SoberMotion: Leveraging the Force of Probation Officers to Reduce the Risk of DUI Recidivism

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In this study, we sought to assist probation officers in their efforts to reduce the risk that offenders on probation would re-commit the offense of driving under the influence (DUI) of alcohol. We prototyped a support system called SoberMotion, in which a breathalyzer is connected to the offender's smart phone via Bluetooth. Development of the system was based on pilot interviews with probation officers, psychiatrists, and offenders aimed at identifying the challenges and opportunities associated with this type of technology-based support mechanism. A corresponding phone app logs alcohol use behavior and identifies situations in which offenders should evaluate their sobriety before operating a vehicle. We conducted a two-month field study involving eight DUI offenders on probation, with the aim of evaluating the feasibility of the SoberMotion system. Our results indicate that most of the participants who drank alcohol while following the program performed multiple alcohol screening tests before operating a vehicle in order to avoid re-committing DUI. Responses collected via qualitative interviews indicate that SoberMotion is an effective approach to extending the power of probation officers seeking to reduce the risk of DUI recidivism.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; *Ubiquitous and mobile computing systems and tools*; • **Applied computing** → Law;

Additional Key Words and Phrases: Driving Under the Influence (DUI), Alcohol Use Disorder, Therapeutic Jurisprudence (TJ), Mobile Support System

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1 INTRODUCTION

Driving under the influence (DUI) of alcohol refers to the operation of a vehicle while impaired by alcohol. In the United States, someone is killed by a drunk driver every 53 minutes [23]. In Taiwan, the government faces the same challenges. In 2014 alone, a total of 115,253 drunk driving cases were recorded and 169 people died in road accidents related to drunk driving [24]. To avoid overloading the prisons with misdemeanor DUI offenders who did not cause an accident, prosecutors commonly defer prosecution in favor of probation [6, 31]. During DUI probation, probation officers are tasked with helping offenders to alter their behavior as well as monitoring their compliance with sentencing requirements. If completed successfully, deferred probation can lead to criminal charges being dropped; however, many individuals commit DUIs while on probation [91]. This is due largely to the inability of probation officers to track alcohol use, which can hinder their efforts at intervention. Furthermore, offenders lack a mechanism by which to determine whether their breath alcohol level is below the allowable breath alcohol limit (0.15 mg/L in Taiwan) before getting behind the wheel. Probation officers must base their judgments on verbal reports made by offenders; however, interviews between offenders and probation officers have revealed that offenders commonly lie about these issues and/or forgot the specifics pertaining to their alcohol use. This leaves probation officers no choice but to make unannounced visits to the offender's home or place of work. The heavy caseload of probation officers [64] makes this option impractical. Despite the recent hiring of assistant officers to share the workload, dealing with the logistics of such visits remains a considerable challenge [78]. In this study, we applied mobile sensing technology to overcome these problems.

Probation officers organize periodic appointments with offenders or conduct visits at the offenders' homes in order to verify compliance with the conditions of probation. The tracking of offenders usually involves having them check in with probation officers at set intervals. Wearable devices [20], alcohol interlock devices [27], and electronic monitoring systems based on Global Positioning System (GPS) have also been developed to facilitate the monitoring of alcohol use and keep track of offenders. However, many of these schemes are prone to false positive detections [94]. In fact, the government of the Netherlands halted their monitoring program in 2016, following the evaluation of trials conducted between 2011 and 2014. In explaining their decision, authorities cited technical challenges associated with the accuracy of the devices and the ineffectiveness of limited interventions [99]. These methods also bring with them the stigma of confinement, and impose a financial burden on the family of the offender. Nonetheless, courts commonly require that offenders undergo treatment for alcohol abuse [41, 66]. Making a qualified diagnosis and implementing a suitable treatment plan requires the tracking of alcohol use over an extended period. Probation officers have no way of monitoring offenders between scheduled meetings, and most officers must cope with a workload that is too heavy to allow random visits. In this study, we sought to assist probation officers by providing a reliable system for tracking alcohol use behavior with the aim of identifying situations warranting immediate intervention.

We adopted the concept of therapeutic jurisprudence (TJ) [52] to leverage the authority of probation officers in order to reduce the risk of recidivism by DUI offenders during the period of probation. We conducted a pilot study involving probation officers, psychiatrists, and offenders to provide guidance in the design of a mobile support system, referred to as SoberMotion. This system records alcohol use data using a customized portable breathalyzer connected to a mobile phone via Bluetooth. The system uses a unique 2D marker and a server-side face verification module to authenticate the ID of target users as they provide a breath sample. The proposed app was also designed to identify high-risk vehicle use events (i.e., situations in which the offender rides in a vehicle while under the effects of alcohol). Identifying these situations helps to remind users of the need to check their breath alcohol level before getting behind the wheel. A complete record of ID data, test results, triggers leading to alcohol use, and high-risk vehicle use events is transmitted to a cloud-based management server for analysis by probation officers and/or psychiatrists. When the system identifies a situation in which the offender drinks alcohol before riding in a vehicle or fails to comply with data reporting requirements, the probation assistant is immediately notified, leading to a micro-intervention via telephone. This scheme is based on the assumption that early interventions can help to eliminate high-risk behaviors. Probation assistants are in a position to re-categorize offenders as high-risk if they fail to provide a reasonable response explaining their failure to comply with probation requirements. This also makes it possible for probation officers to introduce more intensive interventions designed specifically to deal with dynamic risk factors, such as the offender losing his/her job.

The contributions of this paper are three-fold:

- We designed and prototyped the SoberMotion system, which allows offenders to self-administer breath alcohol tests before operating a vehicle. The design of the system is based on observations gained from a review of the literature and interviews with stakeholders (18 offenders, 3 probation officers, 3 prosecutors, and 3 psychiatrists) in a pilot study. The proposed system is meant to give users a realistic understanding of the rate at which their bodies metabolize alcohol, and in so doing undermine the optimistic bias typically observed in the self-evaluation of sobriety [70, 72].
- The proposed system leverages the authority of probation officer in supervising offenders in order to prevent risk accumulation between scheduled visits. Behavioral data uploaded to a cloud-based server can be used in an early-warning system that proactively alerts probation officers to issues requiring immediate attention. Identifying offenders who fail to comply with probation requirements also makes it easier for probation officers to prioritize their cases; i.e., reserve intensive interventions and resources for those who are more likely to re-commit driving offenses.
- A prototype of the system was evaluated in a two-month field study involving eight DUI offenders. Treatment for alcohol-related problems was shown to slightly reduce alcohol use. Participants who consumed higher volumes of alcohol were shown to perform a greater number of breath alcohol tests before operating vehicles than were those who consumed less alcohol. Qualitative interviews were conducted to identify salient themes in the use of SoberMotion system, which could be useful in reducing the risk of DUI recidivism.

The remainder of this paper is organized as follows. Section 2 provides background information pertaining to current practices in DUI probation as well as a review of the related literature. Section 3 summarizes the difficulties and opportunities identified in interviews with related stakeholders. Section 4 outlines the design of the SoberMotion system. Section 5 describes the implementation of SoberMotion. Section 6 describes the 2-month field study involving eight DUI offenders using the SoberMotion system, the objective of which was to obtain quantitative and qualitative verification of the feasibility of the proposed system. Section 7 discusses valuable design considerations and actionable insights regarding the implementation of the system. Section 8 outlines the limitations of this study. Section 9 presents the conclusions and future work.

2 BACKGROUND & RELATED WORK

DUI cases are felonies; however, many cases that do not result in injury are prosecuted as misdemeanors. The effective supervision of offenders depends on an assessment of the likelihood that an offender will re-commit DUIs. These assessments are generally based on the behavior of the individual in terms of alcohol consumption and their use of vehicles after drinking. Researchers have devised various schemes to infer drinking and driving behavior (as described in the following subsections). Many of these schemes are applicable to the self-management of drinking. Others can be used in conjunction with medical interventions to deal with more serious cases. These methods can also be used by probation officers to prevent DUI recidivism. In the following, we summarize related studies addressing three crucial issues: (1) Sensing methods for use in monitoring alcohol use behavior, (2) medical or technology solutions aimed at promoting safe drinking, and (3) therapeutic methods aimed at preventing DUI recidivism.

2.1 Sensing Methods for Detecting DUI Behavior

Inferring DUI behavior depends on associating the consumption of alcohol with the operation of a vehicle by the target individual. It is not always possible to determine both conditions conclusively; however, we can infer that DUI is likely when a positive alcohol screening result coincides with vehicle use. In the following, we examine previous research dealing with the problem of identifying individuals impaired by alcohol. The first breathalyzer was invented in 1952 [58], and first used for roadside testing in Britain in the 1970s [14]. In the intervening years, it has become a standard protocol for the enforcement of laws pertaining to drinking and driving. Subsequent innovations include the SCRAM Remote Breath [36], which integrates GPS to detect the location of the user as well as facial recognition functions to prevent cheating by having other people take the test for them. The SCRAM CAM ankle bracelet enables continuous alcohol sensing 24/7 [35]. Embedded transdermal sensors detect alcohol levels by collecting a sample of sweat from the participant's skin every 30 min. They also detect the removal of the device or the placement of obstructions between the sensor and skin. Unfortunately, an ankle bracelet of this type is widely stigmatized and researchers have run into a number of challenges in implementing transdermal sensors. Under low alcohol conditions (fewer than five drinks), transdermal sensors have been shown to detect only 54% of drinking episodes when applied to female users and 33% when applied to males (compared with self-reported data) [55]. Several studies have sought to leverage the popularity of smartphones by connecting them to breath alcohol sensors. BACtrack Mobile Pro [3] is a portable Bluetooth breathalyzer based on the BACtrack View remote alcohol monitoring system [5]. This device makes it possible to self-administer alcohol breathalyzer tests and share with others a photo-verified record of the results directly from a smartphone. Kao et al. [76] developed an algorithm that detects alcohol-related anomalies in the walking patterns of an individual carrying a mobile phone. Data collected by the accelerometer on the phone detects anomalies in one's gait through the extraction of features specific to the walking patterns of intoxicated individuals. Bae et al. [54] examined the utility of smartphone sensors to track various physical behavioral markers (e.g., movement and geo-location) and social behavioral characteristics (e.g., call and text patterns), which are associated with drinking episodes among young adults. Using mobile phone sensors, they collected data for 28 consecutive days from 30 young adults who exhibited hazardous drinking behavior. They employed the experience sampling method (ESM) in conjunction with models based on machine-learning to differentiate between non-drinking and heavy drinking episodes. Mariakakis et al. [85] used performance metrics and sensor data to measure how alcohol affects one's motor coordination and cognition (e.g., how users draw unlock patterns in the lock screen). They also developed user interfaces that utilized phone sensors and machine learning models to estimate the blood alcohol level of the user. These machine-learning based solutions were not designed for law enforcement, but rather to inform the user of their blood alcohol level (BAL)) before driving a vehicle. BACtrack SKYN [4] integrates similar drinking detection technology within a stylish wristband and forwards notifications to the user's mobile device. However, the wristband estimates alcohol consumption by measuring the blood alcohol content in sweat; therefore, it is prone to the same limitations as the transdermal sensor [55]. The accuracy of this device (developed in 2017) has yet to be validated.

On the other side of the equation are technologies used to detect the mode of transportation in order to infer whether an individual is operating (or simply riding) in a vehicle. Some of the research in this area has exploited location information [68] and mobility sensors on the phone [73] to characterize vehicle use behavior.

