SoberDiary: A Phone-based Support System for Assisting Recovery from Alcohol Dependence

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ABSTRACT

Alcohol dependence is a chronic disorder associated with severe harm in multiple areas, and relapsing is easy despite treatment. For alcohol-dependent patients, completing alcohol withdrawal treatment is an achievement. However, returning to daily life and remaining sober are often more challenging tasks. This study proposes SoberDiary, 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. Through a portable Bluetooth breathalyzer wirelessly connected to the patients' smartphones and various supporting functions provided by the SoberDiary client, SoberDiary can facilitate alcohol-dependent patients' self-monitoring and self-management to prevent relapse. The results from a 4-week user study involving 11 clinical patients from Taipei City Psychiatric Center show that patients can self-monitor their alcohol use by completing at least 2.3 breath alcohol tests per day and self-managing their alcohol use behavior to significantly reduce their total alcohol consumption and the number of drinking or heavy drinking days after intervention through SoberDiary. Compared with patients who received only standard treatment, SoberDiary users exhibited reduced alcohol craving and a lower drop-out rate, indicating that SoberDiary shows potential to provide continuing care for relapse prevention.

Categories and Subject Descriptors

H.4.m [**Information Systems Applications**]: Miscellaneous

General Terms

Design, Experimentation, Performance

Keywords

Mobile support system, recovery of alcohol dependence

1. INTRODUCTION

Alcohol dependence is a debilitating psychiatric disorder worldwide that is associated with maladaptive and destructive behaviors and characterized by persistent, compulsive, and uncontrolled drinking, leading to marked impairment and distress and tremendous interpersonal or social problems. A recent study [29] demonstrated that, among a range of drug-related causes of harm, alcohol is listed as the most harmful drug (overall harm score, 72), with heroin (55) in second place, in all areas concerning physical damage, mortality, mental malfunctioning, loss of tangibles and relationships, family adversity, and economic cost. The prevalence of alcohol abuse and dependence has increased worldwide. In addition, a mortality analysis showed that as many as 45% of recruited alcohol-dependent patients died during a 7-year follow-up period [12]. Alcohol dependence is also a potent risk factor of suicide [14, 33] and is associated with a higher risk of depressive and anxiety disorders [19]. Furthermore, even after alcohol-dependent people achieve abstinence, they are at risk for relapse. Up to 50% of people treated for alcohol dependence experience periods of relapse in the 2 years following treatment [23]. Therefore, developing a rational approach for enhancing relapse prevention in alcohol-dependent patients who struggle with craving or the desire to resume alcohol use after they have initiated abstinence is crucial [32].

This study proposes SoberDiary, which is a phone-based support system that helps alcohol-dependent patients maintain sobriety in their daily lives after completing an alcohol withdrawal treatment. SoberDiary facilitates ongoing self-monitoring by enabling users to self-administer breath alcohol tests using a portable Bluetooth breathalyzer, provides various supporting functions that enable users to self-manage their addictive behavior, suggests proper relapse prevention skills that reduce alcohol cravings, and promotes their spiritual health. Because of the recovery support, which is always available through patients' smartphones, SoberDiary has the potential to continue aftercare treatment as well as reduce the cost and improve the effectiveness of existing alcohol treatment programs.

Previous researchers [18, 10, 24] have identified mobile phones as a platform for extending the well-proven prac-

tice of cognitive behavior therapy. After reviewing multiple elements required for providing services to prevent alcohol relapses, the researchers designed various technology-based services for providing positive social support or sampling patients' moods by using cognitive behavioral therapeutic exercises to help them cope with their stress. However, people managing recovery from alcohol dependence should focus not only on mental and emotional aspects but also on physical and spiritual aspects. Therefore, SoberDiary introduces an extended Bluetooth breathalyzer and various supporting functions for smartphones that enable self-monitoring, which raises users' awareness of their alcohol use, and self-management, which encourages spiritual growth for remaining sober. Because of the lack of continuing care for relapse prevention in the current alcohol treatment infrastructure, which is financially overburdened, labor-intensive, and unstable, SoberDiary leverages patients' smartphones and supports the relapse prevention of alcohol-dependent patients after they complete alcohol withdrawal treatment.

Although most experts consider alcohol dependence to be a chronic and relapsing disorder, aftercare appointments and ongoing monitoring are rare in the alcohol addiction field. The purpose of SoberDiary is to prolong alcohol-dependent patients' participation in continuing care to improve sobriety outcomes. By carrying a Bluetooth breathalyzer wirelessly connected with the SoberDiary client installed on their phones, patients can perform breath alcohol tests to self-monitor their alcohol use. To motivate behavioral change, SoberDiary also records personal progress and achievement in maintaining sobriety for patients to review. Furthermore, SoberDiary incorporates the principles of the 12-step program [28] in depicting a story of the struggle with alcohol in 12 sketched images on the phone to enable patients to learn the concepts associated with each step and, thus, promote their spiritual health. All testing results as well as momentary emotion and craving indices sampled by the SoberDiary client are used to provide appropriate suggestions for reducing alcohol cravings and are uploaded to a remote backend server to enable continuous patient monitoring.

The contributions of this paper are the design, prototype, and evaluation of SoberDiary, a phone-based support system that consists of an extended Bluetooth breathalyzer, which enables self-monitoring, and various supporting functions that enable patients to self-manage their recovery from alcohol dependence. A 4-week user study, involving 11 alcohol-dependent patients who completed alcohol withdrawal treatment, was conducted. The results show that patients using SoberDiary can self-monitor their alcohol use by completing at least 2.3 breath alcohol tests per day and self-managing their alcohol use behavior to significantly reduce their total alcohol consumption and the number of drinking or heavy drinking days after intervention through SoberDiary. Compared with patients who received only standard treatment, SoberDiary users exhibited reduced alcohol cravings and a lower drop-out rate, indicating the potential of SoberDiary to provide continuing care for relapse prevention.

The rest of this paper is structured as follows. Section 2 presents the background of current alcohol treatment and describes the theoretical foundations of the SoberDiary system. Section 3 overviews the architecture of the SoberDiary system, and Section 4 describes the detailed design of the SoberDiary phone app. Section 5 presents the implementation of the SoberDiary system, and Section 6 describes a 4-week user study of the effectiveness of the SoberDiary system involving 11 clinical patients. Section 7 discusses the lessons learned from the user study, and Section 8 summarizes the related work. Finally, Section 9 concludes the paper and describes future work.

2. BACKGROUND AND THEORETICAL FOUNDATION

Before briefly introducing the background of current alcohol withdrawal treatment, the following terms are used in this article:

- A *standard drink* (or *drink*) [22] is a unit of alcohol quantifying the amount of alcohol intake. The amount of alcohol in one drink varies among countries. In the United States, a drink is 14 g of pure alcohol, which is approximately equivalent to the amount of alcohol in one regular beer containing 5% alcohol (approximately 340 mL).
- A *lapse* occurs when patients consume any alcoholic beverage containing approximately one drink of pure alcohol.
- A *relapse* occurs when male (female) patients consume more than six (four) drinks per day.

2.1 Background of Current Alcohol Withdrawal Treatment

Treatments rates for alcohol-use disorders exhibit a disappointing lack of progress. This lack of progress differs sharply from the improvements observed in treatment rates for major depression [19]. Three medications for relapse prevention have been approved, namely naltrexone, acamprosate, and disulfiram [32]. However, the efficacy of drugs in relapse prevention is often inconsistent among studies or is present only among a subpopulation of patients, such as those with low levels of depression and alcohol dependence severity [25, 21, 34, 35]. These observations suggest that alcohol treatment professionals cannot rely only on medications and that an alternative treatment modality that improves the efficacy of relapse prevention must be identified.

Preliminary studies on people using phone-based services for managing recovery from alcohol dependence are encouraging. Many people managing substance abuse problems are interested in self-help tools for evaluating their behavior, and computerized interventions have been identified as being attractive for this purpose. The appeal of cell phones as a support for therapy lies in their low cost and ability to capture data and offer coaching, which can continue over a

long period. Therefore, a technology-based system delivered through cell phones might overcome the barriers to implementation and have the potential to continue aftercare treatment as well as reduce costs and improve the effectiveness of existing alcohol treatment programs.

