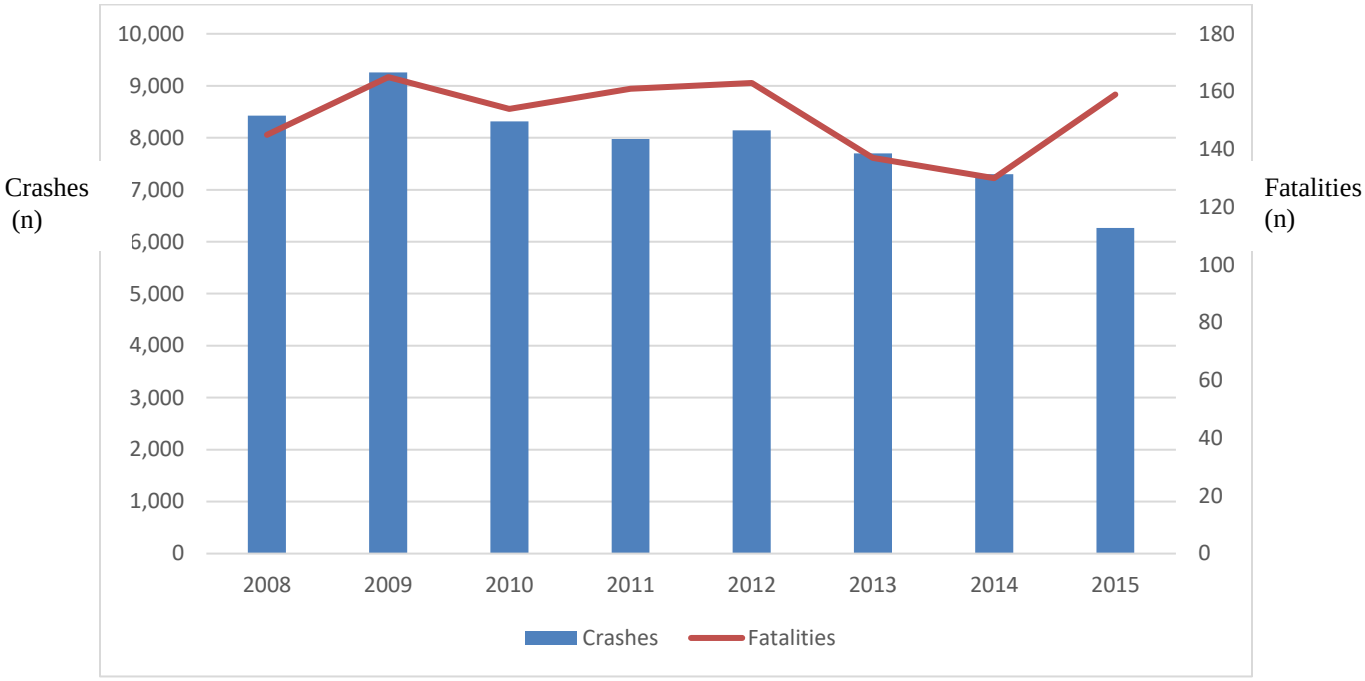
D. Results

As shown in Figure 4.1, there were 113,573 Maryland licensed drivers who were issued an OS for AID in Maryland between January 1, 2008 and December 31, 2015. Of those, 107,426 (94.6%) were linked to the licensing, citation, and crash data to provide additional demographic and behavioral characteristics. Thirty percent (32,509) subsequently installed an ignition interlock device on their vehicle between January 1, 2008 and December 31, 2015. The remaining 74,618 drivers did not install an interlock

on their vehicle subsequent to their OS (control group). The majority of drivers who installed an interlock device did so within one year of their OS date. To maintain proximity with the OS date, subjects who installed the interlock device more than 365 days after they received their OS (n=4,386) were excluded. This left the final interlock group with 28,123 subjects. The median length of ignition interlock device installation for the interlock group was 425 days. The distribution of the propensity scores for the interlock and control groups were compared using a box plot. The box plots indicated significant overlap of propensity scores between the two groups which indicated that individual observations from both the interlock and control were available across the complete range of the propensity scores.