The Google Activity Detection API [1] automatically detects activity by periodically reading short bursts of sensor data for processing using machine learning models. To optimize resources, the API halts activity reporting when the device remains static for a given duration, and resumes reporting when it detects movement. However, determining that the user is moving in a vehicle does not imply that the user is actually operating the vehicle. Yang et al. [103] sought to differentiate the driver from passengers using the infrastructure of the car stereo (i.e., speakers and Bluetooth network). This acoustic approach has the phone transmit a series of specific high frequency beeps through the car stereo. The beeps are spaced temporally as well as spatially across the left, right (and if available), front and rear speakers. After sampling the beeps, a sequential change-point detection scheme is used to derive the time of their arrival, whereupon a differential approach is used to estimate the distance of the phone from the center of the vehicle. Unfortunately, the performance of this scheme depends on the specifications of the car stereo system, which can vary considerably according to the model of car. The fact that alcohol metabolizes over time means that the accuracy of DUI predictions depends on obtaining test results at or near the time that the vehicle is operated. The interlock device in [27] largely overcomes this issue by having the driver undergo alcohol screening before being allowed to operate the vehicle. However, users can still bypass alcohol screening by driving someone else's vehicle or by pumping air into the interlock device. The Driver Alcohol Detection System for Safety (DADSS) [17] integrates breath- and touch-based systems to detect the driver's blood alcohol concentration (BAC) and disable the vehicle if he/she is over the legal limit. This system detects alcohol vapor in the breath exhaled by drivers and matches the alcohol readings with a particular subject through the simultaneous recording of carbon dioxide (CO2) at the same location. Sensors based on infrared spectroscopy have been developed to detect and quantify low concentrations of alcohol and CO2. Ljungblad et al. [80] evaluated the DADSS system by measuring the concentration of alcohol and CO2 at various locations in the vehicle cabin, as human subjects got into the car and prepared to drive. A video camera directed at the driver seat was used to record images of the driver's upper body and face. The images were then analyzed with respect to breathing behavior and breath detection, such as the opening of the mouth and direction of the head. Their results confirmed the feasibility of passive driver breath alcohol detection schemes based on the DADSS system. Nonetheless, further improvements in sensor resolution and system robustness will be required before the device is released on the market.

To summarize, we adopted the standard alcohol breath detection device used in roadside testing since the 1970s [14]. The proposed device can be carried conveniently in one's pocket, thereby allowing the self-administration of tests anytime and anywhere without the social stigma associated with many existing devices. Users are free to select the time at which they self-administer breath alcohol tests (e.g., before operating vehicles) to make using the system less obtrusive. We employed fuel cell sensors to enhance the accuracy of the breathalyzer device and minimize maintenance [38]. We also employed the mobility sensors found on most smartphones to identify when the user is riding in a vehicle without the need to impose on their privacy in terms of location. The correlation between alcohol screening events and vehicle use events is used to infer DUI behavior. The proposed system is meant to identify high-risk situations and provide early alerts to initiate interventions aimed at preventing risk accumulation over time [95].

2.2 Existing Solutions to Promote Safe Drinking

Most court-mandated alcohol treatment programs [24, 84] require that offenders convicted of alcohol- or drug-related crimes participate in programs for the treatment of substance abuse. This policy has long been a component of efforts to combat the problem of driving under the influence (DUI). It is also primary path of entry into treatment for alcoholism. Numerous medical interventions have been developed to promote responsible drinking behavior. Numerous technology-based systems [49, 60, 61, 65, 71, 82, 104] have also been developed to leverage medical and/or social support in the promotion of safe drinking behavior. Researchers have applied mobile phone technology to prolong participation in continuous care programs for heavy drinkers and alcohol-dependent patients. Alessi et al. [49] evaluated the feasibility of a cellphone-based Contingency Management (CM) system to monitor real-world drinking behavior and encourage patients to abstain from alcohol consumption. Patients with drinking problems underwent a stand-alone breathalyzer test and then texted the results back to the researchers. The participants with the best scores were rewarded with tangible incentives. Experiment results demonstrated the feasibility of the CM scheme in reinforcing one's will to abstain from alcohol. The addiction-comprehensive health enhancement support system (A-CHESS) [60, 65, 71] is a smartphone application that provides support for individuals recovering from alcoholism. This scheme is based on the provision of motivation and support as outlined in Self Determination Theory [71]. In [60], the researchers constructed a Bayesian network model based on patient responses to weekly surveys conducted by the mobile phone app for use in predicting the likelihood of relapse. The effectiveness of that system in assisting patients to remain sober was evaluated by conducting a large-scale study [65] involving three hundred alcohol-dependent patients. Unfortunately, drinking data was based on the vague recollections of patients obtained via phone interviews at intervals of four months. SoberDiary [104] is also a phone-based support system that enables alcohol-dependent patients to self-monitor and self-manage their behavior to remain sober in their daily lives. It includes a portable Bluetooth breathalyzer wirelessly connected to the patient's smartphone as well as functions provided by the SoberDiary client aimed at providing support for individuals seeking control over alcohol use behavior. A number of previous researchers [82, 100] analyzed social media data to identify the difficulties involved in abstaining from alcohol or tobacco. Tamersoy et al. [100] performed statistical and linguistic analysis on data extracted from self-reports and posts on Reddit's StopDrinking & StopSmoking online social communities. They were able to create statistical models differentiating between long-term and short-term abstinence. MacLean et al. [82] examined an addiction recovery forum (Forum77) to examine the process of opioid withdrawal, recovery, and relapse. They examined linguistic features associated with the phases USING, WITHDRAWING, and RECOVERING, and then used these features to train classifiers aimed at identifying the phase of addiction as relapse or recovery at the time of the last post. Their results determined that nearly 50% of the members eventually relapse and that leaving Forum77 in a state of recovery was the most probable outcome. It was also found that members identified as RECOVERING at the time of their last post were significantly more engaged with the community, compared to those who were USING or WITHDRAWING.

The fact that most offenders on probation are reluctant to divulge personal information on social media greatly undermines the effectiveness of this approach in reducing the risk of DUI recidivism. In contrast, SoberMotion leverages a variety of persuasion-related constructs used in the design of previous technology-based systems [60, 65, 71, 104] to assist DUI offenders to self-manage their alcohol use. The system is meant to enhance awareness of alcohol use within the context of driving. It is also meant to assist probation officers and psychiatrists to promote the skills of self-control and prevent relapse.

2.3 DUI Prevention and Support Solutions

Avoiding DUIs or DWIs (Driving While Intoxicated) involves multiple control issues [51]. A multi-disciplinary approach [90] is required to ensure compliance with designated conditions, assess the resources available for targeting risk, and obtain the information required to impose equable penalties and restrictions. Situations involving serial convictions without injury often result in deferred prosecution [10] with probation for an extended period of time. When the court deems that a repeat offender has an ongoing alcohol-related problem, harsher penalties may be imposed or the offender may be compelled to engage in an alcohol treatment program. Probation officers typically help the offender to understand the conditions stipulated by the court and their options in seeking to fulfill their responsibilities. Throughout the probation period, offenders are expected to report regularly to their probation officer, who forwards reports on those meetings to the court. Completion of the deferred prosecution agreement also depends on the participation of the offender in the alcohol treatment program, as scheduled by the treatment team. A failure to comply with any of these obligations can lead to the termination of the agreement, such that the case is returned to the court for adjudication and/or sentencing.

The availability of community correction strategies varies according to jurisdiction [90]. This means that probation officers are limited in their ability to monitor individuals in a manner that addresses the risks they face, their needs, and their convictions. Several electronic monitoring tools have been developed to enable cost-effective supervision, including the Alcohol Interlock [27], SCRAM Remote Breath [25, 29], and SCRAM bracelets [34]. However, those devices do not necessarily embody the spirit of therapeutic jurisprudence, such that offenders lack motivation to comply and may even try to cheat the system. Furthermore, having participants wear a tracking device all day may also be a violation of their rights and at the very least brings up serious questions pertaining to privacy [93]. In fact, those devices were designed for monitoring individuals who do not want to be tracked, and may therefore try to cheat the system or destroy the device. It has also been shown that once these devices are removed, DUI recidivism rates reach the same levels as those who never had the device in the first place [86]. Moreover, these schemes are prone to false positive detections [30], they increase the stigma of confinement, and impose a financial burden on indigent families. Furthermore, offenders with alcohol use problems often attempt to cheat the system to prevent their alcohol use being detected. Offenders diagnosed with uncontrolled or serious alcohol use problems should receive alcohol withdrawal treatment or enter rehab centers; however, their alcohol use behavior must be monitored for extended periods in order to make a qualified diagnosis.

Babb et al. [52] proposed the concept of therapeutic jurisprudence (TJ) to promote the psychological well-being of the people affected by the law, wherein the healing power of the law is used to bring peace to society. Many community correction programs have been based on this concept. Most comprehensive probation programs are interdisciplinary. For instance, the Sobriety Court Program [32] in Ottawa County (Mich.) combines biweekly court sessions, alcohol treatment, Alcoholics Anonymous/Narcotics Anonymous (AA/NA) meetings, and alcohol testing in conjunction with random home visits through several phases. However, only a small portion of the corrections budget is allocated to these programs, and the resulting lack of manpower makes it difficult to confirm that the conditions of probation are followed. We conducted a pilot study to identify the concerns of users in order to develop a system that would motivate participation. We also sought to improve the allocation of treatment resources to offenders at greatest risk of re-offending by establishing a cloud-based early-warning service based on data uploaded automatically by the mobile phone of the participant.

3 PILOT STUDY: UNDERSTANDING THE DIFFICULTIES INVOLVED IN SUPPORTING DUI OFFENDERS ON PROBATION

Comprehensive DUI probation programs require collaboration and supports from other justice and community stakeholders to ensure compliance with supervision conditions [90]. Thus, we interviewed DUI offenders and related justice and community stakeholders, including prosecutors, probation officers, and psychiatrists, to elucidate the difficulties and opportunities involved in supporting DUI offenders on probation. This study was conducted in Taiwan, which is facing difficulties handling DUI offenses similar to those in the US [8, 24]. The deferred prosecution agreements are also similar to those used in the US. The Taipei City government has been working actively with the Ministry of Justice and rehab specialists to expand alcohol treatment programs for repeat offenders in prison [24]. This is similar to rehabilitation treatment mandated by courts in the US [84]. Therapeutic support has been expanded by having repeat offenders on probation enroll in alcohol treatment programs as a condition of entering the deferred prosecution program. The therapeutic aspects of the law have been shown to reduce DUI recidivism; however, this inevitably requires additional manpower to track participants and assess the risk of re-committing DUIs. This program also requires the efforts of a team of professionals in addiction treatment as well as the cooperation of offenders. In this study, we explored the challenges and opportunities associated with a mobile support system aimed at reducing the risk of repeating DUI offenses by individuals enrolled in a mandatory alcohol treatment program. We began by conducting interviews with eighteen DUI offenders on probation as well as three probation officers, three prosecutors, and two psychiatrists involved in treatment programs. Our aim was to tap into their experience with DUI convictions, probation requirements, treatment programs, and interactions with offenders. We also sought to assess the current state of treatment programs. Affinity diagrams were derived from the interview transcripts to assist in the grouping of observations. In the following, we outline some of the issues that were deemed crucial to the formulation of a mobile support system for DUI offenders on probation.

3.1 Difficulties Faced by Probation Officers

The National Highway Traffic Safety Administration (NHTSA) of the USA [33] reported that approximately 1.5 million alcohol-impaired drivers are arrested annually. In Taiwan approximately 5% of all vehicle-related injuries involve DUI, and nearly 20% of the deaths are due to alcohol-related accidents [59]. Between 2006 and 2015, authorities in Taiwan increased the severity of punishments for DUI offenders; however, DUI remains one of the major causes of traffic accidents in Taiwan. Intensive supervision has been identified as an effective approach to reducing the risk of DUI re-offense. Unfortunately, the three probation officers interviewed in this study reported that the overwhelming number of offenders makes it impossible to implement this option in all cases. PO #2: *"At present, I have to keep track of 290 cases, including convictions for robbery, drug use, and drunk driving. My 20 DUI offenders are required to attend scheduled meetings with me and participate in alcohol-related problem treatment programs. This workload does not allow me the time to arrange random home visits or phone calls to check up on them between visits."* In an effort to reduce the caseload, prosecutors now place first-time offenders on unsupervised probation. Unfortunately, even in cases where the offender is placed in an intensive probation program, the time between scheduled meetings with probation officers can be a month or even longer. PO #1: *"The time between each revisit is typically one to two months. This makes it very difficult to keep track of the events that could impact the lives of participants and/or monitor alcohol use behavior. For example, one of my clients suddenly relapsed several weeks after losing his job, and I was unaware that such a devastating event had even occurred."* Without supervision between visits, probation officers are unable to overcome the reticence of offenders to divulge their drinking behavior. Probation officers are also tasked with reiterating the dangers of operating a vehicle while under the influence. In the current climate, probation officers lack the background data required to keep tabs on their clients. PO #3: *"I need to understand the life patterns and behavior of offenders. If I were able to identify the factors associated with drinking (e.g., BrAC value, drinking time, or location), it would be far easier to provide guidance."* Access to behavioral data can help to reduce/prevent the likelihood of re-offending.

