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Exploratory analysis of blood alcohol concentration-related technology use and drinking outcomes among young adults

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Abstract

Background: Mobile health (mHealth) technology use may reduce alcohol use and related negative consequences; however, little is known about its efficacy without prompting from researchers or pay-per-use. This exploratory analysis assessed relationships between mHealth technology use frequency and alcohol-use outcomes.

Methods: Young adults who drink heavily ($N = 97$, $M_{age} = 23$, 51% male, 64% non-Hispanic White, $M_{drinks/week} = 21$) had the option to use three mHealth technologies (breathalyzer device/app, blood alcohol content estimator app, drink counting via text message) while drinking for 2 weeks. Relationships between alcohol-related outcomes and any, multiple, and specific mHealth technology use across study days and drinking days were evaluated via bivariate correlations and multiple regressions.

Results: Participants used one or more mHealth technologies on approximately 68% of drinking days (33% of field days), with multiple technologies used on 34% of drinking days. Bivariate

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CONFLICTS OF INTEREST
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correlations revealed that a higher percentage of study days with any mHealth technology use was related to higher mean weekly drinks. However, a higher percentage of drinking days with any mHealth technology use was related to lower mean weekly drinks, percent of heavy and high-intensity drinking days, and negative consequences. There were several significant, inverse correlations between alcohol variables and using the mHealth technologies that provided personalized feedback. Multiple regression analyses (holding sex and baseline alcohol variables constant) indicated that a higher percentage of drinking days with any mHealth technology use was related to lower mean weekly drinks and lower percentage of heavy drinking days.

Conclusions: Using mHealth technologies to moderate drinking without direct prompting from the research team or per-use incentives was related to less overall alcohol use and heavy drinking. This indicates potential real-world engagement with mHealth apps to assist with in-the-moment drinking. Normalizing mHealth technology use during drinking could help curb the public health crisis around harmful alcohol use in young adult populations.

Keywords

blood alcohol concentration; harm reduction; mhealth; negative consequences; young adults

INTRODUCTION

Harmful alcohol use is common among young adults (i.e., ages 18–25), with 29% reporting past-month heavy drinking and 15%, or 5 million, meeting the criteria for current Alcohol Use Disorder (AUD; SAMHSA, 2022). While trends have shown a decrease in young adult alcohol use over the last decade (SAMHSA, 2022), heavy alcohol use remains common. Alcohol use is associated with negative consequences, including injuries and fatalities to self and others, and approximately 100,000 deaths per year in the United States (Mokdad et al., 2018). Notably, the most severe consequences occur when blood alcohol concentrations (BACs) are above the legal limit of 0.08, when judgment tends to become significantly impaired (De Andrade et al., 2023; Mallett et al., 2013). Thus, interventions explicitly targeting heavy alcohol use and high BACs in young adults are critical to addressing this public health crisis.

Despite the seriousness of harmful alcohol use, young adults have reported difficulty with and lack of motivation to reduce heavy consumption (Marino & Fromme, 2018; Weaver et al., 2013). Empirically supported, accessible interventions that appeal to young adults are needed to mitigate these associated harms. Mobile health (mHealth) technologies are one easily accessible, feasible option for this population. Over 95% of young adults own a smartphone (Pew Research Center, 2022), and evidence indicates young adults are comfortable with daily technology use and are open to using smartphone applications (apps) for health purposes (Krebs & Duncan, 2015; Sillice et al., 2022). Currently, the most commonly used mHealth technologies, products, and platforms target health behaviors other than substance use, such as sexual health, weight management, and hydration (Bond et al., 2022). mHealth technologies could be effective in helping young adults manage their alcohol use and reduce the risk of associated consequences; however, it remains unclear how effective these technologies are for reducing alcohol use and related consequences or how frequently young adults may use them during actual drinking sessions.

Evidence supports the efficacy of in-person and web-based, brief interventions for young adult alcohol use, mainly built around providing non-judgmental, personalized feedback in line with motivational interviewing (MI) principles (DiClemente et al., 2017; Huh et al., 2015; Mun et al., 2023; Murphy et al., 2022). While these techniques are well received by young adults due to their focus on autonomy and enhancing self-efficacy (Naar & Suarez, 2021; Tanner-Smith & Lipsey, 2015), to date, efficacious options for in-the-moment assistance while drinking are extremely limited for this population. Previous literature indicates that young adults more frequently implement indirect drinking strategies, such as having a designated driver or going out in groups, as opposed to strategies that would directly reduce their consumption, like alternating alcoholic with non-alcoholic beverages (DeMartini et al., 2013; Leeman et al., 2016). Therefore, young adults could benefit from tools that can be used while drinking, such as mHealth technologies, to assist with the essential but more challenging task of implementing direct strategies for reducing alcohol consumption.