There were, on average, 8,024 AID-related driving crashes annually between 2007 and 2015 (Figure 4.2). During that time period, there were, on average, 155 Maryland fatalities each year in which at least one of the drivers involved in the crash had a BAC level of 0.08 g/dL or higher.

Figure 4.2: Alcohol impaired driving related crashes and fatalities in Maryland 2008-2015



Demographic characteristics

There were 28,123 drivers in the interlock group and 74,618 in the control group (Figure 4.1). The interlock group had a lower proportion of females (22.2%) than the control group (24.2%), and a higher mean age than the control group (36.5 years vs 34.3 years, respectively) (Table 4.2). Interlock participants were also more likely to have a higher BAC level at the time of their initial OS than the control group. More than 46% of those in the interlock group had a BAC of 0.15 g/dL or above as compared with 24.7% in the control group. Additionally, the BAC test refusal rate was higher in the interlock group than in the control group (41.4% vs 33.0%, respectively). A higher proportion of those with three or more prior citations installed an interlock device (43.8%) as compared to the control group (36.6%).

Table 4.2. Characteristics of study subjects, by study group

Characteristic	Overall (n=102,741)		Interlock (n=28,123)		Control (n=74,618)	
	n	%	n	%	n	%
Sex						
Male	78,411	76.3	21,869	77.8	56,542	75.8
Female	24,330	23.7	6,254	22.2	18,076	24.2
Age Groups						
<21 years	6,043	5.9	1,360	4.8	4,683	6.3
21-34 years	52,109	50.7	12,846	45.7	39,263	52.6
35-49 years	29,412	28.6	9,095	32.3	20,317	27.2
50-64 years	13,522	13.2	4,365	15.5	9,157	12.3
≥65 years	1,655	1.6	457	1.6	1,198	1.6
Race						
Black	26,546	25.8	4,735	16.8	21,811	29.2
White	59,421	57.8	19,234	68.4	40,187	53.9
Other	16,774	16.3	4,154	14.8	12,620	16.9
Median income in zip code of residence						
Less than $50,000	11,443	11.1	2,576	9.2	8,867	11.9
$50,000-$99,999	74,368	72.4	20,393	72.5	53,975	72.3
$100,000-$149,999	15,700	15.3	4,800	17.1	10,900	14.6
$150,000 or more	1,230	1.2	354	1.3	876	1.2
County of arrest						
Rural	31,044	30.2	8,325	29.6	22,719	30.4
Urban	71,697	69.8	19,798	70.4	51,899	69.6
Prior citations						
0	28,019	27.3	6,397	22.8	21,622	29.0
1-2	35,060	34.1	9,397	33.4	25,663	34.4
3 or more	39,662	38.6	12,329	43.8	27,333	36.6
BAC level						
0.15 g/dL or greater	31,390	30.6	12,976	46.1	18,414	24.7
0.08-0.14 g/dL	35,017	34.1	3,490	12.4	31,527	42.3
0.00-0.07 g/dL	57	0.1	6	<0.1	51	0.1
Refused BAC test	36,277	35.3	11,651	41.4	24,626	33.0
Mean age (years ± SD)	34.9±12.3		36.5±12.2		34.3±12.3	

Table 4.3. Characteristics of drivers with subsequent AID-related crash

		Subsequent AID crash		
Characteristics	N	n	%	p-value
Study group				
Interlock	28,123	692	2.5	0.49
Control	74,618	1,892	2.5	
Sex				
Male	78,411	2,101	2.7	<0.01
Female	24,330	483	2.0	
Age groups				
Less than 21 years	6,043	205	3.4	<0.01
21-34 years	52,109	1,315	2.5	
35-49 years	29,412	724	2.5	
50-64 years	13,522	307	2.3	
65+ years	1,655	33	2.0	
Race				
Black	26,546	715	2.7	<0.01
White	59,421	1,514	2.6	
Other	16,774	355	2.1	
Median income in zip code of residence				
Less than $50,000	11,443	281	2.5	0.50
$50,000-$99,999	74,368	1,880	2.5	
$100,000-$149,999	15,700	400	2.6	
$150,000 or more	1,230	23	1.9	
County of arrest				
Rural	31,044	753	2.4	0.23
Urban	71,697	1,831	2.6	
Prior citations				
0	28,019	28,019	2.5	<0.01
1-2	35,060	35,060	2.2	
3 or more	39,662	39,662	2.8	
BAC level				
≥0.15g/dL	31,390	865	2.8	<0.01
0.08-0.14g/dL	35,017	645	1.8	
0.00-0.07 g/dL	57	3	5.3	
Refused BAC test	36,277	1,071	3.0	

During the study period, there were 2,584 AID crashes involving drivers in the study groups, 2.5% in the interlock group and 2.5% in the control group (Table 4.3).