2.2 Theoretical Foundation

The theoretical frameworks for this study are the cognitive behavioral theories [17], which emphasize triggers and coping strategies for relapse prevention, and self-determination theory [18], which focuses on the internalization of recovery management. The relapse prevention model consists of interventions that address each of the dimensions that precede relapse. A key component of relapse prevention or sustained recovery is the involvement of patients in the management of their own health care, in collaboration with their caregivers, and assuming responsibility for wellness management for various conditions. Cognitive behavioral theories suggest the importance of self-efficacy and developing effective coping skills for recognizing, avoiding, and coping with triggers or situations that increase the risk of drug use. The self-determination theory is a theory of individual change based on the concept that change is likely to occur when it comes from within, which has three basic elements: relatedness, competence, and autonomy. The theory suggests that genuine recovery is likely to occur when a patient's motivation for recovery is mostly autonomously directed or *internalized*. According to this model, internalized motivation for recovery occurs when patients feel able to maintain recovery (competence), perceive the decision to abstain from drug use as the result of free will (autonomy), and feel supported in their recovery efforts by others (relatedness). In particular, the theory suggests that motivation for recovery can be enhanced by positive feedback that is provided while recovery occurs within a recovery-supportive environment.

Therefore, self-monitoring and self-management have emerged as critical skills for managing disease because patients who actively monitor their behaviors attain greater success in achieving recovery goals. Self-monitoring increases patients' awareness of risky situations and behaviors, enhances their self-efficacy and competence, and enables them to build the relationships and skills necessary for preventing relapse and sustaining abstinence. Patients who have completed detoxification and initiated abstinence are often involved in multiple risk behaviors, and assisting them to identify triggers and coping responses is a crucial step for their establishment of self-monitoring and self-management, which can ultimately reduce risk behaviors and associated problems. However, self-monitoring can be difficult to maintain without adequate support. Cell phone tools can be used for gathering data efficiently as well as for querying in a way that increases trigger and risk awareness, self-regulation and self-efficacy, and behavioral change.

3. SYSTEM OVERVIEW

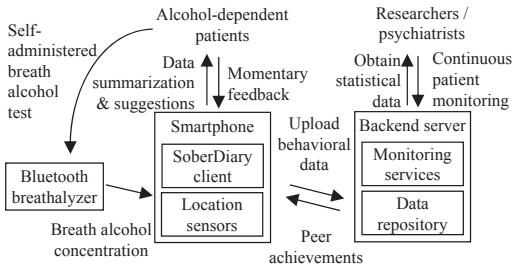


Figure 1: System architecture of SoberDiary.

Figure 1 shows the system overview of SoberDiary, which consists of three components: (1) a portable Bluetooth breathalyzer, (2) a phone application, and (3) a backend server. Alcohol-dependent patients regularly self-administer breath alcohol tests by using their breathalyzers and input their momentary feedback through smartphones. Through the Bluetooth interface, the breathalyzer wirelessly sends the test results to their phones, which are installed with a SoberDiary phone app. All test results, as well as momentary feedback recorded in the phones, are transmitted to the backend server for further analyses and monitoring by researchers or psychiatrists. These components are described in the following sections.

3.1 Portable Bluetooth Breathalyzer

Figure 2 shows from front, left-side, and right-side views the customized portable Bluetooth breathalyzer, which measures the breath alcohol concentration (BrAC) of the patients by using semiconductor-based sensing technology. Semiconductor-based breathalyzers are much less expensive than law-enforcement-grade breathalyzers, but are affordable and sufficient for the personal screening tests required by SoberDiary. During each breath test, an alcohol gas sensor [8] in the chamber measures the BrAC in the air users breathe through the blow-in straw. Alcohol absorption on the semiconductor causes the electrical resistivity characteristics of the sensor to vary, thereby altering the voltage output of the sensor sampled by the microcontroller. According to the voltage-to-BrAC lookup table learned from a calibration process (described in Section 5), an instantaneous BrAC reading is interpolated and is sent back through a built-in Bluetooth module.

3.2 Phone Application: SoberDiary

The architecture of the SoberDiary client consists of (1) a user interface, (2) a supporting functional module, (3) a behavioral data store, and (4) an app use logging module.

User interface. The user interface is used to guide patients in performing tests and reviewing personal progress. Three full-screen pages were designed, and patients can easily switch between these pages to perform breath alcohol tests, review personal progress, share their recovery process, acquire managing skills, and input current emotions.

Supporting functional module. The supporting functional module contains five major functional blocks that fa-

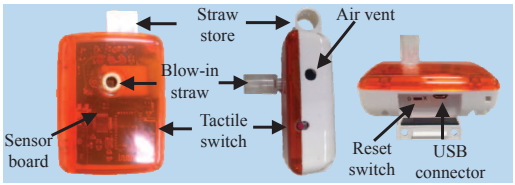


Figure 2: Photos of the Bluetooth breathalyzer captured from three view angles.

cilitate self-monitoring and self-management in alcohol-dependent patients' daily lives.

The *alcohol use detection block* guides patients in turning on breathalyzers to send BrAC results to (or receive control signals from) the phone. After establishing the connection between the phone and the breathalyzer, this functional block directs patients to complete a breath alcohol test, input their emotion and craving indices, and, optionally, upload their current locations.

The *progress feedback block* enables patients to review their personal progress in alcohol recovery, motivational incentives rewarded when maintaining sobriety or using the app, and the ranking of patients in relation to other patients according to how well they perform during alcohol recovery.

The *storytelling visualization block* depicts patients' struggles with alcohol addiction through stories to enable the patients to recognize positive elements and, thus, promote their spiritual health and share their struggles with their family members or friends to enhance social support.

The *managing skill suggestion block* suggests lapse and relapse management and prevention skills according to current breath alcohol test results and momentary emotion and craving indices to help patients resist alcohol cravings.

The *mood sampling block* samples a patient's moods and triggers by selecting one of seven primary feeling words (e.g., happy, sad) that describes the patient's current emotion and identifies negative thoughts by letting patients type in triggers that lead to the emotion.

Behavioral data store. The behavioral data store is a database on the phone that stores patients' alcohol use data (i.e., testing results and momentary feedback, namely emotion and craving indices and emotional triggers). To enable continuous monitoring of the patients, the data store uploads the behavioral data to the backend server for future analyses.

App use logging. In app use logging, application use events are generated when patients use the SoberDiary app (i.e., performing clicking or scrolling actions on the phone screen). All recorded app use logs are uploaded to the server once each day.

3.3 Backend Server

A backend server was set up to receive behavioral data uploaded from patients' phones for future analyses and continuous monitoring. Furthermore, to provide information on how well other patients perform, the server tracks the rankings of peers' achievement in alcohol recovery. To ease the management of the alcohol recovery patients who participated in this study, a monitoring web service was deployed to continuously monitor all data uploaded from patients and provide the researchers or psychiatrists a daily summary of patients who did not perform adequately (e.g., patients who did not complete the tests for one day).

4. SOBERDIARY PHONE APPLICATION

The four modules, namely the (1) user interface, (2) supporting functional module, (3) behavioral data store, and (4) app use logging, of the SoberDiary app as described in the following sections.

4.1 User Interface

A simple user interface was designed with three full-screen main pages, namely (1) test, (2), statistical, and (3) storytelling pages. Patients can intuitively switch between these pages by using three software buttons located at the bottom of the screen. When patients launch the app, they first see the test page for self-administering breath alcohol tests. After they complete a test, an instantaneous summary appear on the statistical page. To enable social sharing and learn positive spiritual concepts, patients can switch to the storytelling page. Other infrequently used functions (e.g., mood sampling and managing skill suggestion) can be initiated by tapping the menu key. Because this study was conducted by recruiting patients in Taiwan, all messages and instructions in the user interface in the current implementation are represented in traditional Chinese characters; however, the messages can be easily translated to other languages for future applications. The designs and functions of each page are described in detail in the following subsections.

4.2 Supporting Functional blocks

Five functional blocks, namely (1) alcohol use detection, (2) progress feedback, (3) storytelling visualization, (4) managing skill suggestion, and (5) mood sampling, are included in this module to assist patients in maintaining abstinence and are described in the following subsections.

