

Detecting and Understanding Social Influence during Drinking Situations: A Study Protocol for Establishing Feasibility and Acceptability of a Bluetooth-based Sensor

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Detecting and Understanding Social Influence during Drinking Situations: A Study Protocol for Establishing Feasibility and Acceptability of a Bluetooth-based Sensor

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Abstract

Background: High-risk drinking among young adults frequently occurs in the presence of peers who are also drinking. Fine-grained data analytic approaches such as ecological momentary assessment (EMA) are growing in popularity for studying real-time social influence, but these studies exclusively rely on participant self-report. Passive indicators of peer presence using Bluetooth-based technology to detect real-time interactions have the potential to assist in the development of just-in-time interventions.

Objective: This paper describes the protocol for a study that seeks to examine the feasibility and acceptability of using a Bluetooth-based sensor and Smartphone application to measure social contact in real-world drinking situations.

Methods: Heavy drinking young adults (n=25) who report social drinking will be recruited to participate in a 3-week EMA study. Using a social network interview, index participants will identify and recruit up to three of their friends to carry a Bluetooth beacon. EMA will measure indices of alcohol use and characteristics of the social environment, including who is nearby and who is drinking. Feedback on the study protocol will be ascertained through weekly contact with both index and peer participants followed by a qualitative interview at study end.

Results: Feasibility will be determined by indices of eligibility, enrollment, and recruitment; acceptability will be determined by participant retention, protocol compliance, and participant-reported measures of acceptability.

Conclusions: The protocol allows us to examine the feasibility and acceptability of a Bluetooth-based sensor for detection of social contact between index participants and their friends, including social interactions during real-world drinking situations. Data from this study will inform just-in-time adaptive interventions seeking to address high-risk drinking.

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Original Manuscript

Running Head: BLUETOOTH-BASED PEER DETECTION

Detecting and Understanding Social Influence during Drinking Situations: A Study Protocol for Establishing Feasibility and Acceptability of a Bluetooth-based Sensor

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Abstract

Background: High-risk alcohol consumption among young adults frequently occurs in the presence of peers who are also drinking. A high-risk drinking situation may consist of particular social network members who have a primary association to drinking. Fine-grained approaches such as ecological momentary assessment (EMA) are growing in popularity for studying real-time social influence, but these studies exclusively rely on participant self-report. Passive indicators of peer presence using Bluetooth-based technology to detect real-time interactions have the potential to assist in the development of just-in-time interventions. **Objective:** This paper describes the protocol for a study that seeks to examine the feasibility and acceptability of using a Bluetooth-based sensor and Smartphone application to measure social contact in real-world drinking situations. **Methods:** Heavy drinking young adults (n=20) who report social drinking will be recruited from the community to participate in a 3-week EMA study. Using a social network interview, index participants will identify and recruit three of their friends to carry a Bluetooth beacon. Participants will complete a series of EMA reports on their own personal Android devices including random-reports, morning reports, and first drink reports, as well as signal-contingent reports which are triggered following the detection of a beacon carried by a peer participant. EMA will measure indices of alcohol use and characteristics of the social environment, including who is nearby and who is drinking. For items on peer proximity and peer drinking, a customized peer list will be presented to participants. Feedback on the study protocol will be ascertained through weekly contact with both index and peer participants followed by a qualitative interview at study end. **Results:** We will examine feasibility and acceptability of recruitment, enrollment of participants and peers, and retention. Feasibility will be determined by indices of eligibility, enrollment, and recruitment. Acceptability will be determined by participant enrollment and retention, protocol compliance, and participant-reported measures of acceptability. Feasibility and acceptability for peer participants will be informed by enrollment rates and latency to enrollment as well as compliance carrying the beacon

and self-reported reasons for (non-)compliance with beacon procedures. Finally, EMA data on peer proximity and peer drinking will support validity of the peer selection process. **Conclusions:** The protocol allows us to examine the feasibility and acceptability of a Bluetooth-based sensor for detection of social contact between index participants and their friends, including social interactions during real-world drinking situations. Data from this study will inform just-in-time adaptive interventions seeking to address drinking in the natural environment by providing personalized feedback about a high-risk social context and alerting an individual that they are in a potentially unsafe situation.

Keywords: Bluetooth technology; passive sensing; social influence; alcohol use; ecological momentary assessment; social network; feasibility; acceptability

Introduction

Alcohol use typically begins and escalates between 16 to 20 years of age and prevalence rates for heavy drinking and related consequences are highest among 18 to 25 year-olds compared with every other age group [1]. During this time of emerging adulthood, individuals spend approximately 10 hours per week socializing with their friends [2] and many of these interactions occur in the context of alcohol use. Young adult drinking most frequently occurs in a social context, in groups and with close friends [3–5]. Moreover, youth who drink in social settings consume more alcohol than they do when drinking alone [6,7] and report more alcohol-related consequences such as interpersonal violence, risky sexual behavior, and driving under the influence [8,9]. Thus, understanding how peers influence and interact with each other during drinking situations is of utmost importance.

Influence of Peers on Drinking

Survey research demonstrates that regular exposure to peers who value alcohol use and support heavy drinking is associated with higher adolescent alcohol use [10] and that in young adulthood the proportion of alcohol-consuming friends is concurrently and prospectively associated with an individual's drinking [11–13]. The expansion of social networks during young adulthood and the increase in proximity and salience of same-age peers [14–16] may exacerbate increases in alcohol use during this time [17].