Adjusted Analysis

The Cox proportional hazards model was used for three analyses: 1) an overall comparison to determine the rate of a subsequent AID-related crash in the interlock group as compared to the control group; 2) a comparison of the rates of a subsequent AID-related crash for drivers in the study population during the time the interlock was installed on the vehicle compared to the time when it was not; and 3) a comparison of the rates of a subsequent AID-related crash for drivers in the interlock group for the period of time after the device had been removed from the vehicle as compared to a comparable period of time for drivers in the control group.

For the first analysis, a weighted model, based on propensity scores, was estimated to balance the study groups with respect to the covariables described in Table 4.1. Subjects in the interlock group were more likely to be involved in a subsequent AID-related crash as compared to subjects in the control group (HR=0.89; CI: 0.82-0.96, $p<0.01$) (Table 4.4).

For the second analysis, a time-dependent variable was created through the use of programming statements in the PHREG procedure (Allison, 2010). This variable was set to 1 while a driver has the interlock device installed in their vehicle and to 0 when it is not installed. A weighted model was used to estimate the hazard of receiving a subsequent AID-related crash while the device was installed. While the interlock was

installed on the vehicle, study subjects were 29% less likely to be involved in a subsequent AID-related crash as compared to the time the device was not installed on the vehicle (HR=0.71; CI:0.60-0.84, $p<0.01$) (Table 4.5).

For the third analysis, controls were matched to cases in order to identify a time interval in the controls similar to that of the interlock cases between citation and device removal. A comparison was made between the interlock and control groups based on removal time of the ignition interlock device as the new index date. After removal of the ignition interlock device, no difference were noted between the interlock and control groups with respect to a subsequent AID-related crash (HR=1.14; CI: 0.96-1.35, $p=0.14$) (Table 4.6).

Table 4.4 Hazard ratios comparing interlock group to control group

Characteristics	Hazard Ratio	95% Confidence Interval	p value
Interlock			
No	reference		
Yes	0.89	0.82-0.96	<0.01
Sex			
Male	1.34	1.22-1.47	<0.01
Female	reference		
Age (years)	0.992	0.989-0.995	<0.01
Race			
Black	reference		
White	0.98	0.90-1.08	0.73
Other	0.83	0.73-0.93	<0.01
Median income			
Less than $50,000	reference		
$50,000-$99,999	1.05	0.93-1.18	0.47
$100,000- $149,999	1.10	0.95-1.27	0.20
$150,000 or more	0.71	0.47-1.09	0.12
County of Arrest			
Rural	reference		
Urban	1.06	0.98-1.16	0.02
Prior Citations			
0	reference		
1-2	0.90	0.81-0.99	0.03
3 or more	1.08	0.99-1.18	0.10
BAC Level			
0.08-0.14g/dL	reference		
0.15g/dL+	1.47	1.34-1.62	<0.01
0.00-0.07 g/dL	1.47	0.43-5.00	0.54
Refused	1.66	1.51-1.82	<0.01

Table 4.5. Results of adjusted* Cox proportional hazards model – interlock installed

Time	Hazard Ratio	95% Confidence Interval	p value
Interlock installed Yes No	 0.71 Reference	 0.60-0.84	 <0.01

*****Adjusted hazard ratio obtained from Cox models controlling for study group, demographic, and behavioral factors as described in Table 4.1

Table 4.6. Results of adjusted* Cox proportional hazards model – post interlock removal

Time	Hazard Ratio	95% Confidence Interval	p value
Study Group Interlock Control	 1.14 Reference	 0.96-1.35	 0.14

*****Adjusted hazard ratio obtained from Cox models controlling for demographic and behavioral factors as described in Table 4.1

E. Discussion

The goal of this study was to examine the effectiveness of ignition interlock devices in preventing future AID-related motor vehicle crashes. Drivers who had an ignition interlock device installed were older, more likely to be white, and more likely to live lived in a zip code with a high median income than those in the control group. Drivers in the interlock group were also more likely to have received multiple prior citations for impaired driving and other 'risky' driving behaviors (e.g. driving unrestrained, speeding, driving while suspended). These results are consistent with earlier research (Marine, 2001; Bierness, 2004).

