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Exploring the Use of Smartphone Geofencing to Study Characteristics of Alcohol Drinking Locations in High-Risk Gay and Bisexual Men

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Abstract

Background: Geofencing offers new opportunities to study how specific environments affect alcohol use and related behavior. In this study, we examined the feasibility of using geofencing to examine social/environmental factors related to alcohol use and sexual perceptions in a sample of gay and bisexual men (GBM) who engage in heavy drinking and high-risk sex.

Methods: HIV-negative GBM ($N=76$) completed ecological momentary assessments for 30 days via a smartphone application, and were prompted to complete surveys when inside general geofences set around popular bars and clubs. A subset ($N=45$) were also asked to complete surveys when inside personal geofences, which participants set themselves by identifying locations where they typically drank heavily.

Results: Approximately 49% of participants received a survey prompted by a general geofence. Among those who identified at least one personal drinking location, 62.2% received a personal geofence-prompted survey. Of the 175 total location-based surveys, 40.2% occurred when participants were not at the location that was intended to be captured. Participants reported being most able to openly express themselves at gay bars/clubs and private residences, but these locations were also more “sexualized” than general bars/clubs. Participants did not drink more heavily at gay bars/clubs, but did when in locations with more intoxicated patrons or guests.

Conclusions: Geofencing has the potential to improve the validity of studies exploring environmental influences on drinking. However, the high number of “false positive” prompts we observed suggests that geofences should be used carefully until improvements in precision are more widely available.

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Conflicts of Interest

The authors have no conflicts of interest to report.

Keywords

Alcohol use; gay and bisexual men; context; location; ecology; geospatial data; ecological momentary assessment

Introduction

Heavy alcohol use among gay and bisexual men (GBM) in the United States is a key public health concern (Patterson et al., 2009, Cochran and Cauce, 2006), with up to 23% of GBM reporting binge drinking in the last six months, and 12% showing signs of problematic drinking (Stall et al., 2001, Mustanski et al., 2007). Heavy drinking contributes to considerable morbidity and mortality among GBM, as it does in other populations (Gustafson et al., 2014, Uthman, 2016). However, it is particularly unsafe for GBM, given that heavy drinking is a key risk factor for HIV infection in this population (Koblin et al., 2006, Sander et al., 2013).

Alcohol use often occurs in social or public environments (e.g., parties, bars), and past research suggests that several characteristics of these locations may increase the risk for heavier drinking. For example, several studies have shown that being around friends, being around a number of other people who are intoxicated, and playing drinking games were all associated with drinking heavily (i.e., for men, having 5 drinks or more) at an event (Labhart et al., 2013, Clapp et al., 2006). Others suggest that GBM who frequent gay bars may tend to drink more heavily than those who do not (Wong et al., 2008, Greenwood et al., 2001). However, aside from one field study (Clapp et al., 2008), much of this research has relied on participants' retrospective recall of previous drinking.

Since becoming a standard feature of newer mobile phones approximately ten years ago (GPS World Staff, 2009), the Global Positioning Systems (GPS) has achieved near complete penetration of modern smartphones, which over 77% of Americans now own (Pew Research Center, 2017). These integrated GPS capabilities have afforded new opportunities to study how being at or near specific drinking locations might affect alcohol and other substance use (Andreev et al., 2014, Bertz et al., 2018). For example, by continuously monitoring participants' exact physical locations, researchers have been able to pair GPS data with other publicly-available data (e.g., addresses of liquor stores, bars) to explore whether drinking behavior is affected by one's proximity to places where alcohol is sold or consumed (e.g., bars, liquor stores, supermarkets), or "alcohol outlets." One such study showed that adolescents who drank spent about 1.5–2 times more time within a city block (≈ 100 m) of alcohol outlets, compared to adolescents who did not drink (Byrnes et al., 2015). Despite the growing accessibility of GPS, the literature in this area consists mainly of pilot and feasibility studies and with few focusing on alcohol use (Duncan et al., 2016, Mitchell et al., 2014, Theall et al., 2018).