A high-risk drinking situation may consist of particular social network members who have a primary association to drinking. Influential peers, colloquially “drinking buddies,” have many traits that are characteristic of close friends, including frequent contact, relationships of long duration, and high levels of emotional and concrete social support [18,19]. The presence of these individuals in one's social network confers additional alcohol-related risk, even after controlling for the number of drinkers in the network [20–22]. Heavy drinking could potentially be triggered by the presence of these influential peers in close proximity, indeed, the presence of influential peers could be a single

key indicator of heavy-drinking situations. Additionally, peers are a frequently cited source of alcohol [23,24] often by directly offering alcohol [25] or by pressuring others to drink [26].

Examination of Drinking Contexts Using Technology

Ecological momentary assessment (EMA) involves repeated sampling of individuals' behaviors and experiences in real time and in naturalistic settings [27]. Because data are collected in situ, findings are more generalizable to real-world, real-life experiences and processes [27]. Data also are less prone to retrospection bias [28]. Individuals are better at recalling their cognitions and behavior across a day compared with weekly or monthly retrospective reports [29]. Indeed, EMA reports show poor concordance with timeline follow-back (TLFB) assessments and EMA data have been demonstrated to both over- [30] and under-estimate [31] number of drinks relative to TLFB. EMA designs also allow for the examination of changes in a behavior over time and across contexts and permit within-person comparisons. For example, researchers can test whether there are unique differences in the social context on days that a person drinks alcohol versus on days they do not drink alcohol. EMA has been used to examine situational predictors of drinking behavior, including social context (with who?) and physical context (where?) [32–34]. However, there are two primary limitations of EMA when applying it to study peer influence. First, individuals must be actively aware of and be able to report on peer influence. Second, there is a significant bias toward recent and salient peer proximity when self-reported [35]. Because of these two significant limitations, there is value in research that relies less on self-report and more on passive assessment.

App-based ambulatory assessment of behavior is on the rise [36,37] with smartphones collecting multiple types of data from built-in sensors in real time [38]. Examples of passive sensing in alcohol research include transdermal alcohol biosensors to continuously measure alcohol consumption [39,40] and heart rate variability to study associations with stress and anxiety. [42] EMA studies in the tobacco and cannabis fields have used geographic EMA (GEMA) methods to passively capture contextual changes as individuals move through their days [43–45]. These methods

combine ecological momentary assessment (EMA) with real-time mobile geographic location tracking technology obtained through global positioning systems (GPS) and geographic information systems (GIS). A drinking report can be triggered when an individual enters a specific zone (a geofence), reducing the burden on the individual to self-initiate reports in this location. Thus, there is support for work that identifies and targets high-risk situations based on a link between a given context and substance use.

However, despite the well-established importance of peer influence on alcohol use, no extant studies have used passive assessment to understand the real-world social contexts of drinking. As a ubiquitous low-power connectivity protocol embedded in mobile phones and many other wearable sensors, Bluetooth provides a possible method to study peer contact in settings in which peers are influential. Specifically, Bluetooth-based transmitters or beacons (e.g., Apple AirTags or other transmitters including smartphones themselves) have unique addresses that can be identified by Bluetooth receivers (e.g., smartphones) and thus Bluetooth beacons carried or worn by individuals can be used with smartphone applications to assess the duration and frequency of interpersonal interactions [46]. A limited body of research has used Bluetooth sensors to study health behaviors [47,48], including COVID-19 spread [49–51], but to our knowledge passive sensor technology has not been used to investigate the social context of alcohol use.

Study Objective

The goal of this paper is to describe the protocol to evaluate the feasibility and acceptability of (1) using a social network interview (SNI) to identify influential drinking peers and (2) using a Bluetooth-based sensor for detection of contact between heavy drinkers and their peers. In a companion paper, we describe the technology that utilizes Bluetooth-based sensors to detect social contact [52]. Together, these papers summarize the procedures for a study that will develop and test the utility of a Bluetooth-based sensor to detect contact between individuals in drinking studies. Methods for evaluating feasibility and acceptability are described in Table 1.

Table 1. Project primary goals and methods for evaluating feasibility and acceptability

Goal	Definition	How Determined	Data Source
<i>Index Participant Feasibility/Acceptability</i>			
Feasibility	Proportion of screened respondents who are eligible based on inclusion criteria	Number eligible over all respondents who completed the screening survey.	Screening survey Indices of consent and enrollment
Feasibility	Proportion of screened respondents ineligible due to phone operating system	Number eligible from the screening survey except do not have an Android phone.	Screening survey Indices of consent and enrollment
Feasibility	Length of time it takes to enroll index participants	Number of months from start of recruitment to reaching desired sample size.	Indices of consent and enrollment
Feasibility	Duration between notification and survey completion	Time elapsed between when signal-contingent report notification was sent and EMA survey completion/submission.	EMA report notification and data timestamps
Acceptability	Proportion of eligible index participants who enroll in the study. Proportion of enrolled index participants who participate in the study	Number who enroll in the study over the number eligible. Number who participate in the study over number who enroll (defined as proportion of enrolled participants for whom eligible peers are identified and enrolled). Post-screening self-reported reasons for non-participation.	Screening survey Indices of consent and enrollment
Acceptability	Retention of index participants through the study protocol: defined as high retention rate at 90%	Number of index participants completing the study protocol over number enrolled.	Project tracking database Post-participation interview
Acceptability	Index participant compliance with project procedures: defined as typical completion rate of EMA reports for substance use research: 75% for signal-contingent and random reports [53]	Separate indices of number of signal-contingent and random reports completed over expected. Total number of triggered signal-contingent and random reports will be considered to evaluate the impact of participant burden on compliance.	EMA report notification and data timestamps Post-participation measure of reasons for non-compliance
Acceptability	Index participant ratings of the functionality and utility of the EMA app	High ratings on system utility measures and few reports of barriers to use.	EMA morning report of prior-day app errors Post-participation measures (adapted System Usability Scale and interview)
<i>Peer Participant Feasibility/Acceptability</i>			
Feasibility / Acceptability	Peer consent and enrollment rate	Proportion of eligible peers who consent; Proportion of peers who consent but do not enroll. Post-consent form peer self-reported reasons for non-participation.	Social network interview Indices of consent and enrollment
Acceptability of peer protocol	Peer evaluation of protocol	Initial reactions to participation request, privacy concerns, perceived impact on behavior or relationship with peer.	Post-participation peer interview
Feasibility	Length of time it takes to enroll peers following identification by participant	Average length of time to enroll first, second, and third peer.	Indices of consent and enrollment
Feasibility	Enrollment of three peer participants per index participant	Total number of eligible peers who enroll.	Indices of consent and enrollment