Focusing on young adults' BAC is one way for mHealth technology to target harmful alcohol use through the provision of direct drinking strategies and objective, personalized feedback. Research shows that young adults are more likely to underestimate their BACs at higher levels of impairment, which are more likely to result in severe consequences (De Andrade et al., 2023). However, many young adults do not know what BAC is, how to estimate it (Eby et al., 2017; Kraus et al., 2005), or the myriad factors that affect BAC (i.e., biological sex, weight, stomach contents, and volume of drinks over time; Fisher et al., 1987; Jones, 2019). As such, young adults are left to estimate their levels of intoxication and BAC based on potentially inaccurate, in-the-moment perceptions, without understanding how BAC is determined and changes over time. These judgments present a problem as BAC continues to climb for an average of an hour after consumption of alcohol (Paton, 2005), so individuals may mistakenly make decisions based on perceived, real-time effects without considering time-dependent BAC changes and potential increased impairment.

In-the-moment feedback could raise awareness about alcohol effects at certain BACs, such as the legal limit for operating a vehicle and factors that can cause a person's BAC to change at different rates. Research shows that adults who drink more heavily tend to experience fewer effects from alcohol at given levels of consumption due to the development of behavioral tolerance and lower sedative effects from alcohol (Elvig et al., 2021; King et al., 2016). However, young adults may not experience similar effects. In a study of adolescents and adults, younger participants reported greater levels of stimulation from alcohol compared with older participants (Treloar et al., 2017), possibly contributing to the desire to drink heavily. In behavioral performance tests, young adults who reported heavy drinking performed worse than they presumed and demonstrated comparable impairment to those who reported lighter drinking and reported more substantial subjective alcohol effects (Brumback et al., 2017; Marczinski et al., 2008). These findings emphasize a critical need for brief alcohol intervention efforts to focus on providing young adults with BAC education and personalized in-the-moment feedback.

BAC education as a stand-alone intervention has been largely ineffective in reducing college student drinking (Cronce et al., 2018). However, when combined with effective intervention strategies, such as brief motivational interviewing, BAC psychoeducation could be valuable and a strong candidate for in-the-moment personalized feedback (Cronce et al., 2018). Estimated BAC (eBAC) is often included as a component of personalized feedback in brief, MI-based interventions like BASICS (Dimeff, 1999), but tends not to be one of the main topics. Several reliable and accurate mHealth tools exist that can determine breath alcohol concentration (BrAC; Motschman et al., 2022) and eBAC (Luczak et al., 2018). Portable, commercially-available breathalyzer devices use fuel cell technology and have similar accuracy to police breathalyzers when used correctly (e.g., waiting 15 min after completing a drink before taking a reading), but they tend to consistently measure BrACs at slightly higher levels (Delgado et al., 2021). Applications producing eBAC readings have been found to provide estimated values with similar accuracy to portable breathalyzers, capturing peak BrAC to within 0.003%, and time of peak to within 17 min, on average, (Luczak et al., 2018). However, these tools have been underutilized in brief interventions for young adults.

Most alcohol studies using in-the-moment mHealth tools have reported moderate-to-high engagement but mixed results for alcohol use reduction compared to a control condition (Berman et al., 2019; Gajecki et al., 2017; O'Donnell et al., 2019; Suffoletto et al., 2018; Thompson et al., 2020; Wright et al., 2018). While young adults may be interested in mHealth technologies for behavior change, such as alcohol use reduction (Boendermaker et al., 2015; Bond et al., 2022; Sillice et al., 2022), a recent systematic review found that most studies with high engagement incentivized participants per mHealth technology use (Perski et al., 2022). Paying participants per technology use is appropriate for certain research questions, particularly in the early stages of testing when demonstrating initial usability; however, this approach does not apply to real-world conditions. To our knowledge, few studies have demonstrated that mHealth apps have an efficacious effect on in-the-moment drinking compared to a control condition when technology use frequency is left to choice (Berman et al., 2019; Gajecki et al., 2017; Thompson et al., 2020). Thus, research is needed to investigate in-the-moment interventions prioritizing participant choice for engagement instead of study staff actively prompting or incentivizing technology use each time. Emphasizing participant choice will bring the field closer to sustainable approaches that can be implemented in young adults' everyday lives.

The present project's parent study (Leeman et al., 2022) assessed the feasibility, acceptability, usability, and preliminary efficacy of mHealth technology targeting harmful alcohol use by measuring eBAC and providing personalized feedback. Results demonstrated favorable acceptability and usability for in-the-moment mHealth technology, and alcohol use was significantly lower during a two-week field period compared to baseline according to multiple drinking metrics (e.g., drinks per week, drinks per drinking day; Leeman et al., 2022).

Because all participants underwent the same experience during the 2-week field period, it is challenging to determine conclusively whether using the specific technologies reduced alcohol consumption or whether the findings were due to behavioral reactivity (Haynes & Horn, 1982; Walters et al., 2009). Though it does not substitute for a controlled study, relationships between patterns of mHealth technology use and alcohol variables might suggest that drinking reduction observed during the study was not merely due to behavioral reactivity. This secondary analysis explored relationships between use of three mHealth technologies (breathalyzer device/app, BAC estimator, and self-text method) and alcohol use outcomes among young adults during the field period where participants chose their level of engagement (i.e., unprompted and without compensation-per-use). Exploratory objectives were to determine whether more frequent use of any, multiple, or specific technologies was associated with lower alcohol involvement across different metrics, including fewer alcohol-related negative consequences. Based on the parent study outcomes, we expected that increased mHealth technology use would be related to lower alcohol involvement overall, yet no specific hypotheses were made for particular alcohol outcome variables.