3.2 Considerations When Applying Tracking Technology

Electronic monitoring systems can help probation officers to track offenders in order to ensure compliance with the terms of probation. However, these devices can be obtrusive and inevitably raise concerns pertaining to privacy, increase the stigma of confinement, and impose a financial burden [94]. For example, the interlock program in the Netherlands was stopped due to legal and technical problems [19]. We conducted interviews with eighteen DUI offenders with regard to the impact of tracking technology on their daily lives. Nine of the interviewees commented that they had no difficulty in regularly self-administering alcohol screening tests. Six others responded that the self-administration of alcohol screening tests was inconvenient and/or they did not feel the need to record their alcohol use behavior, based on their belief that they could control their behavior just fine. Offender #15: *"[In an impatient tone] I am sober ... Why do I need to do tests? It is inconvenient and ... I don't want my kid watching me taking tests. However, if you [i.e., the probation office] force me to comply with the requirement, OK then ... What can I do?"* The last three expressed that they did not want to give up their privacy and did not feel comfortable being screened as though they were common drunks. They refused to participate in any testing and would likely falsify their test results if forced to participate. The other offenders would be willing to self-administer 1 ∼ 3 tests per day, and would probably be willing to conduct additional tests if required by prosecutors. All three of the probation officers explained that the purpose of DUI probation is to reduce the likelihood of repeated DUI. PO #2: *"Drinking alcohol and driving under the influence are two entirely different matters. As probation officers, we care primarily about DUI prevention."* The proposed system is able to detect vehicle use behavior by correlating alcohol screening results to the period in which a vehicle was operated, based on location information [68] and mobility sensors on the phone [73]. Among the eighteen offenders in this study, seven reported a reluctance to divulge location information. Nonetheless, they said that they would be willing to comply if this condition were mandatory. Offender #3: *"I feel that GPS information should be carefully preserved and not revealed to others. This is a privacy concern. I did not hurt anyone when I was drunk driving. Why do I have to provide GPS information?"* These concerns prompted us to carefully consider the issue of privacy (e.g., location information) in the formulation of the monitoring scheme.

3.3 Incorporating Technology to Complement DUI Probation

Motivating offenders to adopt the proposed scheme in their daily lives requires an understanding of the situations in which participants are liable to get into trouble. All of the offenders enrolled in the deferred prosecution scheme had more than one DUI offense, but fewer than three offenses within five years. We found that two thirds of the study group trusted their fate to luck, in terms of drinking and driving. These twelve offenders have since adopted a more balanced approach. Nonetheless, six of the participants have been convicted a second time based on an inaccurate estimation of their breath alcohol concentration (BrAC), by not allowing insufficient time before getting behind the wheel. Offender #7: *"I remember that I had a lot of drinks with my friends before getting my first two DUI offenses. Then, when I was riding my scooter home, I was caught by the police. When I got off work, a couple of hours had passed from the time I drank alcohol, and I had drank some hot soup as a late night snack. I was sure that enough time had passed to metabolize the alcohol. I felt perfectly sober, but I still failed the breath alcohol test."* The other six offenders who claimed to follow strategies to avoid DUIs also failed to estimate their BrAC accurately. This may be due to variations in their metabolic rates. Offender #14: *"My prior offense ... I drank a lot of beer. After a short snooze, I felt I was sober. Then, I was caught while riding my scooter home."* The BrAC standard of 0.15 mg/L for legally operating vehicles is very strict. It is easy to exceed this level simply by consuming two cans of beer. The psychiatrists reported that most DUI offenders have alcohol use problems or alcohol dependence prior to being convicted [102]. Psych #1: *"I would estimate that 80% of cases referred by the Prosecutor's Office involve issues pertaining to alcohol use."* Even offenders with a drinking problem are sober most of the time; however, they can get into trouble when having a few drinks recreationally with friends. Unfortunately, most people are unable to accurately gauge their level of sobriety based on how they feel or the amount of time elapsed since their last drink. Individuals require an objective means to assess their level of sobriety.

3.4 Leveraging the Law in Support of Offenders

Most DUI cases that do not involve death or injury are treated as misdemeanors. More serious offenses can result in jail, fines, loss of driving privileges, and increased life-insurance premiums. Many offenders seek to enter the deferred prosecution program, and tend to be highly motivated to complete the program successfully. PROS #3: *"Many offenders seek inclusion in the deferred prosecution program. Nonetheless, I have to evaluate their alcohol use based on their CAGE score [7]. I also tend to select individuals who have a strong vested interest in avoiding criminal prosecution. For example, one of my DUI cases was an amateur sommelier. The fact that he is actively engaged in sampling wines at work makes it very easy for him to exceed the legal limit. Nonetheless, he was planning to take a sommelier certification exam, which would be impossible if he had a criminal record. I felt that this was* *sufficient motivation to face his alcohol use problem, and therefore placed him in the deferred prosecution program."* Upon successful completion of the deferred prosecution contract, the court would agree to dismiss or amend the charges. DUI offenses are more socially acceptable than drug offenses, which means that DUI offenders are more willing to admit to alcohol use. PO #2: *"DUI offenders are far more communicative than drug users. They also tend to be more forthright. Drug users lie over and over, forcing me to dig out confessions again and again."*

DUI offenders tend to come from a lower socioeconomic background, which makes it difficult for them to arrange the time for visits with probation officers [16, 56]. PO #2: *"One of my cases was a blue collar worker who was unable to get the time to regularly meet with me."* Two-thirds to the offenders interviewed in this study were concerned about scheduling meetings with probation officers, which could impact their work schedules or business trips. They even expressed concern that they might be fired if they asked for leave every month. Offender #5: *"I quit my job as a janitor in a hospital because I was afraid that I would be unable to attend scheduled meetings with my probation officer. As a result, I am forced to juggle a number of part-time jobs."* Four of the offenders have more flexible working hours.

In summary, most DUI offenders are motivated to successfully complete the probation program, and are perfectly willing to share behavioral data. However, scheduling meetings only once a month tends to limit the benefits provided by this kind of monitoring. We believe that mobile technology could be used to monitor participants without forcing them to take off time for scheduled appointments, thereby minimizing the effect on their daily lives.

4 SOBERMOTION SYSTEM

We adopted the therapeutic jurisprudence (TJ) approach [52] as the theoretical foundation for the design of SoberMotion. Our focus was on cognitive behavioral theories that emphasize triggers and coping strategies for the prevention of DUI recidivism. Participants in these programs are taught the means to implement cognitive self-change, reduce their alcohol use, and accurately determine their level of sobriety.

Individuals with the ability to actively monitor their alcohol and vehicle behaviors have greater success in avoiding DUIs. Self-monitoring can be used to alert individuals of high-risk vehicle use situations and alcohol use behavior. It can also help them to develop the skills necessary to prevent relapse, while promoting one's sense of self-efficacy or competence. Many offenders display multiple risk behaviors; therefore, self-monitoring and management should be based on the identification of triggers and the development of coping responses. Nonetheless, self-monitoring can be difficult to maintain without adequate support.

The SoberMotion system comprises (1) a phone app, (2) a breathalyzer device, and (3) a management server. The portable breathalyzer is pre-assigned a unique identifier (ID). When the device is first switched on, a unique ID pattern appears on the display panel. The START button initiates an alcohol screening test. The offender positions the breathalyzer in front of his/her phone, such that the ID of the breathalyzer can be seen by the front camera. The phone authenticates the ID and then signals the offender to blow air into the breathalyzer. The phone uses the received alcohol readings to calculate the final BrAC level, which is then uploaded to a remote management server hosting face verification and early-warning services. This data can be used in conjunction with observations made by psychologists and responses from patients during interviews in the formulation of treatment strategies. It can also be used to facilitate frank communication with the user about their alcohol use. Probation officers can use this information as clues to identify further questions requiring clarification or warnings to identify situations requiring intervention. The proposed system makes it possible for offenders on probation to share data pertaining to alcohol consumption and vehicle use behavior with their psychiatrists and probation officers. It also facilitates the implementation of DUI prevention plans in their daily lives.

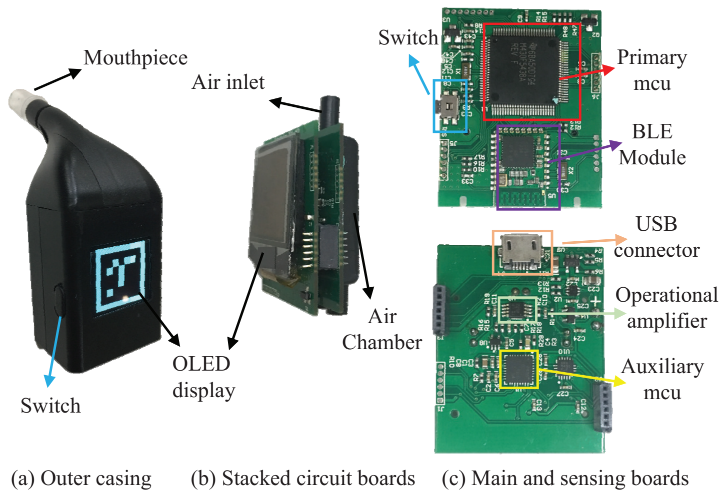


Fig. 1. Schematic illustration showing: (a) Outer casing of SoberMotion breathalyzer; (b) Stacked circuit boards in the device; (c) Components on main and sensing boards.

4.1 Portable Breathalyzer

Figure 1(a) illustrates the design of the proposed breathalyzer. A rugged casing protects the inner components. A single button is used to start or end a breath alcohol test. When the breathalyzer is turned on, an OLED display [47] on the front indicates the status of the breathalyzer. A binary square fiducial marker [69] encodes a unique identification number assigned to each participant to ensure that devices are used only by their owners. To ensure that air from deep within the lungs enters the device, the user is required to blow continuously into the device for at least 6 seconds [57]. A sensor reacts with the alcohol to produce an electrical signal proportional to the breath alcohol concentration (BrAC). By sampling the electrical signal via an Analog-to-Digital (ADC) converter, the device converts electrical signals into a corresponding target BrAC value, using a linear equation with the slope determined using the calibration process outlined in the following section.

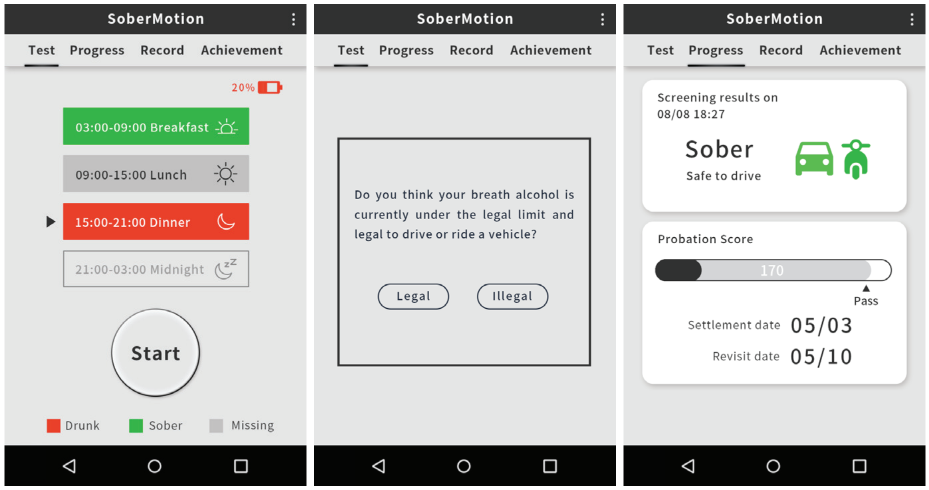
4.2 SoberMotion Phone App

The SoberMotion phone app performs four functions: 1) assisting offenders to determine whether the alcohol they ingested has been metabolized before operating a vehicle; 2) recording alcohol use behavior; 3) tracking compliance with probation requirements; and 4) and reporting vehicle use to probation officers. The user interface and functions are outlined in the following:

4.2.1 User Interface. Figures 2 and 3 illustrate the user interface of the SoberMotion app. We adopted a full-screen design with a tab bar at the top of each page. When launched, the app enters the test page (Fig. 2(a)) and initiates a breath alcohol test. Users can toggle between tabs to access other functions. A card-based user interface is used to arrange the information provided by each function [9]. The cards are arranged in a single row on each page to make it easier for individuals lacking experience with smart phones.