4.2.1 Alcohol use detection

Self-administering breath alcohol tests enables patients to self-monitor their alcohol use in their daily lives. Continuous patient monitoring has been identified as crucial to relapse prevention and has long been absent from the current alcohol treatment infrastructure. To achieve this goal, the user interface includes a test page for patients to easily perform the breath alcohol test step-by-step, as shown in Figure 3(a). To reduce the effort for completing the required tests in a day, we divided a day into three time slots, namely (1) a *morning slot* from 0 AM to 12 PM, (2) an *afternoon slot* from 12 PM to 6 PM, and (3) a *night slot* from 6 PM to 0 AM. In each slot, patients must perform a test to complete the alcohol use detection task. If patients perform multiple tests in a slot, then the first test in a slot is identified as the

(a) Screenshot of the 5-second exhalation process page (b) Questionnaire for collecting momentary feedback

Figure 3: Screenshots of the test page. In (a), an orange circle is drawn around the rim of a viewing area during the 5-second exhalation process. In (b), a questionnaire appears to collect patients' emotion and craving indices, and, optionally, their current locations after completing a test.

Figure 4: Screenshots of the statistical page. The summary region presents test results in a daily dashboard, a weekly summary, and a monthly trend from left to right. The incentive region lists the number of credits and coupons the patients have earned, the amount of money they have saved, and the rankings of the patients.

primary test and other tests are viewed as *secondary tests*. Patients were asked to complete at least 2 slots per day. In each slot, a notification reminding the patient to complete the primary test appears every 2 hours until the test is completed.

When a patient performs the test, he or she clicks the start button on the test page and a message appears to remind the patient to turn on the breathalyzer. Once the phone is connected with the breathalyzer, the app shows a timer counting down from 10 to 0. As the timer is counting down, the breathalyzer initializes its alcohol sensor and prepares for the alcohol measurement. After the breathalyzer is ready, the patient begins to breathe air into the straw. To ensure that enough air from the deep lung accumulates in the sample chamber, the chamber contains a pressure sensor that monitors whether the patient exhales air into the sample chamber for a time longer than an empirical threshold (i.e., a 5-second exhalation process in this study). To prevent cheating, the patients performed the BrAC test with their faces appearing in view of the phone's camera. During the 5-second exhalation process as shown in Figure 3(b), the phone application captures three photos of the patient's face. After the patient completes the test, the final BrAC value is extracted by calculating the median of all instantaneous samples. Finally, a questionnaire appears, and users record their momentary emotion and craving indices by responding to a visual analogue scale (VAS) on the screen of the phone. To encode user responses to their cravings for alcohol and emotions in numeric values, a 10- and 5-level Likert scales are used to represent the craving and emotion indices, respectively. Optionally, patients can also provide their current locations by agreeing to upload their GPS positions. These BrAC results and momentary feedback are uploaded to the backend server through the 3G or WiFi interface.

4.2.2 *Progress feedback*

Figure 4 shows a screenshot of the statistical page, which enables patients to review personal progress and motivates them with achievements and rewards. The statistical page consists of two separate regions: (1) the upper summary and (2) lower incentive regions. The summary region summarizes personal test results to enable patients to review their recent alcohol use. By flipping the region to the right or left by performing scrolling gestures, patients can switch the upper region among three views (i.e., a daily dashboard, a weekly summary, and a monthly trend). The daily dashboard shows the BrAC value, craving index, and emotion index of the latest test and shows whether patients maintained sobriety in morning, afternoon, and night slots. Each slot is represented in one of three possible state colorings: (1) the *sober* state, encoded by the green color, indicating that the patient passed all tests, (2) the *drinking* state, encoded by the red-orange color, indicating that the patient failed a test, and (3) the *missing* state, encoded by the dark gray color, indicating that the patient forgot to perform a test. In addition, a weekly summary and monthly trend list all slot states in 7 and 28 days, respectively, using the same color encoding system as that used in the daily dashboard.

To provide positive feedback to patients, the incentive region shows the rewards they earn and how well they perform in the process of alcohol recovery. Two rewards are shown to motivate patients to continue using the app, namely the number of coupons they have earned and the amount money they have saved. SoberDiary accumulates the number of credits as patients perform more tests, pass more alcohol screening tests, or continue to use supporting functions. Once the number of credits increases by a predefined value (i.e., 40 credits in this study), SoberDiary rewards patients a McDonald's coupon, costing approximately USD$6.5 each. Similarly, SoberDiary increases the amount of money saved by each patient because they are not buying alcoholic beverages when they maintain sobriety and fill monitoring slots. Furthermore, to encourage competition among participating patients, SoberDiary also shows the rankings of patients according to the average number credits that they have accumulated since they began participating in the study.

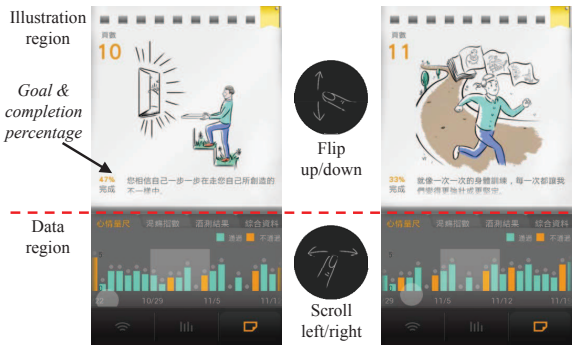


Figure 5: Screenshots of the storytelling page. The illustration region is a storybook with pages containing drawings illustrating the principles of AA's 12-step program. The data region has four tabs; the emotion index, the craving index, and daily BrAC values are plotted as three individual bar charts and these trends are overlayed aggregately as a line graph in different tabs.

4.2.3 *Storytelling visualization*

Figure 5 demonstrates the storytelling page, which enables patients to recognize positive spiritual elements and share their personal feelings about their battles against alcohol. Alcohol recovery involves addressing patients' physical and mental symptoms as well as improving their spiritual health. To encompass the spiritual aspects of the process of alcohol recovery, Alcoholics Anonymous (AA), a 12-step program, proposed the principles of the 12-step program [28] to delineate the recovery process from alcohol dependence. In the delineated recovery process delineated by the 12-step program, patients are admitting weakness to alcohol, recognizing that positive spiritual elements strengthen persistence and determination, understanding and treasuring themselves after examining past failures, asking for forgiveness for past errors, beginning a positive life by remaining sober, and able to help other alcohol-dependent patients. This process is decomposed into 12 steps to guide patients promoting their spiritual health and maintaining sobriety. To clearly depict the goal of each step in a nonreligious manner, we adopted a humanist alternative [2] to the 12 steps of AA and slightly simplified the descriptions to concisely display them on the screen, as shown in the subcaptions of Figure 6.

The storytelling page also consists of two separate regions: (1) the upper illustration and (2) lower data regions. To lead patients through the struggles with alcohol dependence, a storybook is presented in the illustration region, containing 12 pages depicting the 12 steps. These 12 steps sequentially appear in the order specified according to the 12-step principle, with durations evenly distributed over the process of alcohol recovery. When a step begins, the app shows a new page containing a drawing without colors drawn in the middle of the illustration region, along with the goal sentence and the completion percentage for the slots in the period of a step shown below the drawing. As patients complete tests, the completion percentage increases and parts of the drawing are colored. By encoding the increase in the completion percentage as a coloring process, patients can flip between the pages of their storybook to easily perceive their achievements by observing the differences in the amount of the drawing that is colored.