As one of the few studies to use actual AID-related motor vehicle crashes as an outcome measure (McCartt, 2012; Vanlaar,2017) this study estimated that the risk of a subsequent AID-related crash was lower for subjects in the interlock group than for those

in the control group (HR=0.89; CI: 0.82-0.96, p<0.01) . Furthermore, the risk of a subsequent AID-related crash was much lower while the device was installed on the vehicle than when it was not (HR=0.71; CI:0.60-0.84, p<0.01) . After removal of the device, however, no difference was noted between the two study groups (HR=1.14; CI: 0.96-1.35, p=0.14) . These results are similar to what has been observed in other studies that use subsequent AID convictions or citations as an outcome measure (Roth, 2007; Elder, 2011; Vanlaar, 2017). Specifically, ignition interlock devices are a very effective deterrent to AID while they are installed on the vehicle but these effects are not long-lasting.

The majority of research studies related to ignition interlocks focus on repeat convictions for alcohol impaired driving as their outcome measure to determine the effectiveness of the interlock program (Rickard, 2016). Impaired driving crashes are a relatively rare event, which means that a study's sample size and follow-up time must be sufficiently large to capture a sufficient number. In addition, many studies rely on one data source (e.g. Motor Vehicle Administration), and are not able to identify crashes involving the study subjects. When impaired crashes are included as part of an ignition interlock study, a surrogate such as late-night, single-vehicle crashes, is often used (McCartt, 2013).

Strengths and Limitations

This study addressed the effect of ignition interlock devices on the subsequent occurrence of an AID-related motor vehicle crash. It builds on previous ignition interlock analyses in several ways. First, through a linkage between police reported crash

data and MVA data files, over 3,000 AID-related crashes were identified among study drivers. As mentioned, earlier studies that used a crash event as an outcome were limited either by the number of crashes or relied on crash circumstances (e.g. single-vehicle, late-night crashes) as a surrogate for an AID-related crash (McCartt, 2013). Second, these drivers were followed for a period of up to 7 years. This allowed comparisons not only of the study groups as a whole, but also of the interlock group to the control group both during and after installation of the device.

Since the study design precluded the random assignment of study drivers into interlock and control groups, it is possible that pre-existing differences between the groups could confound the associate between use of an interlock device and subsequent crashes. To address this problem, demographic characteristics, BAC test results, and citation history were used to calculate propensity scores for each subject. Using the propensity scores to calculate and apply an inverse probability of treatment weight resulted groups that were more balanced with respect to the measured covariates. However, it is possible that there were unmeasured covariates that could confound the association between interlock use and crash rates. A further limitation is the inability to measure the individual subject's vehicle miles travelled which would be an important predictor of involvement in a crash. An AID arrest may also change a person's driving habits and reduce the number of miles travelled outside of critical trips (e.g. commuting to work). For those who have an interlock installed on their vehicle, there is no feasible way to know the number of miles driven or even if they exclusively use the vehicle in which the device has been installed. Likewise, for those who do not have an interlock

device installed but have their license suspended as the result of an OS, their driving habits may change.

Information bias with respect to the outcome measure, an AID-related crash, is also possible. First, the database used for the analysis includes only crashes occurring in Maryland. Crashes occurring outside of the State are not recorded.

Second, it is possible that the investigating officer does not have sufficient evidence to define a crash as being related to AID at the time they complete their report. In that event, a supplemental form is completed once the investigation has concluded and, while that document is added to the case file, the electronic data file may continue to reflect 'unknown' with regard to impairment. This situation would result in an undercounting of AID-related crashes which could mean that subsequent AID-related crashes are occurring at a higher rate, among both the interlock and control group, than reported in this study. Maryland crash data indicate that only 6.8% of all crashes over the last five years were considered to be AID-related.