Geofencing could offer new opportunities to study how specific environments affect drinking behavior, without the need to analyze complex GPS data. Geofencing essentially involves creating virtual boundaries around GPS coordinates in order to detect a user's presence in a specific area of interest (Andreev et al., 2014, Cardone et al., 2014). These

boundaries can be set by researchers based on the known characteristics of locations (e.g., that a given location is a bar or club), and can also be set by users who identify specific locations (e.g., places in which they often drink). Once these boundaries are specified, researchers can trigger any smartphone action based on when the user enters, exits, or dwells inside the boundary for a certain amount of time. Like GPS studies, only a few studies on health behaviors using geofencing are available, and nearly all have used this tool to intervene in some way (Pramana et al., 2018, Nguyen et al., 2017). For example, an app called Q-Sense automatically creates personalized geofences for users around locations at which they have previously reported smoking, and after their goal ‘quit date’, provides push notifications with encouraging messages when inside a geofence of 100m around those locations (Naughton et al., 2016). Although these studies illustrate that geofencing tools already have intuitive value for digital interventions, using these tools in basic research to study behavior can help refine geofencing approaches used in intervention programs and may help study environmental factors that characterize locations in which heavy drinking occurs.

In this study, we conducted a 30-day Ecological Momentary Assessment (EMA) procedure with heavy drinking GBM who were at high-risk for HIV and were living in the metro areas of Providence, Rhode Island and Boston, Massachusetts. Participants in the study completed daily diary surveys at 9 a.m. each day. For one wave of participants ($N=76$), several popular general and gay-oriented bars were geofenced in the downtown area of each metro, and participants were prompted to complete surveys assessing social/environmental aspects of these locations when inside these geofences. In a subsequent wave ($N=45$), participants were also asked to identify up to five places where they were likely to “drink more than is typical” for them, which were then used to create a geofence. Participants were prompted to complete the same location survey when inside these geofences. In this manuscript, we (1) report data addressing the feasibility and acceptability of each of these approaches, (2) report summary statistics of the characteristics of these locations, and (3) explore whether specific social/environmental characteristics are associated with drinking more heavily that day.

Methods

Seventy-six participants were recruited from gay-oriented smartphone dating applications (e.g., Grindr, Scruff, Hornet), general social media sites (e.g., Facebook, Instagram), and in-person outreach (e.g., flyers). Eligible participants were: (1) 18+ years old, (2) assigned male sex at birth, (3) HIV-negative or unknown status, (4) not currently prescribed or taking PrEP, (5) able to speak/read English fluently, and (5) reported having had condomless anal sex (CAS) with a non-exclusive partner at least once in the past 30 days. As this study focused primarily on alcohol use, those eligible were also (6) “hazardous drinkers,” defined by NIAAA as consuming an average of 14+ drinks per week or five or more drinks on a single occasion at least once in the past month. Advertisements sought gay and bisexual men for a research study, but did not mention anything about alcohol use.

Procedures

After screening online, participants first completed an in-person or videocall orientation session to review study procedures, obtain informed consent, and guide participants through downloading the *MetricWire* app (<https://www.metricwire.com/>) onto their personal smartphones. Staff then provided thorough training on the software's features and walked participants through a typical day in the study, demonstrating how to initiate various types of assessments and explaining the meaning of each of the items involved. Participants were instructed to complete two types of assessments on their personal smartphones over a 30 day period: (1) A self-initiated, daily diary assessment, to be completed upon waking up each morning, and (2) a location-based survey assessing various characteristics of participants' current drinking locations.

We also established two types of geofences, which were both used to prompt participants to complete the location-based survey. The first created boundaries around several popular general and gay-oriented bars and clubs in the downtown areas of Providence, RI and Boston, MA (see Figure 1 for a map of some locations in Providence, RI). These geofences were not unique to each participant and would prompt surveys when any participant entered that location. We selected 15 of the most popular bars in each of these metro areas based on the knowledge of local staff and internet ratings. These geofences were active for all participants analyzed in this manuscript ($N = 76$), but no participants were told which bars/clubs had been geofenced. After observing that participants visited these general locations much more rarely than expected, however, we began asking participants to also identify several personal drinking locations during their baseline assessments ($N = 45$). Participants were asked to mark up to five locations where they were likely to "drink more than [was] typical for [them] or where [they] often end up more intoxicated than usual" on a map of the area (shown using Google Maps). They indicated these locations by either pressing/clicking on that location on the map or entering a street address. Given the sensitivity of this task (and to better gauge the acceptability of this request), participants were explicitly informed that they could opt-out of this procedure. Participants were not informed that these personal geofences would earn them additional compensation. If willing to identify personal drinking locations, participants did so before being informed of the compensation schedule. For both general and personal locations, circular geofences with radii of 10–30m were established, and a push notification prompting participants to complete the location survey was triggered after a dwell time of 350 seconds.