MATERIALS AND METHODS

Participants

Young adults of legal drinking age in the US (aged 21–25) were recruited to the parent study using social media, web ads, and flyer postings. Inclusion criteria included alcohol use on 10 or more days, heavy drinking on four or more days (i.e., four or more drinks for women, five or more for men), and at least 1 day with an eBAC of 0.10% or higher in the preceding 30 days. Exclusion criteria included treatment-seeking or having undergone substance use treatment in the past 12 months; positive urine test for other controlled substances excluding tetrahydrocannabinol (THC); current Diagnostic and Statistical Manual of Mental Disorders, fourth edition (DSM-IV) substance dependence (outside of alcohol); history of medically assisted detoxification or current withdrawal; two BrAC readings >0.00% at the outset of appointments; medical conditions where alcohol use could cause significant harm; Body Mass Index <18.5 kg/m^2 or >35 kg/m^2; pregnancy, lactation, or birth control refusal in women; recent prescription for or current use of psychotropic drugs; presence of psychosis/ severe psychiatric conditions; aversion to beer; or past use of moderate drinking apps within the past 12 months.

The study received institutional review board approval, and data were collected between February 2017 and April 2020. Of the 99 participants in the parent study, 97 young adults engaged in the 2-week field period following the laboratory alcohol self-administration session and were included in the present secondary data analysis. At baseline, participants were evenly distributed between males (50.5%) and females, with the majority being White and non-Hispanic (64%). The sample reported consuming nearly six drinks per drinking day, with an average weekly consumption of over 21 drinks, and endorsed approximately 13 negative alcohol-related consequences in the past 30 days (Table 1).

Procedures

Initial study procedures: Participant eligibility was determined through pre-screening over the phone or web, followed by in-person screening, including obtaining informed consent and assessments to determine the history of and current substance use, medical history, cognitive and psychomotor functioning, and other self-reports. Participants then engaged in a brief, in-person counseling that encompassed BAC-focused psychoeducation and MI, which included personalized feedback on participants' patterns of alcohol use, including recent estimated typical and peak BAC.

Following brief counseling, participants were randomly grouped in threes for a laboratory alcohol self-administration session. Each participant was randomly assigned to use one of three mHealth technologies during the alcohol self-administration session: (a) the BACTrack Mobile Pro breath alcohol device/app (version 2.5.6), (b) the IntelliDrink BAC estimator app (Luczak et al., 2018), and (c) a self-texting control procedure where participants sent themselves a text after each drink. Study staff provided participants with written instructions and visual aids on how to use all three forms of technology after the alcohol self-administration period ended and prior to departing from the laboratory session. Participants were able to practice using each technology with study staff after reviewing individual instruction materials. Study staff also: (1) verified that participants were able to use each technology correctly; (2) answered questions about the technologies as needed, and; (3) discussed common troubleshooting issues (e.g., syncing the BACTrack Mobile Pro breath alcohol device with the corresponding app). Further information on complete procedures is provided in the parent study publication (Leeman et al., 2022).

Field period: Participants were given access to all three mHealth technologies to use unprompted, as desired, during drinking events for 2 weeks. Compensation for the entire field period was $10 per day regardless of mHealth technology use, with an additional $20 if they used each technology at least once over the 2 weeks. No additional technology use incentives were given. At the end of the 2-week field period, participants' alcohol consumption over the past 14 days was reassessed. Their mHealth technology use was downloaded from their smartphone. They also provided feedback about their technology preferences and experiences (see Leeman et al., 2022, for acceptability and usability findings), and received compensation.

mHealth technologies: Two of the three mHealth technologies yielded a measure of BAC or BrAC. The BACTrack Mobile Pro is a mobile breathalyzer and Bluetooth-connected smartphone app. Participants were instructed to blow into a small plastic tube connected to the device about 15 min after finishing each drink, with the resulting BrAC reading appearing on the phone screen in the app. The IntelliDrink BAC estimator app (Luczak et al., 2018) calculated eBAC based on standard measurements, including weight, biological sex, and alcohol consumption over a specified time. The app considers stomach fullness (low, medium, and high) and recent drinking history (rare, occasional, or frequent alcohol use) in a proprietary fashion, though the algorithm is based on the Widmark equation (Matthews & Miller, 1979). After profile creation, participants set their profile to "low" stomach fullness and "occasional" drinker status and were asked to maintain these settings throughout the study. Participants were instructed to enter their beverages and approximate alcohol amounts into the app and indicate the time to finish each drink. The third technology was a self-texting procedure. Participants were instructed to message themselves after finishing each drink, identifying the beverage (e.g., "beer") and noting the number of texts they sent themselves before subsequent drinking decisions.

Measures

Demographics: Demographic information such as biological sex, race, and age was collected during the in-person screening.

