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BMJ Open

Use of Geofencing Interventions in Population Health Research: A Systematic Scoping Review

Journal:	BMJ Open
Manuscript ID	bmjopen-2022-069374
Article Type:	Original research
Date Submitted by the Author:	02-Dec-2022
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Keywords:	EPIDEMIOLOGY, HIV & AIDS < INFECTIOUS DISEASES, MENTAL HEALTH, PUBLIC HEALTH





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4	1	Use of Geofencing Interventions in Population Health Research: A Systematic Scoping
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4	29	Use of Geofencing Interventions in Population Health Research: A Systematic Scoping	
5	30	Review	
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7	32		
8	33	Key Points	
9 10 11	34	Question	
12 13 14	35	What geofencing interventions have been implemented in population health research?	
15 16	36		
17 18	37	Findings	
19 20 21	38	The majority of the 9 studies included in this systematic scoping review were published in the	
22 23	39	five years preceding the search (89%). Geofences in most studies (n=5) were fixed and	
24 25	40	programmed in the mobile application carried by participants without their input. Intervention	
26 27 28	41	delivery of geofencing interventions were classified as direct or indirect with five studies (56%)	
29 30	42	being found to have utilized direct interventions.	
31 32	43		
33 34 35	44	Meaning	
36 37	45	This review found geofencing to be an emerging technology that is an acceptable and feasible	
38 39	46	intervention.	
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4	8	Abstract	
49	9	Importance	
5	0	Technological advancements that utilize global positioning system (GPS), such as geofencing,	
5	1	provide the opportunity to examine place-based context in population health research. However	,
52	2	systematic review of the use of geofencing intervention research is lacking.	
5.	3		
54	4	Objectives	
5:	5	To systematically identify, assess, and synthesize the existing evidence on geofencing	
5	6	intervention design, acceptability, feasibility, and/or impact.	
5'	7		
5	8	Evidence Review	
5	9	Searches were conducted in PubMed, CINAHL, EMBASE Web of Science, Cochrane, and	
6	0	PsychINFO for articles in English published by December 31st, 2021. This systematic scoping	
6	1	review examined existing literature and excluded articles that met the following criteria: 1) a	
62	2	component or combination of global positioning system (GPS), geographic information system	
6.	3	(GIS), or ecological momentary assessment (EMA) was utilized without delivery of an	
64	4	intervention; 2) did not include a health or health-related outcome from the geofencing	
6:	5	intervention; or 3) was not a peer-reviewed study. Several researchers independently reviewed	
6	6	all abstracts and full-text articles prior to their final inclusion.	
6	7		
6	8	Findings	
6	9	Using the search strategy in six databases, a total of 2171 articles were found. Nine studies were	;
7	0	included. The majority were published in five years preceding the search (89%). Geofences in	
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most studies (n=5) were fixed and programmed in the mobile application carried by participants without their input. Mechanisms of geofencing interventions were classified as direct or indirect with five studies (56%) being found to have utilized direct interventions. Of note, there was not a consistent health outcome (from smoking to problematic alcohol use) across the five studies that utilized an direct geofencing intervention and four studies utilized a behavioral mechanism in their geofencing intervention.

78 Conclusions and Relevance

This review found geofencing to be an emerging technology that is an acceptable and feasible intervention. Moreover, geofencing interventions have been applied to various populations and health outcomes. However, future studies should be specific about the rationale for the type of locations that are geofenced and the user input. Moreover, attention to the mechanisms of actions will enable the field to understand not only whether geofencing is an appropriate and effective intervention but why it works to achieve the outcomes we observe.

85 Strengths and Limitations

- This scoping review focused on hypothesized mechanisms of action.
- The number of published studies that met criteria were limited and did not assess impact of
 - the intervention.