Feasibility / Acceptability	Peer retention	Number of peers completing the study protocol (completing the weekly surveys and end-of-study survey) divided by the number of peers enrolled in the study.	Peer participant weekly surveys Post-participation peer interview
Acceptability of beacon procedures	Compliance with beacon procedures, defined as the peer carrying the beacon with them throughout the length of the study	Self-reported noncompliance defined as the number of days and times when peer participants report not carrying the beacon. Self-reported reasons for not carrying the beacon.	Peer weekly surveys Post-participation peer interview
Feasibility of beacon procedures	Bluetooth beacon return rate	Proportion of peer participants who return their beacon.	Project beacon log
<i>Validity of the Peer Selection Process</i>			
Validity	Successful identification of influential drinking peers	Proportion of participant drinking episodes in which peers identified in the SNI were present.	Social network interview Project beacon log EMA report data
Validity	Successful selection of influential drinking peers to carry beacons	Proportion of drinking episodes a beacon-carrying peer was noted as present. Proportion of drinking episodes a beacon-carrying peer influenced participant's drinking (offering alcohol, refilling a drink).	Social network interview Project beacon log EMA report data

Methods

Design

Young adults from the community will be recruited to participate in a 3-week EMA study with three peers. At the baseline session, participants will complete a battery of self-report measures and an interview-administered social network interview (described more below) and will download a smartphone application (app). In the social network interview, participants will identify influential peers, three of whom will carry beacons. Each day during the study, index participants will report on their own drinking behavior, which of their peers are nearby, and if their peers are drinking using the smartphone app. At study end, index participants will participate in a semi-structured interview in which we will collect qualitative information, including feedback about their experiences in the study. Peers who carry sensors will complete weekly surveys and an interview at study end to collect additional information about feasibility and acceptability.

Participants

We will recruit 20 participants, anticipating that 15 will complete data collection. Participant inclusionary and exclusionary criteria include: (1) between the ages of 18 to 29, (2) a minimum of

one non-solitary drinking day per week, including one heavy drinking episode (4+ drinks for women, 5+ drinks for men) per week in the past month, (3) able to read English, (4) own an Android smartphone with an OS of 11 or newer and carry it throughout the day, (5) have a data plan (limited or unlimited); (6) are willing to approach peers to participate, (7) not in or seeking treatment for substance use, and (8) no plans to travel for an extended period of time or other significant deviations in routine.

Procedures

Eligibility and recruitment. We will recruit young adults from the community, including college and noncollege young adults. Recruitment methods include social media advertisements, flyers posted in retail establishments and on public streets, and notifications and email listservs at local universities. Advertisements describe the study, including that participants will be asked to identify peers to include, and will refer respondents to a brief Qualtrics screening survey which will establish initial eligibility; those who are eligible will be redirected to a separate survey where they will provide their contact information. Eligible individuals who decline to participate will be directed to an anonymous survey with a check-list of reasons for non-participation (e.g., do not understand the study, do not think they have friends who would be willing to participate; see Table S1).

Participant orientation and baseline assessment. A Research Assistant (RA) will schedule the 90-minute in-person baseline session at which index participants will complete the informed consent process, as well as a brief battery of self-report measures and the RA-led social network interview (SNI). The RA will assist the index participant in downloading and logging into the EMA app, and in adjusting phone settings and permissions. The RA will also demonstrate the EMA reports.

Participants will complete four types of EMA reports on their own personal Android devices via the PiLR platform application developed by MEI Research. *Signal-contingent* reports are triggered by the app following its detection of a beacon carried by a peer participant when a peer

comes within approximately 15 feet of the index participant for at least 15 minutes. *Random* reports are intended to sample experiences throughout the day; index participants will receive 3 random reports per day between 12PM and 12AM (distributed across 3 blocks of time: 12PM-6PM, 6PM-9PM, 9PM-12PM). *Signal-contingent* and *random* reports will have identical notifications in the app and will assess identical information so participants cannot differentiate between the two; both reports will assess alcohol use as well as the presence and drinking of peers identified in the SNI. Participants will be instructed to complete these reports in response to notifications as soon as possible. *Morning* reports will be completed by participants every day, with the app providing a reminder at 10:00am. These reports will ask the participant about the previous day with items similar to random and signal-contingent reports (i.e., measuring who of their peers they have spent time with and whether they have consumed alcohol). *Drinking event-contingent* reports will be initiated by participants when they start their first drink. Over the course of the study, study personnel will contact participants several times a week via text and as needed to check progress, encourage compliance, and address technical issues. Additionally, research assistants will schedule weekly phone calls with participants to ensure any issues and questions are addressed. We will ask participants to keep their phone on and charged and not to change phone settings for the duration of the study and will encourage the use of phone pins or passwords.