Alcohol use: Alcohol use was collected at the in-person screening and after the field period using the Timeline Followback (TLFB; Sobell & Sobell, 1992), which includes a calendar with memory prompts to aid recall of alcohol and cigarette use for each day. The reliability and validity of estimates for TLFB over 30 days have been verified (Carey, 1997). A TLFB was administered at baseline, covering the prior 30 days; before the laboratory alcohol self-administration session covering all days since baseline (not included in this report); and at the end of the field period, covering all days since the lab session. All alcohol-use variables were derived from TLFB data (i.e., mean weekly drinks, number of drinks, mean and peak eBAC, percent of heavy and high-intensity drinking days). No day-level alcohol variables were calculated based on mHealth technology use because participants chose whether to use any technology each day. Thus, it was not expected that technology use would occur on every day or every drinking day of the field period. Further, participants specifically selected which technology to use, and the technologies yielded different drinking metrics (i.e., actual BrAC, estimated BAC, and drink quantity). The one exception was if the number of technology use days was greater than the number of reported drinking days on the TLFB. In these cases, the number of technology use days was substituted for alcohol use frequency derived from the TLFB on the assumption that this indicated a recall error during the TLFB. In this secondary analysis, for both the TLFB and mHealth technology use, we defined drinking days as social rather than calendar days (i.e., beginning and ending at midnight). Thus, on all modalities, alcohol use that began on a given day and ended after midnight the next day was considered part of the first day's drinking.

Alcohol-related negative consequences: Consequences were assessed at baseline and follow-up using the Young Adult Alcohol Consequences Questionnaire (YAACQ; Read et al., 2006), which examines 48 drinking consequences. At baseline, participants indicated whether they had experienced each consequence during the past 30 days, and at follow-up, they reported on consequences during the field period. The number of endorsements was totaled to yield each participant's score.

Data analysis

Data analyses were performed using SPSS version 27. The main objective of these exploratory analyses was to relate patterns of mHealth technology use to various alcohol metrics based on the field period. This study did not provide daily direct prompts for technology use, and participants could select the days and frequency of technology use, including if they wanted to use no technology or multiple forms in a single day. There was also no daily assessment of alcohol use as we wanted the field period to be as natural and reflective of the participants' typical drinking experiences as possible. Because accurate, day-level alcohol use could not be derived from the mHealth technologies, and the TLFB is best at capturing patterns of alcohol use rather than precise, day-level use (Carney et al., 1998; Dulin et al., 2017; Merrill et al., 2020), there was no consistent, daily source of alcohol frequency and quantity data. Thus, we related variables capturing patterns of mHealth technology use to summarize alcohol metrics across the field period compared to baseline using TLFB for alcohol use and YAACQ score for negative consequences.

Technology use variables were created to capture the percentage of any, multiple, and specific technology use by dividing the number of days each specific technology was used by the overall number of study days and drinking days and multiplying by 100: (*total tech use days/number of study days*) × *100* and (*drinking days technology was used/drinking days*) × *100*. Technology use days were counted singularly without regard for the number of times in a day technologies were used. Thus, five uses of the breathalyzer during a drinking day would be counted as one instance of use for the purpose of these analyses.

Distributions were examined for all technology use variables, baseline and field period drinking variables calculated via TLFB: drinks per drinking day, peak drinks (i.e., the highest number of drinks consumed during a single drinking occasion), number of drinks per week, mean eBAC, peak eBAC (i.e., highest eBAC during a single drinking occasion calculated with a formula based on the Widmark equation; Matthews & Miller, 1979), percent of heavy and high-intensity drinking days (i.e., 10 or more drinks for males, eight or more drinks for females), and YAACQ scores for negative consequences (see Table 1).

Several variables were skewed near or beyond the acceptable range of <3.0 (Kline, 2023). To correct skew, square root transformations were applied to the percent of overall study days when multiple technologies were used, the smartphone breathalyzer was used, the BAC estimator app was used, and self-text was used, as well as to the percentage of drinking days when multiple technologies and when self-text was used. We winsorized several alcohol variables with outliers down to a level of mean plus three standard deviations. This step did not reduce skew sufficiently; thus, transformations were also applied. The baseline variable mean drinks per week was winsorized and log transformed, while baseline drinks per drinking day, peak drinks, and percent heavy drinking days were log-transformed only. Baseline variables for mean and peak eBAC and percent high-intensity drinking days were winsorized and square root transformed, while baseline negative consequences score was square root transformed only. Regarding field period alcohol variables, mean drinks per week, percent of high-intensity drinking days, and peak drinks were winsorized and log-transformed. Mean and peak eBAC and percent of heavy drinking days were winsorized and square root transformed, while negative consequences score was square root transformed.

Exploratory bivariate correlations were then calculated to determine the strength of relationships between each technology-use and alcohol variable during the field period (see Table 2). Where there were statistically significant correlations between technology use and alcohol-related variables, alcohol-related variables were regressed on technology use in multiple regression models, holding constant the baseline level of the alcohol variable and participant sex. Given the exploratory nature of these analyses and our goal to learn which technology use variables related most closely to which alcohol variables, we set alpha at 0.05 despite the high number of analyses conducted.