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89 Introduction

Population health outcomes and health disparities result from multi-level factors beyond
the individual. For example, poverty can lead to a lack of access to healthy food¹ and medical
care²; unstable housing can lead to inability to adhere to medications ³ and exposures to
unhealthy environments⁴; homophobia and racism leads to stigma and discrimination, and
mistrust and avoidance of medical systems.⁵⁻⁷

95 Often in behavioral research, theories or frameworks do not consider the place-based context of behavior despite literature on the consistent and enduring impact of places such as 96 neighborhoods and communities on population health outcomes and disparities.⁸⁻¹⁰ Place-based 97 98 context can be conceptualized as both geographic areas defined by boundaries or as socially constructed out of symbolic meanings and social relations.^{11,12} In both cases, place-based context 99 100 operates to perpetuate hierarchical social structures, facilitate and constrain resources, and 101 protect or hinder health. Moreover, place-based context may facilitate specific health-related 102 interactions such as drug or alcohol use, experiences of violence, or engagement in 103 healthcare. Yet behavioral interventions often conceptualize place-based context as static (e.g., 104 place of risky sex) and do not consider how place-based contexts vary over time. Real-time 105 geospatial methods, including the use of global positioning system (GPS) technology, are the 106 cutting-edge, best-suited methods to overcome limitations of most neighborhoods and other 107 environments health research because they better capture place-based contexts corresponding to 108 individuals' lived experiences, referred to as "activity space".¹⁴⁻¹³

109 There are numerous types of GPS-based methods that collect data from individuals and in
 110 some cases deliver intervention content. For example, ecological momentary assessment (EMA)
 111 has been shown to be an acceptable method of data collection.¹⁴ Ecological Momentary

Interventions (EMI) allow researchers to deliver intervention content through mobile devices.¹⁵ Just-in-time adaptive interventions (JITAI) attempt to address the changing needs of an individua where the intervention algorithm is programmed to determine if and what intervention content should be delivered to participants at set times throughout the day, whenever a participant requests one, or based on the participant's current state (e.g., stress) or environmental changes (e.g., weather).¹⁶⁻¹⁷ Finally, geofences are virtual boundaries drawn around a location and allow for monitoring and messaging when individuals enter or exits the geofenced parameter.¹⁸ Geofencing interventions are a subset of JITAI where there is continuous monitoring of the participant's location using GPS and delivery of an intervention based on a spatial context trigger. Reviews of JITAI and EMI show the promising potential of this evolving technology¹⁹⁻²¹, yet, such reviews are noted to lack the inclusion of geofencing, representing a major gap in the literature. This gap is vital to address as geofencing has the capability to address an array of different health issues ranging from tobacco cessation to HIV medication adherence. The lack of a clear and systematic understanding of the scope of geofencing interventions undermines its potential to impact population health. The purpose of this systematic scoping review is to describe of the state of the evidence on geofencing intervention design, acceptability, feasibility, and impact. In addition, we examine what behavioral mechanisms were targeted across the interventions assessed, as discussed below. Conceptualizing mechanisms of action Another limitation in the literature of EMA and JITAI interventions is the lack of attention to

134 specific mechanisms of action that operate to achieve outcomes.²² Therefore, we sought to

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135	develop a framework based on several complementary theories and frameworks (e.g., Turan's
136	HIV Stigma Framework and Social Cognitive Theory ²³⁻²⁵) to evaluate geofencing interventions
137	included in this review. The framework posits three key mechanisms operate for place-based
138	context to influence health outcomes (Figure 1). Each mechanism has both a protective and risk
139	dimension. The Cognitive mechanism includes cognitive processes such as sense of control,
140	knowledge, attitudes, self-efficacy, maladaptive thoughts, risk perceptions and internalized
141	stigma. ²⁶⁻³¹ The Behavioral mechanism refers to both protective behaviors such as adaptive
142	coping as well as risky behaviors such substance use, condomless sex and non-adherence to
143	medication and care. ^{32-34 35} The Social mechanism refers to interactions with others in the
144	personal social networks and broader community such as emotional or instrumental support or
145	enacted stigma and conflict which have been shown to exacerbate or mitigate health outcomes. ³⁶⁻
146	³⁸ The framework can be applied to multiple spatial scales from a micro-level (e.g. a room in
147	one's residence) to community-level (e.g. a neighborhood activity space or census tract) to
148	macro (e.g. state, region).
149	[Figure 1 here]
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151	Methods
152	This systematic review was conducted in accordance with the 2018 PRISMA Extension for
153	Scoping Reviews checklist. ³⁹
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155	Patient and public involvement
156	No patient involved.
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158 Inclusion criteria