After the 3-week EMA assessment is completed, we will conduct a 60-minute end-of-study qualitative phone interview with index participants to determine their reactions to participating in the study, any hesitation about participating, and their opinions on the EMA assessment, the Bluetooth beacon technology, and the peer selection process; participants will also complete several end-of-study survey measures about their experience (see Table S1). We will assess whether index participants changed any of their behaviors or interactions with others due to their participation in the study. Research staff will review information about peer presence reported during the 3-week period with the participant. Index participants will be instructed how to delete the app from their phone at

study end and their login to the app will expire on their last day of data collection.

Measures and Peer Selection

Baseline survey. A web-based survey will assess socio-demographics including sex, gender, age, racial and ethnic groups, living arrangement, and college/employment status. *Alcohol consumption* will be measured using a series of items adapted from NIAAA [54] including past-year and past-month frequency of alcohol use and heavy alcohol use; typical quantity of use; maximum number of drinks; frequency intoxicated, and age of first use. *Alcohol consequences* and alcohol problems will be assessed using the BYAACQ (Brief Young Adult Alcohol Consequences Questionnaire [55,56]; BYAACQ) and AUDIT [57], respectively. A measure of *physical context*, stratified by time of day (day/evening/late at night), will assess drinking across the various locations (all that apply) with options such as your home (house/apartment/dorm/residence hall); friend's place; restaurant; bar, nightclub, pub. A measure of *social context* (who do you drink with) will assess frequency (0=*never/almost never* to 4=*almost always/always*) that the participant spends time (1) together without drinking; (2) together drinking; (3) together getting drunk; (4) as a "drinking buddy" across various persons such as roommates/housemates, romantic partner/boyfriend/girlfriend; classmates/co-workers. Frequency of *obtaining alcohol from various sources* will be assessed (0=*never* to 2=*frequently*); with options such as buy it at a store; available at a party; someone gives it to me. Social norms will include *descriptive norms* (number of close friends and same-age peers who drink alcohol and get drunk monthly) and *injunctive norms* (perceived approval of drinking by a close friend and same-age peer) [58]. A 20-item measure of *drinking motives* assesses reasons for drinking alcohol related to coping, conformity, enhancement, and social reasons (0=*never/almost never* to 4=*almost always/always*) [59]. *Other substance use* (tobacco, Juul/vaping, marijuana, illicit drugs) will be assessed. We will collect measures of *impulsivity* (18-item measure of sensation seeking [60,61]) and *drinker identity* such as "Drinking is part of my self-image" (Alcohol Self-Concept Scale, ASCS [62]).

Social network interview (SNI). The SNI entails asking the index participant to name up to six people their age who are important to them. These people may be friends, family members, or anyone who they regularly spend time with in person [63,64]. Age, gender, and residence (e.g., do you live together) of network members will be collected, as well as relationship type (e.g., family, friend) and frequency of meaningful social interaction (“How often in a typical month do you spend at least 15 consecutive minutes with this person?”). In addition, we will assess the alcohol use of the peer including: (1) frequency of drinking (“How many times in the past month do you think this person drank alcohol?”) and (2) frequency of drinking with the peer (“In the past month, how often did you drink with this person [while both of you were drinking]?”). Lastly, using a yes/no format, we will assess whether participants think the network member would be interested in carrying the beacon for the research study.

Peer selection. During the baseline session, following the completion of the SNI, the RA will work with the index participants to identify 3 peers to ask to carry the beacon. The three inclusionary criteria for peers to carry the beacons are: (1) between the ages of 18-29; (2) frequency of meaningful in-person social interaction at least once a week in a typical week; and (3) drinking with the peer at least twice a month in a typical month. At the baseline session, with the assistance of the RA, the index participant will try to contact each of their selected peers via text, a phone call, or video chat. If during the session, the index participant is able to contact the peer and the peer is interested in learning more about the study, the index participant will then provide the contact information of the peer to the RA and then the RA will send the peer an authenticated Qualtrics link. The Qualtrics link will contain an explanation of the study and informed consent. If the peer does not respond to the index participant during the baseline session, the participant will send the peer a brief study description with the Qualtrics link. Peers who do not provide consent will be asked to complete a check-list indicating reasons for declining to participate which immediately follows the consent form (e.g., not enough time, do not trust that the research won’t be tracking them; see Table S1).