RESULTS

On average, participants used mHealth technology to monitor drinking on approximately 33% of field period days and 68% of drinking days. Additionally, participants used multiple mHealth technologies on 34% of drinking days. Overall, frequency of use was similar across the three technologies. Participants used the breathalyzer on 18% of field period days and 38% of drinking days, the BAC estimator on 19% of field period days and 41% of drinking days, and self-text on 15% of field period days and 31% of drinking days (Table 1).

Technology use during field period days overall

Exploratory bivariate correlations indicated several significant small-to moderate-effect relationships between mHealth technology use and alcohol use variables based on contemporary effect size guidelines (Funder & Ozer, 2019). Significant, positive correlations existed between percentage of overall field period days when any technology was used and mean drinks per week. However, there were no significant correlations between any alcohol variables and the percentage of overall days when multiple technologies were used, when the breathalyzer, or when the BAC estimator was used. The percentage of overall days when participants used self-text was significantly and positively correlated with mean drinks per week and percentage of heavy drinking days. Multiple regression analyses (Table 3) for overall study days demonstrated that more frequent use of any mHealth technologies during the field period was significantly related to a higher number of drinks per week consumed.

Technology use during drinking days

When examining the percentage of drinking days when any technologies were used, there was a significant inverse correlation between any technology use and the following alcohol variables: mean drinks per week, percent of heavy and high-intensity drinking days, and negative consequences. There were no significant correlations between the percentage of drinking days when multiple forms of technology were used and any alcohol variables. Regarding the specific technologies, there was a significant inverse relationship between the percentage of drinking days using the breathalyzer and mean drinks per week and negative consequences. Lastly, there were significant, inverse correlations between the percentage of drinking days when the BAC estimator was used and mean drinks per week, percentage of heavy drinking days, and negative consequences.

When controlling for baseline alcohol variables and sex, results from the multiple regression analyses indicated that the percentage of drinking days with any technology use was significantly related to fewer drinks per week and a lower percentage of heavy drinking days, but not fewer high-intensity drinking days or negative consequences. Regressions for specific technologies did not yield any significant relationships between the percent of drinking days using the breathalyzer or using the BAC estimator with any alcohol variables where significant bivariate correlations were observed.

DISCUSSION

Harmful alcohol use among young adults is a serious public health concern, yet this population tends to report a lack of motivation to change (Marino & Fromme, 2018;

Weaver et al., 2013). Unfortunately, there are few efficacious tools to assist with reducing alcohol use in the moment and avoiding alcohol-related negative consequences (Bendtsen et al., 2021; Businelle et al., 2024). Mobile health apps have the potential to assist, yet little is known about how mHealth technology use impacts drinking outcomes in the real world. Given these challenges, it is essential to learn more about how young adults freely engage with technologies without regular prompting from study staff or payment per technology use, as commonly seen in mHealth technology studies targeting alcohol reduction (O'Donnell et al., 2019; Suffoletto et al., 2018; Wright et al., 2018).

This exploratory study focused on three different mHealth apps to facilitate BAC monitoring and consumption tracking over a 2-week field period. Participants could opt to use the mHealth technologies as desired and interchangeably to monitor their alcohol consumption in real-time. They were compensated for overall study participation and could earn a bonus if they used each technology at least once during the field period. However, there was no additional compensation for technology use during the field period other than this bonus payment, yet participants used one or more forms of technology on an average of 33% of overall field period days and 68% of drinking days. While additional research is warranted for longer study periods to fully determine the viability of these mHealth technologies, our findings indicate that young adults will use mHealth technologies voluntarily, without prompting and pay-per-use incentives, and underscores their potential utility to reduce drinking and avoid consequences.

mHealth technology use across the overall field period was significantly and positively associated with number of drinks per week, although notably, not with negative consequences. There are a few possible explanations for this finding, though participant self-selection of technology type and frequency of use precludes causal interpretations of the findings. Participants in our sample who were the most frequent, heaviest drinkers may have opted to use the technologies most frequently. Participants may have also tended to use the technologies on days when they planned to drink the most. Research shows that young adults' intention to drink is a significant predictor of heavy drinking, compared to days when drinking is spontaneous (Collins & Carey, 2007; Jones et al., 2018; Northcote, 2011). Alternatively, mHealth technology use in this study may have had iatrogenic effects and was associated with increased alcohol consumption compared to days when technology was not used.

Our findings that more frequent use of mHealth technologies on drinking days was significantly correlated with fewer drinks per week, fewer heavy drinking days, and fewer alcohol-related negative consequences make the iatrogenic effect scenario unlikely. Specifically, the use of technologies providing feedback on BrAC or eBAC was inversely related to alcohol use and negative consequences. Since higher BACs are linked to increased injury and mortality risk (De Andrade et al., 2023; Mallett et al., 2013), having accurate tools to measure BAC during drinking episodes could reduce injury and mortality rates among this vulnerable, at-risk population. Moreover, self-texting on field period days was positively correlated with mean weekly drinks and percent of heavy drinking days, whereas breathalyzer and BAC estimator use was not. However, breathalyzer and BAC estimator use on drinking days was related to reduced drinking, whereas self-texting was not. Whether this pattern was simply due to mHealth devices that provide personalized feedback being more effective tools for drinking and consequence reduction and/or due to young adults self-selecting self-texting for their heavier drinking occasions requires further investigation in future studies.

