ABSTRACT
Alcohol dependence is a chronic disorder associated with severe harm in multiple areas, and relapsing is easy, despite treatment. This study proposes SoberDiary, a phone-based support system that helps alcohol-dependent patients to self-monitor and manage their own alcohol behavior, and remain sober in their daily lives. We tested SoberDiary in a real-life 12-week user study involving 27 clinical patients. The quantitative and qualitative results revealed that SoberDiary helped patients self-monitor and manage their alcohol use, and reduced their total alcohol consumption as well as the number of heavy drinking days. Compared with patients who received standard treatment alone, this study demonstrated SoberDiary successfully complemented current alcohol treatment in reducing patients’ alcoholic cravings and dropout rate over 3-month study period. Follow-up interviews further revealed the sophisticated use practices and value of SoberDiary.

Author Keywords
Mobile support system; recovery from alcohol dependence.

ACM Classification Keywords
H.4.m. Information Systems Applications: Miscellaneous

INTRODUCTION
Alcohol dependence is a debilitating psychiatric disorder, and is associated with maladaptive and destructive behavior. Characterized by persistent, compulsive, and uncontrolled drinking, it leads to marked impairment, distress, and substantial interpersonal and social problems. Up to 50% of patients treated for alcohol dependence relapse within 2 years following treatment, even after achieving abstinence [12]. Therefore, developing a rational approach for enhancing relapse prevention is crucial for alcohol-dependent patients who experience cravings or the desire to resume alcohol use once they have achieved abstinence [15]. This study proposes a phone-based support system that helps alcohol-dependent patients stay sober in their daily lives after completing alcohol withdrawal treatment.

Previous researchers have developed self-monitoring techniques [19] and cognitive behavioral therapy (CBT) [19] to engage or motivate patients to self-manage triggers or challenging life events. To self-monitor their drinking behavior, psychiatrists ask patients to keep a drinking diary, so that they can find triggers by reviewing their diary. Because of memory recall errors, patients might easily forget or record the time or amount of alcohol consumption incorrectly. Furthermore, patients are reluctant to invest effort into maintaining a drinking diary. To extend the well-proven treatment of CBT, recent studies [6, 10, 20] have identified cellphones as a platform. However, these systems either have not incorporated breath analyzers to facilitate the self-monitoring of patients’ drinking behavior during the study [10, 20], or they did not provide real-time feedback that visualizes patients’ progress on their phones [6]. Furthermore, these studies have evaluated the patients’ sobriety performance based on telephone-based surveys [10, 20], or excluded alcohol-dependent patients [6]. By contrast, SoberDiary uses a Bluetooth breathalyzer (Figure 1) to assist patients in self-monitoring their drinking behavior by taking breath alcohol tests and providing real-time feedback to their progress, to raise users’ awareness of alcohol use. Various support functions are also provided, so that patients can appropriate them to better manage their emotions and become more sensitive to triggers.

This study involved the use of a phone-based support system, SoberDiary, to help alcohol-dependent patients maintain sobriety in their daily lives once they have completed alcohol withdrawal treatment. By carrying a Bluetooth breathalyzer that is wirelessly connected with the SoberDiary application installed on their phones, patients can perform breath alcohol tests to self-monitor their own alcohol use. To motivate behavioral change, SoberDiary also records personal progress.
and achievements in maintaining sobriety for patients review. SoberDiary also incorporates the principles of the 12-step program [19] to enable patients to learn the concepts associated with each step, thereby promoting self-fulfillment to recognize the values and beliefs of the community and the self. All test results and momentary feedback sampled by the SoberDiary client are used to provide appropriate recommendations for reducing alcohol cravings, and is uploaded to a backend server to enable continuous patient monitoring.

The contributions of this paper are the design, prototype, and evaluation of SoberDiary. A 12-week real-life study involving 27 alcohol-dependent patients using SoberDiary was conducted. The quantitative results revealed that the participants using SoberDiary were able to self-monitor and -manage their alcohol-use behavior, and reduced their total alcohol consumption and the number of heavy drinking days following intervention. The qualitative results, obtained from participant interviews, revealed how patients appropriated SoberDiary in their regular lives to assist them in staying sober. Compared with patients who received the standard treatment alone, this study demonstrated SoberDiary effectively complemented current alcohol maintenance treatment in reducing patients' alcoholic cravings and dropout rate over 3-month study period.

DIFFICULTIES IN STAYING SOBER IN DAILY LIFE

This section provides an explanation on the challenges for alcoholics in maintaining sobriety after completing treatment at hospitals/centers and returning to normal life. First, we define the following terms used in this article:

- A **standard drink** (or **drink**) [11] is a unit of alcohol used to quantify the amount of alcohol intake. In the United States, a drink is 14 g of pure alcohol, 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.

After completing withdrawal treatment, patients need to revisit the hospital regularly to attend follow-up maintenance programs. To monitor their alcohol use in daily life, psychiatrists ask patients to maintain a drinking diary, so that patients can identify triggers by reviewing them. However, patients tend to forget to record drinking behavior easily, or recall the time or amount of alcohol consumption incorrectly, thereby failing to maintain their drinking diary accurately and consistently. Without the drinking diary, psychiatrists can provide only limited recommendations to patients to improve their sobriety outcomes during each revisit.