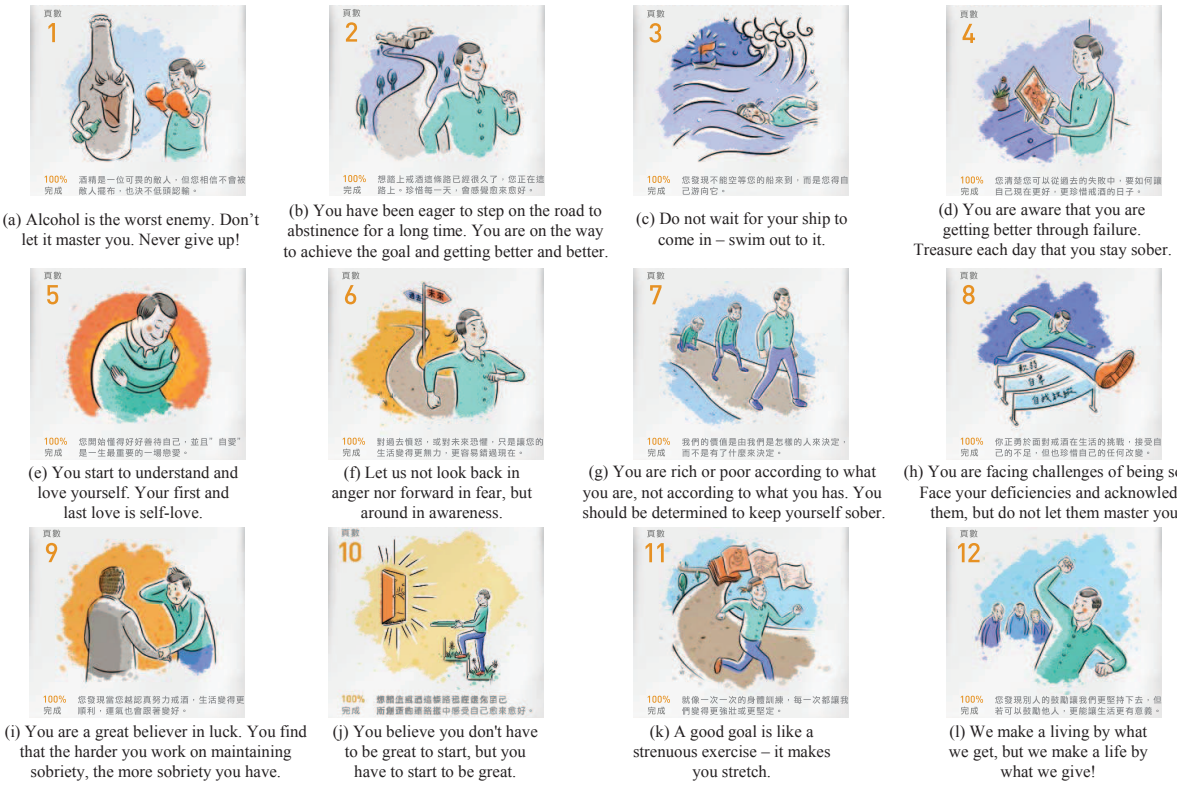
To encourage patients to share the story of struggling, each step is depicted in the upper illustration, accompanied with test results collected from patients in the lower data region. By reviewing this storytelling summarization, patients can recall relapse prevention skills learned in the alcohol withdrawal treatment and recognize positive spiritual elements described in the goal sentence. When they observe abrupt behavioral changes in the collected data, they can record their feelings by using voice recording to remind themselves of the cause of the feelings in the future. Furthermore, patients can share their struggles with their family members or friends by using the storytelling content so that others can help the patients remain sober.

4.2.4 *Managing skill suggestion*

The managing skill suggestion block suggests self-managing skills for managing (or prevent) alcohol relapses. After patients return to their daily lives, several factors can lead to alcohol relapse, including immediate determinants (e.g., being in high-risk environments or situations, or lacking coping skills) and covert antecedents (e.g., depression, anxiety, or cravings) [17]. To manage relapses and resist alcohol cravings, Marlatt's relapse prevention model [17] is widely accepted for facilitating patients' self-management of the illness based on cognitive behavioral therapy treatment. Depending on their current test results and momentary emotion and craving feedback, SoberDiary provides lapse and relapse prevention and management skills to support patients who might be exhibiting a high craving index (e.g., usually passing places with alcoholic beverages, such as convenience stores) or a low emotion index (e.g., experiencing depression). SoberDiary provides effective ways to contact the patient's family or request medical help. When lapses or relapses occur, SoberDiary suggests skills that enable the patient to manage the lapses independently (e.g., suggesting that they exercise if they feel stressed) or to recover from relapses (e.g., going home or contacting their family or friends), because their perception might be affected by alcohol.

4.2.5 *Mood sampling*

The mood sampling supporting block samples emotions and their triggers to identify patients' negative thinking. Because negative moods (e.g., being stressed, anxious, or depressed) in daily lives trigger alcohol cravings, these factors may cause patients to turn to alcohol for relief. To prevent negative moods, identifying and breaking the negative feedback is crucial. By using their smartphones, patients can record what triggers their negative moods when they have symptoms of depression and anxiety through ecological mo-



(a) Alcohol is the worst enemy. Don't let it master you. Never give up!

(b) You have been eager to step on the road to abstinence for a long time. You are on the way to achieve the goal and getting better and better.

(c) Do not wait for your ship to come in – swim out to it.

(d) You are aware that you are getting better through failure. Treasure each day that you stay sober.

(e) You start to understand and love yourself. Your first and last love is self-love.

(f) Let us not look back in anger nor forward in fear, but around in awareness.

(g) You are rich or poor according to what you are, not according to what you has. You should be determined to keep yourself sober.

(h) You are facing challenges of being sober. Face your deficiencies and acknowledge them, but do not let them master you.

(i) You are a great believer in luck. You find that the harder you work on maintaining sobriety, the more sobriety you have.

(j) You believe you don't have to be great to start, but you have to start to be great.

(k) A good goal is like a strenuous exercise – it makes you stretch.

(l) We make a living by what we get, but we make a life by what we give!

Figure 6: Screenshots of 12 drawings (a)-(l) displayed in the upper region of the storytelling page. All drawings are completely colored when the completion percentage is 100%.

mentary assessment (EMA) [26]. By inputting a current feeling (e.g., happy, sad) corresponding to one of the seven primary feeling words, patients can identify which factors (e.g., people, things, events, or contexts) result in the specified feeling.

4.3 App Use Logging

To analyze how patients use the SoberDiary app in this study, we designed the app use logging module to record their clicking or scrolling actions used to control the app as well as timestamps. All clicking and scrolling actions are uploaded to the backend server once per day. To calculate the application use time associated with one of the five supporting functions described previously, the monitoring services on the server label each action as belonging to one of five supporting functions and then aggregates individual use time in each use session of a function to calculate the total use time of a specific function.

4.4 Behavioral Data Store

To manage the behavioral data generated by patients, the behavioral data store was designed to both record data locally in the memory of the phone and to enable a copy to be uploaded to the backend server. The behavioral data consists of BrAC values, the testing time, the sampled emotions, their triggers, and the corresponding timestamps. The collected behavioral data is sent to the server immediately after patients complete testing or uploaded in a batch when patients launch the app to provide continuous monitoring.

5. IMPLEMENTATION

Both software and hardware components of the SoberDiary system are described in this section.

5.1 Hardware Component

To create the Bluetooth breathalyzer shown in Figure 2, we fabricated a small plastic case (7 cm $\times$ 5.8 cm $\times$ 2.5 cm) to hold a customized Arduino-compatible sensor board. The sensor board was equipped with an Atmel 8-bit microcontroller [4] used for sending and receiving data through an EGBT-04 Bluetooth module [6] and processing sensor readings. To create an alcohol sample chamber, another small shell was fabricated to cover a BMP085 digital pressure sensor [5] and a MR513 alcohol sensor [8]. The microcontroller on the board can be programmed using the Arduino programming language [3] to sample the ADC voltage output of the pressure and alcohol sensors to detect when patients blow air into the chamber and to measure the alcohol concentration in the exhaled air. The sensor board is powered by an 840-mAh lithium-ion battery, which can be recharged using a USB with an LTC4054 battery charger [9] approximately every 10 days. Three color LEDs emitting red, yellow, and green light were used to inform patients whether the sensor is running (red LED on), has low battery power (yellow LED blinking), or charging (green LED on).