Articles were only included if they included if geofencing was utilized as a mechanism for intervention delivery. Articles were excluded if 1) a component or combination of GPS, geographic information system (GIS), or ecological momentary assessment (EMA) was utilized without delivery of an intervention; 2) did not include a health or health-related outcome from the geofencing intervention; or 3) was not a peer-reviewed study.

165 *Search strategy*

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Authors first met to develop the list of potential search terms and refined after initial searchers were conducted. Then searches were conducted in PubMed, CINAHL, EMBASE Web of Science, Cochrane, and PsychINFO for articles published through the end of 2021 (Appendix 1). Search terms were for broad concepts regarding mobile delivery of a geofencing intervention: "Geographic Information Systems"; "Georeferencing"; "Global Positioning System"; or "Geofenc*" combined with "Smartphone" or "Mobile Applications." The search was conducted on 12/1/2022 and was not registered. A protocol was not prepared.

174 Study selection

Screening of article titles and abstracts was conducted with two reviewers (SS, CV) in maximize scrutiny of all records. Each reviewer independently screened all articles identified from the initial search for relevance to the pre-defined inclusion criteria that was highlighted during a training session where it was emphasized that the reviewers should apply a liberal approach. Next, the same two reviewers independently reviewed each of the full texts for inclusion in the data extraction phase. Any disagreements in both phases were adjudicated by a third reviewer

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181 (OH). In all phases reviewers were not blinded to authors, funding, or information regarding182 publication of all the records.

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184 Data extraction

Two reviewers (OH, KT) extracted data for details of study design, target population, sample
size, duration of follow-up, theoretical framework, software or mobile application use, goal, and
mechanism of geofenced intervention, and impact of the intervention of outcomes. Place-based
mechanisms associated with the intervention included: 1) Behavioral, 2) Social support:
Emotional, Instrumental, Informational, and Social monitoring, and 3) Cognitive. Finally,
established guidance for reporting health intervention using mobile phone was utilized to
evaluate the quality of each article.⁴⁰

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193 Included studies

Using the search strategy in six identified databases, a total of 2,171 articles were found after removing duplicates. 2,039 studies were irrelevant and 132 full text studies were assessed for eligibility (Supplementary Figure 1). Reasons for exclusion of the 122 articles in the full-text phases included the article not being peer reviewed (n=46), a review articles (n=19), was not the correct study design or intervention (n=14), or utilized a combination of GPS, GIS, and or Ecological Momentary Assessment, but was not a geofencing intervention (n=44). Nine studies were included in this scoping review.

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202 Study characteristics

The majority were published in five years preceding the search (89%) (Supplemental Table). Most employed a pre/post study design to assess changes in measured outcome or feasibility and acceptability of the geofencing intervention (78%) with 2 unblinded randomized control trials. Sample sizes ranged from 4-3,443; one study's intervention quantified its reach with the geofencing intervention displaying on 516,073 mobile phones, though these impressions do not represent unique individuals receiving the intervention.⁴¹ Most studies (78%) were conducted in the United States, one in the United Kingdom⁴² and one in Spain.²²

211 Geofencing methods: User input

Geofences in most studies (n=5) were fixed and programmed in the mobile application without participant input. These included hospital emergency departments^{18,43}, hospitals where participants worked^{44,45}, and a specific rural dental clinic⁴¹. Two studies utilized participants input in determining where to geofence related to smoking⁴² or problematic alcohol use⁴⁶. Two studies utilized a mix of fixed and user input. Dorsch et al. utilized user input to geofence locations where foods were consumed or purchased as well as a cloud-based web service to predict when participants entered grocery stores or restaurants. Besoain et al., used a moderated system where participants suggested locations to geofence that were venues for high-risk sexual encounters, but these venues were moderated by the study team and locations could be added or removed.