Study payments were determined based on response rates. Participants earned \$2 for each morning assessment, plus a "bonus" of \$10 for every 10 day period in which all assessments were completed. Participants were also paid a \$30 bonus for completing at least one of the geofenced location-based surveys. As such, participants could earn a total of \$230 over the course of the study.

Measures

Daily diary data.—Participants completed daily diary surveys each day over the 30-day study period, and these surveys were used to assess *alcohol use* the previous day. Participants reported the number of *standard drinks* the previous 24h (12 oz. beer, 5 oz.

wine, 1 oz. liquor, graphic key provided), the number of hours over which they drank, and their peak level of intoxication on a 0 (*not at all*) to 4 (*extremely*) scale.

Location-based surveys.—Location-based surveys assessed whether participants were currently drinking, categorical location type (e.g., bar, club, house party, friend’s house, restaurant, etc.), and if they were at a bar, whether this bar was considered a “gay bar.” They also asked about who they were with (e.g., friends, acquaintances, work colleagues, etc.), their perceptions about how intoxicated other people at this location, the other people they were with, and participants themselves were, how sexualized the environment was, and their perceptions of the percentage of other men that they believed were hoping to “hook up” at that location.

Analysis plan

We first calculated summary and descriptive data for the location-based surveys, including average number of surveys participants received of each type (e.g., general, personal) and the number of false alarms our geofencing approach resulted in. We also calculated summary data for variables collected in location-based surveys and compared each across location type. Finally, we matched location survey responses to drinking data collected from daily diary surveys, and then estimated random-effects mixed models to explore whether certain environmental/social characteristics were associated with alcohol use level and perceived intoxication that same night. We specified a Poisson model since the alcohol use variable reflected a count of standard drinks, and a linear model for intoxication ratings. Although we initially included individual-level covariates for age and education in these models, both were non-significant and so were dropped from final models.

Results

Descriptive Data and Response Rates

See Table 1 for demographics. Only 48.7% ($N=37$) of all enrolled participants received a prompt based on public bar/club geofences. Those who received at least one survey prompt based on these public geofences received an average of 3.4 ($SD=2.7$) across the 30-day study. Among those who did *not* receive a location survey prompt, 71.8% reported having visited a bar/club at some point over the 30 days.

A total of 45 enrolled participants (59.2%) started the study after we began setting geofences around personal drinking locations. Of these, 33.3% elected not to identify *any* personal drinking locations, suggesting that identifying specific locations at which participants tended to drink heavily was acceptable only for a slight majority of these non-treatment-seeking, heavy drinking GBM. Participants who identified at least one location selected an average of 3.4 ($SD=1.2$) locations, out of five possible. Table 2 shows the types of drinking locations that participants identified. Most of these locations (45.7%) were bars/clubs, but a significant minority (36.9%) were private residences. Two of the private residences identified were participants’ own homes. Surveys completed after being prompted by geofences around participants’ own homes were not included in any subsequent analyses.

Of those who identified at least one personal drinking location, 62.2% ($N = 23$) actually received a survey based on these locations during the 30 days. Those who received at least one prompt received an average of 2.3 ($SD = 1.3$) prompts based on personal geofences. A total of 174 survey prompts were issued to 41 participants for both types of geofences (public, personal). Of these prompts, 40.2% ($n = 70$) were issued when participants were not in the location that was intended to be captured by the geofence. As such, more than a third of all prompts issued based on these geofences may be considered “false positives.”