To calibrate the breathalyzers, an air bump is used to blow

air into a standard alcohol-breath test simulator (i.e., the Guth Model 2100 Alcohol Breath Simulator) [7] filled with a certified premix solution. This simulator then exhales air with specified alcohol concentrations (0, 0.1, 0.2, 0.25, 0.4, and 0.75 mg/L). By collecting the voltage response to various BrAC values, the BrAC-voltage response characteristics can be modeled as a curve by using the smooth spline fitting technique. To test the accuracy, we tested the breathalyzer by blowing in air with six BrAC values (the same as those used in the training phase). The resulting accuracy was +/- 0.05 mg/L of breath alcohol within the range of $0 \sim 0.5$ mg/L and was within 10% in the BrAC range of $0.5 \sim 0.75$ mg/L. This accuracy level is sufficient for categorizing each patient's BrAC values into three coarse classes. However, to reduce the impact of mouth alcohol (discussed in Section 6.5.1), the final screening threshold was set to 0.061 mg/L in this study, slightly higher than the original screen threshold. Three classes were defined, namely the *sober* class, who exhibited measured BrAC values lower than 0.061 mg/L, the *lapse* class, who exhibited measured BrAC values in the range of $0.061 \sim 0.25$ mg/L to detect whether a lapse of alcohol use occurs, and the *relapse* class, who exhibited measured BrAC values greater than 0.25 mg/L to detect whether a relapse of alcohol use occurs.

5.2 Software Components

SoberDiary consists of a phone app containing 22,000 lines of Java code using the Android platform, which runs on Android-powered smartphones. The SoberDiary app communicates with the Bluetooth breathalyzer through Android Bluetooth APIs. An SQLite database (i.e., the behavioral data store) is used to store a patient's breath alcohol test results and momentary feedback locally on the phone. The application use logs are stored in a log file, which is sent to the server once each day for future analyses.

The backend server was set up to record the breath alcohol test results, momentary feedback, and application use logs from all patients in a MySQL database hosted by an Apache server. To manage the data of all patients, a monitoring web service was built in the backend server for securely transporting patients' data through an HTTPS channel to researchers and psychiatrists, who can remotely access patients' results.

6. USER STUDY

To determine the feasibility and efficacy of the SoberDiary system in assisting patients to remain abstinent in their daily lives, we conducted a 4-week user study by recruiting 11 alcohol-dependent patients. The goal of this study was to answer the following inquiries by using standard research methods.

- How well does SoberDiary enable patients to persistently self-monitor and self-manage their drinking behavior to maintain sobriety?
- How well does the frequency of alcohol use screened using breath alcohol tests reflect the number of drinking days recalled by patients using the timeline follow-back method (TLFB) [22]?

First, an observational research method was used to identify the contribution of SoberDiary to patients' sobriety. This contribution was determined by observing whether patients using SoberDiary exhibited a lower average relapse rate, a longer time to the first relapse, a lower average drinking amount, and fewer average drinking days than did patients recruited in an ongoing project, in which 23 patients were recruited to collect drinking data by using the TLFB method from June 2013 to September 2013. Second, a comparison method was used to compare the drinking behavior monitored using the TLFB method with that monitored using the SoberDiary system. Third, statistical methods were used to analyze the application logs and interpret application use behavior. This section describes the experimental settings and results of this study.

6.1 Participants

We recruited 11 participants, 8 men and 3 women, with ages ranging from 27 to 55 years (average and standard deviation were 39.1 and 8.35 years). Five of the participants were unemployed and the other participants were salespeople, clerks, or self-employed. All participants were clinical patients who achieved abstinence after completing alcohol withdrawal treatment at Taipei City Psychiatric Center of Taipei City Hospital, Songde Branch (hereafter called *TCPC*) and passed a screening test (i.e., a structured interview). To compensate for the cost of revisiting the hospital for follow-up assessments, the participants were reimbursed NT$200 (approximately US$6.5) for each revisit. Depending on the frequency in which the supporting functions provided by the SoberDiary client were used, each participant was also rewarded a maximum of 4 coupons (approximately US$6.5) per week.

Table 1 summarizes the variables assessed by baseline and follow-up medical reviews, including the participants' self-assessed craving index (I_c), severity of alcohol dependence (S_s), severity of depression (S_d), severity of anxiety (S_a), quality of life (Q_l), life satisfaction (S_l), and the number of drinking and heavy drinking days (D_d and D_h) and the total alcohol consumption (C_a) recalled by the participants prior to and during the study. When responding to the Severity of Alcohol of Dependence Questionnaire (SADQ) questionnaire, all participants expressed that they severely craved alcohol ($S_s^0 > 30$). Furthermore, patients might resort to alcohol to provide temporary relief for the symptoms of depression and anxiety when they experience negative feelings about their lives, (i.e., lower quality of life or life satisfaction). Therefore, we also monitored the severity of depression and anxiety symptoms and how well the participants felt about their lives by administering Beck Depression Inventory (BDI), Beck Anxiety Inventory (BAI), World

Table 1: Variables assessed according to baseline and follow-up medical reviews and evaluation results derived from the drinking data recalled by patients in case and control datasets. The maximal values of the craving index, and SADQ, BDI, BAI, WHOQOL-BREF, and SWLS scores are indicated by numbers in parentheses. In the control dataset, patients did not respond to the WHOQOL-BREF and SWLS questionnaires (indicated by the "-" symbol). For patients who did not experience a relapse of alcohol use, the time to first relapse is 28 days.

ID	Variables assessed prior to the study (baseline) and assessed by follow-up medical reviews at Weeks 1, 2, and 4											Results derived from drinking data collected by the TLFB method							
	Craving index (9)		SADQ (80)	BDI (63)		BAI (63)		WHOQOL-BREF (140)		SWLS (35)		# of drinking days (day)		# of heavy drinking days (day)		Total alcohol consumption (drink)		Time to first relapse (day)	Recalled relapse rate (%)
P_i	I_c^0	I_c^4	S_s^0	S_d^0	S_d^4	S_a^0	S_a^4	Q_l^0	Q_l^4	S_l^0	S_l^4	D_d^0	D_d^4	D_h^0	D_h^4	C_a^0	C_a^4	T_r	R_r
Case dataset collected in this study																			
P01	Drop out																		
P02	2	2	33	12	8	4	7	100	112	15	26	12.1	1	12.1	1	555.0	29	21	0.04
P03	2	2	40	10	10	15	14	104	113	25	26	0	0	0	0	0	0	28	0
P04	9	0	39	19	9	8	2	89	105	12	15	28	0	28	0	396.1	0	28	0
P05	4	4	36	18	22	25	29	79	70	17	20	18.7	4	18.7	3	284.4	31	21	0.11
P06	2	0	40	35	51	11	16	75	68	14	11	23.6	1	23.6	1	90.1	13.3	22	0.04
P07	Drop out																		
P08	0	0	42	10	17	2	1	93	93	31	29	28	2	28	0	281.4	4	28	0
P09	2	1	36	5	3	5	4	82	98	7	10	1.9	0	1.9	0	73.3	0	28	0
P10	7	9	50	28	32	9	36	71	76	14	11	28	22	28	22	1911.0	111.4	6	0.79
P11	3	1	40	17	5	28	9	86	105	30	35	28	8	28	2	1991.0	20.14	7	0.07
Avg (std)	3.4 (2.8)	2.2 (2.9)	39.6 (4.8)	17.1 (9.5)	17.4 (15.6)	11.9 (9.2)	13.1 (3.6)	86.6 (11.1)	93.3 (17.7)	18.3 (8.4)	20.3 (9.1)	18.7 (11.4)	4.2 (7.2)	18.7 (11.4)	3.2 (7.1)	620.3 (734.0)	23.2 (35.3)	21.0 (8.79)	0.12 (0.26)
Control dataset collected from surrogate respondents, followed up regularly with standard treatment, recruited in a previous controlled study																			
Avg (std)	0.6 (1.3)	1.1 (1.3)	31.1 (19.3)	21.6 (12.5)	19.9 (17.9)	14.9 (12.8)	13.4 (12.9)	-	-	-	-	26.0 (4.0)	5.0 (8.9)	23.0 (8.2)	3.5 (6.7)	497.3 (342.5)	40.4 (74.7)	3.25 (3.9)	0.14 (0.29)

Health Organization Quality of Life-Brief, Taiwan version (WHOQOL-BREF), and Satisfaction With Life Scale (SWLS) questionnaires to collectively measure the severity of alcohol dependence during the study. Based on the responses, various patients with unique alcohol addiction behavior were recruited. Prior to the study, the baseline total alcohol consumption recalled using the TLFB method (i.e., C_a^0) showed that 7 of the participants drank excessively with high values of C_a^0, whereas others drank a few days per month but were still craving alcohol (i.e., high self-assessed craving indices). Some participants experienced various mental problems that might lead to lapses or relapses of alcohol use, such as depression (e.g., participant P06), easily becoming anxious (e.g., participant P05), feeling that life is poor (e.g., participant P10), or feeling unsatisfied with life (e.g., participant P09).