222 Intervention content delivery: Direct versus Indirect

223 Intervention content was delivered in direct or indirect methods. Five studies (56%) sent
 224 participants intervention content directly to their phones based on triggering the geofence

- boundary. These interventions included informing individuals living in a rural area of a dental

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clinic⁴¹ or sending behavioral messages regarding problematic alcohol use when near a bar⁴⁶, smoking cessation in areas detected as high likelihood of smoking⁴², making low-sodium diet choices in grocery stores, restaurants, or at home, or HIV and STI prevention messages when in venues associated with high-risk sexual activity²². The remaining 4 studies were categorized as indirect as they collected data when participants triggered geofence boundaries and in some cases delivered content at a later time from when the fence was triggered.

Outcomes of interest

There was not a consistent health outcome across the five studies that utilized a direct intervention. Both studies that utilized a randomized control design showed improved outcomes in the group randomized to geofencing. A-CHESS sent context and place-based messages and included multiple other services such as a phone and data plan, access to a virtual counselor, and other interactive features (Table 1).⁴⁶ LowSalt4Life contained features including low sodium options and alternatives at grocery stores or restaurants, and the ability to scan product barcodes to find similar low sodium options. Q Sense intervention participants decreased from 60% of pre-quit smoking days to 39% post-quit. UBESafe intervention reported that all participants were able to trigger a hot zone where sexual contacts often took place and received a place-based prevention message.²² Finally, Wright et al.,⁴¹ used a pre/post design, and found increases in community knowledge about the dental clinic (p=0.045) and increased number of dental visits post intervention.

Indirect intervention outcomes

Two studies used the geofence to track time working from medical practitioners or surgical residents (Table 1). Owei et al., found the mean number of working hour violations for surgical residents' post-intervention significantly decreased (p=0.04) compared to pre-intervention and compared to the previous year (p < 0.01).⁴⁴ Connor et al., showed a significant correlation of early departures from operating room duties following late departures the previous day (p<0.01) and better dispersion of working hours (p=0.002) compared to the previous year.⁴⁵ Two other studies geofenced major hospitals to detect hospitalization of high priority patients. Nguyen et al., found the geofenced mobile application detected 800 unique participants who triggered a geofence, with a predictive value of true hospitalization between 65-78%.¹⁸ Similarly, from a sample size of 21, 4 of the participants activated the alert system for patients with a ventricular assist device to their on-call care team when they triggered an emergency room geofence.⁴³

260 Acceptability measures

Five studies reported data regarding acceptability of the geofencing mobile application in which all participants were positive regarding the value of the intervention. Participants in two studies with indirect intervention found the application useful and described knowledge of being monitored provided a sense of security^{43,44}. Additionally, participants in two studies did not have concerns regarding the continuous geolocation tracking for intervention purpose^{42,44}, but did stress the importance of transparency regarding the use of this data⁴². Finally, in one interactive study, participants contributed to the creation and curation of geofenced hot zones as well as the prevention messages received when hot zones were triggered, accounting for 67% of hot zones created and used by the study²².

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271 *Place-based mechanisms*

Four studies utilized a behavioral mechanism in their geofencing intervention.^{22,42,46,47} Four 272 273 studies utilized a social mechanism which included informational support such as existence of a rural dental clinic⁴¹ and availability of menu grocery store items that were low in sodium.^{22,41,46,47} 274 275 Additionally, participants were able to interact with counselors though the application and 276 review their data concerning visiting high-risk locations for further intervention⁴⁶ or sharing 277 context specific messages with other users on the application.²² Finally, five studies utilized a 278 cognitive mechanism that provided the participant a sense of safety, security, or knowing that their information was captured.^{45,46} These included reporting to care teams when the participants 279 280 were hospitalized^{18,43}, capture of time and effort spent working in a clinical environment^{44,45}, and 281 participants counselor viewing their location and interacting with their place-based data of 282 proximity and time spent in high-risk areas for binge drinking.⁴⁶

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284 *Reporting and quality measures*