The findings from this study suggest that ignition interlock devices are an effective deterrent to AID while they are installed on the vehicle resulting in a reduction in the number of AID-related crashes, and potentially the number of AID-related fatalities. Reducing fatal motor vehicle crashes involving AID are a key component of Maryland's highway safety programs and ignition interlocks are a proven countermeasure that can support this effort. However, since the effect of an ignition interlock device is not sustainable, the characteristics and driving behaviors of those drivers that re-offend after

the interlock intervention should be further explored so that additional programs and policies can be developed to keep alcohol impaired drivers off the road.

Chapter V: Conclusion and Discussion

The Centers for Disease Control and Prevention estimate that 28 people in the United States die each day as the result of a motor vehicle crash involving alcohol impaired driving (CDC, 2015). In 2010, these crashes result in an annual cost of over $44 billion to society (Blincoe, 2015). The National Highway Traffic Safety Administration reported that 10,265 people were killed in alcohol-impaired crashes in 2015. This accounted for nearly 30% of all motor vehicle fatalities in the country (NHTSA, 2016)

Significant progress has been made over the past 30 years in reducing the number of alcohol impaired driving related crashes and fatalities in the United States. The implementation of strong impaired driving laws in states across the nation has played a critical role in this reduction (Voas and Tippetts, 1999 and Zador, 1989). The enactment of stricter laws was accompanied by high visibility law enforcement campaigns that strengthened the perception that drivers will be arrested if they are found to be operating a motor vehicle while under the influence of alcohol or drugs (Lacey, 1990 and Wells, 1992). These enforcement campaigns included the use of sobriety checkpoints and saturation patrols, both of which have been shown to reduce impaired driving at the local level (Bergen, 2014 and Fell, 2008). Unfortunately, in recent years, the reduction in AID-related crashes has plateaued and this number has remained relatively steady since 2010 (Fell, 2016).

In recent years, ignition interlocks have become a common tool by state legislatures in the ongoing battle against alcohol impaired driving. The interlock device is designed to prevent drivers from starting their vehicles if they have a measurable quantity of alcohol in their system. A review of ignition interlock studies compiled by the Centers for

Disease Control and Prevention found that the re-arrest rate for offenders decreased by 67% while the device was installed on the vehicle when compared to drivers who did not have the device installed (Elder, 2011). A more recent study (Kaufman, 2016) looked at the impact of state ignition interlock laws on alcohol-related crash deaths in the United States through the use of the Fatality Analysis Reporting System (FARS) data. States requiring interlocks for all impaired driving convictions were associated with 15% fewer fatalities as compared to states without this requirement. While there is sufficient evidence to demonstrate the effectiveness of the device while it is installed on the vehicle, less is known about any lasting effects after its removal. As states pass additional legislation to require the use of ignition interlocks for first time convictions, additional research is needed to demonstrate whether there is a lasting effect on the target population.

In Maryland, law enforcement officers arrest approximately 23,000 drivers for impaired driving each year. The penalties for an impaired driving arrest include both administrative and criminal sanctions ranging from license suspension or revocation, to fines, and incarceration. These penalties can increase for repeated offenses and/or driving with higher blood alcohol content. According to a 2014 survey by Roth Interlock (Roth, 2014), Maryland is 6th in the nation in the number of interlocks installed and has the 9th highest number of per capita interlock installations in the nation (19.1 per 10,000 residents). To further strengthen Maryland's approach to impaired driving, the Maryland Drunk Driving Reduction Act of 2016, also known as Noah's Law, became effective on October 1, 2016 and requires an interlock installation on the vehicle for all persons who are convicted of impaired driving.

The primary objective of this study is to identify all individuals who received a citation for alcohol impaired driving in Maryland between January 1, 2007 and December 31, 2015 to estimate differences in the risk of a subsequent alcohol impaired driving citation or alcohol impaired crash between those who installed an ignition interlock device on their vehicle and those who did not. The hypothesis was that those who received treatment in the form of an ignition interlock device would be less likely to have another impaired driving arrest or be involved in an impaired driving crash than a comparison group who did not use the device. This concluding chapter summarizes the key findings of this study, discusses its primary strengths and weaknesses, and discusses its relationship to other ignition interlock studies and its implications on the use of interlock devices as a primary means of impaired driving remediation.