Notably, no significant relationships were found between mHealth technology use and drinks per drinking day, peak drinking, or the eBAC equivalents of these variables. Instead, technology use was only associated with a reduction in overall alcohol consumption, less frequent heavy/high-intensity drinking, and fewer consequences. Perhaps a more extended intervention or observation period is needed to observe reductions in peak drinking and drinks per drinking day, or additional intervention content tailored specifically to these technologies is needed to address these alcohol use variables specifically. These findings may also relate to the nature of the variables. Our mHealth technology variables related to patterns of use throughout the field period. It may not be surprising then that these variables had closer relationships to alcohol outcomes that also captured patterns over time rather than variables capturing alcohol use by day.

It was also notable that there were few significant relationships between mHealth technology use and alcohol involvement in regression models when controlling for baseline measures and sex. Exceptions included the percentage of drinking days when any technology was used, which was significantly related to fewer drinks per week and fewer heavy drinking days. However, it should be noted that the inclusion of the appropriate baseline alcohol variable in these models set a high bar for detecting significant effects. Larger sample sizes may be needed in future studies to determine whether these correlated relationships would maintain statistical significance in models, including baseline values and other predictors.

The relatively common practice of using multiple technologies during the same drinking event stood out despite participants not being encouraged or coached to do so. In qualitative data not reported here, some participants stated that they tailored technology use to their context, with the breathalyzer being particularly well suited to smaller, private gatherings and the estimator or self-texting being a better fit for larger, public gatherings. Young adults report drinking in two different environments within drinking occasions around 50% of the time, often opting to pregame in a more private environment before transitioning to either a larger house gathering, bar, or club (Labhart et al., 2017; Northcote, 2011). Trends such as drinking at multiple locations and starting before 8 p.m. have been linked to heavier consumption (Finan & Lipperman-Kreda, 2020; Kaestle et al., 2018; Labhart et al., 2017). Indeed, a multiple technology use strategy may be particularly well suited to drinking events that span multiple contexts. Young adults may need interventions tailored explicitly to optimize the use of multiple technologies or a longer intervention period for the beneficial effects of multiple technology use to manifest in reduced alcohol use and/or negative consequences. Thus, future studies could prompt participants to indicate their current drinking environment or ask them to report what determined their choice of technology, serving to capture contextual factors determining their choice of mHealth technologies more effectively.

Limitations

Several limitations must be addressed. First, this secondary analysis was exploratory. As a result, many bivariate correlations were conducted, followed by regression analyses. This research is a new line of inquiry, and accordingly, our purpose was to learn more about which patterns of mHealth technology use were associated with reductions across different alcohol metrics. Due to this approach, we were able to learn that any technology use related to cumulative rather than alcohol outcomes by day and that use of the breathalyzer and estimator were associated with reduced drinking and consequences, whereas self-text use was not. We may have learned less had we been more stringent in our analysis plan.

Second, alcohol outcomes were derived only from the TLFB interview, which relies solely on participants' retrospective recall of their consumption over a specific timeframe. Using the TLFB has several strengths, including a calendar-based approach to aid memory recall, which mitigates this limitation. Further, participants reported their alcohol use over a relatively short timeframe (i.e., 2 weeks) and were encouraged to use information on their phones and social media to prompt their memories. Although this assessment method is reliable among young adults (Carey, 1997), the inherent limitations of retrospective self-reporting cannot be avoided. Several studies have found significant differences in recall of alcohol volume on the TLFB versus daily reports (Dulin et al., 2017; Kaplan & Koffarnus, 2019; Merrill et al., 2020). Future research could include real-time (e.g., ecological momentary assessment) or daily self-reports. In the parent study, we avoided this approach so participants could use the technologies to facilitate drinking reduction in real drinking situations in a manner applicable outside of a research study.

While we believe this approach was a strength due to its ecological validity, self-selection of technology use precluded definitively linking specific mHealth technology use to reductions in alcohol consumption or negative consequences on a particular day or over a particular time period. Additionally, environmental context factors influencing technology use may have impacted drinking outcomes, but these were not captured in the parent study. One limitation of the mHealth apps' accessibility was the requirement for participants to have an iPhone with iOS software to download and use the breathalyzer and BAC estimator. While participants who did not own an iPhone were able to borrow a study phone, some reported not wanting to carry multiple phones and devices out while drinking, which may have impacted technology use during drinking occasions.