285 From the 16-point checklist, all included studies reported on 6 items (Table 1). Position Health⁴³, Stat!⁴⁵, and ResQ⁴⁴ studies described how the intervention and data collected integrated into an 286 existing health information system and described some data security procedures. A-CHESS⁴⁶ and 287 288 the Wright et al.,⁴¹ intervention conducted some cost assessment regarding the delivery of the 289 intervention or cost to the participant to utilize the participant. Finally, no study reported on 290 compliance of the intervention or data collection mechanism compliance with national guidelines 291 or federal statutes. We did not assess confidence in the body of evidence or risk of bias. 292 293 Discussion

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The purpose of this review was to describe the use of geofencing as an intervention and mechanisms that were targeted to achieve various health outcomes. We identified only 9 studies that fit criteria and as expected, most publications were relatively recent.

297 Of the studies included, only one was focused on a sexual and gender minority sample 298 and only one with majority Black, Indigenous People of Color (BIPOC), who experience 299 disparities on a vast number of health outcomes due to social and structural factors such as 300 racism and homophobia.²² Lack of inclusion of these populations is a significant gap that should 301 be monitored as more studies are conducted. In addition, most studies were in the U.S. (North 302 America) with no studies in developing countries, South America, Africa or Asia, which could 303 represent an important opportunity.

304 The included studies described a range of user input of the geofenced locations from 305 researcher only selection to user selection. This characteristic of an intervention merits 306 consideration. User selection of geofenced locations may be prone to bias and recall issues.⁴⁸ 307 Researcher selected locations may not consider the variability of their sample's place-based 308 contexts and may under count locations that should be geofenced. The hybrid approach has the 309 potential to address both limitations. Future studies using geofencing technology may warrant 310 comparative studies of the user input approaches and be specific about the rationale for the type 311 of locations that are geofenced and the user input of these so that studies can be comparable and 312 be conducted in non-western contexts.

313 Some of the interventions explicitly identified a theoretical model or foundation, and all 314 the studies described targeting at least one of the mechanisms of action from our proposed 315 framework. The studies in which the geofencing intervention targeted the cognitive mechanism 316 were primarily addressing surveillance of the participants and messages to cue cognitions about

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their location. Cueing is a significant component of many effective interventions as they serve as reminders to engage in behaviors of interest.⁴⁹⁻⁵¹ Cues can focus on both the protective and risk dimensions of the mechanism. For example, if an individual triggers a geofence of a place they have identified as associated with a sense of control, cues to engage in coping and self-care will be more relevant. Cues in places where stigma is anticipated can also encourage adaptive coping behaviors.

323 Studies utilizing the behavioral mechanism described very specific behavioral targets 324 such as buying lower sodium food, avoiding places of alcohol use, condom use and smoking 325 cessation. As building self-efficacy is a well-established theoretical construct necessary for 326 behavioral change²³, future studies should include opportunities to watch the desired behaviors 327 be role-modeled and practiced to enhance the efficacy of the geofencing intervention.⁵² 328 Studies that utilized the social mechanism were focused on the provision of both 329 informational and emotional support. One study included a component in which the participants 330 could create messages for other user of the geofencing application. As there are different types of 331 social support (e.g., emotional, appraisal, economic and informational) future studies should be 332 specific and transparent about the types being targeted. With additional geofencing studies, a 333 future review can be conducted using meta-analytic methods to determine the quantitative 334 effectiveness of geofencing interventions in population health research.

5 335 Limitations

The search strategy was limited to PubMed, CINAHL, EMBASE Web of Science, Cochrane,
 and PsychINFO and we acknowledge other publications may not have been captured with these.
 There was heterogeneity in how studies reported intervention development, theoretical
 frameworks, and feasibility and acceptability of the intervention. This reduced the ability to