Characteristics of Drinking Locations and Alcohol Use

Using the 104 available surveys about the geofenced drinking locations, we explored whether there were differences in the characteristics of drinking locations across location type (Table 3). Unsurprisingly, GBM reported being less able to openly express themselves at bars/clubs that catered to general audiences, when compared to gay-oriented bars/clubs and private residences. There were no systematic differences in participants’ perceptions of how intoxicated other patrons or guests were across location categories. However, participants rated gay-oriented bars/clubs as significantly more “sexualized” than general bars/clubs and private residences. Similarly, participants reported perceiving that a higher percentage of patrons at gay-oriented bars/clubs were there to meet someone to “hook up” with than at general bars/clubs and private residences.

In a series of mixed models, we explored whether certain characteristics of the drinking locations that participants visited were associated with alcohol use level and with participants’ level of intoxication that same night (Table 4). Among the select drinking location characteristics we explored, participants’ perceptions of how intoxicated the other patrons/guests at these locations were was positively associated with the number of drinks consumed. However, none of the location characteristics we explored were associated with participants’ self-reported level of intoxication that night.

Discussion

In this study, we explored the acceptability of using smartphone geofencing to study characteristics of drinking locations among heavy drinking GBM, and tested whether specific characteristics of those locations were associated with drinking more heavily when participants visited them. Our results showed that less than half of participants ever received a prompt, despite nearly 80% of these participants having visited a bar at some point during the study. Although we likely could have captured a larger share of drinking locations by establishing geofences around every possible drinking location in these metro areas, doing so would be exceedingly problematic in large metro areas, given the wide variety of locations at which drinking might occur (e.g., restaurants, events, sporting venues) and the close proximity of these spaces. It may be more feasible, however, to provide more complete coverage of possible drinking locations in smaller cities and towns.

In a second wave ($N = 45$), we asked participants to record up to five personal locations at which they often ended up drinking heavily. We then set geofences around these locations and used them to prompt participants to complete the same location survey. This approach was better-suited for surveying drinking locations that typically are not publically known

(e.g., private residences). However, nearly a third of participants did not identify *any* personal drinking locations.. Among those who identified at least one personal location, the percentage of those who ever received a location survey also increased only slightly over relying on geofences of public places (e.g., bars and clubs) alone (62% versus 49%).

Across both types of geofences, two in every five surveys prompted were also “false alarms,” meaning that a survey was delivered when participants were not in the location intended. This high rate was likely due to several aspects of current geofencing approaches and the geographic areas we studied. First, the most widely available geofencing tools use point-and-size methods, wherein a circular boundary with a custom radius (i.e., size) is established around a specific GPS coordinate. So, these circular boundaries can often include areas outside of a structure or building of interest. Although we ensured that most public geofences were small enough to include only areas *inside* each location, this was likely insufficient to reduce the number of false positives. Most geofencing approaches also rely almost exclusively on two GPS coordinates (latitude, longitude), making it especially difficult to precisely tag locations in densely populated metro areas. This is because many locations of interest may be co-located with other types (e.g., a bar that is a floor above a coffee shop in the same building). Although altitude readings have become much more accurate in recent years, they still may not achieve the reliability needed to be used for this purpose. As we did not collect participants’ GPS data on an ongoing basis throughout the study, we cannot distinguish between these explanations for false positives. It is important to note, however, that newer positioning tools have begun allowing developers to achieve much more precise positioning, including inside indoor locations, by integrating GPS data with other available data that is relevant to the user’s context and location (e.g., the identity, count, and strength of WiFi signals, mobile data, Bluetooth beacons). However, these tools have not yet been widely adopted in many third-party apps.

Using valid surveys collected when participants were inside geofenced locations, we then explored whether various characteristics of drinking locations differed across location type. There was no difference in participants’ perceptions of how intoxicated the other patrons or guests were across each type of location, suggesting that no location type stood out for having especially inebriated attendees. However, GBM reported being most able to openly express themselves in gay-oriented bars/clubs and private residences. At the same time, participants also rated gay bars/clubs as particularly “sexual” environments. Not surprisingly, then, GBM also reported perceiving that an average of half of all gay bar/club patrons were actively looking for “hookups,” a much higher percentage compared to general bars/clubs and private residences.