The lack of a continuing maintenance program further degrades the efficacy of CBT [19], which can highlight triggers and coping strategies for relapse prevention. When patients return to their lives, alcohol cues (e.g., alcohol beverages in convenience stores or alcohol cravings triggered by emotions; for instance, stress might trigger alcohol use). Without continuing care to assist them in learning relapse prevention or alcohol management skills, they are bound to relapse easily when facing cues or craving alcohol. These observations suggest that alcohol treatment professionals cannot rely only on current approaches, and a complementary treatment modality to improve the efficacy of relapse prevention is required.

SOBERDIARY DESIGN

The SoberDiary system contains three components: (1) a portable Bluetooth breathalyzer, (2) a phone application, and (3) a backend server, which are described as follows.

**Portable Bluetooth Breathalyzer**

Figure 1 shows the front and left and right sides of the breathalyzer, which measures patients’ breath alcohol concentration (BrAC). During each breath test, alcohol absorption on the alcohol gas sensor [4] causes the electrical resistivity of the sensor to vary, altering the voltage output of the sensor. According to the voltage-to-BrAC lookup table learned from a calibration process, a BrAC reading is interpolated and returned through a built-in Bluetooth module.

**SoberDiary Phone Application**

The SoberDiary application provides various supporting functions that (1) enable users to self-manage addictive behavior, (2) suggest proper relapse prevention skills to reduce alcohol cravings, and (3) promote self-fulfillment. Relapse prevention [16] involves complex interactions with lifestyle factors (e.g., lifestyle imbalance or stress), intrapersonal factors (e.g., personal mental or physical status), and interpersonal factors (e.g., social relationships). To develop skills for staying sober, multiple behavioral theories were used to influence patients’ behavior from various aspects [19] in this study (i.e., self-efficacy theory [21], CBT [19], and self-determination theory [10]). According to self-efficacy theory [21], self-monitoring increases patient awareness of risky situations and behaviors, enhances patients’ self-efficacy and competence, and enables them to build the relationships and skills necessary for relapse prevention and sustaining abstinence. However, self-monitoring can be difficult to maintain without adequate support. Therefore, the SoberDiary application also includes CBT modules enabling cognitive behavioral theories [19] to emphasize triggers and coping strategies for relapse prevention and functional modules based on self-determination theory [10], to internalize the motivation for recovery when patients feel that they are able to maintain recovery (competence), perceive the decision to abstain from alcohol use as resulting from free will (autonomy), and feel
support from others in their recovery efforts (relatedness). In the next section, the application is described.

**Backend Server**
A backend server receives behavioral data uploaded from patients’ phones for future analysis and continuous monitoring. To provide information on sobriety outcomes, the server tracks the rankings of peers’ achievements in alcohol recovery. To facilitate the management of patients participated in this study, a monitoring web service was used to monitor all data uploaded by patients continuously, and provide researchers and psychiatrists with a daily summary including the details of patients who did not perform adequately.

**SOBERDIARY PHONE APPLICATION**
The four modules of the SoberDiary application are the (1) user interface, (2) supporting functional module, (3) app use logging, and (4) behavioral data store, as follows.

**User Interface**
A simple user interface with three full-screen main pages—test, statistical, and self-fulfilling pages—was designed. Patients switch between these pages by using three buttons located at the bottom of the screen. When patients launch the application, they view the test page for self-administering breath alcohol tests. After a test is conducted, a summary appears instantaneously on the statistical page. To facilitate social sharing and learn positive self-fulfilling concepts, patients can switch to the self-fulfilling page. Mood sampling can be initiated by tapping the menu key. The designs for each page are described in the following subsections.

**Supporting Functional Module**
Four functional blocks—alcohol use detection, progress feedback, a self-fulfilling guide, and mood sampling—are included to assist patients in maintaining abstinence, described as follows.

**Alcohol use detection**
Continuous patient monitoring [21] was identified as crucial for relapse prevention, and has long been absent from current alcohol treatment. To reduce the effort required to complete the tests allocated daily, we divided a day into three time slots: (1) a morning slot from 0:00 to 12:00, (2) an afternoon slot from 12:00 to 20:00, and (3) an evening slot from 20:00 to 24:00. Patients are required to perform at least one test in each slot to complete the alcohol-screening task and are asked to complete at least two slots per day.

To ensure that a sufficient amount of air from the deep lung accumulates in the sample chamber, a pressure sensor monitors whether patients exhale air into the sample chamber for longer than an empirical threshold (i.e., a 5-s exhalation process in this study). To prevent cheating, patients are asked to perform the test with their face in view of the phone’s camera. During the 5-s exhalation process, the application captures three photos of the patient’s face. After the test, the final BrAC value is extracted by calculating the median of all samples. Finally, a questionnaire appears, and patients record their momentary emotion and craving indices by responding to a visual analogue scale (VAS) on the screen. To encode the indices in numeric values, 10- and 5-point Likert scales are used for their momentary indices, respectively.