4.2.2 DUI Preventing Functional Module. The system includes four functional modules: (1) alcohol screening, (2) recent progress, (3) alcohol use history, and (4) probation achievement.

Alcohol Screening: Self-administered breath alcohol tests can be used to indicate drinking behavior and to assess one's level of sobriety before driving. The results of our pilot study indicate that many offenders are unaware of



(a) Test page (b) Self assessment dialog box (c) Progress page

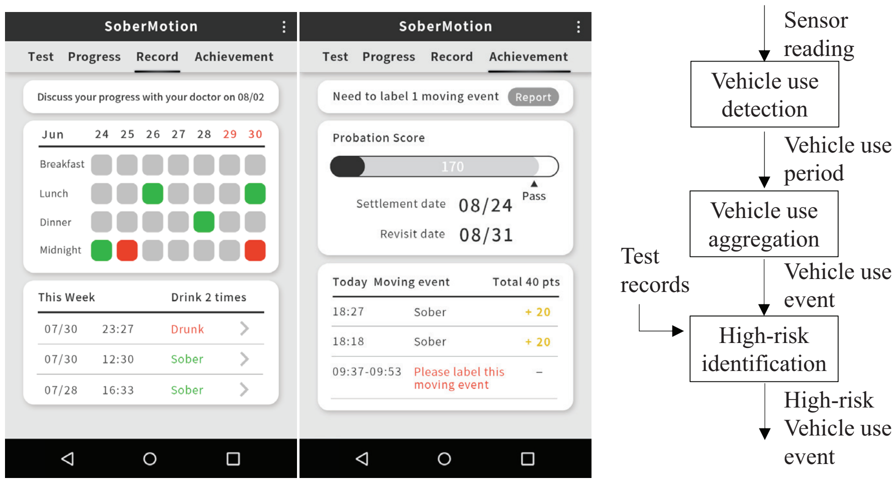
Fig. 2. App pages showing (a) test schedule; (b) self assessment dialog box; and (c) probation progress.

their alcohol use problems, which makes them reluctant to record their drinking behavior. Nonetheless, offenders are required to perform breath alcohol tests to enable probation officers to keep track of their alcohol use and assist psychiatrists in formulating strategies by which to overcome alcohol-related problems. To keep track of alcohol use without imposing too much of a burden, we divided the day into four time slots, (breakfast (3am to 9am), lunch (9am to 3pm), dinner (3pm to 9pm), and mid-night (9pm to 3am) slots). Participants were asked to perform at least one test in any two of the time slots each day.

Figure 2(a) presents the user interface used for the alcohol screening test. After the breathalyzer is switched on, a Bluetooth connection is established between the breathalyzer and the phone. The user then clicks the START button to initiate a test. The app presents a self assessment dialog box (Figure 2(b)), which prompts the user to predict whether his/her reading will be below the permitted BrAC standard for driving. The response is given by pressing “legal” or “illegal” on the app. The app reminds the user to keep his/her their face within a rectangle appearing on the screen while holding the breathalyzer near the mouth. Before instructing the user to blow, the app uses the 2D marker [69] to verify that the breathalyzer is indeed assigned to the user (specified at the time of app installation). The app instructs the user to blow into the breathalyzer mouthpiece (for at least 6 seconds) [57]. The app counts down the time, while the front camera records the face of the user. If the test comes back positive, then the app prompts the user to input the triggers of their alcohol use. All of the test results, including the feedback and captured photos, are then uploaded to a server for analysis by probation officers and/or psychiatrists. The face verification module running on the management server confirms that the identity of the user taken by the front camera matches that of the intended user, based on a model trained offline.

Recent Progress Visualization: Figure 2(c) presents the results of alcohol tests, including the time and sobriety status (upper card), and an overall evaluation of performance in fulfilling probation requirements (lower card). The app automatically switches to this page after completing a screening test to summarize the test results. This page can also be called up by clicking the “Progress” tab.

The lower card visualizes the overall performance in fulfilling probation requirements as well as the dates available for arranging scheduled interviews with the probation officers in the event that they fail to meet the expectations of probation officers. We sought to encourage users to self-report their alcohol screening results and sobriety level after operating a vehicle under high-risk conditions. All of the results were then tabulated as an



(a) Record page (b) Achievement page (c) High-risk event detection

Fig. 3. App pages showing (a) recent test results; (b) overall testing achievements; and (c) sequence of steps used to detect high-risk vehicle use events.

overall probation score. As long as their score reached a predefined threshold, the app would inform the user that he/she did not have to attend the meeting scheduled for the following week (Figure 2(c)).

Alcohol Use History: Figure 3(a) displays the alcohol screening results (in calendar view), which are meant to encourage users to continue with the program. The app also summarizes related information, including their next scheduled appointment at the clinic, a weekly summary of their activity, and alcohol screening results. The upper card lists the date scheduled for the next visit as a reminder to reserve that day for a visit to the clinic. We also sought to make it easier to review the records of alcohol use. The middle card includes several small rectangles presenting the various time slots, as an indication of whether the user passed a test during that period or skipped it throughout the week. Users could switch to views of the previous and following weeks by sliding the page to the left or right, respectively. The lower card lists all individual tests chronologically from top to bottom to facilitate access to specific tests.

Probation Achievement: Figure 3(b) shows the performance of the user in meeting the requirements of probation. In the pilot study, the probation officers mentioned that they were also tasked with assisting offenders to alter their behavior [67]. However, in some situations the probation officer is unsure whether the user was sober while operating a vehicle. Thus, we also formulated a vehicle use detection module to identify high-risk vehicle use events. Figure 3(c) illustrates the sequence of steps used by the app in detecting such events. The detection module first determines whether the user is "using a vehicle" or "not using a vehicle", based on data from the accelerometer and gyroscope on the phone (Google Activity Detection API) [1]. This enables the app to identify time fragments of vehicle use, which when aggregated according to proximity provide a complete picture of the vehicle use event from the time the offender starts the vehicle until they stop. Correlating vehicle use events (events occurring when driving vehicles themselves, using mass rapid transit, etc.) with test records within a 24 h period also helps to identify high-risk vehicle use events; i.e., situations in which the user may have operated a vehicle while under the influence of alcohol. In such situations, the system reminds the user to self-report whether they were operating the vehicle or simply riding in the vehicle. This is done by clicking the "Report" button on the top card. The accuracy of the vehicle use detection module was evaluated by having paid volunteers ride in a variety of vehicles while carrying a smart phone equipped with a data collection app. We collected a total of 2548 min of data (681 minutes driving, 542 minutes riding on buses, 532 minutes riding on the mass rapid transit (MRT), 288 minutes riding scooters, 505 minutes on a high-speed train). The app was able to detect movement 90% of the time, with false detections totaling 137 min (10%). The loss of accuracy and precision can be attributed to walking involved in taking the bus or subway as well as the jostling one undergoes while riding on some vehicles. Overall, the app achieved overall precision of 0.90 and recall of 0.94.

The middle card has the same layout as the lower card on the "Progress" page. It is used to summarize the overall performance of users in fulfilling probation requirements. The bottom card lists the details, with an indication of the actions required to improve their score; i.e., the scores earned by completing self-reporting actions.

4.3 Management Server

A web interface is used to visualize alcohol use behavior in calendar view. For each time slot, this webpage indicates whether face verification was passed and provides the results of alcohol testing as well as the BrAC values of each screening test. A line graph is used to illustrate the BrAC results over time. Specific life events (identified by the color of the dots on the line graph), can be used to identify the triggers of alcohol use. Thus, the web monitoring module can be used to identify correlations among alcohol use records, inferences concerning the mode of transport, aberrant alcohol use behavior, and situations in which the user failed face verification. This information can be used by probation assistants/officers to identify situations in which the offender drinks alcohol before riding in a vehicle (as indicated by the self report of using a vehicle in a detected vehicle use event). Further correlations would generate an alert.

Face Verification: We installed a face recognition module on the management server to verify the identity of the users. This module is based on a deep neural network architecture, implemented using the Openface [50] toolkit. We prepared 3200 photos of celebrities and 400 photos of the target users to train the deep neural network in the extraction of features for a recognition model. To avoid over-fitting and boost performance, we employed an ensemble of classifiers, including GNB (Gaussian Naive Bayes), SVM (Support Vector Machine), and DBN (Deep Belief Networks). This resulted in a more stable model with higher recognition accuracy. The GNB classifier is responsible for making an initial judgment. When the GNB output score exceeds a given threshold, second stage SVM and DBN classification is activated. If the candidates predicted using SVM and DBN present a match (i.e., both scores surpass a given threshold), then the ensemble classifier concludes that the detected face belongs to the target user.

Upon receiving a photo, it is necessary to locate the face before seeking to verify the identity. Openface provides a dlib face detector [13]; however, the miss rate is somewhat high. We therefore included a second OpenCV face detector [21] to remedy this problem. To overcome variations in capture direction and illumination conditions, we first normalized each face using an affine transform. The extracted features are then sent to the aforementioned ensemble classifier to make predictions. To overcome the effects of noise, six photos were uploaded to the server by the app every time the user blew air into the breathalyzer. The ensemble classifier then processed each of these photos and adopted majority voting to generate the final decision.

Early-warning Service: Figure 4 presents the cloud-based early-warning system, which was designed to notify probation officers/assistants of situations in which the offenders are most likely to face new challenges (i.e., dynamic risk factors), which could lead to re-committing DUI. In a report released from American Probation and Parole Association (APPA), it was noted that most probation officers are overwhelmed by heavy caseloads. We observed the same situation in our pilot study, in which PO #2 described having to keep track of 290 cases simultaneously. An inability to prioritize cases or check the status of offenders makes it nearly impossible to conduct interventions when they are most needed. The initial classification of offenders (as high-risk or low-risk) by probation officers is generally based on static risk factors (historical attributes of an offender that cannot be

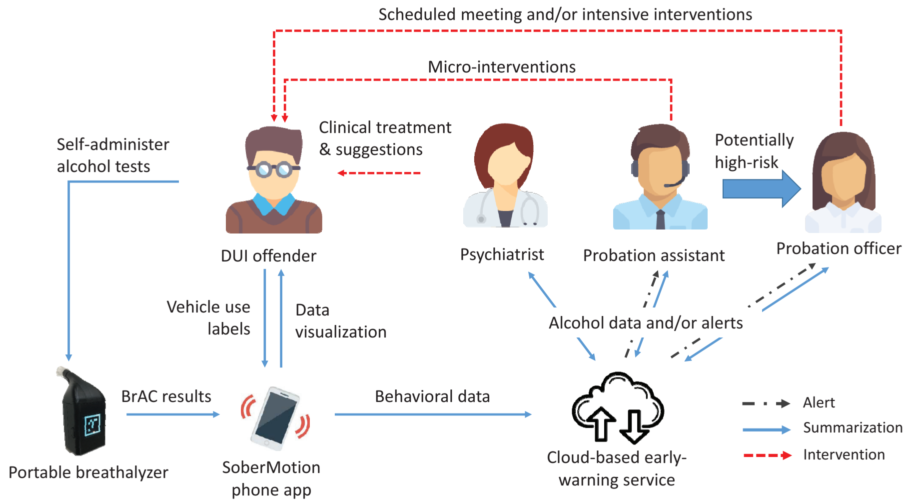


Fig. 4. Interventions introduced by probation assistants/officers and psychiatrists after receiving alerts generated by the early-warning system.

changed, such as age, age of first offense, number of prior convictions) as well as dynamic risk factors (personal attributes that may change over time, such as employment or educational status, family dysfunction, negative peer associations). The supervision of offenders presenting low static risk is usually delegated to probation assistants who also have the authority to follow up on alerts generated by the SoberMotion system. Those alerts indicate situations warranting micro-interventions, such as a failure to conduct breath alcohol tests, notable changes in alcohol use behavior, and unreported or high-risk vehicle use events. The system generates alerts in the following situations:

- *Poor conformance*: Completion of fewer than two tests on two consecutive days.
- *Excessive alcohol use*: Impairment in four non-consecutive time slots or in cases of relapse after being sober for periods exceeding two weeks.
- *Unreported or frequent high-risk vehicle use events*: A failure to self-report high-risk vehicle use events (automatically detected by the system) four times in a given week.