6.2 Apparatus

Each participant was assigned a Bluetooth breathalyzer as described in Section 3.1, which was paired with the participant's smartphone installed with the SoberDiary app. According to the study conducted by Hasin *et al.* [19], a small amount (24.1%) of alcohol-dependent people have sought alcohol withdrawal treatment. Therefore, identifying clinical patients with alcohol dependence to participate in this study was difficult. To increase the probability of recruiting qualified patients who carry smartphones equipped with an earlier release of Android OS (with versions earlier than 4.0) or iOS, we lent the participants Android smartphones and asked them to use the lent phone as their primary phone during the study.

6.3 Design and Procedure

We conducted a case-control study, a type of observational study, for evaluating the potential effectiveness of SoberDiary. For comparison with the data collected from the participants using SoberDiary (i.e., the "cases") on causal attributes (as described in Section 6.4) related to the participants' drinking behavior, a control dataset was collected from 23 participants (i.e., the "controls") who were controlled not to use SoberDiary in another ongoing project as a surrogate measure of drinking behavior. All participants recruited in this study received the baseline and follow-up clinical reviews (the same as those received by controls in the other study) at the same time and the help from SoberDiary in maintaining sobriety during the study.

The evaluation procedure consisted of two phases, namely (1) a screening phase to verify the qualifications of each interested person, and (2) a 4-week intervention phase. All participants were recruited through various recruitment channels, including hospital referral and advertisement. In the screening phase, all people were first diagnosed to ensure that they fulfilled the diagnostic criteria of alcohol dependence and achieved abstinence before participating in this study. The following preparation steps were performed for only eligible patients from TCPC: (a) conducting structured interviews for the inclusion and exclusion criteria, (b) explaining the goal of this study, (c) asking eligible patients to provide informed consent, and (d) setting up identities for each participant in the system. The treatment procedure and

frequency of assessments were explained to all eligible people. The participants were informed about the study objectives and the data we collected using mobile phones. They were informed that they would not be excluded from the study if they relapsed during the trial and that they could withdraw from the study at any time. The participants were asked to sign a consent form and undergo a medical assessment used to collect baseline scores for the SADQ, BDI, BAI, WHOQOL-BREF, and SWLS questionnaires. Recent alcohol consumption and compliance were measured using the TLFB method in the baseline assessment and all clinical assessments (described later in this subsection) of follow-up medical reviews through participants' self-reports. The structured drinking diary recorded the type and the amount of alcohol intake in grams per day of pure alcohol. To teach participants how to use the phone app and the Bluetooth breathalyzer, all participants attended a 30-minute tutorial session explaining the goal and the procedures of the study and a 30-minute training session describing how to operate the SoberDiary app and the breathalyzer in detail.

During the intervention phase, the participants were intervened by immediate momentary feedback from the phone application for assisting recovery from alcohol dependence. To collect ground truth data and help participants solve their technical problems, the participants were required to attend scheduled medical reviews held at Weeks 1, 2, and 4 in TCPC. Each medical review consisted of two sessions, clinical assessment and technical support.

Clinical assessment session: The participants received medical care typically available in hospital-based alcohol treatment services in each clinical assessment session, which had average durations of $15 \sim 20$ minutes during the intervention phase and were held at Weeks 1, 2, and 4. The participants were asked to respond to BDI, BAI, WHOQOL-BREF, and SWLS questionnaires during the final medical review held at Week 4. Recent alcohol consumption and compliance were also measured using the TLFB method in all medical reviews. If the participants lapsed, then they were encouraged to resume abstinence.

Technical support session: We asked the participants about any problems related to using the application and verified that the Bluetooth breathalyzer functioned correctly at Weeks 1, 2, and 4. We then distributed rewards (i.e., the number of McDonald's coupons indicated by the SoberDiary app) to each participant and reimbursed the monthly fee for accessing the Internet during the study.

When participants failed to attend scheduled medical reviews, follow-up telephone calls were made to arrange another appointment. A maximum of three contact attempts were made to ensure the retention of each participant in the study. All behavioral data collected from the participants were logged on the phones and transferred to the backend server through WiFi or the Internet connections of the phones for analysis. Participants who did not complete the breath alcohol tests within 24 hours during the intervention phase, as evidenced by the data recorded in the backend server, were immediately contacted by staff, who reminded the patients of their participation in the study and offered assistance regarding technical problems.

6.4 Evaluation metrics

After collecting data from the participants, data collected from medical reviews and the SoberDiary application were compared for consistency and used to justify abstinence.

Evaluation metrics derived from variables measured using medical reviews. The frequency and quantity of alcohol consumption in the 4 weeks preceding the alcohol withdrawal treatment (i.e., baseline data) and during the study were recalled by the participants using the TLFB method. The number of drinking days (D_d^0 and D_d^4) (or heavy drinking days (D_h^0 and D_h^4)) were measured 4 weeks prior to and during the 4-week study. Similarly, the total alcohol consumption (C_a^0 and C_a^4) was measured 4 weeks prior to and during the study. Based on the recalled drinking data, the time to first relapse (T_r), defined according to the criteria of Volpicelli *et al.* [20], and recalled relapse rate (R_r), the percentage of days during the study in which the participants experienced a relapse of alcohol use, can be derived.

Evaluation metrics derived from data recorded in the backend server. Completion frequency (f_c) measured the average daily number of slots in which the participants completed at least one test. In each day, patients might complete less than 2 slots per day (i.e., the mandatory daily completion frequency), and thereby have an insufficient number of slots to meet the mandatory daily completion frequency. Insufficient number (n_i) in a time period measured the aggregate value of insufficient number of slots in each day within the time period. Lapse number (n_l) (or relapse number (n_r)) in a time period measured the total number of slots classified as having a lapse (relapse) of alcohol use by SoberDiary. Error number (n_e) in a time period measured the total number of slots for which SoberDiary misclassified participants who self-reported being sober (drinking) rather than drinking (being sober). Application use time (t_u) measured the average time spent using SoberDiary.

6.5 Results

The frequency and quantity of alcohol consumption derived from data on the backend server were collected and compared with those recalled by the participants in medical reviews using the TLFB method. The participants' application use behavior was analyzed according to their application logs.

6.5.1 Results for participants' self-monitoring behavior

The right of Figure 7 shows the average completion frequency in each week. The average completion frequency was 2.3 slots per day (i.e., at least 2.3 tests per day), with six participants performing tests in more than 2 slots per

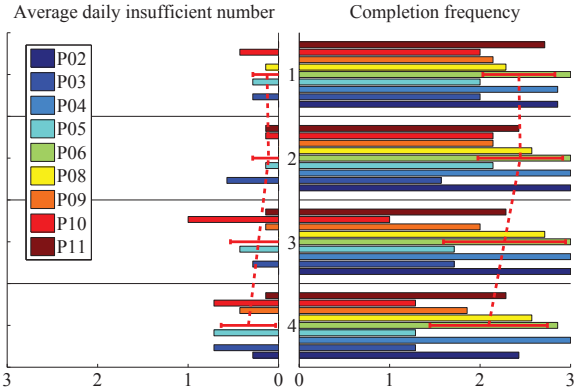


Figure 7: The completion frequency (right) and the average daily insufficient completion number (left) in each week (indicated by number on the y axis). The dotted red line shows the trend of the average completion frequency and average daily insufficient completion number among weeks.

day. The left of Figure 7 shows the average daily insufficient number in each week, which was calculated by dividing the insufficient number n_i by the total number of days in a week. The average daily insufficient number was 0.20 slot per day. Overall, the high average completion frequency (2.3 slots per day) and the low average daily insufficient number (0.20 slot per day) show that SoberDiary can offer most patients an efficient self-monitoring technique for their daily lives. However, three incompliant participants, P03, P05, and P10, caused the completion frequency (the daily insufficient number) to decrease (increase) significantly in the final 2 weeks ($p < 0.05$). Because P03 and P05 carried two smartphones and used the phone with SoberDiary as a nonprimary phone, they easily ignored reminders and forgot to perform tests. By contrast, because of a phone malfunction in Week 3, P10 missed tests for 3 days before we restored the SoberDiary app on the participant's phone. Furthermore, because P10 began a new job in Week 3, P10 adapted the testing time to accommodate the change in the life pattern, thereby resulting in a higher insufficient number in both Weeks 3 and 4. When excluding the data of P03, P05, and P10, no significant differences between the completion frequency (the average daily insufficient number) in the first two and the final two weeks ($p = 0.32$ (0.07)). A discussion on the causes for high insufficient numbers is provided in the following section.