Summary of findings

Comparisons between the interlock and control groups were made by age, gender, race, blood alcohol content at time of citation, prior citation history, median income, and county of offense. A comparison was also made between the study groups on the risk of receiving a subsequent AID citation. Three separate comparisons were made: 1) an overall comparison to determine the rate of a subsequent AID citation in the interlock group as compared to the control group; 2) a comparison of the rates of a subsequent AID citation for drivers in the study population during the time the interlock was installed on the vehicle compared to the time when it was not; and 3) a comparison of the rates of a subsequent AID citation for drivers in the interlock group for the period of time after the device had been removed from the vehicle as compared to a comparable period of time

for drivers in the control group. Similar comparisons were made with respect to subsequent AID-related motor vehicle crashes.

Those who had an ignition interlock device installed in their vehicle were older, white, and lived in a zip code with a higher median income than those in the control group. Drivers in the interlock group were also more likely to have received multiple citations for impaired driving and other high risk driving behaviors (e.g. driving unrestrained, speeding, driving while suspended) prior to entering the study. These findings are consistent with earlier findings (Marine, 2001; Bierness, 2004).

To balance the characteristics between these two study groups, propensity scores were used in two ways. The first was by calculating a weight from the inverse probability of treatment which was used in the Cox models (Meier, 1985). The second matched on propensity score to impute a time interval in the control group that is similar to the - OS to removal of interlock device – time interval in the interlock group.

Over the course of the whole study period, no differences were noted in the risk of a subsequent AID citation in the interlock group as compared to the interlock group (HR=1.01; CI: 0.98-1.05, p=.49) while the risk of an AID-related crash was slightly lower (HR=0.89; CI: 0.82-0.96, p<0.01) . Using the time-dependent variable to compare the risk of subsequent AID citation or crash during the time the interlock was installed on the vehicle as compared to the time when it was not revealed that drivers were 22% less likely to receive a subsequent AID citation (HR=0.78; CI:0.73-0.84) and 29% less likely to be involved in an AID-related crash (HR=0.71; CI:0.60-0.84, p<0.01) while the device was installed.

A key component of this study was the ability to follow the interlock group for an extended period of time after the device had been removed. By matching the interlock and control group by their propensity score, calculating the length of time from initial OS to removal of the device, and adding that same period to the matched controls, a better comparison could be made that would measure the lasting effect of the interlock device. After removal of the device, drivers in the interlock group were 32% more likely to receive a subsequent AID citation than those drivers in the control group (HR=1.32; CI: 1.22-1.42, $p<0.01$) . No differences were noted between the interlock and control group with respect to an AID-related crash (HR=1.14; CI: 0.96-1.35, $p=0.14$) .

With respect to subsequent AID-related motor vehicle crashes, those in the interlock group demonstrated a lower risk as compared to the drivers in the control group both overall, and when the device was installed in their vehicle. However, similar to what was seen using AID citations as the outcome, once the interlock device was removed from the vehicle, drivers in the interlock group also had a higher risk of a subsequent AID-related motor vehicle crash as compared to those who did not install the device.

Strengths

This study addressed the effect of ignition interlock devices on the subsequent occurrence of an alcohol involved motor vehicle crash or alcohol impaired driving arrest and builds on previous ignition interlock analyses in several ways. First, I identified all persons cited for AID and not just those convicted which is the case in many other studies. Second, through a linkage between police reported crash data, district court citation data, and MVA data files, a broader level of outcomes can be observed. By not limiting the outcome to convictions, this study provides a better measure of recidivism by

identifying instances of impaired driving without relying on the subjective nature of the court system. Many earlier studies relied upon an impaired driving conviction that was reflected on the driving record or used a surrogate measure to identify impaired driving crashes by relying upon a set of crash circumstances (e.g. single vehicle, night-time) to calculate the number of impaired driving related crashes.

Thirdly, subjects were followed for a period of up to 7 years. This allowed for comparisons of not only the study groups as a whole, but to look at both the period of time while the device was installed on the vehicle and also for an extended period of time after it was removed.

Fourth, demographic covariates were used in association with BAC test results and citation history to calculate propensity scores for each subject. Using the propensity scores to calculate and apply an inverse probability of treatment weight, resulted in a treatment and a control group that were much more balanced with respect to their measured covariates.