An alert indicating a failure to comply with probation requirements is usually sufficient to warrant a micro-intervention by the probation assistant. Interventions are usually in the form of a phone call to the offender aimed at identifying emerging risk factors. A failure on the part of the offender to provide a plausible explanation for the lapse could result in the offender being re-classified as high-risk; i.e., subject to more intense scrutiny and/or obtrusive interventions. The interventions should address the criminogenic needs of the offender, as in the case of losing one's job. In cases where the user is suspected of attempting to cheat the system by providing a false self-report label (e.g., reporting that they did not operate a vehicle when they actually did), the probation officers may ask contextual questions to verify their responses. This should make it possible for officers to perceive anomalies in behavior as early as possible. The system is not meant to be an infallible monitoring system, but rather an early warning system. The cloud-based system is also meant to give probation officers an overview of the offenders' behavioral patterns to assist in developing suitable coping strategies that address the criminogenic needs underlying their aberrant behavior.

5 IMPLEMENTATION

5.1 Portable Bluetooth Breathalyzer

Figure 1(b) presents the main board, a plastic housing forming an air chamber over a barometer on the sensing board [40], and an alcohol sensor [38] also on the sensing board. The main board is equipped with a primary microcontroller [43], a Bluetooth 4.0 Low Energy Module [12], and an OLED display [47] to process sensor readings collected by the sensing board. The sensing board is equipped with a secondary microcontroller [44], a breath alcohol sensor, and a barometer. Air blown into the mouthpiece is directed through a polyurethane tube to accumulate in the air chamber. We modified the design of the portable breathalyzer proposed in SoberDiary [104] by replacing the alcohol sensor with a fuel cell alcohol sensor in order to reduce maintenance costs and improve accuracy. The sensing board uses a three-terminal electrochemical amplifier to boost the small signals produced by variations in alcohol concentration. A two-channel amplifier was installed to enable a third electrode amplifier circuit [28]. The abrupt increase in air pressure when air is first blown into the device prompts the main microcontroller to begin collecting readings from the differential output. The breathalyzer has a lithium-ion battery that can be recharged via a USB port [26].

A breath alcohol simulator [22] is used to map the digital values of amplified signals sampled by the ADC interface and its corresponding BrAC value in order to calibrate the breathalyzer. Following calibration, this system achieved accuracy of +/- 0.027 mg/L breath alcohol within a range of 0 to 0.4 mg/L. To reduce the influence of cigarette smoke or other substances (e.g. medications) from influencing the BrAC values [45], we set a final threshold of 0.1 mg/L, below which the user would be deemed “sober”. Between 0.1 and 0.15 mg/L (the standard for a charge of DUI in Taiwan [46]), we defined a “drunk-but-legal-to-operate” class for situations in which the user is still able to drive a vehicle safely despite having had an alcoholic drink. We also defined an “illegal-to-operate” class for BrAC values greater than or equal to 0.15 mg/L, for situations in which the user would be forbidden to operate a vehicle due to excessive alcohol in their system.

5.2 SoberMotion Phone App & Management Server

The SoberMotion application communicates with the breathalyzer via the Android Bluetooth API. The OpenCV library is used to extract and analyze the features of the users face. The Google Activity API is used to classify the activity of the user as “in a vehicle” or “not in a vehicle”. The start and end points associated with each vehicle use event are obtained by aggregating nearby intervals for use in classifying the category of “in a vehicle”. An SQLite database is used to store the patients’ BrAC test results and high-risk vehicle use events on the phone. The management server records the breath alcohol test results, momentary feedback, and application use logs from all patients in a MySQL database hosted on an Apache server.

6 USER STUDY

We conducted a 2-month field study involving 8 DUI offenders using SoberMotion to validate the feasibility of the SoberMotion system in reducing the risk of DUI recidivism. This study was approved by the Institutional Review Board of Taipei City Hospital (IRB No.: TCHIRB-10603109).

6.1 Participant

Participants were recruited via referral from an anonymized probation office. Participants were screened by probation officers using structured interviews to determine eligibility. They were also briefly explained the goals of the study. Eligible offenders were free to choose whether to participate in the experiment. Each volunteer provided informed consent and arranged a date to begin treatment for alcohol-related problems at Taipei City Psychiatric Center (TCPC).

The recruited participants (U1 ~ U8) included eight men aged 39 to 59 years (46.75 years: S.D. +/- 7.74 years). All participants provided ground truth data pertaining to the consumption of alcohol using the timeline follow-back (TLFB) method [79, 83, 96, 97], which is a well-established method used in evaluating self-reports of alcohol consumption. The participants included one retired individual, a cook, a salesperson, a vegetable vendor, a construction worker, two renovation workers, and a truck driver. All participants were DUI offenders with an average of 3 DUI convictions. The CAGE scores of the participants were 2 to 3 with an average score of 2.25, which indicates that their alcohol problems were clinically significant and could be regarded as alcoholism. These individuals consumed an average of 25.81 alcoholic drinks (a unit of alcohol used to quantify the amount of alcohol intake [79]) (S.D. +/- 34.21 drinks) on an average of 7.06 days per month (S.D. +/- 10.48 days) before the start date of the experiment. Due to inter-participant variability associated with alcohol use disorders, these individuals exhibited a wide range of drinking behaviors, which may explain the high standard deviations in total alcohol consumption and number of drinking days. Table 1 lists the data related to alcohol consumption. Drinking alcohol was not deemed a problem as long as the individual avoids operating a vehicle after doing so. Six of the participants continued drinking alcohol after entering the probation program and varied in the severity of alcohol dependence. People with alcohol use problems tend to develop a high tolerance to alcohol [104]. They have a habit of drinking alcohol several times each month. For example, $U8$ consumed the most alcohol (103.21 drinks) and drank with the highest frequency (nearly every day of the month (28 days) prior to the start date of the experiment). In some cases, drinking events are triggered by life events (e.g., losing job, birthday gathering, business lunch/dinner, etc.). For example, $U4$ drank the equivalent of 25.5 standard drinks of Kinmen Kaoliang Liquor (58% alcohol) in one day while hanging out with friends in the month before starting the experiment. Conversely, $U2$ stopped drinking alcohol altogether (0 drinks) for that month. All participants signed a deferred prosecution agreement. Patients were reimbursed US$16.5 for each revisit to the hospital for follow-up alcohol treatment.

Participants were provided a portable Bluetooth breathalyzer with a unique identification number (PID) paired to the SoberMotion application on their smart phone.

Table 1. Total alcohol consumption and number of drinking days in the month prior to the start date of the experiment.

Drinking data	***U1***	***U2***	***U3***	***U4***	***U5***	***U6***	***U7***	***U8***	***Avg***	***Std***
Total alcohol consumption (drink)	40.92	0.00	4.50	25.50	5.25	21.66	1.14	103.21	25.27	34.61
# of drinking days (day)	3.50	0.00	2.00	1.00	1.00	19.00	2.00	28.00	7.06	10.48

6.2 Procedure

The experiment consisted of three parts: (1) pre-study (baseline) medical assessment, (2) 8-week study using SoberMotion, and (3) post-study interviews.

On the first day of the experiment, the goals of the study were explained, and eligible participants were asked to provide informed consent. The participants were informed that their alcohol use, vehicle use, and face verification results would be made available to their psychiatrist and probation officer. The participants, probation officer, probation assistant, and psychiatrist were also informed that the detection results were not 100% accurate and would not provide conclusive evidence of DUI behavior. From an ethical perspective, we sought to prevent the inadvertent operation of a vehicle due to false negative results. Nonetheless, participants were also required to sign a liability waiver explicitly stating the potential risk of false negative results. In signing the waiver, the participants gave up any legal rights to sue our research team in the event that erroneous results led the user to believe that they were fit to operate a vehicle despite being under the influence of alcohol.

All participants underwent a pre-study medical assessment (50 min). Recent alcohol consumption and compliance with probation requirements were measured using the TLFB method [79, 96, 97] based on self-reported data. The TLFB method is a daily estimation (DE) measure [97], which is widely used to assess alcohol consumption in daily life. It can be regarded as a retrospective self-report tool used to measure treatment outcomes in clinical or research settings. The TLFB also provides psychometric support for the assessment of other behaviors, such as spousal abuse and gambling. It has gained international acceptance and been referred to in a large number of academic publications [87]. The procedure begins with the patient being presented a calendar that typically stretches back three months to a year. The calendar initially lists major events on their respective dates of occurrence (e.g., holidays, catastrophic weather, memorable national or local events, professional sports competitions, etc.). The respondents were asked to reveal significant personal events on their respective dates of occurrence in order to fortify memories associated with substance use (e.g., births, birthday celebrations, funerals, work related celebrations, etc.). Once this data was collected, the individuals were asked to identify the type of alcohol (e.g., beer with 5% alcohol) and the amount of alcohol they consumed (e.g., one can of beer) on each of the drinking days. Recent alcohol consumption and compliance were measured by converting those values to a standard drinks (the standard unit of alcohol used) based on the US Standard Drink Conversion Chart [15]. The participants then underwent their first treatment for alcohol-related problems and attended a 30-min training session on the operation of the SoberMotion application and breathalyzer. During the training session, another researcher installed the SoberMotion application on their phones and collected face images to train the model for face recognition on the backend server. Upon completion of the training session, a hospital visit was scheduled. Participants were encouraged to participate in the program by leaving open the issue of whether they would be expected to attend their next meeting with a probation officer, the result of which would be settled according to their compliance one week before the scheduled monthly meeting.

During the subsequent 8-week study, the participants were instructed to use the SoberMotion application to self-administer breath alcohol tests in at least two time slots each day and report whether they operated vehicles during high-risk vehicle use events. One week before each monthly meeting with their probation officer, the participants were reminded to attend the meeting if they failed to meet the probation achievement scoring threshold. Patient performance was evaluated via a clinical assessment session and an evaluation session with a probation officer during scheduled treatment reviews at the TCPC in Months 1 and 2.

Clinical assessment session (30 min): During months 1 and 2, the participants underwent treatment to deal with alcohol dependence in a psychiatrist' office or hospital-based alcohol treatment center. The TLFB method was used to obtain data related to alcohol consumption in order to obtain ground truth data of alcohol use behavior. In cases where participants increased their alcohol consumption significantly, the treatment team encouraged them to reduce alcohol use.

Probation evaluation session (20 min): Probation assistants reviewed all unreported high-risk vehicle use events to determine whether the offenders had operated a vehicle while under the influence of alcohol. Based on the participant's account, the probation assistant summarized a list of high-risk operating events (i.e., situations in which the participant self-operated his/her vehicle), which included those confirmed via the app or from memory during the interview. The probation assistant then asked participants to describe the details of the events and how they operated or avoided operating the vehicles after drinking alcohol. The objective was to gain an indication of whether the user was progressing or regressing in their treatment and to reveal discrepancies in the self-reported data.

After finishing the two sessions, the patients were asked to report any problems related to their experience with the SoberMotion application. At the same time, the accuracy of their breathalyzer was evaluated. Participants were dropped from the study if they committed any of the following: (1) failure to revisit the hospital to receive treatment; (2) failure to attend scheduled meeting with probation officer; (3) persistently skipping tests for longer than 2 days; or (4) committing a DUI while on probation. When a user failed to attend a scheduled treatment, follow-up telephone calls were made by the probation assistant to arrange another appointment. A maximum of three contact attempts were made in order to increase the likelihood of retaining participants. During the hospital follow-up in Month 2, an audio device was used to record a 45-min semi-structured interview on the use of the SoberMotion application, their vehicle operating behavior, the behavioral changes they adopted to prevent further DUIs, and their interactions with probation officers (or assistants) and psychiatrists while enrolled in the SoberMotion program.

6.3 Measure

In the following, we outline the evaluation metrics for ith month, as derived using behavioral data collected by SoberMotion. The *completion rate* indicates the average number of time slots completed by the participants each day. The *miss rate* indicates the average number of time slots missed by participants each day, given that offenders were required to perform tests in at least two time slots per day. The *drinking day difference* refers to the difference in the number of drinking days, as determined using TLFB and SoberMotion. We adopted accuracy, precision, and recall to quantify the performance of breath alcohol tests and face verification modules, where $accuracy = \frac{TP+TN}{P+N}$, $precision = \frac{TP}{TP+FP}$, and $recall = \frac{TP}{TP+FN}$ based on the number of positive samples P, negative samples N, true (false) positive inference TP (FP), and true (false) negative inferences TN (FN). The self-assessment of fitness to operate a vehicle (i.e., legal or illegal to drive) could also be compared with the breathalyzer results to evaluate the participants' awareness of the rate at which they metabolize alcohol. Self assessments that match the corresponding screening results are categorized as *matched-legal cases* (or *matched-illegal cases*). Unmatched tests are categorized as *overly-optimistic cases*; i.e., participants were unaware of residual alcohol in their blood at the time of testing, and *conservative cases* where participants were overly cautious.