Finally, this study was also among the first to explore whether specific, select characteristics of drinking environments were associated with drinking more heavily and/or being more intoxicated the same night participants visited them among GBM. Contrary to most available past studies (Greenwood et al., 2001, Wong et al., 2008, Lea et al., 2013) but consistent with at least one other (Jones-Webb et al., 2013), our results suggest that participants did not drink more heavily on nights when they visited a gay bar/club, versus other types of locations. Given that most past studies finding support for such a relationship explored whether GBM who have heavier patterns of drinking also tended to visit gay bars/

clubs more often, our findings suggest that this association may be due to a common overall pattern of heavier drinking, rather than a tendency to drink more specifically when in gay bars/clubs. Our results also suggest that participants did not drink more heavily when drinking in particularly sexually-charged locations (independent of location type). However, consistent with several past studies (Clapp et al., 2003, Clapp et al., 2008) participants did consume more drinks on nights when they visited locations in which they perceived more patrons/guests at that same location were also intoxicated, above and beyond how intoxicated they believed their friends were. This finding could suggest that individual drinking behavior may be influenced by the norms of other people visiting a given drinking location, even in the absence of direct interaction. This study is also the first to demonstrate this effect among GBM.

Implications for Research and Intervention

In principle, smartphone geofencing could be a powerful tool for both research on alcohol use and interventions intended to reduce it. Using geofencing in research could improve the validity of research exploring the influence of specific drinking locations or aspects of those locations on drinking behavior and related problems by allowing researchers to study these links in real-time in the real world. To be most effective for these purposes, our results suggest that researchers should set geofences around more public drinking locations in the areas being studied to capture a larger volume of data, but also expect that doing so using existing tools may result in high false positive rates, at least for now. This is because geofencing every possible alcohol outlet in densely-populated metropolitan areas would likely trigger an untenable number of survey prompts and would increase the number of false positives due to the dense number of outlets and co-located spaces. For example, in many downtown areas, many of these alcohol outlets overlap and bars/restaurants are located below office and residential spaces. Alternatively, researchers could consider using a more detailed approach to assessing participants' most common drinking locations that helps reduce the number of less relevant locations that are geofenced. For example, researchers could ask participants to identify bars/clubs they frequent most often, and set individualized geofences based on these responses. Asking participants to identify personal drinking locations other than bars/clubs can also help researchers study private drinking locations (e.g., house parties), which is particularly important for those studying certain at-risk populations (e.g., college students, adolescents). However, it is important to establish procedures that encourage participants to identify these locations, such as emphasizing the confidentiality of responses/data and issuing incentives for doing so.

The potential utility of geofencing in alcohol interventions is also high, particularly because it provides a method to intervene with users at the very times they are most at-risk for heavy drinking without the need for other hardware (e.g., biosensors). As such, interventions could be issued that help remind users of their goals, remind them of important priorities, or encourage them to use protective behavioral strategies that could help reduce harm from drinking. So far, geofencing is already being actively used as one component of at least one smartphone application that was designed to support the recovery of those with alcohol use disorder (Gustafson et al., 2014). However, few details are available about the specific approach and intervention used in this component, and no data have yet been published

about its effects. Our data suggests that, while geofencing could prove to be a very useful component of interventions once positioning and indoor location improve, in its current form, it should likely be used with caution. Given the high false positive rate in our results, the biggest concern is that delivering too many interventions when users are inside geofences (e.g., via push notification) but are not drinking could lead users to begin ignoring other “calls to action” or app components, and may lead users to stop trusting the intervention, leading to disengagement. Since so little is known about the utility of interventions delivered based on geofences, incorporating such a component may also do the user more harm than good. Based on the relatively few number of surveys that were triggered when participants were actually in the intended locations over time, interventions that rely on geofences may also fail to expose users to a sufficient amount of content for it to yield effects on behavior. Personal geofences may be of greater utility to interventions, however, because they are capable of capturing a wider variety of personally-relevant locations, including those only known to the participant. To be most effective, though, participants would likely need to be motivated to change, to report these sensitive locations, and be regularly encouraged to update them over time. Together, while personalized geofences may have utility in intervention programs, geofences around public drinking locations should be used carefully.