**Progress feedback**
Figure 2(a) shows a screenshot of the statistical page, which visualizes patients’ personal progress, and motivates them with achievements and rewards based on contingency management therapy [18]. The top of the statistical page provides a summary, and the bottom lists incentives. The summary region visualizes personal test results to enable patients to review their recent alcohol use on a daily dashboard. The dashboard shows the BrAC value as well as the craving and emotion indices of the latest test, and shows whether patients have stayed sober in the morning, afternoon, and evening slots. Each slot is represented in one of three possible state colorings: (1) the sober state, encoded in green, indicating that the patient passed all tests; (2) the drinking state, encoded in red-orange, indicating that the patient failed a test; and (3) the missing state, encoded in dark gray, indicating that the patient missed a test.

To provide positive feedback to patients, the incentive portion shows the rewards earned and their performance in the recovery process. Based on contingency management therapy [18], a reward is shown to motivate patients to continue using the application (i.e., the number of coupons earned). To encourage competition among participating patients, SoberDiary also showed patients’ rankings among all patients according to the average number of credits that all of the patient participants have accumulated since the study began.

**Self-fulfilling guide**
Figure 2(b) shows the self-fulfilling page, which enables patients to recognize positive self-fulfilling concepts. The self-fulfilling page also consists of two separate parts: the top half displays sobriety goal sentences with drawing illustration, and the bottom half provides visualization of the patient’s emotion, craving, and drinking behavior. The sobriety goal sentences come from Alcoholics Anonymous (AA), which proposed the principles of the 12-step program [19] to delineate the recovery process from alcohol dependence. This process comprises 12 steps to guide patients in promoting their self-fulfillment and staying sober, as shown in the

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![Figure 2: Screenshots of the SoberDiary phone application.](image-url)
bel each action as belonging to each supporting function, and porting functions, the monitoring services on the server la-
are uploaded to the backend server once daily. To calculate record their click/scroll streams with timestamps. All streams
ition in this study, we designed the app use logging module to
To analyze how the participants used the SoberDiary applica-
App Use Logging

cal momentary assessment (EMA) [13].

Mood sampling
The mood sampling block samples emotions and triggers to identify participants’ negative thoughts based on CBT treat-
ment. Because negative moods (e.g., stress) trigger alcohol cravings, they may cause patients to turn to alcohol for relief.
To prevent negative moods, identifying and addressing neg-
ative feedback is crucial. Using their smartphones, patients can record triggers of their negative moods when experienc-
ing symptoms of depression and anxiety through an ecologi-

cation as a line graph in different tabs. By reviewing the self-fulfilling summary, patients can recall relapse prevention skills learned during treatment, and recognize positive self-

Behavioral Data Storage
The behavioral data consist of BrAC values, the testing time, sampled emotions, triggers, and corresponding timestamps. To provide continuous monitoring, the collected behavioral data are sent to the server immediately after patients complete testing, or they are uploaded in a batch when patients launch the application.

SOBERDIARY PROTOTYPE
As shown in Figure 1, we fabricated a plastic case (7 cm × 5.8 cm × 2.5 cm) to hold a customized Arduino-compatible sensor board, equipped with a microcontroller [1], a digital pressure sensor [2], a Bluetooth module [3], and an alcohol sensor [4]. The microcontroller samples 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 a lithium-ion battery, which can be recharged approximately every 10 days by using a USB. Three color LEDs are used to inform patients whether the sensor is running (red LED on), low in battery power (yellow LED blinking), or charging (green LED on).

After calibrating the breathalyzers by using a standard alcohol-breath test simulator [5], the resultant accuracy was +/- 0.05 mg/L of breath alcohol within the range of 0 to 0.5 mg/L, and within 10% of the range of 0.5 to 0.75 mg/L. This is a suitable accuracy level for the classification of each patient’s BrAC values into three categories. However, to reduce the impact of mouth alcohol [7], the final screening thresh-
old was set at 0.068 mg/L in this study, slightly higher than the original screening threshold of 0.05 mg/L. Three cate-
gories were defined: the sober class, representing measured BrAC values lower than 0.068 mg/L; the lapse class, repre-
senting measured BrAC values in the range of 0.068 to 0.25 mg/L to detect lapses in alcohol use; and the relapse class, representing measured BrAC values greater than 0.25 mg/L to detect relapses in alcohol use. The SoberDiary applica-
tion communicates with the Bluetooth breathalyzer through Android Bluetooth APIs. An SQLite database (i.e., the behav-
ioral data storage) is used to store the patients’ BrAC test results and momentary feedback locally on the phone. The backend 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.