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2		
3 4	340	properly assess the extent of behavioral mechanism utilized for the given outcome. Additionally,
5 6	341	as geofencing is a new technology, not many peer-reviewed articles have been published and this
/ 8 0	342	scoping review chose to exclude conference abstracts.
9 10 11	343	
12 13	344	Conclusions
14 15	345	In conclusion, this systematic scoping review indicates that geofencing is an emerging
16 17 18	346	acceptable and feasible intervention that has been applied to various populations and health
19 20	347	outcomes. ²² Attention to the mechanisms of actions will enable the field to understand not only
21 22	348	whether geofencing is an appropriate and effective intervention but why it works to achieve the
23 24	349	outcomes we observe. There is a need for future research that includes sexual and gender
25 26 27 28 29 30 31 32 33 34	350	minority and BIPOC populations and populations from non-Western contexts to achieve the
	351	Health People Framework objectives given the persistent findings that BIPOC and SGM
	352	populations. These studies could address those health outcomes where disparities are stark such
	353	as HIV/AIDS, cardiovascular, diabetes, COVID-related and monkeypox. Finally, future research
35 36	354	can reveal place-based contexts that have not been considered which can inform resource
37 38	355	allocation and targets for health-promoting policies.
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	Wright et	Owei et	Gustafson	Nguyen	Naughton	Dorsch	DeFilippis et	Connor	Besoai
	al., 2021	al.,	et al., 2014	et al.,	et al.,	et al.,	al., 2017	&	et al.,
		2021		2017	2016	2020		Herzig, 2016	2020
Infrastructure									
Technology platform									
Interpretability/Health information									
systems context									
Intervention delivery									
Intervention content									
Usability/content testing									
User feedback									
Access of individual participants									
Cost assessment									
Adoption inputs/program entry									
Limitations for delivery at scale									
Contextual adaptability									
Replicability									
Data security									
Compliance with national guidelines or									
regulatory statutes									
Fidelity of the intervention									
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Contributorship statement

All authors conceptualized and contributed to writing this manuscript. Co-first authors Tobin and Heidari led the data abstraction and analysis.

Competing interests

Karin E. Tobin, Omeid Heidari, Connor Volpi, Shereen Sodder and Duston Duncan declare that they have no conflict of interest.

Funding

This work was supported by a grant from the National Institute of Mental Health R34MH118178

Data sharing statement

We will consider requests for access to methods or the data used in this study. Template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review are available upon request to the lead author

Human and Animal Rights and Informed Consent

This article does not contain any studies with human or animal studies performed by any of the authors.