Impact of mouth alcohol on the screening threshold. To determine a proper threshold for screening for alcohol use, we identified a suboptimal screening threshold based on the collected testing samples. Because of the presence of residual mouth alcohol [11], some BrAC results might be slightly higher than the original screening threshold (i.e., BrAC = 0.05 mg/L). However, as patients exhale more air from their lungs, the amount of mouth alcohol vaporized into the exhaled air decreases in the subsequent tests. Therefore, after performing a primary test in a slot, the impact of mouth alcohol decreases because less alcohol is added into the breath air. Because primary tests are easier to be influenced by mouth alcohol, Figure 8 shows the distribution of BrAC values recorded in all primary tests to indicate the impact of mouth alcohol. Based on the ground truth provided by the participants in medical reviews, we categorized all samples of primary tests into either the sober class or drinking class, as shown in Figure 8. To reduce the impact caused by mouth alcohol, we used a decision stump learning technique to determine a suboptimal screening threshold (i.e., BrAC = 0.061 mg/L) to accurately classify the samples in the study. The resulting accuracy in classifying these tests was 99%, which is sufficient for providing a reliable screening test and reducing the number of false lapse results caused by the mouth alcohol, which may cause inappropriate feedback to be provided to patients.

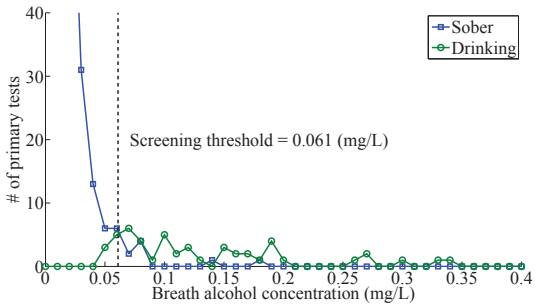


Figure 8: BrAC distribution of samples of primary tests during the study. The sober class, with a peak centered at 0, and drinking class, with samples yielding high BrAC values, are separated at a BrAC value of 0.061 mg/L.

6.5.2 *Effects of patients' self-managing behavior on their alcohol use*

Detection results perceived by the participants. Table 2 lists the insufficient, error, lapse, and relapse numbers since the previous medical visit at Weeks 1, 2, and 4. In other words, the results are summarized in three observation periods, namely the first week (W_1), the second week (W_2), and the final two weeks ($W_{3,4}$). The average insufficient and error numbers exhibited low average values of 1.2 and 0.2 slots per week, respectively. This shows that most participants, except for P03, P05, and P10, completed 2 slots per day with acceptable alcohol screening results. A majority of the participants were detected as having lapses or relapses for alcohol use in one or two slots over the specified monitoring period. Among all lapse and relapse cases, 6 out of 27 cases classified as drinking were error cases caused by false alarms resulting from the slow recovery of the alcohol sensor (17% of error cases), and mouth alcohol introduced by daily activities, such as eating foods or taking night code medicine [1] with alcohol before performing tests (83% of error cases). P05, P10, and P11 exhibited higher numbers of lapses or relapses over some monitoring periods than the other participants did, and thus perceived more lapse or relapse outcomes as feedback for the self-management of their alcohol use. To examine whether SoberDiary generates feedback that can reflect the participants' drinking days, we also

Table 2: Insufficient number (n_i), error number (n_e), lapse number (n_l), and relapse number (n_r), and the number of drinking days (d_s) recorded using the SoberDiary system, accompanied with the corresponding drinking days (D_t) recalled using the TLFB method, since the previous medical visit at Weeks 1, 2, and 4. The SD column shows the signed difference between d_s and D_t in a specified period of time. The weekly average of the SD is calculated by averaging the absolute values of the SD.

ID	W_1 (Total: 21 slots in 7 days)							W_2 (Total: 21 slots in 7 days)							$W_{3,4}$ (Total: 42 slots in 14 days)						
	n_i^1	n_e^1	n_l^1	n_r^1	d_s^1	D_t^1	SD^1	n_i^2	n_e^2	n_l^2	n_r^2	d_s^2	D_t^2	SD^2	n_i^4	n_e^4	n_l^4	n_r^4	d_s^4	D_t^4	SD^4
P02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	1	2	1	$1^{\ddagger}$
P03	2	0	0	0	0	0	0	4	0	0	0	0	0	0	7	0	0	0	0	0	0
P04	0	2	3	0	2	0	$2^{\bowtie}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P05	2	0	0	0	0	0	0	1	0	0	0	0	1	-$1^{\dagger}$	8	0	0	0	0	3	-$3^{\dagger}$
P06	0	1	1	0	1	0	$1^{\bowtie}$	0	0	0	0	0	0	0	0	0	0	0	0	1	-1
P08	1	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	1	1	1	0
P09	0	1	1	0	1	0	$1^{\sharp}$	0	0	0	0	0	0	0	4	0	0	0	0	0	0
P10	3	0	0	1	0	1	-$1^{\dagger}$	1	0	0	4	3	7	-4*	12	0	3	3	6	14	-$8^{\dagger}$
P11	0	0	1	0	1	4	-3*	1	0	3	1	3	4	-1	2	2	2	0	2	0	$2^{\times}$
Weekly avg	0.9	0.4	0.7	0.1	0.6	0.6	0.9	0.8	0.0	0.3	0.6	0.7	1.4	0.8	1.9	0.1	0.4	0.3	0.6	1.1	0.8

compared SoberDiary-monitored and TLFB-recalled drinking behavior.

Differences between SoberDiary-detected and TLFB-recalled drinking days. In Table 2, the columns with a dark background color compare the drinking days (d_s) monitored by SoberDiary with those (D_t) recalled using the TLFB method at Weeks 1, 2, and 4. By subtracting D_t from d_s, a signed difference between SoberDiary-monitored and TLFB-recalled drinking days was defined. The average difference between D_t and d_s was 0.8 days per week, which was calculated by averaging absolute values of SD. Among the 27 monitoring periods, 21 periods resulted in SD magnitudes of zero (i.e., no difference) or one (i.e., only an one-day difference). Regarding the five monitoring periods in which SoberDiary detected more drinking days than the participants recalled (i.e., $SD > 0$), one period was influenced by false drinking slots caused by the slow recovery of the alcohol sensor, as indicated by the "$\sharp$" symbol, the breathalyzers were influenced by residual mouth alcohol in two periods, as indicated by the "$\bowtie$" symbol, one period was influenced by residual alcohol that had not metabolized after heavily drinking alcohol, as indicated by the "$\ddagger$" symbol, and one period was influenced by alcohol in night code medicine taken by P11, as indicated by the "$\times$" symbol. By contrast, regarding the monitoring periods in which SoberDiary detected less drinking days than the participants recalled (i.e., $SD < 0$), the magnitudes of signed differences of SD were relatively higher; 22% of these monitoring periods were influenced by undergoing testing before drinking alcohol, as indicated by the "*" symbol, and 44% of these monitoring periods indicated that the participants forgot to perform the test, as shown by the "$\dagger$" symbol. Because the participants were asked to complete at least 2 slots per day, they might have performed the test unintentionally before drinking alcohol to accommodate their schedules or intentionally before drinking alcohol to prevent their BrACs after drinking from being recorded. Although increasing the minimal mandatory completion rate would increase the probability of detecting alcohol use, it also would result in higher insufficient number because of reasons discussed previously, as observed in the results of P05 and P10 in $W_{3,4}$.