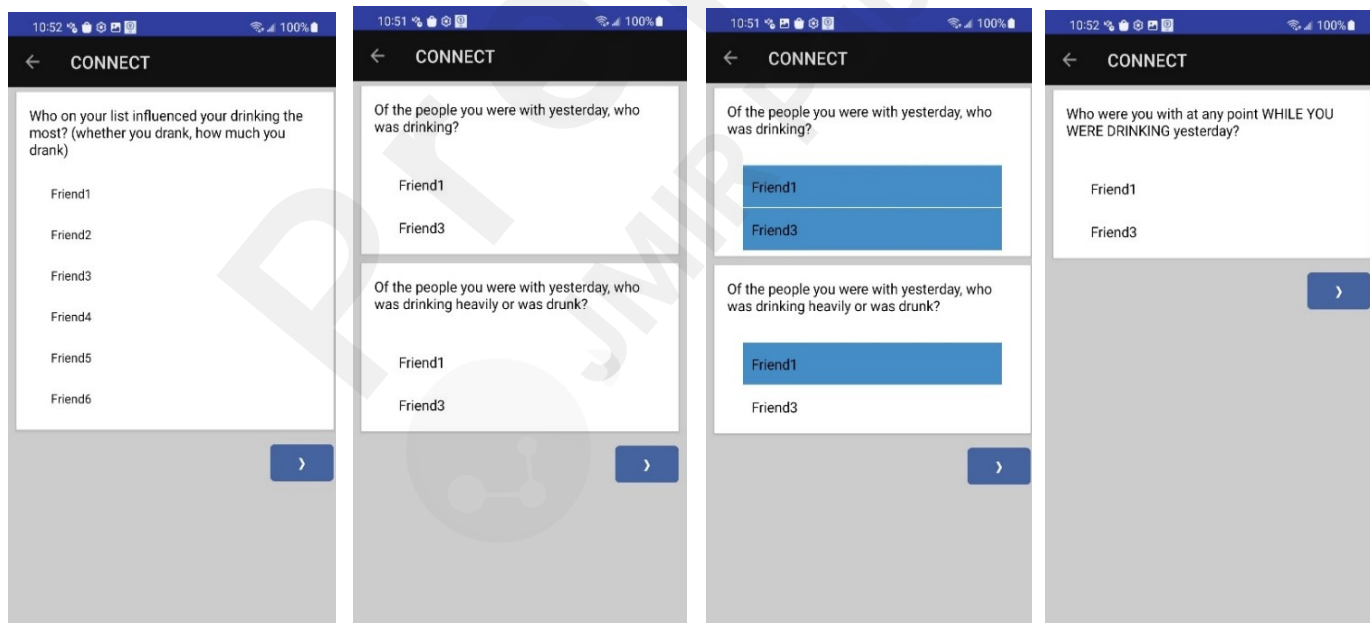
Index participants will be given 5 days to recruit a maximum of 3 peers to carry the beacons; participants who are unable to *identify* influential peers or are unwilling to contact peers in the orientation session will be withdrawn from the study. Index participants who are unable to *recruit* at least one peer to participate will not complete the EMA portion but will complete the end-of-study interview, as it collects information on the recruitment and peer selection process. If any peer who has been contacted has not responded to the participant in 3 days, we will inform the participant to contact the next peer on their SNI list. The end goal is to have 3 peers carry the beacon, but we expect that we will contact more than 3 peers for some participants. To maintain confidentiality, index participants will not be directly told by the project staff which of their friends participated in the study. Peers who have declined to carry the beacon or were not asked to participate will still be listed as a peer in the EMA reports. Although we will not explicitly tell the index participant that they may participate in the full study with fewer than three peers, if we are unable to identify three peers or the peers are non-responsive to the research team, at that point we will inform them that they only need one peer to consent to participate in order to participate in the full study.

Once the set of SNI-identified peer participants have provided consent, each peer will be contacted by the project staff to arrange a time to receive the beacon and ask any questions. Each beacon is assigned a unique ID which associates the beacon with the index participant and the peer. Peer names and unique beacon IDs will be uploaded into the EMA software so that a customized list (maximum of 6 names) is presented to each participant for all EMA reports (asking whether any of their friends are nearby) and so signal-contingent reports triggered by beacon detection can be associated with the correct peer. Peers on the list presented to the index participant may be carrying the beacon, or they may have declined to carry the beacon or not have been asked. Updating this list can occur in real-time without involving the participant to avoid protocol disruptions.

The EMA reports will begin for index participants once the beacons are distributed to peers or within 5 days, whichever comes first. Because up to three peers can be given a beacon, three

signal-contingent reports could be triggered at a time (e.g., if peers who were given a beacon all come into contact with the participant at the same time), although we do not anticipate that this will occur regularly. At the end of each week of data collection, peer participants will complete a brief web survey and at the end of the study they will complete a phone interview and return the beacon.

EMA report measures. A copy of EMA measures is included in Table S1. The random and signal-contingent reports appear identical on the EMA application to minimize unintentional awareness of peer presence. These reports assess peer presence, participant drinking, and peer drinking and influence. *Index participant drinking* is measured with questions about the number of drinks consumed, the time drinking started and stopped, and level of perceived intoxication (“How intoxicated do you feel?”). Peer-related assessments begin with a stem item measuring *peer proximity*: “In the past hour, who have you been around for any length of time?” The list of (up to) six most influential friends as determined in the SNI is presented to the index participant and they can select the names of their friends. Subsequent questions present a revised list of friends according



to which friends were selected; see Figure 1 for screenshots of sample survey flow. We will assess whether the index participant was within 15 feet of the peer for at least 15 minutes and whether they interacted with the peer in-person for at least 15 minutes. *Peer drinking and heavy drinking/drunkenness* are measured with two items: “Of the people you were with in the past hour

while you were drinking, who was also drinking?” and “Of the people you were with in the past hour, who was drinking heavily or was drunk?” *Direct and indirect peer influence* on participant drinking is measured with questions about drink offers: “In the past hour, has anyone offered you a drink?” suggestions to drink: “In the past hour, has anyone suggested that you should drink?” and provision of alcohol to drinkers: “In the past hour, did anyone refill your drink or get you a new drink?” Following affirmative answers, these three questions are followed by determinations of whether the individuals selected were friends on the index participant peer list; if on the peer list, the names of the peers indicated as present are shown.