We also investigated how participants utilized screening tests before high-risk vehicle operating events by calculating the *n-hour screening frequency*; i.e., the average number of screening tests completed within n hours before operating a vehicle (n is specified later in this section). The evaluation metrics based on TLFB included total alcohol consumption and the number of days the participant drank alcohol in the month before the study and in the ith month of the study.

6.4 Data Analysis

Paired t-tests were used to check for differences in the average n-hour screening frequency between the high- and low-alcohol consumption groups. The chi-square test was used to compare the perceptions of offenders with regard to the rate at which they metabolize alcohol in Month 1 with their perceptions in Month 2. Repeated measures ANOVA was used to identify significant trends in the completion rate, missed rate, drinking day difference, verification rate, total drinking amount, and number of drinking days, when comparing the results for the month prior to the study and the two months of the study.

6.5 Quantitative Results

Data from medical reviews and the SoberMotion application were compared for consistency and used to characterize the efficacy of SoberMotion in improving the participants' awareness of their rate of alcohol metabolization, particularly when used as a complement to conventional treatments for the management of alcohol consumption.

Table 2. Detection performance of the breath alcohol test module, in which samples identified as non-sober (sober) are listed in the negative (positive) class; (b) Performance of the face verification module, in which detected faces belonging to the target (others) are listed in the negative (positive) class.

(a) Confusion matrix generated by breath alcohol test module

		Predicted result	
		Non-sober (N)	Sober (P)
Actual	Non-sober (N)	1115	19
	Sober (P)	7	90

(b) Confusion matrix generated by the face verification module

		Predicted result	
		Unknown (N)	Target (P)
Actual	Unknown (N)	1	0
	Target (P)	96	1134

6.5.1 Self-reporting Behavior. Throughout the two months of the study, all of the participants met their obligations pertaining to the use of the SoberMotion system. The overall accuracy of the breath alcohol test and face verification modules were 98%, respectively. Specifically, accurate screening as either sober or non-sober was achieved in 1205 (1115 positive and 90 negative tests) of the 1231 breath alcohol tests. As shown in Table 2(a), the breathalyzer was able to identify 83% of alcohol use events, with 19 false detections of alcohol use (17%), which translates into precision of 0.83 and recall of 0.93. We determined that most of the false positives were associated with the presence of gases that could potentially interfere with the measurement (e.g., carbon monoxide exhaled when smoking) [37] as well as substances that contain alcohol (e.g., cold medications). False negatives were observed when the difference between the detected BrAC value and the threshold of 0.1 mg/L was too small to be differentiated. The overall accuracy of the face verification module was 92%; i.e., the user was accurately identified as the target user in 1134 tests and rejected as unknown in 1 of the 1231 breath alcohol tests. As shown in Table 2(b), the verification module achieved overall precision of 1.0 and recall of 0.92. Only a small number of photos obtained while participants performed tests (8%) failed to verify the user as the intended target. The images that failed to pass were compiled on a webpage by the management service for review by probation officers. Overall, the accuracy of both modules was sufficient to reflect behavioral patterns that could lead to future DUI behavior, as discussed in Section 7.

In Month 1 of the study, the average completion rate was 2.25 time slots per day, the miss rate was 0.20 time slots per day, and the drinking day difference was 1.88 days. In month 2, the completion rate was 2.33 time slots per day, the miss rate was 0.15 time slots per day, and the drinking day difference was 0.625 days. No significant differences were observed in the completion rate, miss rate, or drinking day difference between the two months (p = 0.73, 0.62, and 0.31, respectively). This demonstrates that the offenders complied with the test requirements. Overall, the participants completed an average of 2.29 time slots per day, missed 0.18 time slots per day, and recalled the number of drinking days to within 1.25 days of the TLFB records.

6.5.2 Making Offenders Aware of Alcohol Metabolization. The participants reported finding it difficult to predict the rate at which they metabolize alcohol; therefore, we focused only on the tests in which the participant who drank alcohol earlier was deemed non-sober in the subsequent breathalyzer test. Figure 5 indicates the degree to which SoberMotion improved user awareness of alcohol metabolization during the two months of the study. Among the 25 tests in which participants were deemed non-sober in Month 1, participants were overly optimistic

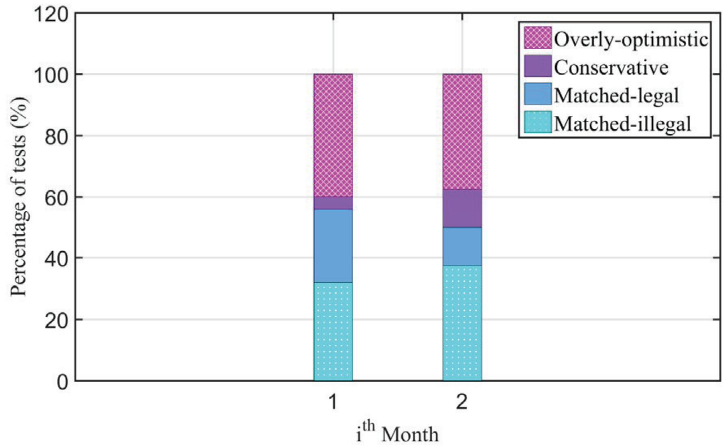


Fig. 5. Percentage of matched-legal, matched-illegal, overly-conservative, and overly-optimistic cases based on a comparison of screening results obtained using the breathalyzer and participants' self assessment of fitness to operate a vehicle (i.e., legal or illegal to drive) in each month of the study.

about their driving fitness in 40% of the cases. Only one of the user predictions was deemed overly conservative (4%). Among the remaining 14 tests in Month 1, the participants made 6 correct predictions that they were legal to drive (24%) and 8 correct predictions that they were not legal to drive (32%). In contrast, among the 40 tests in which participants were deemed non-sober in Month 2, participants were overly optimistic about their driving fitness in 37.5% of the cases, which is slightly lower than the 40% in Month 1. Among the remaining 25 tests (62.5% of the cases) in Month 2, the participants either correctly predicted (matched-illegal cases: 37.5% and matched-legal cases: 12.5%) or were overly conservative (12.5%) with the rate of alcohol metabolization.

Overall, the awareness of participants as to the rate at which they metabolize alcohol differed significantly between the two months ($p < 0.05$). In Month 2, the participants were more cautious about their alcohol metabolization after they drank alcohol, based on the fact that the number of overly conservative cases increased significantly from 4% in Month 1 to 12.5% in Month 2. A review of the data revealed that in month 2, many of the participants began conducting a series of tests before operating a vehicle. Thus, even when their initial estimates were erroneous (i.e., they felt fine but were in fact drunk), they conducted further tests to ensure that they were within the legal limit to operate a vehicle. This means that they failed multiple tests before the alcohol was completely metabolized. Despite the fact that the participants passed the final test, they were unaware that they were legal to drive. As a result, they tended to be conservative in their estimates of alcohol metabolization; i.e., they had begun to err on the side of safety. We refer to this phenomenon as a multiple-test episode, as discussed later in this section.

6.5.3 Alerting Probation Officers of High-risk Operating Events. No significant differences were observed when comparing the results obtained in the month prior to the study and during the 2 months of the study in terms of total alcohol consumption ($p = 0.58$) or the number of drinking days ($p = 0.29$). However, when comparing alcohol use behavior at baseline with that during the 2-month experiment (i.e., after receiving treatment for alcohol abuse), offenders reduced their daily alcohol consumption by 42.79% and the number of drinking days by 63.27% on average. Nonetheless, probation officers are concerned primarily with whether an individual drives after drinking alcohol. Most people eliminate approximately one alcoholic drink from their system each hour [77]. However, it is exceedingly difficult to establish the minimum bounds to ensure the complete metabolization of

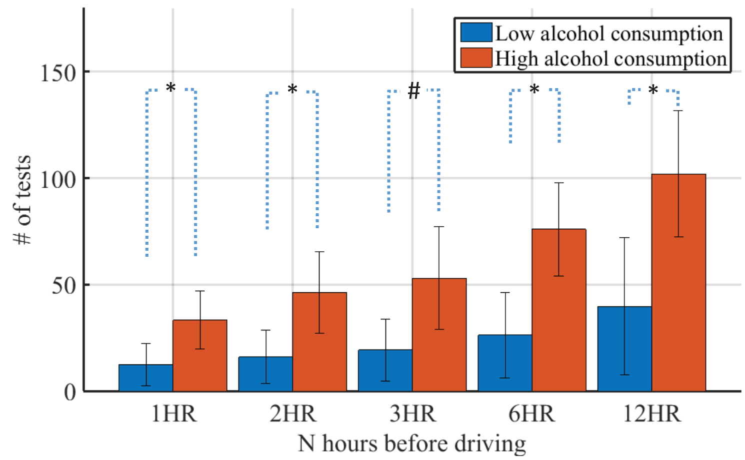


Fig. 6. Average number of tests taken before driving a vehicle. Users were divided into high and low alcohol consumption groups. Significant or nearly significant differences between two groups are respectively indicated by "*" or "#" symbol ($p < .05$ or $.05 \leq p < .1$).

alcohol, due to variations in the amount consumed, the type of alcoholic beverage, and inter-individual variability in alcohol metabolism profiles. A review of the data collected in this study prompted us to set the window of influence by alcohol at 12 h. In Month 1, we identified 5 cases where participants drank alcohol within 12 hours of operating a vehicle, and in Month 2 we identified 1 case. These situations do not necessarily indicate that the participants in question were driving under the influence of alcohol. Rather, they are an indication of behaviors of which probation officers should be aware. The risk of re-committing DUI by individuals not using this system could easily be underestimated, given that the number of high-risk self-operating events cannot be verified; i.e., these events are easily concealed or lost due to memory recall error.

6.5.4 Assist Offenders in Avoiding Re-committing DUIs. The case group was divided into sub-groups according to their total alcohol consumption (high or low). We then derived the n-hour screening frequency with n equal to 1, 2, 3, 6, or 12 hours, as shown in Fig. 6. The sub-group that drank more during the study completed 33.25, 46.25, 53, 76, 102 tests within 1, 2, 3, 6, and 12 hours prior to a high-risk-operating event. These values are significantly higher than those in the group with lower alcohol consumption (12.5, 16, 19.25, 26.25, and 39.75 tests) ($p < 0.05$ within 1, 2, 6, and 12 hours and $p < 0.1$ within 3 hours). Despite the fact that eight of the participants arranged their tests in different time slots (as discussed later); most of the heavier drinkers tended to take more tests before operating a vehicle.

6.6 Qualitative Findings

We manually transcribed the audio recordings of the semi-structured interviews conducted in the post-study phase to identify salient themes [101]. These themes are outlined in the following:

6.6.1 Adoption of Screening Tests. At the beginning of the study, some of the participants ($U1$, $U2$, $U3$, $U4$, $U5$, $U6$, and $U8$) commented that they were reticent about taking self-administered breathalyzer tests, as indicated by the following comment:

> *"I spent three days getting used to using the system in different times and places. I first determined which time slot to perform the tests, and then tried to make the time" — (U1)*

The proposed system was shown to enhance motivation to take alcohol tests. Nonetheless, all of the participants began arranging regular tests during their free time slots in order to increase probation scores and give the probation officer a good impression.

> *"Sometimes I performed test in alternative time slots when I felt bored. I just wanted to do something that would earn some probation points and kill some time." — (U7)*

Six of the participants who did not remain sober throughout the study commented that they would deliberately perform (a series of) extra tests before driving.

> *"Recently, I performed several tests while preparing to go out to work. [...] When I had actually drunk alcohol, just blowing into that thing would ensure that I would not be DUI" — (U8)*

Overall, the users who used the system twice a day did so for two reasons: 1) to earn probation points in order to be exempted from monthly meetings and 2) to ensure that they were fit to operate vehicles.

6.6.2 Becoming Aware of Alcohol Metabolism. The period over which the effects of alcohol last is referred to as the window of influence. In daily life, it is not uncommon for people to unintentionally use alcohol-containing substances, such as mouthwash or some types of food.