6.5.3 The effectiveness of the SoberDiary system

Figure 9 shows differences between evaluation results derived from data collected from the participants using SoberDiary prior to and during the study. Among these variables, total alcohol consumption, the number of drinking days, and the number of heavy drinking days significantly decreased by 96.3%, 77.4%, and 82.8%, respectively, ($p < 0.05$) for participants using SoberDiary. After completing the treatment, the participants in the case group reported less craving for alcohol, and the craving index decreased by 38.7%. By contrast, the craving index in the control group increased by 66.7%. The time to relapse (the relapse rate) was 21.0 days (11.6%) in the case group, which is comparable to the 20.9 days (14.0%) in the control group. The variables collected only in the case study, the WHOQOL-BREF and SWLS scores, showed slight improvements of 7.8% and 10.9%, respectively, after using SoberDiary ($p = 0.17$ and 0.40). Although the BDI and BAI scores slightly increased by 1.9% and 10.3%, respectively, for the participants in the case group, the changes in the BDI and BAI scores between the case and control groups were not significant ($p = 0.59$ and 0.68). Further, the participants using SoberDiary exhibited a lower drop-out rate of 18% than the controls did (39%; 9 out of 23). Compared with the participants who received only the standard treatment, those who used SoberDiary exhibited a craving index reduction and a lower drop-out rate. In summary, the results demonstrate the potential of using SoberDiary to effectively maintain patients' abstinence.

6.5.4 Application Usage behavior

Figure 10 shows the daily application use time for each participant in each week. The average application use times for patients were 8.3, 8.7, 12.6, and 12.7 minutes per day at Weeks 1, 2, 3, and 4, respectively. The average application use time increased as patients participated in the study longer. Moreover, the difference between the application use time for the first two weeks and the final two weeks showed a significant difference ($p < 0.01$). This indicates that the offered incentives motivate patients to continue to use this app. Moreover, after patients have learned how to use a function

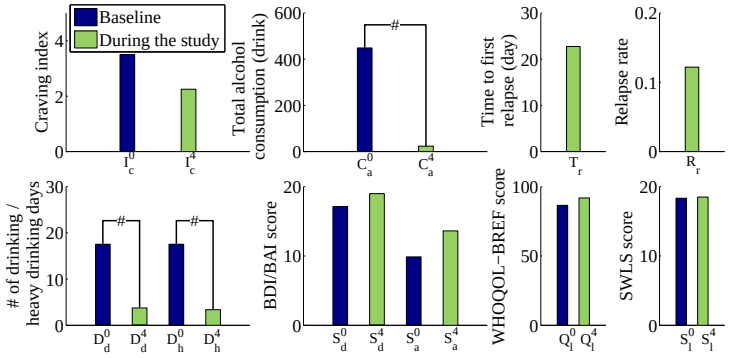


Figure 9: Differences between evaluation results derived from data collected from patients using SoberDiary prior to and during the study. The upper row shows the craving index, total alcohol consumption, time to first relapse, and relapse rate evaluated prior to and during the study. The lower row shows the number of (heavy) drinking days, BDI/BAI score, WHOQOL-BREF score, and SWLS score evaluated prior to and during the study ("#" indicates $p < 0.05$).

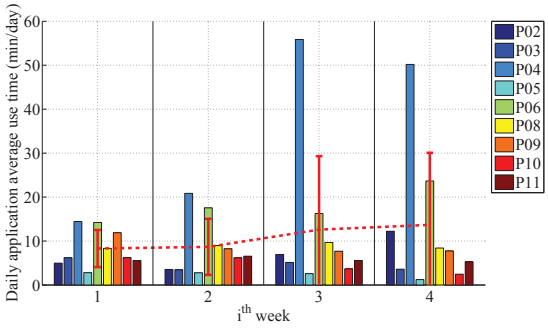


Figure 10: Daily app use time for each patient in each week. The dotted red line shows the trend of the average daily app use time among weeks.

of this app, they begin to interact with the app for longer periods of time, as shown in the case of the P04, who significantly spent more time using the storytelling visualization function in Weeks 3 and 4.

7. DISCUSSION

SoberDiary includes a Bluetooth breathalyzer that the participants used to self-monitor their alcohol use in at least 2 slots per day. When applying this requirement, alcohol use might not be detected if patients perform tests after metabolizing the alcohol or before drinking alcohol to deceive the system. If we were to increase the mandatory completion frequency, patients would need to expend more effort in performing more breath alcohol tests in a day and recharging the breathalyzer. A tradeoff exists between patients' convenience and alcohol screening coverage. The goal of SoberDiary is not to burden patients with frequency breath tests but to raise their awareness of their alcohol use behavior, which is evidenced in responses from patients. For example, P11 commented that "*I usually started drinking alcohol in the afternoon and drank for the rest of day. However, after using SoberDiary, the breath alcohol tests caused me to turn down party invitations from my friends. Because I wanted to pass the test, I had to remain sober for at least 3 to 4 hours before performing a test at night.*" In this study, we demonstrated that the current mandatory completion frequency is feasible for patients and results in a reasonable difference between SoberDiary-monitored and TLFB-recalled drinking days to provide feedback to patients.

8. RELATED WORK

Recently, smartphones [31] have been applied in designing various phone-based intervention applications for promoting well-being or treating additive behavior. Previous research on designing technology-based services for managing recovery from substance dependence have addressed habitual smoking [30], alcohol use [18, 24], and drug use [27]. Among these harmful substances, alcohol is one of the most dangerous drugs in the world [19], and the risk of becoming dependent in daily life is high because it is easy to access. To prolong participation in continuing care for alcohol-dependent patients, researchers have built technology-based services to preliminarily explore how technology can help patients maintain abstinence. Gustafson *et al.* [18] identified several critical elements that reduce the relapse rate of alcoholic patients, such as patients' coping behaviors, social support, and personal motivation. By incorporating these elements into the design considerations of technology-based services, a mobile system, A-CHESS, was designed to help alcoholic patients to cope with their alcohol cravings. McTavish *et al.* [24] used A-CHESS to assist alcoholics in recovering from alcohol dependence. Services designed based on self-determination theory improve patients' competence, social relatedness, and motivation. Results presented in [24] showed that patients sustain their use over time and participants with alcohol and drug dependence demonstrate application use behavior different from those with only alcohol dependence. However, these studies did not monitor patients' drinking behavior during the study and, therefore, provide only preliminary application use results for alcohol-dependent patients. By contrast, SoberDiary provides a Bluetooth breathalyzer for patients' to self-monitor their alcohol use behavior and demonstrates efficacy in enabling patients to maintain sobriety.

Other health-related phone sensing projects have been con-

ducted to enhance the health of users through persuasion, such as Playful Bottle [13], which encourages office workers to drink healthy quantities of water, the UbiFit Garden system [15], which promotes physical activities using on-body sensing and personal displays on phones, and MyExperience [16], which provides a system with automatic logging and in-situ experience sampling to collect usage data on phones. Based on lessons learned from these persuasive mobile systems, SoberDiary incorporates various concepts of persuasive feedback used in these systems to motivate alcohol-dependent patients to maintain sobriety. Furthermore, this study evaluated SoberDiary by recruiting clinical patients and targeted the difficult task of facilitating self-monitoring and self-managing behavior.

9. CONCLUSION

This study presents a novel phone-based support system that enables alcohol-dependent patients to self-monitor and self-manage their alcohol use after completing alcohol withdrawal treatment. By carrying a Bluetooth breathalyzer wirelessly communicating with the SoberDiary client installed on their phones, patients can perform breath alcohol tests to self-monitor their alcohol use behavior. Furthermore, the SoberDiary client offers various supporting functions that enable patients to self-manage relapse prevention. Results from a 4-week user study involving 11 clinical patients from TCPC show that patients using SoberDiary performed breath alcohol tests to self-monitor their alcohol use by completing at least 2.3 tests per day and self-managing their alcohol use behavior to significantly reduce their total alcohol consumption and the number of drinking or heavy drinking days. Compared with patients who received only standard treatment, SoberDiary users exhibited reduced alcohol craving and a lower drop-out rate, indicating the potential for SoberDiary to provide continuing care for relapse prevention.

Our future plans are to refine the design of the SoberDiary client and to conduct a randomized control trial with a greater number of alcohol-dependent participants to further demonstrate the effectiveness of SoberDiary.

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