Figure 1. Survey flow

The morning report is identical to the signal-contingent and random reports but refers to “Yesterday” whereas the signal-contingent and random reports refer to “In the past hour.” Morning reports also assess total number of drinks on the prior day and drinking start-time and end-time. In addition, the morning report includes items measuring non-compliance and the phone’s operational state as indicators of participant acceptability (Table 1) and possible reasons for missingness that could inform missing data analysis [65], including options such as silenced your phone; turned off Bluetooth detection; phone battery died; phone on battery/power saver mode (see Table S1 for full set of responses). We will also ask participants if they did not complete a prior-day report because of their drinking, with response options of No; Yes, because I missed a notification; Yes, because I chose not to respond to a notification.

The first-drink report focuses specifically on alcohol involvement, including any drinking, heavy drinking, and drunkenness of peers. Again, we will query about people on and not on the peer list for specific actions, including offers of drinks. We focus on the first drink because it is an index event that participants can identify and quickly answer questions about. We will not require additional momentary reports about that drinking event given that this information (including who

was there at any time) is reported in the next day morning report and we are cognizant of participant burden.

Peer weekly surveys. Peer participants will receive a link to a brief web-based survey at the end of each week. Peers will indicate day(s) and time of day (day, evening, late night) in the prior week they did not have their beacon with them, times in the prior week they spent time with their friend and drank with their friend, and whether they had difficulty finding a place to keep the beacon or any problems carrying the beacon with them.

Post-participation assessments. As part of our evaluation of acceptability, post-study semi-structured interviews will be conducted with index participants as well as with peer participants. For index participants, we will solicit feedback about the peer recruitment process and the study protocol, including the frequency and timing of the EMA reports. Specifically, these interviews will ask participants about (1) identifying and inviting peers to participate, (2) using the app for answering EMA reports, and (3) appropriateness of contact from researchers and compensation for participating. Questions will also pertain to the usefulness of the technology from the participant's perspective, including applications of the peer proximity technology to risky contexts (e.g., heavy drinking situations), and the usefulness of this technology for safety concerns in the context of heavy drinking. In addition, index participants will complete a modified 15-item System Usability Scale (SUS) [66] with items adapted to our protocol that assess acceptability (e.g., I didn't like that I had to change settings on my phone to use the app). SUS response options range on a 5-point Likert scale from Strongly Agree (1) to Strongly Disagree (5).

For peer participants, we will collect initial reactions to being asked to participate (reasons, concerns about participating), privacy concerns, adequacy of compensation, and perceived impact on behavior or relationship with the friend. We will also receive feedback about the beacon, including ease of carrying the beacon with them every day and if they would prefer to download an app in lieu of carrying the beacon. See Table S1 for full set of post-participation and peer measures.

Ethical Considerations

Human subjects protections. Procedures were approved by the Brown University Institutional Review Board (Protocol Number 2022003448).

Informed consent. Index participants and peer participants will complete informed consent, which includes reviewing detailed consent forms, discussion with the researcher, and documentation of consent.

Privacy and confidentiality. All information obtained during assessments will be confidential and used solely for research purposes. To protect data and prevent unauthorized access, all EMA data will be encrypted and will remain so until they are accessed by the project staff using a username and password specific to this project. All files with participant identifying information will be password protected and stored separately from data on a server accessed only by project staff. To preserve confidentiality, we will de-identify data for both index and peer participants using a numeric code. Participants will have researcher provided credentials for the smartphone app that will not include their names and we will encourage participants to use phone passwords.

Design considerations to maximize confidentiality. As the current protocol involves the passive assessment of social contexts and reporting on the behaviors of proximal others, considerable care was taken during the design phase to maximize confidentiality and increase participant comfort with responding. First, index participant reports inherently identify peers by presenting their names during daily reports. To preserve confidentiality, peer names are replaced by ID numbers in analytic datasets and are thus unavailable for reidentification. Second, index participant discomfort associated with reporting on peer behavior will be minimized by ensuring that index participants understand that the smartphone app only records when it is within range of the beacon, and no other information about their friend is recorded. We will protect peers against coercion by identifying eligible peers in the SNI but recruiting these peers without requiring the presence of the index participant. To further reduce coercion, the participation of peers will not be disclosed to index participants unless the peer

participant discloses this information themselves. It is possible that participants will figure out which of their friends participate in the study or will even encourage their friends to participate. We will also inform the peer participants that we will never share information about them or their weekly survey and interview responses with the index participant. To protect against peer discomfort about their friend's smartphone app detecting their presence, we will clarify that no passively-assessed information (e.g., geolocation) other than peer presence is recorded.

Compensation. Index participants will be paid \$50 for attending the baseline session, \$5 per day for answering the EMA reports, a weekly \$20 bonus if they complete 80% of the random and signal-contingent reports, and \$40 for attending the exit interview. The most they can receive for participation is \$255 (compensation for peer participants is described below, following the section on peer selection). Peer participants will be compensated \$30 for each week they complete the weekly survey/interview, and \$10 for returning the beacon to the research team, so the most peer participants can receive is \$100.

Results

Please refer to Table 1 for a list of project goals, how these goals are defined, the metric by which those definitions are evaluated, and the data source for each goal.