In addition, as the field period occurred outside of a laboratory setting, participants' mHealth use may not have always adhered to instructions (e.g., waiting 15 min after completing a drink before using the breathalyzer). Ensuring that participants know how to use specific mHealth technologies correctly is essential, especially during impairment when the accuracy of self-reports may be less reliable. While prompts per use may not always be feasible or preferable, notifications or periodic alerts could help participants remember to use mHealth devices during drinking events. Lastly, due to the nature of the parent study, which involved laboratory alcohol self-administration, young adults under the age of 21 were not eligible to participate. Additional research is needed to evaluate whether mHealth technology would be used by and is effective among underage individuals who drink.

CONCLUSION

mHealth technology use on drinking days was significantly related to fewer drinks consumed and negative consequences. Additionally, the observed frequency of technology use without prompting by study staff or incentivizing per use suggests potential for real-world engagement with mHealth apps in the moment to aid drinking decisions. Further research is needed to make more definitive statements about the efficacy of different mHealth technologies. Future studies would benefit from larger samples, longer intervention periods, and designs where participants are prompted to use specific mHealth interventions or a control condition (i.e., micro-randomized trials). Support in the current study for participant choice underscores the need to develop additional mHealth technologies to moderate drinking to afford young adults more efficacious options.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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TABLE 1

Sample characteristics by baseline and field period time points.

Variable	Baseline, *M* (SD)	Field period, *M* (SD)
Age	22.81 (1.23)	
Male (%)	50.50%	
Female (%)	49.50%	
Race/Ethnicity		
White non-Hispanic (%)	63.92%	
Black or A-A non-Hispanic (%)	3.09%	
Asian (%)	8.25%	
Hispanic Latino/a (%)	19.59%	
Other (%)	2.06%	
Did not report (%)	3.09%	
Drinks per drinking day	5.63 (2.30)	4.83 (2.46)
Percent heavy drinking days	31.45 (15.99)	23.04 (20.35)
Percent high-intensity drinking days	10.43 (11.43)	7.50 (10.77)
Mean eBAC	0.09% (0.04%)	0.07% (0.04%)
Peak eBAC	0.23% (0.08%)	0.16% (0.09%)
Peak drinks	12.96 (5.47)	9.43 (5.04)
Mean drinks per week	21.13 (10.72)	17.05 (12.08)
Negative consequences	13.09 (9.09)	5.59 (5.88)
Percent of overall days tech was used		
Any technology		32.91% (16.21%)
Multiple technologies		16.47% (17.19%)
Smartphone breathalyzer		17.89% (11.95%)
BAC estimator		19.24% (14.79%)
Self-text was used		15.48% (15.35%)
Percent of drinking days when		
Any technology was used		68.20% (27.15%)
Multiple technologies were used		33.72% (30.22%)
Breathalyzer was used		37.89% (23.08%)
BAC estimator was used		41.21% (27.16%)
Self-text was used		30.86% (25.14%)

Note: $N = 97$; Baseline negative consequences were assessed for the past 30 days and field period negative consequences were assessed for the past 14 days; Windsorized baseline variables = mean eBAC, peak eBAC, mean weekly drinks; Windsorized field period variables = Percent heavy drinking days, percent high-intensity drinking days, mean eBAC, peak eBAC, peak drinks; While several variables were square root and log transformed for analysis, only raw, untransformed results are presented here.

Abbreviations: A-A, African-American; eBAC, estimated blood alcohol concentration.

TABLE 2

Correlations between technology use and alcohol-related outcomes.

Variable	Drinks per DD	Peak drinks	Mean drinks per week	Mean eBAC	Peak eBAC	Percent heavy DD	Percent high-intensity DD	Negative consequences
Percent of overall days used								
Any technology	0.02	0.02	**0.28****	0.04	0.01	0.19	−0.03	−0.05
Multiple technologies	0.06	0.04	0.17	0.07	0.01	0.18	−0.01	−0.07
Breathalyzer	0.09	−0.01	0.16	0.17	0.04	0.12	−0.02	−0.16
BAC estimator	0.01	0.01	0.12	−0.04	−0.07	0.06	−0.09	−0.18
Self-text	−0.01	−0.04	**0.21***	0.07	0.01	**0.22***	−0.07	0.06
Percent of drinking days used								
Any technology	−0.11	−0.14	**−0.30****	−0.08	−0.14	**−0.28****	**−0.26****	**−0.26***
Multiple technologies	−0.01	−0.04	−0.11	0.02	−0.05	−0.07	−0.13	−0.13
Breathalyzer	0.03	−0.05	**−0.21***	0.13	0.02	−0.13	−0.09	**−0.30***
BAC estimator	−0.09	−0.09	**−0.24***	−0.11	−0.14	**−0.24***	−0.20	**−0.31***
Self-text	−0.03	−0.09	−0.05	0.05	−0.05	−0.01	−0.15	0.02

Note: All variable data are from the field period.

* $p \leq 0.05$,

** $p \leq 0.01$;

Baseline negative consequences were assessed for the past 30 days and field period negative consequences were assessed for the past 14 days; Winsorized and square root transformed variables: Percent heavy drinking days, mean eBAC, peak eBAC, percent high-intensity drinking days; Winsorized and log transformed variables: peak drinks, mean drinks per week; log transformed variables: drinks per drinking day. Bolded values are to signify primary analyses that were found to be statistically significant above a p value of 0.05.