> *"One day I ate mutton hot pot with my friends. I showed the breathalyzer to my friends. I also demonstrated how it worked and was surprised to find that I failed the test. One of my friends reminded me that the cook may have added alcohol to the dish we were eating." — (U2)*

Many of the participants ($U3$, $U4$, $U5$, $U6$, and $U8$) who tried to wait for the alcohol to metabolize complained that they were unsure how long the window of influence would last. Nonetheless, all six of the non-sober participants began taking multiple tests to figure out how their bodies dealt with alcohol.

> *"On two days, I tried drinking two cups of an energy drink and waited about one and half hours. As I prepared to drive my car, I performed another test just to be sure. The result was consistent with my expectation that one and half hours was long enough to metabolize that much alcohol." — (U6)*

Still, offenders do not always know when they will need to operate their vehicle. In situations where they really needed to use their vehicles, four of the six non-sober participants ($U3$, $U5$, $U6$, and $U8$) conservatively performed multiple tests to confirm that the alcohol had completely metabolized before operating their vehicles. We refer to this process of confirming sobriety using multiple tests as a multiple-test episode. All of the users commented that they altered their schedules to put off driving.

> *"One night ... I remembered that I drank alcohol with friends in my home ... The following morning, I failed the breath alcohol test. However, I planned to go out for work. [...] To be sure that I was legal to drive, I stayed in my house for a while and took several tests. After I passed the test, I went to work and felt more confident that I was legal to drive my car." — (U3)*

6.6.3 Reinforcing the Importance of Testing before Driving through the Use of Alerts Related to High-risk Situations. Confirming that alcohol is completely metabolized before operating vehicles is the best way to prevent DUIs. The proposed system alerts probation officers when a user is involved in a high-risk vehicle use event. A failure to follow through with self-reporting gives probation officers a bad impression; therefore, all of the participants were very good about self-reporting.

> *"Well, you know ... if you are convicted of a DUI, you have to follow what he [the probation officer] tells you. The court deferred your sentencing by enrolling you in the deferred prosecution program. What else do you want? All you can do is to try hard ... really hard to fulfill the requirements." — (U6)*

In this study, we used self-reported facts only to assist probation officers to assess the risk of re-committing a DUI; i.e., the data was not used as evidence that participants were driving while under the influence. This greatly increased the willingness of participants to report when they operated vehicles even after using alcohol. This also made it easier for probation officers to initiate interventions.

> *"If the self-reported data were given to the prosecutors as evidence that the user were likely to drink and drive, then most people would provide false answers." — (U7)*

Even though the system was designed to support offenders rather than catch them, some of the participants either reported false data or avoided reporting at all. Nonetheless, probation officers are still able to probe the status of the user by telephone. Probation officers can use screening tests and high-risk vehicle use events to identify discrepancies in self-reported data in order to better assess the possibility of recommitting DUIs and evaluate whether the user was progressing or regressing in their treatment.

> *"When offenders repeatedly avoid reporting operating a vehicle after drinking, I ask other questions to verify their story. For example, if they reported taking a taxi, I might ask them where they went and how much the taxi cost to determine whether their answers are reasonable." — (PO)*

Two ($U5$, and $U6$) of the three users who had a high number of high-risk vehicle use events replied that the alerts worked as a reminder that to take a breathalyzer test before driving.

> *"The sudden occurrence of a number of high-risk vehicle use events made me wonder if it was due to recent alcohol use. I had been sober for a while but had a family event on that day. The only thing that stood out was the alcohol I had recently been drinking." —(U6)*

6.6.4 Facilitating Communications with Probation Officers and Psychiatrists. None of the participants were identified as alcoholics. Thus, all of the participants went to the hospital for follow-up treatment on their own; i.e., without friends or family.

> *"Sometimes I would ask a family member about the patients' condition. However, these DUI offenders are relatively stable, that is ... they do not drink excessively, they are not emotionally unstable, and they are not violent... Thus, they have no problem coming alone." — (PSY)*

Psychiatrists cannot ask accompanying family members to gather behavioral information of patients between revisits; i.e., they can only determine the condition of patient using patient responses, which might be partial and incomplete. Nonetheless, the psychiatrists still commented that the drinking records collected by our system were helpful in identifying factors that influence alcohol use behavior.

> *"U1's alcohol use appeared unstable and he refused to follow my suggestion to complete additional homework assignments between visits. Nonetheless, when I asked him about these issues during an interview, he answered with an unconvincing "yes". Considering the dubious nature of his reply, I had no choice but to use other data from the app." — (PSY)*

On the other hand, 6 of the 8 participants ($U2$, $U3$, $U5$, $U6$, $U7$, and $U8$) expressed concern about others playing with their breathalyzer, which could generate records that might degrade their probation performance. To prevent anyone from using the breathalyzer for malicious purposes (i.e., to sully the record of a user), all six participants were happy that the face verification module would demonstrate to probation officers that the test was really performed by the target user. This was a surprising finding, contrary to our expectation that participants would be inconvenienced by the camera or would feel reluctant to perform face verification before tests.

> *"If there is no face verification ... , how do others [i.e., probation officers] know if the test is done by me? I think that allowing others to use my breathalyzer is not a good idea. As with my phone, it's mine. Would you lend your phone to others?" — (U7)*

Alerts to probation officers concerning abnormal events resulted in phone calls to four of the six participants who were not sober during the study period ($U1$, $U5$, $U6$, and $U8$). They claimed that they tried to listen to the probation officer's suggestions in order to pass.

> *"I was shocked when the probation officer called me. I was wondering if anything was wrong. I then realized that the officer only wanted to know why I suddenly started drinking after being sober for several weeks." — (U8)*

This kind of reinforcement could be used to remind offenders that they are still on probation.

7 DISCUSSION

In the following, we present a summary of the valuable insights gained in the design of this mobile support systems for DUI offenders on probation. We also discuss actionable insights into the application of this explorative system as a complement to current practices in dealing with DUI probation.

7.1 Design Consideration of Mobile Support Systems

Most of the participants reported an unwillingness to completely abstain from the use of alcohol and would therefore remain at risk of re-committing DUIs. Furthermore, the more they drink - the greater the risk. Our findings revealed that offenders under the influence of alcohol are not entirely aware of the rate at which their bodies metabolize alcohol, and that offenders tend to optimistic in their assessment of risk [70, 72], particularly when the BrAC value is close to the DUI limit. It would also be reasonable to expect that after completing their scheduled meetings with probation officers and returning to their daily lives, their resolve in avoiding potential DUI behavior would gradually diminish. We therefore designed the SoberMotion system to raise one's awareness of risk in order to prevent optimism bias [70, 72]. We also implemented the proposed system in a manner that would bring to bear the full force of probation officers (through interventions) in order to head off the accumulation of risk. In the following, we discuss how SoberMotion achieves our two primary objectives: (1) raising awareness and (2) preventing risk accumulation.

7.1.1 Raising Awareness of Risk to Avoid Optimism Bias. The quantitative and qualitative results in the previous section demonstrate that the SoberMotion system provides an effective tool by which to increase one's awareness of the rate at which alcohol is metabolized (Sections 6.5.2 and 6.6.2) and reduce the objective risk by having users perform a series of tests before operating a vehicle (Section 6.5.3). While designing the breathalyzer system, we considered whether to present a BrAC number or categorical status indicators (sober, drunk-but-legal-to-operate, or illegal-to-operate). Most existing breathalyzers present exact BrAC numbers; however, we felt that this may encourage users to make guesses concerning the rate at which they metabolize alcohol. We found that users would make a game of predicting their future BrAC values based on their current measurements. The fact is that most people underestimate the effects of alcohol and overestimate the rate at which they metabolize it, and in so doing increase the risk of DUI. For example, $U1$ in the field study made the following comment: *"I would try to predict my future BrAC number based on my current BrAC number. When the app showed a BrAC value close to the DUI limit [0.15 mg/L], I felt confident that I would soon metabolize the alcohol remaining in my system and be legal to drive. In other words, I would predict my future BrAC value in a way that was convenient for me."* A number of participants mentioned that it would be great if the BrAC values were provided; however, we were convinced that this would make it easier for them to formulate overly optimistic predictions, thereby contradicting the primary aim of this study. Behavior is strongly mediated by one's mood (e.g., anxious about being late for work) and/or control-related mediators (e.g., believing that one can prevent DUIs) [72]; therefore, it would be reasonable to expect that participants would be optimistically biased in estimating their level of sobriety when interpreting BrAC value close to the legal limit. We sought to impress upon participants that the time required to metabolize alcohol is unpredictable. We therefore had the system generalize the information through the use of status indicators, rather than specific BrAC numbers (Section 5). Ultimately, our objective was to remind offenders to undergo alcohol screening tests rather than make guesses (even educated guesses) pertaining to their level of sobriety.

7.1.2 Assisting Probation Officers by Providing Early Warnings. Our results also demonstrate that the SoberMotion system can make probation officers aware of the offenders' behavior, and in so doing prevent the escalation of risk between two schedule meetings. In our experiments, the participants were not asked to use this system as a requirement of their probation agreement; however, all of the participants expressed a desire to give the probation officers a good impression by reporting their vehicle use behavior and conducting breathalyzer testing on time. All of the uploaded data (including self-reported data) is available for review by probation assistant/officers in order to assess dynamic risk factors (referred to as criminogenic needs) [63, 74] and provide useful suggestions or impose necessary interventions during the monthly meeting with offenders (as described in Section 6.5.4). Many real-life events can alter the dynamic risk factors; however, it would be easy for a probation officer to overlook many of the events that occur between meetings. For example, PO #1 in the pilot study made the following comment; *"I remember that one offender under my supervision lost his job between two scheduled meetings. This event was the source of depression and frustration, which triggered the consumption of alcohol on multiple nights. One morning after one of these bouts, he received a phone call from the site manager of another construction company offering him a temporary construction job. He accepted the job but was identified as DUI on the way to the construction site while riding his scooter. [...] One month [between two scheduled meetings] is a long time. Many things can happen in a month. This makes it really hard for me to track their alcohol use behavior. Even when they are trying to reduce the amount of alcohol they consume, they are prone to relapse when faced with significant life are events."* Thus, the system was designed to automatically alert probation assistants of situations warranting intervention, as described in Section 6.6.3. After receiving an alert of a high-risk situation, the probation assistant can immediately call the offender to clarify the situation and provide just-in-time micro-intervention (e.g., asking offenders to continue to perform tests, self-report if they operating vehicles in the detected vehicle use event, or clarify the reason for frequently failing to pass tests) (as described in Section 6.6.3). Offenders are usually shocked when they receive a call from a probation assistant. They also have to describe the reasons for their failure to comply with the requirements, and promise to follow through on their obligations (as described in Section 6.6.4). In cases where the offender fails to provide a reasonable response, the probation assistant may forward the case to the corresponding probation officer to introduce stronger interventions (e.g., scheduling additional meetings). Automated risk detection and notification can help probation officers to keep an eye on the offenders and deliver early interventions to prevent the relapse of drunk driving. Based on the feedback that we received, we conclude that the SoberMotion system prompts offenders to report their behaviors, while making it easier for probation officers to monitor their progress and provide just-in-time interventions.

7.2 Application of SoberMotion as a Complement to Current Practices for the Delivery of Effective Interventions

The supervision of DUI offenders requires a multi-disciplinary approach [90] to ensure compliance, assess the availability of resources used to target risk, and identify areas that must be addressed to elicit behavioral change. The supervision of DUI offenders can be time-consuming (i.e., probation for DUI offenders is typically 2 years) and resource-intensive. It is important to engage prosecutors, probation officers, and alcohol treatment specialists to develop cost effective ways of incorporating technology-based systems in current DUI probation practices without jeopardizing public safety. In the following, we outline a number of actionable recommendations to be explored in the future: (1) using SoberMotion to prioritize and allocate supervision and treatment resources; and (2) promoting collaboration between supervisory bodies to make SoberMotion a practical tool for rehabilitation during probation.