USER STUDY
We conducted a real-life 12-week user study involving 27 alcohol-dependent patients who tested the SoberDiary sys-
tem. To demonstrate the feasibility of using SoberDiary to self-monitor patients’ alcohol use behavior, this study quantitatively evaluated patients’ self-monitoring adherence and measured differences between SoberDiary-detected and TLFB-recalled drinking days. To further explore how well SoberDiary complements current treatment in a real-world setting, we follow the quasi-experimental design to compare

Figure 3: Screenshots of drawings (a)—(d) displayed in the top half of the self-fulfilling page.
the data from 27 patients in this study with another data from other 20 participants who only received standard treatment in an ongoing project (i.e., a surrogate measure of sobriety outcome improvement contributed by standard treatment). Finally, this study also qualitatively evaluated how well SoberDiary helped patients self-monitor and -manage their drinking behavior to maintain sobriety.

**Participants**

We recruited participants through hospital referrals and advertisements. To screen participants, we conducted structured interviews to determine their eligibility according to the inclusion and exclusion criteria. We explained the goal of the study, and asked eligible participants to provide informed consent.

For the intervention group, we recruited 27 participants (i.e., 23 men and 4 women) aged from 31 to 58 years. The average age and standard deviation (std) were 42.7 years and 7.4 years, respectively. Eight participants were unemployed, and the others were engineers, salespeople, or clerks, or were self-employed. All participants were clinical patients who had completing withdrawal treatment and passed a screening test at Taipei City Psychiatric Center (herein referred to as TCPC). To compensate for the cost of revisiting the hospital for follow-up assessments, patients were reimbursed US$6.5 for each revisit. Depending on the frequency and conformity of the requested SoberDiary usage, each patient was also rewarded with a maximum of four restaurant coupons (approximately US$6.5 in value) per week.

For the control group, we leveraged the data from 20 participants (i.e., 20 controls comprising 16 men and 4 women) from another ongoing project from June to September of 2013. All controls collected ground-truth drinking data by using the timeline follow-back (TLFB) method [11]. Similarly, all of the controls were clinical patients who had passed the same inclusion and exclusion criteria as those used to recruit the intervention group. Each control was reimbursed US$6.5 for each revisit. The age distribution of the controls ranged from 28 to 53 years, and the average and std were 42 and 7.44, respectively. The occupations of the control group were similar to those of the intervention group.

Table 1 lists the variables assessed using baseline medical reviews, including the participants’ self-assessed craving index, the number of heavy drinking days, and total alcohol consumption, as recalled by the participants over 12 weeks before the study. Based on the responses, the participants exhibited various unique alcohol addiction behaviors. One-tailed *t*-test results revealed no significant differences between these two groups, except for a significantly higher craving index (*p* < .05) of the intervention group, indicating that the participants in the intervention group had a higher alcohol craving compared with the control group.

We provided a Bluetooth breathalyzer to each participant in the intervention group, and the breathalyzer was paired with every smartphone. We also installed the SoberDiary application on all smartphones and asked participants to use them as their primary phones during the study.

**Procedure**

The procedure for the intervention group consisted of three parts: (1) a pre-study medical assessment, (2) a 12-week real-life study with SoberDiary, and (3) post-study interviews.

The purpose of the pre-study medical assessment was to collect the baseline craving index and alcohol consumption and compliance. Recent alcohol consumption and compliance were measured using the TLFB method in the baseline assessment and clinical assessments (described later in this subsection) of follow-up medical reviews, obtained from participants’ self-reports. The structured drinking diary recorded the type and amount of alcohol consumed per day in grams of pure alcohol. To teach the intervened patients how to use the phone application and breathalyzer, they all attended a 30-min training session teaching them how to operate the SoberDiary application and the breathalyzer.

During the 12-week real-life study, the intervened patients used the SoberDiary application for recovery from alcohol dependence. To collect ground truth data and address questions related to application use, the intervened patients were required to attend scheduled medical reviews held during Weeks 1, 2, 4, 8, and 12 at the TCPC. Each medical review consisted of a clinical assessment session and a technical support session.

**Clinical assessment session:** The intervened patients underwent medical care, typically available in hospital-based alcohol treatment services, in Weeks 1, 2, 4, 8, and 12. Intervened patients were asked to complete the questionnaires assessing the craving index in the final medical review in Weeks 4, 8, and 12. When intervened patients lapsed, they were encouraged to resume abstinence.

**Technical support session:** We asked intervened patients to report any problems related to application use, and tested the breathalyzer’s accuracy in Weeks 1, 2, 4, 8, and 12. We provided rewards (i.e., restaurant coupons) to each intervened patient. When they failed to attend the 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 intervened patient.

For the post-study interviews, we randomly selected 8 participants from the intervention group who completed the 12-week study. For each selected participant, an audio recorder was set up to record a 45-min semi-structured interview that inquired into the intervened patients’ daily application use behavior, opinions toward each supporting function of Sober-

<table>
<thead>
<tr>
<th>Name</th>
<th>Intervention Avg (Std)</th>
<th>Control Avg (Std)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Craving index (9)*</td>
<td>2.9 (2.7)</td>
<td>1.4 (2.0)</td>
</tr>
<tr>
<td># of heavy drinking days (day)</td>
<td>53.1 (35.1)</td>
<td>70.3 (26.4)</td>
</tr>
<tr>
<td>Total alcohol consumption (drink)</td>
<td>1239.1 (1524.0)</td>
<td>1406.1 (1061.0)</td>
</tr>
</tbody>
</table>

Table 1: Variables assessed in baseline medical reviews. The maximal values of craving index is indicated by numbers in parentheses. Significant differences of craving index between two groups are indicated by the asterisk symbol (*p* < .05).