Analytic plan: Feasibility and acceptability of recruitment, enrollment of participants and peers, compliance, and retention. The *feasibility* of recruiting index participants will be determined by three indices: (1) proportion of people who meet inclusionary criteria among those who complete the screening survey; (2) proportion of screened respondents ineligible due to phone operating system (e.g., iOS instead of Android), and (3) length of time it takes to reach the desired sample size. *Feasibility* complying with the protocol is determined by time elapsed between receiving a signal-contingent report notification and EMA survey completion/submission. *Acceptability* of the procedures for index participants will be determined by four indices: (1) proportion of eligible individuals who enroll and participate in the study after reading a written

explanation of the study; we will also calculate post-screening self-reported mean ratings of reasons for nonparticipation and inspect each item as a measure of (poor) acceptability; (2) number of index participants completing the full study protocol compared to the number of index participants enrolled in the study; (3) proportion of completed reports over the total number of possible reports (morning and random reports only) and number of expected reports based on the project beacon log (signal-contingent reports only); latency (in minutes) between triggering and completing a given report, calculated separately for randomly- and signal-contingent reports (we will also examine whether compliance systematically varies as a function of timing and number of reports within a day); and (4) mean ratings on system utility measures and barriers to use, including ratings on the functionality and utility of the EMA app.

We will explore *feasibility* and *acceptability* of recruitment and retention for peers. Feasibility will be determined by three indices: (1) of the total number of peers who are asked to carry the beacon, the number who provide consent, and the number who enroll, calculated across the full sample; (2) length of time it takes to recruit the first, second, and third peer by calculating the duration of time between participant baseline and peer consent; and (3) whether three peer participants are successfully enrolled for each index participant. We will also informally explore best practices for enrolling peers with respect to timing (amount of time to make contact) and method to make contact (e.g., text, call, face-to-face). Feasibility of retaining peers will be determined by the number of enrolled peers completing the study protocol (weekly surveys and end-of-study survey) by the number of peers enrolled in the study. Mean ratings of peer reasons for nonparticipation will likewise be calculated and each item inspected.

The *feasibility* and *acceptability* of beacon procedures for peers will be determined by two indices: (1) number of days and times the peer carried the beacon with them and (2) proportion of distributed beacons that are returned to study staff. Mean ratings of reasons for non-compliance with beacon procedures will be also be calculated and each item inspected.

Analytic plan: Validity of the peer selection process. We will use three indications of whether (up to six) influential peers were selected in the SNI and whether (up to three) influential peers were selected to carry Bluetooth beacons, supporting the *validity* of our protocol. First, data from all EMA reports will be used to calculate the proportion of drinking episodes reported by the participant in which they reported one or more of their listed peers were present. Second, we will calculate the proportion of drinking episodes in which the participant indicated that present peers were also drinking. Third, when a participant indicates that someone (a) offered them a drink, (b) suggested they drink, (c) refilled their drink, or (d) influenced their drinking, the proportion of these peers that were on the participants peer list (vs. not) will be computed. Since these latter experiences could show low rates in some participants, we will combine them.

Attrition, nonresponse, and missing data. We will investigate person-level correlates of attrition for both index and peer participants by comparing the proportions of participants completing each week of the study (i.e., days 7, 14, and 21) across baseline demographic and behavioral factors. We expect compliance with the study protocol to be consistent with current estimates ~75% (see Jones and colleagues for a meta-analytic review across substance use studies using EMA designs [53]). Time-varying predictors of nonresponse will be examined within a conceptual framework that considers the impact of participant characteristics, protocol burden (e.g., number of notifications received), and situational factors (e.g., context and behavior [67]). We will regress attrition or missingness onto these variables at their appropriate level of analysis and use identified predictors of systematic missingness to inform future analyses in order to help maintain the missing at random assumption.

Power. Although our sample size of $n=20$ is similar to other pilot work using ecological momentary assessment (EMA) [68,69] and power to detect moderate-size Level 1 effects exceeds .80 (conservatively assuming 70% missingness and a binary grouping variable with an even split) we are likely underpowered for formal tests of moderation [70]. Instead, we will descriptively explore

differences in SNI member presence in drinking events across sex (across all SNI members) and peer consent (across SNI members selected to carry beacons) by running stratified analyses.

Data analysis and dissemination. Data management and analysis will be conducted when all data have been collected (anticipated Winter 2024), and manuscripts will be submitted thereafter.

Discussion

In this paper we describe a protocol that advances the literature by leveraging a newly developed Bluetooth-based detection system to understand influential social contact during real-time drinking situations. Understanding how young adults engage with and feel about this technology is important for determining if just-in-time interventions using Bluetooth-based sensing can be implemented. Furthermore, evaluating if the peers who are most influential on an individual's drinking behavior can be identified and are willing and compliant in carrying a Bluetooth beacon is necessary in evaluating the feasibility of this protocol to identify situations where the index individual is most at-risk.

Study Implications

Most interventions aimed at reducing youth drinking are delivered distal in time to actual drinking events. Unfortunately, programs that neglect the social-ecological context in which risky behaviors occur may have limited effectiveness, in part due to constraints on an individual's ability to make sound decisions in a highly charged, typically social, context [71,72]. However, in recent years, there have been targeted efforts to reduce drinking in the natural environment, at a time when behavior is opportune for modification [73–77]. In just-in-time interventions, also referred to as Ecological Momentary Interventions (EMIs), individuals receive intervention components at specific moments throughout the day to increase health promoting behaviors and reduce risky behavior [78–80]. However, although studies have identified effective just-in-time content across domains of health behavior [78], less is known about the appropriate timing or context in which to intervene.