Limitations

The study limitations are similar to those reported elsewhere (Elder, 2012). Since the study design prevented the random assignment of study subjects into treatment and control groups, it is possible that pre-existing differences in characteristics between the two groups might result in differing citation and crash rates. Despite the use of propensity scores as describe above, there may still be unmeasured covariates that could bias the composition of these groups.

Another limitation is the inability to measure the individual subject's vehicle miles travelled which would be a measure of their exposure for involvement in a crash. An alcohol involved driving arrest or crash may change a person's driving habits and reduce the number of miles travelled outside of critical trips (e.g. commuting to work). Those who choose to install an interlock device may have a greater need to drive. Those who chose the license suspension may more closely follow those restrictions and refrain from driving or restrict their trips to short distances. For each group, however, there is no feasible way to know the number of miles driven or, with regard to the interlock group, if they exclusively use the vehicle in which the device has been installed.

Information bias with respect to one of the outcome measures, an alcohol involved crash, is also possible. First, the database used for the analysis includes only all police-reported crashes occurring in Maryland. Crashes occurring outside of the State are not recorded. Second, it is possible that the investigating officer does not have sufficient evidence to define a crash as being related to AID at the time they complete their report. In that event, a supplemental form is completed once the investigation has concluded and, while that document is added to the case file, the electronic data file may continue to reflect 'unknown' with regard to impairment. This situation would result in an undercounting of AID-related crashes which could mean that subsequent AID-related crashes are occurring at a higher rate than reported in this study. However, the same bias is likely to apply to both those who installed and interlock device and those who did not.

Research and Policy Implications

The findings from this study suggest, as have other studies, that ignition interlock devices are an effective deterrent to AID while they are installed on the vehicle. This effectiveness has resulted in many states including the use of such devices as a mandatory sanction for AID. In 2014, over 300,000 ignition interlock devices were installed in vehicles in the United States (Roth, 2014). However, it has been suggested in previous studies that the risk of subsequent AID convictions may begin to increase upon removal of the interlock device (Elder, 2011; Voas, 2015). This study indicates that the rate of a subsequent AID citation, a much more commonly recorded event than AID convictions, increases significantly after removal of the ignition interlock device. As a result, additional interventions and programs may be needed to reinforce the initial behavioral changes provided by the use of an interlock device.

Florida has recently instituted a policy mandating alcohol use disorder treatment along with the use of an interlock device for drivers with three or more violations. A study of that program found that the group using an interlock device and receiving alcohol use disorder treatment experienced a 32% lower rate of recidivism for subsequent AID offenses as compared to a control group who only used the interlock device (Voas, 2016).

Another program that has been used for drivers who have repeat AID offenses after the use of an interlock device is South Dakota's 24/7 Sobriety Program that requires DUI offenders to demonstrate sobriety through monitored testing. This program assesses compliance with a requirement to stop consuming alcohol at-all-times, not just prior to driving, using a Secure Continuous Remote Monitor (SCRAM) system. The SCRAM is an ankle bracelet that measures alcohol consumption 24 hours a day, 7 days a week by

measuring alcohol excreted through the skin. An analysis of the program conducted by Mountain Plains Evaluation (Loudenberg, 2013), revealed that AID offenders who wore the device for 90 days or more had a 10% recidivism rate as compared to 21% for the control group over a two-year follow-up period. However, this study also noted that the behavior change was temporary and, over time, recidivism rates rose in the intervention group after the device was removed (Kubas, 2016).

In addition to ignition interlock devices, other emerging technology will allow the alcohol level in a driver's exhaled breath to be measured unobtrusively by their vehicle or will measure the BAC under the skin by integrating an infrared light into the vehicle's controls (MADD, 2006; NHTSA 2015). These technologies will be part of the next generation of tools that can be used to prevent AID in the United States. In the meantime, ignition interlock devices are an important tool for the short-term prevention of future AID behaviors, but their effectiveness is not sustained after removal and additional measures must be considered to reduce the risk of future AID events.