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After collecting data from the participants, a quasi-experimental research method was used to determine how the participants’ use of SoberDiary affected their drinking behavior. Data from medical reviews and the SoberDiary application were compared for consistency, and used to justify abstinence by observing whether patients using SoberDiary exhibited a lower average drinking amount and fewer average heavy drinking days compared with 20 controls. The drinking behavior monitored using the TLFB method was compared with that monitored using SoberDiary. Statistical methods were used to analyze the application logs and interpret application-use behavior.

The evaluation metrics derived from the variables measured using medical reviews were total alcohol consumption and the number of heavy drinking days measured both 12 weeks before and in the 6th month during the study. By contrast, the evaluation metrics for the 6th month derived from SoberDiary-monitored data are as follows. The completion rate measured the average daily number of tests (or slots) completed by the participants. The missed rate measured the average daily number of tests (or slots) missed by participants, because patients were required to complete at least two tests in two time slots per day. The application-use time measured the average time a participant spent using SoberDiary daily.

The statistical methods for analyzing the data are as follows. We used repeated measures ANOVA as the statistical test to check whether or not completion rate, missed rate, and application-use time exhibit significant trends over 3-month period. We used independent samples t-test and paired t-test as the statistical tests to compare the means of measures between two groups and the means of variables between baseline and final assessments on controls or intervened patients, respectively.

Results of patients’ self-monitoring behavior

To examine whether SoberDiary generated feedback that reflected the participants’ drinking days accurately, Table 2 lists the differences between the SoberDiary-detected and TLFB-recalled drinking days. The columns in Table 2 enable a comparison between the number of drinking days detected by SoberDiary and those recalled using the TLFB method at the 6th month. Subtracting the number of drinking days recalled using TLFB (i.e., the recalled row) from that detected by SoberDiary and those recalled using the TLFB method at the 6th month. Subtracting the number of drinking days recalled using TLFB (i.e., the recalled row) from that detected by SoberDiary and those recalled using the TLFB method at the 6th month. Subtracting the number of drinking days recalled using TLFB (i.e., the recalled row) from that detected by SoberDiary (i.e., the detected row) yields the data for the diff row, which is the absolute value of signed difference between SoberDiary-monitored and TLFB-recalled drinking days. The average diff was small (i.e., 2.44 days per month). Several possible explanations for the reporting inconsistencies between the SoberDiary-detected method and the TLFB-recalled method are provided in the following section.

How well SoberDiary complements current maintenance treatment

Total alcohol consumption and the number of heavy drinking days in the intervention group decreased significantly by 94.4%, and 86.5% (p < .01 for both two variables), respectively, which were comparable to the reductions of 93.3% and 88.6% of total alcohol consumption and the number of heavy drinking days in the control group (p < .01 for both two variables), respectively. Because both groups received the standard maintenance treatment for abstinence, participants in both groups showed significant reductions in total alcohol consumption and the number of heavy drinking days.

Table 2: The number of drinking days detected by SoberDiary (i.e., the second row) or recalled using TLFB (i.e., the third row) and the difference between detected and recalled drinking days (i.e., the fourth row) in the 6th month. The monthly average (i.e., the last column) of the difference between detected and recalled drinking days is calculated by averaging the absolute values of the difference.

<table>
<thead>
<tr>
<th>Drinking days</th>
<th>M1 (84 slots in 28 days)</th>
<th>M2 (84 slots in 28 days)</th>
<th>M3 (84 slots in 28 days)</th>
<th>Monthly average</th>
</tr>
</thead>
<tbody>
<tr>
<td>detected</td>
<td>3.22 4.65 3.96 6.44</td>
<td>2.71 5.59 2.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>recalled</td>
<td>2.81 5.23 3.21 6.00</td>
<td>4.90 8.69 3.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>diff</td>
<td>2.41 4.08 2.65 4.74</td>
<td>3.43 5.69 2.44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
After completing treatment, the intervened patients reported fewer cravings, and the craving index significantly decreased by 59.0% \( (p = .001) \). By contrast, the craving index for the controls slightly increased by 53.8% \( (p = .09) \). The dropout rate in the intervention group was 22% (i.e., 6 of 27 intervened patients), which was nearly significantly lower than 45% (i.e., 9 of 20 controls) of the control group \( (p = .051) \). Although both groups showed comparable significant reductions in sobriety outcomes, the intervention group showed lower dropout rate than the control group. In other words, this study shows that SoberDiary successfully complements current maintenance treatment in reducing patients’ alcoholic cravings and dropout rate in the 3-month follow-up program. Furthermore, 5 intervened patients expressed that they were very willing to continue using SoberDiary after the 3-month study period.