Beckjord and Shiffman [81] have recommended using a combination of EMA and EMI

where the delivery of real-time intervention is predicated on user-reported contextual data and/or passively recorded data to coincide with high-risk events. Some of the challenges with using self-reported EMA data as the antecedent for just-in-time intervention include the risk for systematic user non-compliance with EMA during high-risk events (e.g., not reporting drinking events) and the need for burdensome EMA algorithm development, high utilization of devices (e.g., geolocation leading to battery drain), and considerable monitoring by researchers which may limit dissemination and impact [81]. Making just-in-time intervention content contingent on passive sensing overcomes many of these barriers and could facilitate timely delivery of intervention content that is less reliant on user interaction. Future interventions could incorporate Bluetooth-based sensor technology to help individuals who are trying to reduce their alcohol use. This technology could notify an individual on a smartphone or smartwatch that they need to be mindful of their alcohol intake. For example, personalized feedback could be provided when a “risky” peer is nearby and could alert the individual that they are in an unsafe situation, similar to smartwatch vibrations after a period of inactivity [82], or tailored messaging that are provided based on geolocation) [83]; indeed, our passive sensing approach could intersect well with GEMA in identifying influential high-risk social contexts (peers) and high-risk physical contexts (locations). A friend or accountable individual could also be alerted that the participant is in a risky situation.

Challenges and Limitations

There are several limitations in our protocol related to index participant behavior. It is possible that our use of a 15-minute criterion for a meaningful interaction will be inaccurate, resulting in (for example) us not detecting an influential encounter between a participant and a peer that is too brief to trigger a report. The decision to trigger signal-contingent reports after 15-minute interactions was based on a tradeoff between sensitivity and burden. While meaningful social interactions shorter than 15 minutes that influence drinking may occur, triggering signal-contingent reports after shorter durations would yield more triggered reports, leading to potential disengagement

(longer latency between trigger and completion of report) and/or non-compliance with the study protocol [53]. Although we plan to examine the relationship between burden and compliance in the current protocol, future research should systematically examine these tradeoffs. We query both current behavior in the past 15 minutes and past-hour behavior in an attempt to accommodate delayed compliance.

Another potential limitation related to index participant behavior that is inherent to all substance use research using ambulatory methods is the possibility that non-compliance is associated with use of the substance itself. Participants may miss notifications when they are highly intoxicated [84]. Thus, we might expect alcohol use at the survey or day level to be associated with nonresponse. We will assess this potential source of missing self-report data by examining the relationship between compliance with triggered or random reports and past-day drinking as reported in the morning report and self-reported reasons for missing a prior-day report as reported in the morning report. Intoxicated participants also may not recognize or record that a friend was present or influenced their drinking (e.g., by offering alcohol or refilling a drink) resulting in underreporting of important peer interactions. Further, there may be systematic non-compliance that is related to drinking context (e.g., lower response rates when drinking in social situations such as loud parties or bars); this too can be explored using self-reported EMA data. However, one strength of this protocol is the capability to *passively* detect interactions with proximal peers without the need for self-report.

Technological limitations precluded suspension of random reports after a signal-contingent report is triggered or vice versa. Thus, it is possible for both random and signal-contingent reports to be triggered around the same time, resulting in the index participant being notified to complete multiple identical reports. We expect this will happen infrequently. Although triggering of multiple signal-contingent reports may increase participant burden and increase the likelihood of nonresponse to a survey, detection of these unique social interactions by the smartphone app and completion of these reports will provide increased resolution of index participants' social contexts and is critical to

validate the overall protocol.

Next Steps

This proof-of-concept study supports a long-term line of etiological research characterizing the real-time social context of hazardous drinking, in turn informing the timing and context of mobile-delivered interventions to reduce hazardous alcohol use in young adults. Feasibility, acceptability, and initial substantive data will inform a large-scale study with a wider age span and broader representation of social context, permitting the study of multiple dynamic determinants of drinking behavior including social and physical context, craving, affect, and motivation [85]. Passive peer detection can be used with other passive technology such as GPS (geolocation) for identification of localized risk, accelerometers for gait sensing, and ambient noise recording to evaluate the situational risk associated with social interactions. It also can be integrated with alcohol biosensors or other more objective measures of intoxication (e.g., balance and gait assessed passively by the smartphone) to fill in gaps in reporting related to non-compliance or under-reporting of alcohol use.

This protocol involves carrying Bluetooth beacons and requires Android OS smartphones, but future research should explore the possibility for peers to download an app instead (which utilize the phone's Bluetooth to transmit a unique signal similar to the beacon), and to use Apple phones, although this approach may be technologically limited by host operating systems that restrict development of features that duplicate extant commercially-available products (e.g., iOS and AirTags). Finally, although the proposed study targets peers associated with increased risk for alcohol use, future studies could also consider peers who are protective against heavy drinking. It is our hope that this proof-of-concept study stimulates future work that leverages passive technology to understand the social nature of young adult drinking and ultimately reduce alcohol-related harms.

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Data Availability. Data sharing is not applicable to this article as no data sets were generated or analyzed for this protocol. Once data are generated, data sets will be available from the corresponding author on reasonable request.

Conflicts of Interest.

None declared.

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Supplementary Files

Related publication(s) - for reviewers eyes onlies

The submitted paper is a companion paper to: Barnett, N. P., Sokolovsky, A. W., Meisel, M. K., Forkus, S. R., & Jackson, K. M. Detection of peer proximity: Protocol for evaluating functionality and validity of a Bluetooth-based smartphone application. JMIR Protocols. Both papers were developed within the same NIH-funded research program, but a single manuscript would be too complicated to present both protocols. We respectfully request that these two papers be handled by the same field editor to ensure that they are tracked in tandem in the hope that they might eventually receive favorable reviews and be published in the same issue.

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