Abbreviations: DD, drinking days; eBAC, estimated blood alcohol concentration.

TABLE 3

Regression analyses of mHealth variables on alcohol use variables.

Outcome variable	**Predictor variable**	***B***	**SE, *B***	**95% CI, *B***	***B***	***p***
Mean drinks per week	Percent of overall days any technology used	**0.04**	**0.01**	**0.01, 0.07**	**0.21**	**0.005**
	Constant	−0.29	0.18	−0.65, 0.07		0.112
	Sex	0.03	0.04	−0.05, 0.11	0.06	0.480
	Baseline value	0.93	0.11	0.72, 1.13	0.68	<0.001
	Percent of overall days self-text used	0.01	0.01	−0.01, 0.04	0.09	0.239
	Constant	−0.10	0.18	−0.45, 0.25		0.570
	Sex	0.02	0.04	−0.06, 0.11	0.04	0.619
	Baseline value	0.91	0.11	0.70, 1.13	0.67	<0.001
	Percent of drinking days any technology used	**−0.002**	**0.001**	**−0.003, 0.000**	**−0.18**	**0.022**
	Constant	0.17	0.20	−0.24, 0.57		0.413
	Sex	−0.01	0.04	−0.10, 0.08	−0.02	0.850
	Baseline value	0.88	0.11	0.66, 1.10	0.64	<0.001
	Percent of drinking days breathalyzer used	−0.001	0.001	−0.003, 0.001	−0.12	0.152
	Constant	0.03	0.19	−0.35, 0.41		0.860
	Sex	0.01	0.05	−0.07, 0.10	0.03	0.747
	Baseline Value	0.90	0.11	0.67, 1.13	0.66	<0.001
	Percent of drinking days BAC estimator used	−0.001	0.001	−0.003, 0.0004	−0.12	0.143
	Constant	0.07	0.21	−0.31, 0.54		0.762
	Sex	−0.01	0.05	−0.11, 0.08	−0.02	0.784
	Baseline value	0.91	0.12	0.67, 1.16	0.66	<0.001
Percent of heavy drinking days	Percent of overall days self-text used	0.15	0.11	−0.08, 0.38	0.12	0.188
	Constant	−4.65	1.60	−7.82, −1.47		0.005
	Sex	0.004	0.38	−0.76, 0.77	0.001	0.992
	Baseline value	5.73	1.01	3.73, 7.73	0.51	<0.001
	Percent of drinking days any technology used	**−0.02**	**0.01**	**−0.03, −0.001**	**−0.19**	**0.039**
	Constant	−2.52	1.81	−6.10, 1.07		0.167
	Sex	−0.18	0.38	−0.94, 0.58	−0.04	0.639
	Baseline value	5.56	0.99	3.59, 7.52	0.49	<0.001
	Percent of drinking days BAC estimator used	−0.01	0.01	−0.03, 0.002	−0.17	0.095

Outcome variable	Predictor variable	*B*	SE, *B*	95% CI, *B*	*B*	*p*
	Constant	−3.91	1.75	−7.38, −0.44		0.028
	Sex	−0.07	0.40	−1.13, 0.55	−0.02	0.859
	Baseline value	5.91	1.02	3.87, 7.94	0.52	<0.001
Percent of high-intensity drinking days	Percent of drinking days any technology used	−0.003	0.02	−0.007, 0.001	−0.13	0.163
	Constant	0.38	0.28	−0.17, 0.93		0.176
	Sex	0.01	0.11	−0.21, 0.22	0.01	0.950
	Baseline value	0.14	0.03	0.08, 0.20	0.45	<0.001
Negative consequences	Percent of drinking days any technology used	−0.01	0.01	−0.02, 0.001	−0.18	0.077
	Constant	0.17	0.67	−1.16, 1.49		0.802
	Sex	0.29	0.26	−0.22, 0.80	0.11	0.263
	Baseline value	0.57	0.10	0.36, 0.77	0.54	<0.001
	Percent of drinking days breathalyzer used	−0.01	0.01	−0.02, 0.003	−0.15	0.068
	Constant	−0.11	0.62	−1.35, 1.13		0.857
	Sex	0.38	0.26	−0.15, 0.90	0.14	0.154
	Baseline value	0.56	0.10	0.35, 0.76	0.54	<0.001
	Percent of drinking days BAC estimator used	−0.01	0.01	−0.02, −0.0003	−0.19	0.096
	Constant	0.20	0.70	−1.21, 1.60		0.781
	Sex	0.28	0.28	−0.29, 0.84	0.11	0.327
	Baseline value	0.49	0.12	0.26, 0.72	0.48	<0.001

Note: Baseline negative consequences were assessed for the past 30 days and field period negative consequences were assessed for the past 14 days; Winsorized baseline variables = mean eBAC, peak eBAC, mean weekly drinks; Winsorized field period variables = Percent heavy drinking days, percent high-intensity drinking days, mean eBAC, peak eBAC, peak drinks. Bolded values are to signify primary analyses that were found to be statistically significant above a p value of 0.05.