**Application-use behavior**

Regarding the daily application-use time for each participant in each week, the average use times were 15.3 min, 16.4 min, and 13.7 min per day in Months 1, 2, and 3, respectively. The application-use time increased moderately in \( M_2 \), but decreased slightly in \( M_3 \). \( (F(2, 68) = .38, p = .68) \). This indicated that the incentives offered to motivate patients to continue using this application were effective.

**Qualitative Findings**

Data for the qualitative findings were retrieved from the audio recordings of the semi-structured interviews with 8 intervention participants. We manually transcribed the recorded audio from the intervention-patient interviews, and coded the transcriptions to identify salient themes. We organized the emerging themes and findings as follows.

**Self-administered monitoring improved self-efficacy**

The participants’ beliefs on self-efficacy produced effects in cognitive development, and determined how they behave. We found that participants underwent a process of adopting the self-monitoring function of SoberDiary to identify self-efficacy. All interviewees responded that they were able to complete two test slots in a day, and to fit the test time into their working schedules.

_My working hours are not from 9:00 AM to 5:00 PM. Because I am a consultant, I spent more time reading reports after conference calls with my colleagues abroad from 10:00 PM to midnight. Therefore, I often slept late, at 2:00 or 3:00 AM. [...] So, I usually performed the tests before going to the bed early in the morning and after finishing my lunch and dinner._ \( (P17) \)

Four interviewees commented that requiring tests in two arbitrary time slots in a day (e.g., one early in the morning and one late in the evening) could create a cheating window of opportunity that was sufficiently long for the body to potentially metabolize a certain amount of alcohol, resulting in undetected drinking.

_I thought that even completing all three test slots in a day is not enough [to close the cheating gap]. The night slot starts at 8:00 PM, and ends at midnight. There are 12 hours [of a window] until 8:00 AM the next day. So, if I complete a test for the night slot, and immediately start drinking or at midnight, can SoberDiary detect this alcohol use at 8:00 AM the following morning?_ \( (P16) \)

Among these four interviewees, two interviewees reported higher levels of alcohol cravings immediately after completing withdrawal treatment. Specifically, they commented a craving for strong alcoholic drinks such as whiskey. However, they wanted to achieve good results on SoberDiary by attempting to prevent SoberDiary from catching them drinking. This motivated them to gradually learn and exploit this cheating window by drinking at a controlled amount (i.e., they partially relieved their craving and still passed the next SoberDiary test).

_When you fail a test, it is just like … a kid doing something wrong (Uneasy laugh), and being caught by SoberDiary that I drank alcohol again. [...] I thought a good part of SoberDiary for me was to remind me not to drink too much. If I drank too much, I would fail the [morning] test after I woke up. So, I control myself … I mean only to drink a small amount of alcohol to relieve my cravings. Meanwhile, I can still pass the test tomorrow morning._ \( (P13) \)

Although the proposed system presented a window of opportunity for participants to cheat, exploiting this window requires that participants be aware and control the amount of alcohol intake, such that sufficient time exists for their body to dissipate the alcohol and pass the next test. The participants commented that they avoided situations where they risked out-of-control drinking.

_In the beginning of the study, I might have cheated the system to pass the tests. But later, I felt that it is important to be determined, and that I should not continue cheating the system. So, I gradually controlled my behavior. [...] Now, I think I am more capable of controlling my drinking behavior. For example, I usually attended parties invited by my colleagues before using SoberDiary. Now, I would be more aware of these occasions, which trigger alcohol use, and know how to refuse such invitations._ \( (P34) \)

Many participants gradually learned how to control their alcohol intake. This increased perceived control over their drinking behavior helped participants improve their personal efficacy to stay sober through the efficacy-activated processes \( [21] \).

_Coupons and performance ranking encouraged routine application usage, but was ineffective to alter determination_

Two incentives to motivate participants’ continuous use of SoberDiary were (1) restaurant coupons, and (2) the application showing each participant’s ranking in a group. Seven interviewees responded that the reward coupons had an effect on encouraging them to spend more time exploring and using the various application functions.

_Sometimes, I did care how many coupons I earned. [...] These coupons were … mental and material encouragements for myself. I would click through buttons to use different func-
tions. As I clicked the buttons, I might have accumulated more coupons. This is just like self-encouragement. (P5)

In addition, SoberDiary generated competition among patients [19] by ranking each participant’s performance in a group. All of the interviewees responded that they cared for their standing, because they did not want to finish with a low rank, suggesting a poor sobriety outcome.