7.2.1 Using Self-reported Data to Prioritize Supervision and Treatment Resources for High-risk Offenders. Data collected by the SoberMotion system (e.g., alcohol test results and vehicle usage) can be used to assess and classify DUI offenders. Incarceration rates in the United States have grown from 105 offenders per 100,000 U.S.

residents in 1975 [98] to approximately 700 offenders per 100,000 in 2016 [75]. There has also been dramatic, simultaneous growth in community correctional populations, which imposes numerous challenges for scholars and governments struggling to shift the emphasis from incarceration toward community punishments [62]. There is a problem of prison overcrowding [42] in Taiwan as well. The Taipei District Prosecutors Office is seeking to reduce the number of inmates [39] by collaborating with community-based hospitals to promote the use of deferred prosecution agreements (DPAs) through alcohol and drug addiction treatment. The number of offenders on probation has increased by 30%, from 6,576 cases in 2012 to 7,556 cases in 2016, based on a statistical report released from Taipei District Prosecutors Office in Taiwan [39]. As a result, each probation officer must now supervise approximately 250 cases every month. PO #2 recruited in the pilot-study made the following comment; *"I have so many jobs to perform each day. Two days a week are for interviewing offenders at the probation office. On the other days, I have loads of paperwork, such as reviewing court orders or placement documents, and keying in shorthand notes from interviews with offenders. I also have to visit some of the offenders to check up on their progress and living situation [...] The caseload is simply too heavy for us. A typical caseload is 70 or 80 cases in the US, and 100 cases in South Korea; however, the case load in Taiwan is around 250 cases."* As mentioned in Section 4.3, SoberMotion allows probation officers to delegate to their assistants routine micro-interventions for low-risk offenders after obtaining an automated alert. This frees up probation officers to take over cases that are deemed high-risk. This also helps experienced supervision officers (i.e., individuals who are well-trained in the use of programs adhering to the principles of effective intervention and treatment delivery) [81] to use their time more efficiently in handling offenders at high risk of re-committing DUIs or other felony crimes.

Uploaded behavioral data can also be used to evaluate the severity of alcohol problems when prioritizing scarce treatment resources. Researchers have developed early screening tools, such as AUDIT [53], to screen patients in terms of alcohol use in order to identify the most appropriate interventions. However, when patients first enter alcohol treatment programs, the difficulty of assessing drinking problems can be exacerbated in cases where the patient provides vague or incomplete answers, where the patient's score is inconsistent with other evidence, or where the patient has a prior history of alcohol dependence. For example, Psych #2 made the following comment in the pilot study; *"The severity of one's alcohol problem can be diagnosed during their first visit to the hospital. However, patients who are unable to clearly describe the alcohol problems they face must undergo further assessments in the following two or three revisits."* The data collected by SoberMotion can be used in conjunction with the assessments performed during clinical revisits to gain a clearer understanding of an offenders' drinking behavior. Understanding the severity of an alcohol problem allows the treatment team to identify the most appropriate interventions, such as alcohol education, simple advice, advice plus brief counseling, or referral to a specialist [53]. SoberMotion also allows treatment teams to track changes in alcohol use behavior between clinical revisits through the ongoing collection of data. When the data collected by SoberMotion indicates an improvement in alcohol use behavior, the treatment team may be able to impose less intensive interventions and/or reduce the number of mandatory alcohol tests per day. DUI offenders with less severe alcohol problems are less likely to recommit. For example, $U7$ in the field study made the following comment: *"I remember that my colleagues prepared ribs stewed with medicinal herbs cooked in a small amount of rice wine. As soon as I tasted it, I realized that they had added wine to the dish. But, ... I still had two bowls. Fifteen minutes later, I had to rush out to pick up my child from school by scooter. On the way, I was caught by the police. It seemed strange to me that the court would have me undergo alcohol treatment under the deferred prosecution agreement. I did not feel that I had an alcohol use problem since I rarely drink alcoholic beverages in my daily life. Still, it is not a good idea to argue with the prosecutor [...] I do not crave alcohol. Why do I still need to receive treatment to maintain abstinence??? I don't know what benefit I have received from these clinical treatments."* Nonetheless, reducing the burden of having to take multiple alcohol tests every day should be discussed with the treatment team to ensure that the available data is sufficient to reflect important changes in criminogenic needs.

7.2.2 *Future Collaboration Efforts to Make SoberMotion a Practical Tool for Rehabilitation during Probation.*

We initiated this project with the aim of facilitating collaborations between community-based and governmental organizations. However, adopting SoberMotion as a rehabilitation tool during probation requires an understanding of all potential issues related to the integration of existing alcohol treatment services with the proposed mobile support system. There are two important issues that must be considered: (1) making SoberMotion a required component for entry into a deferred prosecution agreement; and (2) implementing a reasonable fee for the installation and maintenance of the system. In the current study, the participants volunteered to use SoberMotion; i.e., they were under no obligation to participate in the proposed system. Furthermore, a failure to complete the two tests required each day would not automatically lead to the revocation of deferred prosecution. This left participants free to choose when and how to self-report their alcohol screening and vehicle use data. The participants reported this data in order to learn about the process of alcohol metabolization and to obtain probation scores that would exempt them from visits to the probation office. Thus, the offenders were motivated to self-report data, even when it was inconvenient to do so. Second, we lent breathalyzers to each participant in the experiment; i.e., they did not have to pay to use the rehabilitation tool. The cost of a customized breathalyzer is approximately $50 USD. This is less expensive than other state-of-the-art Bluetooth portable screening devices [3], thanks to our use of inexpensive electric components, plastic cases using surface mount assembly, and easily automated manufacturing. Mass production of the devices and economy of scale would no doubt lower the cost of the system even further. Nonetheless, the pilot study revealed that DUI offenders from a lower socioeconomic background would be unable to afford high program fees. To enhance the practicality of the proposed system as a rehabilitation tool, it would be advisable to engage legal experts to discuss the requirements of inclusion in the program as well as the conditions that would lead to expulsion from the program. It will also be necessary to conduct trials to evaluate how the updated requirements affect their self-reporting behavior and negotiate a program fee that would be affordable for most offenders of low socioeconomic status.

8 LIMITATION

8.1 Relying on Potentially Imperfect Screening Outcomes to Reduce Uncertainty before Driving

The customized breathalyzers used in this study were not 100% accurate. Interference from medication and a lack of precision (i.e., average error: +/- 0.027 mg/L) lowered the accuracy of the devices to slightly above 90%. It should be noted that in real-world situations, even police-grade breathalyzers [11] are less than perfectly accurate. This situation would no doubt lead to confusion on the part of participants in cases where the results were contradicted by their actual alcohol use behavior. In this trial, most of the false positive results appeared when users smoked or ate grilled foods before performing the tests (e.g., $U1$, $U3$, and $U8$). Nonetheless, the participants generally performed subsequent follow-up tests to resolve the confusion caused by false positive detections, thereby ensuring that they were sober before operating a vehicle. After performing multiple tests, the participants would collectively consider all of the screening results in order to formulate a complete picture of their sobriety status. False negative results could lead an individual to inadvertently drive a car while still under the influence of alcohol. In this trial, we were careful to inform the participants that the breathalyzers were liable to generate false negatives when the alcohol in their system was near the legal limit. Nevertheless, the system was able to detect 93% of the situations in which alcohol was consumed, as self reported by participant. In the future, we are planning to exploit the simultaneous use of multiple sensors to compensate for cross interference in order to reduce the number of false positive and false negative results [37]. We have also identified portable alcohol sensors of higher accuracy in a small form factor [11]. These devices will no doubt improve the accuracy of BrAC measurements in subsequent versions of the system.

8.2 Difficulties in Collecting Alcohol Consumption Data from DUI Offenders on Probation

TimeLine-FollowBack (TLFB) provides a standardized system for the assessment of alcohol use outcomes. It is widely used in clinical and research settings and can be administered by trained interviewers or even self-administered on online [88] or via a smartphone [61, 89]. In this study, we adopted TLFB for the collection of alcohol consumption data from DUI offenders on probation. Despite the benefits of TLFB in terms of capturing accurate and detailed data pertaining to drinking habits, there are a number of situations when it is not possible to obtain accurate TLFB data (e.g., recall bias or participant refusal). In this study, we installed the SoberMotion app on the participants' smartphones and had them use the app regularly when self-administering breath-alcohol tests. To relieve the burden of having to regularly report their drinking behavior via a webpage or smartphone app, we had trained medical staff administer the TLFB in 5 ∼ 10 minute sessions when the participants revisited the hospital each month. None of the participants were expected to completely abstain from alcohol use; therefore, they felt no obligation to record their drinking data. Nevertheless, they were still willing to recall when and how much they drank when administered the TLFB by staff members. During these sessions, we also asked the participants to bring notes pertaining to their work schedule to help in recalling their drinking behavior during the previous month. Considering that the TLFB method has proven effective in gathering information for up to 12 months before an interview [96, 97], we believe that this method provides valid ground-truth drinking data suitable for detailed analysis.

8.3 Difficulties in Recruiting DUI Offenders on Probation

Designing technology systems to support DUI offenders on probation involves multi-disciplinary collaboration between those in the justice system, treatment specialists, and those developing the technology. This type of research must also be conducted in multiple phases. Before initiating a field study to evaluate the SoberMotion system, we were working closely with the justice and treatment teams for around six months. We began with a pilot study to elucidate the process of supervising offenders by probation officers. This information was used to formulate the overall scheme of the mobile support system. We ran into difficulties in recruiting DUI offenders (particularly female offenders) for our exploratory field study. We targeted offenders who had recently been placed in the deferred prosecution program and were waiting for probation officers to schedule their first clinical visit for alcohol treatment (usually a wait of one to two months). We aligned the date on which participants began using the SoberMotion system with the date of their first clinical visit for alcohol treatment. Probation officers assisted the authors in recruitment by petitioning the court (or prosecutors) to place offenders into a deferred prosecution agreement (DPA). Unfortunately, this process was a heavy imposition on prosecutors, requiring that they spend additional time doing paperwork and arranging supervision resources (as described in Section 7.2.1). The prosecutors were also tasked with identifying DUI offenders who were suitable for the program [48]. The fact that all of the offenders in this initial study were male can be attributed to the fact that most DUI offenders are male (86% in the US) [92] and (92.9% in Taiwan) [2]. Many of the candidates turned down invitations from probation officers to participate in this exploratory field study, explaining they did not have time to comply with mandatory assessments or evaluation sessions. This limited us to a small population of DUI offenders (eight male DUI offenders) for our field study. Nonetheless, we believe this study population was sufficient to reveal valuable insights for subsequent research in this area. The next stage of development will include a larger number of DUI offenders on probation and will explore how well SoberMotion works when making participation a requirement of entering DPA agreements.

9 CONCLUSION

Dealing with the effects of DUI on society is a complex challenge in many countries. For instance, alcohol-related crashes in the US cause approximately US $44 billion in annual damages and the death of one person every hour

[18]. Probation programs have been widely adopted for the supervision of offenders; however, heavy caseloads make it difficult for probation officers to track alcohol use. As a result, many individuals commit DUIs while on probation [91]. In this study, we collaborated with probation officers and psychiatrists in formulating a system aimed at augmenting the power of probation officers in order to reduce the risk of recidivism among DUI offenders on probation. We conducted a pilot study involving probation officers, psychiatrists, and offenders to assist in the design of a mobile support system, called SoberMotion. This system records data pertaining to alcohol use, which is obtained using a customized portable breathalyzer connected to a mobile phone via Bluetooth. The system uses a unique 2D marker and a face recognition module to authenticate the ID of the target users as they provide breath samples. The proposed app also identifies high-risk vehicle use events to remind users of the need to check that the alcohol they ingested has been completely metabolized before getting behind the wheel. The test results, triggers causing alcohol use, high-risk vehicle use events, and ID data are transmitted to a management server for analysis by probation officers and/or psychiatrists. The feasibility of the SoberMotion system was evaluated by recruiting eight DUI offenders on probation for a two-month study using the proposed system. The participants performed alcohol screening tests before driving in order to avoid DUIs. After undergoing treatment for alcohol-related problems, the participants slightly reduced their intake of alcohol. Participants that consumed higher volumes of alcohol performed more breath alcohol tests than did those who consumed less alcohol. Qualitative interviews were conducted to identify salient themes related to the use of the SoberMotion system in reducing the risk of DUI recidivism. Overall, our goal in this study was to demonstrate the efficacy of the proposed system in extending the reach of probation officers. Nonetheless, designing this type of support system requires interdisciplinary collaboration among experts in the law as well as those in the medical, social, and technology domains. It is our hope that the results of this study will encourage decision makers to incorporate the proposed scheme in real-world applications.

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