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3	References:
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5	1 I argan MI Stary MT Nalgan MC Naighborhood any ironmanta, dignarities in appage to
6	1. Larson NI, Story MI, Nelson MC. Neighborhood environments, dispartites in access to
7	healthy foods in the US. American journal of preventive medicine. 2009;36(1):74-81. e10.
8	2. Lazar M, Davenport L. Barriers to health care access for low income families: a review
9	of literature. Journal of community health nursing, 2018;35(1):28-37.
10	3 Kalichman SC Kalichman MO HIV-related stress and life chaos mediate the association
11	between powerty and mediaction adherence among people living with HIV/AIDS Journal of
12	between poverty and medication adherence among people nying with HTV/AIDS. <i>Journal of</i>
13	clinical psychology in medical settings. 2016;23(4):420-430.
14	4. Taylor SE, Repetti RL, Seeman T. Health psychology: what is an unhealthy environment
15	and how does it get under the skin? Annual review of psychology, 1997;48
16	5 Farnshaw VA Bogart LM Dovidio IF Williams DR Stigma and racial/ethnic HIV
17	disparities: maying toward resiliance 2015:
18	dispanties. moving toward resinence. 2015,
10	6. Lutete P, Matthews DW, Sabounchi NS, et al. Intersectional Stigma and Prevention
20	Among Gay, Bisexual, and Same Gender–Loving Men in New York City, 2020: System
20	Dynamics Models. American journal of public health. 2022;112(S4):S444-S451.
21	7 Ouinn K. Dickson-Gomez J. Zarwell M. Pearson B. Lewis M. "A gay man and a doctor
22	are just like a recipe for destruction". How racism and homonegativity in healthcare settings
25	influence DrED writely a group a plash MCM (IDC and Delawier 2010.22(7):1051-1062
24	influence PTEP uptake among young Black MISM. AIDS and Benavior. 2019;23(7):1951-1965.
25	8. Arcaya MC, Tucker-Seeley RD, Kim R, Schnake-Mahl A, So M, Subramanian S.
26	Research on neighborhood effects on health in the United States: a systematic review of study
2/	characteristics. Social Science & Medicine. 2016;168:16-29.
28	9 Duncan DT Kawachi I Neighborhoods and health vol 10 Oxford University Press New
29	Vork: 2019
30	101K, 2010.
31	10. Ritkin SB. Examining the links between community participation and health outcomes: a
32	review of the literature. <i>Health policy and planning</i> . 2014;29(suppl_2):ii98-ii106.
33	11. Gesler WM. Therapeutic landscapes: medical issues in light of the new cultural
34	geography. Social science & medicine, 1992:34(7):735-746.
35	12 Keene DF Padilla MB Snatial stigma and health inequality <i>Critical public health</i>
36	12. Receive DE, 1 duma MD. Spatial sugma and nearth mequanty. Critical public nearth.
37	2014,24(4).592-404.
38	13. Duncan DT, Kawachi I, Subramanian S, Aldstadt J, Melly SJ, Williams DR. Examination
39	of how neighborhood definition influences measurements of youths' access to tobacco retailers: a
40	methodological note on spatial misclassification. American journal of epidemiology.
41	2014.179(3).373-381
42	14 Palmer IR Espenshade TI Bartumeus E Chung CV Ozgencil NE Li K New
43	14. I annoi JK, Espenshade 15, Dartameds 1, Chang C1, Ozgenen NE, Er K. New
44	approaches to numan mounty. Using moune phones for demographic research. <i>Demography</i> .
45	2013;50(3):1105-1128.
46	15. Heron KE, Smyth JM. Ecological momentary interventions: incorporating mobile
47	technology into psychosocial and health behaviour treatments. British journal of health
48	nsychology 2010.15(1).1-39
49	16 Wang L Miller I.C. Just in the moment adaptive interventions (IITAI): A mate
50	wang L, which LC. Just-m-ule-moment adaptive interventions (JTAI). A meta-
51	analytical review. Health Communication. 2020;35(12):1531-1544.
52	17. Nahum-Shani I, Smith SN, Spring BJ, et al. Just-in-time adaptive interventions (JITAIs)
53	in mobile health: key components and design principles for ongoing health behavior support.
54	Annals of Behavioral Medicine. 2018:52(6):446-462.
55	J7- (-)
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58	20
59	20
60	For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml

18. Nguyen KT, Olgin JE, Pletcher MJ, et al. Smartphone-based geofencing to ascertain hospitalizations. *Circulation: Cardiovascular Quality and Outcomes*. 2017;10(3):e003326.

19. Carpenter SM, Menictas M, Nahum-Shani I, Wetter DW, Murphy SA. Developments in mobile health just-in-time adaptive interventions for addiction science. *Current addiction reports*. 2020;7(3):280-290.

20. Naughton F. Delivering "Just-In-Time" smoking cessation support via mobile phones: current knowledge and future directions. *Nicotine & Tobacco Research*. 2017;19(3):379-383.

21. Thomas JG, Bond DS. Review of innovations in digital health technology to promote weight control. *Current diabetes reports*. 2014;14(5):1-10.

22. Besoain F, Perez-Navarro A, Aviñó CJ, Caylà JA, Barriga NA, de Olalla PG. Prevention of HIV and other sexually transmitted infections by geofencing and contextualized messages with a gamified app, UBESAFE: design and creation study. *JMIR mHealth and uHealth*. 2020;8(3):e14568.

23. Bandura A. Social cognitive theory: An agentic perspective. *Asian journal of social psychology*. 1999;2(1):21-41.

24. Turan B, Hatcher AM, Weiser SD, Johnson MO, Rice WS, Turan JM. Framing mechanisms linking HIV-related stigma, adherence to treatment, and health outcomes. *American journal of public health*. 2017;107(6):863-869.