I wanted to maintain the above-middle ranking. [Ranking] served as a reminder to me. For example, this was like when I took exams (in class). If I was ranked 10th on this exam and dropped to the 30th on the next exam, it made me realize that ... I should work harder. (P34)

The findings revealed that both restaurant coupons and performance ranking motivated participants’ continuous and routine use of SoberDiary. However, routine usage did not help strengthen participants’ determination or competence in staying sober, which is the essential construct of self-determination theory [10]. Six interviewees shared similar thoughts, as shown in the following:

I didn’t think the ranking information made me more determined to keep up with sobriety. Keeping up with sobriety is more about self-regulating drinking behavior. I cared about my ranking because I felt ashamed to lose to other participants. (P13)

Experience reflection and goal setting enhanced determination

Most participants suggested that coupon rewards and performance ranking were not sufficiently strong incentives to affect their determination to stay sober. Instead, the participants found the application’s self-filling guide to be more effective in strengthening determination compared with the coupons and ranking system. Six interviewees provided a similar response:

The goal sentence [in the application’s self-fulfilling guide] for each week gave me a weekly target. It informed me which stage I was currently on. Because I might not know what should be achieved in these 12 weeks. The only thing I knew was that I wanted to maintain sobriety, but didn’t know how long I should take to achieve these goals. [...] I thought this [stepwise] self-fulfilling guide, other than suggestions from psychiatrists or clinical psychologists, is an information source for understanding how well you performed. (P17)

The weekly goal sentences in the self-fulfilling guide were designed to appear repeatedly as a part of the routine SoberDiary usage. They reminded participants of the course of action they could conduct for alcohol recovery. The weekly goal sentences provided them with positive behavior principles, and enhanced their determination to fight the cravings. Four interviewees responded that the scenarios in these goal sentences were connected to their past experiences of struggling with alcohol.

Some sentences made me realize that I have been through the same scenarios before. I thought my job was good, but why couldn’t I do or keep my job properly? Because of alcohol use, I could not show up regularly for work. Then, my boss became less willing to interact with me. These events occurred again and again. Finally, I quit my job. (P18)

Because these goal sentences touched on their experiences, many participants commented that they remembered these goal sentences so well that these goal sentences helped them engage in more self-reflection on events in their daily life.

I remembered some sentences or ... keywords in sentences. It’s easy to relate my experiences to these sentences. These sentences described... to be determined to maintain sobriety. And another one was ... your health conditions or life would be better if you continue to stay sober, and so on. [...] Furthermore, one day, when I watched a movie, I was deeply impressed by a line in the movie “Respect yourself” (i.e., the principle behind the goal sentences of Week 7). Once you decide to participate in this study to maintain sobriety, you should respect yourself. That is, I am doing this not for others, but for myself. This is about self-discipline, not about doing it for someone else. (P34)

Frequent self-reflection helped participants raise their self-determination and self-discipline to better handle cravings.

During the third week, I remembered that something had happened suddenly. That thing ... made me unable to focus on staying sober. I can’t remember what happened. But I read the sentence on the third page of the self-fulfilling guide, and realized that ... it was my own responsibility to solve this problem. I should be actively accountable for solving this, not counting on other people’s help. (P16)

Present SoberDiary results as a way to communicate with family members

For most participants, their uncontrollable and repeated abuse of alcohol in the past had seriously harmed their family relationships. Even after medical treatment, their family members still remained skeptical and suspicious regarding the truthfulness of their words, and that they had stopped drinking. Two interviewees expressed sadness that their words had lost their family’s trust completely.

In place of their words, many participants presented the breathalyzer’s results and our coupon rewards as a way to communicate with their family members that they were expending effort and progressing toward sobriety.

I think those rewards (i.e., coupons) are an extra for me. The most crucial point for me was that SoberDiary proved that I didn’t drink alcohol. First, I proved to my family that ... after wasting 20 years on drinking alcohol ... with the help of [my psychiatrist], I provided proof that I really did not drink anymore. (P18)

After using SoberDiary, I felt that I had more interactions with my parents. Actually, I felt that they would be even happier that I performed the tests in their presence. It seemed that I was actively proving that I don’t drink alcohol. (P08)

Because the family members felt greater confidence because of the application and the breathalyzer results compared with the participants’ words, two participants responded that
SoberDiary had helped them reestablish trust and improve family communication.

DISCUSSION
One interesting observation is that the requirement for participants to engage in self-administered alcohol screening and monitoring appears to produce positive influence on their drinking behaviors and attitudes in more than one way. Some of the ways that SoberDiary produces impacts are not fully calculated or intended at the design stage.

Consideration of Alcohol-Screening Frequency
There are several ways to cheat the SoberDiary system. For example, patients may purchase another breathalyzer for pretesting, whereby they would not use the SoberDiary breathalyzer until they had passed the pretest by using the pretest breathalyzer. Increasing the frequency of alcohol screening from twice to three or four times daily may rectify such issues. However, remembering and performing additional tests would necessitate additional effort, and place a greater burden on users. The goal and purpose of SoberDiary is not to burden patients with frequent breath tests, but to raise their awareness of their alcohol-use behavior, which is evidenced in the interviewee responses. Increasing awareness is believed to be a relatively apparent mechanism how SoberDiary influences the patients.

Constructive Cheating
What’s less apparent yet noteworthy is that allowing people to cheat may still be constructive and can be useful to transforming their attitudes and behaviors toward reducing alcohol consumption. On the one hand, cheating certainly discredited the results of SoberDiary. However, our interviews revealed the other side of cheating. Cheating suggested that participants cared and were actively engaged in SoberDiary. It is a signal that they wanted to do well, such as having a good standing in their group and presenting positive results to family members, even when they lacked full capability to control their drinking behavior.