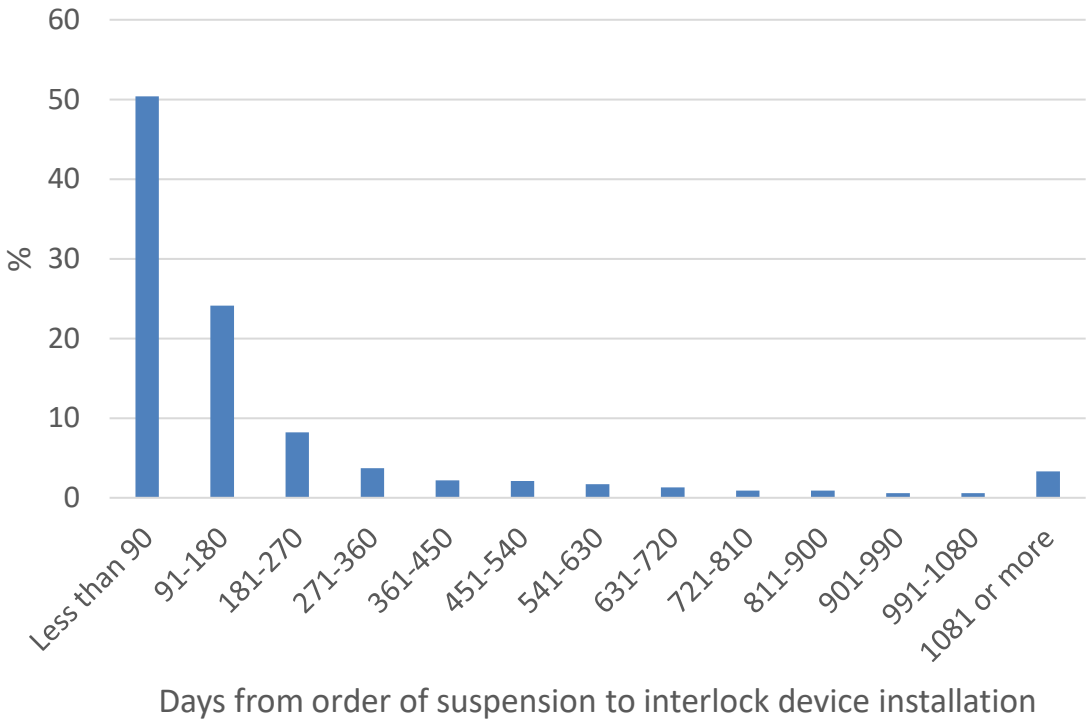
In Maryland, the lower rate of subsequent AID citations and crashes for drivers while the device was installed on their vehicle has likely resulted in a short-term improvement in those individuals' driving behaviors and the use of ignition interlock devices should be continued to help prevent impaired driving in the State. However, since this effect does not appear to be sustainable, other programs such as Florida's should be explored.

This study provides additional evidence that ignition interlock devices are an effective deterrent against AID violations, while installed on the vehicle. It is also one of the few, and the largest, to be able to use AID-related crashes as an outcome measure against which interlock devices are also effective while on the vehicle. This study, which uses

one of the largest combined sample sizes and post-interlock device removal follow-up periods to date, also found higher rates of subsequent AID citations among the interlock group as compared to the control group after the device had been removed. This requires further investigation. The characteristics and driving behaviors of those subjects that re-offend after the interlock intervention should be further explored so that additional treatment options or sanctions can be considered to help maintain safe driving behavior among persons who have a history of AID. Ignition interlocks are not a magic bullet and should not be the only tool used to prevent repeat AID behavior that may lead to subsequent AID citation and crashes.

Appendix 1

Length of time from order of suspension to installation of ignition interlock device



Appendix 2

Correlation Matrix for Covariables

Variable	Male	Age	Priors	BAC	Median Income	Race	County
Sex	1.00	0.04	0.10	-0.01	-0.02	-0.09	0.03
Age	0.04	1.00	-0.07	0.11	-0.03	-0.03	-0.01
Priors	0.10	-0.07	1.00	0.02	-0.01	-0.00	-0.04
BAC	-0.01	0.11	0.02	1.00	-0.04	-0.00	-0.00
Median Income	-0.02	-0.03	-0.01	-0.04	1.00	0.08	0.13
Race	-0.09	-0.03	-0.00	-0.00	0.08	1.00	-0.25
County	0.03	-0.01	-0.04	-0.00	0.13	-0.25	1.00

Correlation is indicated by a value of 0.55 or higher

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