Limitations

Several limitations should also be noted. First, our sample reflected a small group of heavy drinking, but non-treatment-seeking gay and bisexual men. As such, our results may not generalize to other populations, like heterosexual men and women or those seeking treatment for alcohol-related problems. These participants also drank heavily once per week on average, and heavier drinking samples may yield different results. All participants also resided in the greater Providence, RI and Boston, MA metro areas, so these findings may also differ from those collected in participants living in other areas, especially less densely populated areas. The approach to geofencing we employed also yielded a relatively small number of surveys ($n = 104$) for use in modeling. The specific characteristics of drinking environments we surveyed also represented a very small proportion of factors that may have influenced drinking behavior, and most of them were likely primarily relevant to GBM. As such, our findings about the influence of specific drinking location characteristics on alcohol use should be considered preliminary, and future research should explore a number of other characteristics of drinking environments that could influence behavior (e.g., price of drinks, drinking games, music, dancing).

In summary, in a 30-day study, establishing geofences around public and personal drinking locations in major metro areas resulted in a high number of false positive prompts and more sparse survey data than expected. However, modeling results suggested that GBM consumed more alcohol on days when they visited drinking locations in which they perceived more patrons/guests to be intoxicated, suggesting that this may be one characteristic of drinking environments that could influence individual drinking behavior.

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Figure 1.
Illustration of active geofences in downtown Providence, Rhode Island

TABLE 1

Demographic and Behavioral Characteristics of the Study Sample (N = 76)

<i>Characteristics</i>	<i>Mean (SD) or N (%)</i>
Age (Range: 18 – 54)	26.8 (7.9)
Male gender	76 (100.0)
Race	
White	58 (76.3)
Black or African American	3 (4.0)
Asian	6 (7.9)
American Indian/Alaska Native	1 (1.3)
Multiracial	5 (6.6)
Other	3 (4.0)
Ethnicity (Hispanic or Latino)	11 (14.5)
In sexually exclusive relationship	3 (4.0)
College degree	41 (54.0)
Low income ¹	23 (30.3)
Unemployed	12 (15.8)
Average number of drinking days, past 30 days	10.3 (5.6)
Average number of binge drinking days, past 30 days	4.4 (4.9)
AUDIT ² > 8	54 (71.1)

Note.

¹ Represents those with a household annual income <\$30,000/year.² Alcohol Use Disorders Identification Test. Scores > 8 suggest potential alcohol-related problem.

TABLE 2

Types of locations participants identified as heavy drinking locations for personal geofences

Location type	N	%
Home/residence	38	36.9%
Bar/club	29	28.2%
Gay bar/club	18	17.5%
Restaurant	5	4.9%
Performance venue	3	2.9%
Public space (e.g., park)	4	3.9%
Unknown	6	5.8%

TABLE 3

Ratings of location characteristics by location type

Variable	Gay Bar/Club		Bar/Club		Residence		F	p
	M	SD	M	SD	M	SD		
<i>How openly are you able to express yourself?</i>	3.37	0.79	2.29	1.14	3.67	0.82	7.94	0.001
<i>How intoxicated do you think others at this location are right now?</i>	1.78	1.09	1.86	1.03	1.83	1.17	0.03	0.973
<i>How "sexualized" is this location?</i>	1.59	1.05	0.79	1.05	0.50	0.84	4.51	0.017
<i>What percentage of the guys who are at this location do you think are hoping to meet someone to "hook up" with?</i>	50.0	26.0	32.9	27.4	22.8	15.6	3.91	0.027

Linear mixed models exploring associations between characteristics of drinking locations and alcohol use level among heavy drinking gay and bisexual men

TABLE 4

Variable	Number of Drinks				Perceived Intoxication (Self)			
	b	SE	p	95% CI	b	SE	p	95% CI
Avg. # drinks/drinking day (past 30 days)	0.07	.06	.202	−0.04–0.19	0.14	.08	.069	−0.01–0.28
Gay bar/club (vs. other locations)	0.16	.19	.409	−0.26–0.45	−0.22	.13	.101	−0.48–0.04
Open expression	0.02	.09	.784	−0.17–0.16	0.10	.09	.286	−0.08–0.27
Estimated % of other patrons hoping to “hookup”	0.01	.01	.818	−0.01–0.01	−0.01	.01	.434	−0.01–0.01
Perceived intoxication of other patrons/guests	0.38	.11	.001	0.12–0.53	0.07	.09	.435	−0.11–0.24
Perceived intoxication of others participants were with	−0.17	.11	.124	−0.37–0.06	0.07	.12	.541	−0.16–0.31