By keeping participants engaged in SoberDiary, they will have more opportunities to learn how to control their drinking behavior, as suggested in this study. For the higher level goal of design, some space or flexibility for participants’ constructive cheating may help control the drop-out rate. High drop-out rate is certainly not a desirable outcome for this sort of system. While it is important in the design of behavior modification applications to ensure the accountability of logged behaviors, we believe that there exists a design space on how to leverage the positive aspect of cheating toward the benefit of the participants by keeping them engaged.

Alternative Stakeholders to Manage SoberDiary in the Process of Alcohol Treatment
In this study, the SoberDiary system was managed by researchers from National Taiwan University and National Tsing Hua University, who closely collaborated with psychiatrists from TCPC. Because participants trusted medical specialties of psychiatrists (i.e., medical specialists), they tended to respect feedback or recommendations made by the SoberDiary system. Furthermore, patients who have established long-term psychiatrist-patient relationships felt responsible for maintaining sober to adhere to expectations from psychiatrists. For example, P13 expressed “If I drank alcohol and failed a test, I felt sorry to [the psychiatrist]”. Therefore, to integrate the SoberDiary system into future alcohol withdrawal treatment, finding reputable institutes/organizations to manage the SoberDiary system should be crucial for properly transferring SoberDiary to a supervising representative of psychiatrists. Future studies are required to explore ways to collaborate medical institutes/organizations with psychiatrists to manage the SoberDiary system and evaluate impacts on the efficacy of patients’ sobriety outcomes.

Reasons Causing Inconsistencies between System-Detected and Human-Recalled Sobriety Outcomes
In this study, SoberDiary-detected drinking days were compared with TLFB-recalled drinking days to measure the accuracy of sobriety outcomes with SoberDiary use. The reasons attributed to inconsistencies between these two data sets are as follows: (1) Participants made memory recall errors, leading to over-reporting or under-reporting lapses/relapses in each revisit. For example, patients tended grossly exaggerated the number of drinking days as the time between two successive hospital revisits increased to 1 month; and (2) breathalyzers might be subject to a false or missed detection because of the slow recovery of the sensor, the morning breath problem (i.e., residual mouth alcohol not yet metabolized), or substances (e.g., certain cold medicines) containing alcohol. Based on interviewee feedback, they may eat foods or take nighttime cold medicines containing alcohol, which would influence the screening outcomes.

Difficulties in conducting randomized controlled trials
Randomized controlled trials (RCTs) are the gold standard for demonstrating the efficacy of medical interventions. However, we faced difficulties in recruiting clinical patients for the control group because they expressed strong desires to be in the intervention group during the screening phase. When clinical patients found out that they were in the control group (not using the SoberDiary application), they tended to refuse to participate. As a result, this study was based on the quasi-experiment design to explore how well SoberDiary helped patients self-monitor and manage their drinking behavior to maintain sobriety and complemented with deeper qualitative interviews to draw useful results and valuable insights. In our next study with a different setup, we are accumulating the number of controls and will be able to use the randomized controlled trial to further validate the efficacy of SoberDiary.

RELATED WORK
Previous research on designing technology-based intervention applications for managing recovery from substance dependence has addressed habitual smoking [14], alcohol abuse [6, 10, 20], and drug use [17]. To prolong participation in continuing care for adults who drink frequently or alcohol-dependent patients, researchers have devised technology-based services [6, 10, 20] to explore how technology can help
patients maintain abstinence. However, these systems have either evaluated patients’ sobriety outcomes based on inaccurate long-term recall data collected through telephone surveys every 4 months [10, 20], or they excluded alcohol-dependent patients from the study [6]. By contrast, SoberDiary provides a Bluetooth breathalyzer and various supporting functions for patients to self-monitor their alcohol use.

Numerous health-related phone sensing projects have been conducted to facilitate health data collection or enhance the health of users through persuasion, such as Playful Bottle [8], which encourages office workers to drink healthy quantities of water, and the UbiFit Garden system [9], which promotes physical activity by using on-body sensing and personal displays on phones. Based on the design concepts learned from these related studies, we devised SoberDiary to incorporate the various concepts of persuasive feedback, to motivate alcohol-dependent patients to stay sober. Furthermore, this study evaluated SoberDiary by recruiting clinical patients, and we undertook the difficult task of facilitating self-monitoring and -managing behavior.

CONCLUSION
This study presented a novel phone-based support system that enables alcohol-dependent patients to self-monitor and -manage their alcohol use after alcohol withdrawal treatment. The results of this 12-week user study with 27 clinical alcohol-dependent patients revealed that patients using SoberDiary reduced their total alcohol consumption and the number of heavy drinking days. The themes identified in a qualitative study showed how patients appropriated SoberDiary in their regular lives to assist them to stay sober. Compared with patients who received standard treatment alone, this study demonstrated SoberDiary effectively complemented current alcohol maintenance treatment in reducing patients’ alcoholic cravings and dropout rate over 3-month study period.

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