25. Macintyre S, Ellaway A, Cummins S. Place effects on health: how can we conceptualise, operationalise and measure them? *Social science & medicine*. 2002;55(1):125-139.

26. Khawcharoenporn T, Mongkolkaewsub S, Naijitra C, Khonphiern W, Apisarnthanarak A, Phanuphak N. HIV risk, risk perception and uptake of HIV testing and counseling among youth men who have sex with men attending a gay sauna. *AIDS research and therapy*. 2019;16(1):1-11.

27. Machowska A, Bamboria BL, Bercan C, Sharma M. Impact of 'HIV-related stigmareduction workshops' on knowledge and attitude of healthcare providers and students in Central India: a pre-test and post-test intervention study. *BMJ open*. 2020;10(4):e033612.

28. Mi T, Li X, Zhou G, Qiao S, Shen Z, Zhou Y. HIV disclosure to family members and medication adherence: role of social support and self-efficacy. *AIDS and Behavior*. 2020;24(1):45-54.

29. SeyedAlinaghi S, MohsseniPour M, Aghaei E, Zarani F, Fathabadi J,

Mohammadifirouzeh M. The Relationships Between Early Maladaptive Schemas, Quality of Life and Self-care Behaviors in a Sample of Persons Living with HIV: The Potential Mediating Role of Cognitive Emotion Regulation Strategies. *The Open AIDS Journal*. 2020;14(1)

30. Steptoe A, Jackson SE. The life skills of older Americans: association with economic, psychological, social, and health outcomes. *Scientific Reports*. 2018;8(1):1-10.

31. Yigit I, Bayramoglu Y, Weiser SD, et al. Changes in internalized stigma and HIV health outcomes in individuals new to HIV care: The mediating roles of depression and treatment self-efficacy. *AIDS Patient Care and STDs*. 2020;34(11):491-497.

32. Gonzalez A, Barinas J, O'Cleirigh C. Substance use: impact on adherence and HIV medical treatment. *Current HIV/AIDS Reports*. 2011;8(4):223-234.

33. Logie CH, Williams CC, Wang Y, et al. Adapting stigma mechanism frameworks to explore complex pathways between intersectional stigma and HIV-related health outcomes among women living with HIV in Canada. *Soc Sci Med.* 2019;232:129-38.

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3 Safren SA, Blashill AJ, Lee JS, et al. Condom-use self-efficacy as a mediator between 34 4 syndemics and condomless sex in men who have sex with men (MSM). Health psychology. 5 2018;37(9):820. 6 35. Weinstein ER, Harkness A, Ironson G, Shrader C-H, Duncan DT, Safren SA. Life 7 instability associated with lower ART adherence and other poor HIV-related care outcomes in 8 older adults with HIV. International journal of behavioral medicine. 2022:1-11. 9 10 Bekele T. Rourke SB, Tucker R, et al. Direct and indirect effects of perceived social 36. 11 support on health-related quality of life in persons living with HIV/AIDS. AIDS care. 12 2013;25(3):337-346. 13 Koegler E, Kennedy CE. A scoping review of the associations between mental health and 37. 14 factors related to HIV acquisition and disease progression in conflict-affected populations. 15 *Conflict and health*. 2018;12(1):1-22. 16 17 Vaughan E, Power M, Sixsmith J. Experiences of stigma in healthcare settings by people 38. 18 living with HIV in Ireland: a qualitative study. AIDS care. 2020;32(9):1162-1167. 19 Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-39. 20 ScR): checklist and explanation. Annals of internal medicine. 2018;169(7):467-473. 21 40. Agarwal S, LeFevre AE, Lee J, et al. Guidelines for reporting of health interventions 22 using mobile phones: mobile health (mHealth) evidence reporting and assessment (mERA) 23 checklist. bmj. 2016;352 24 25 41. Wright WG, Rafferty AP, Winterbauer N, Locklear K, Tucker-McLaughlin M. 26 Geofencing: Mobile Technology as a Health Promotion Tool to Raise Awareness of a Dental 27 Clinic in Rural North Carolina. The Journal of Rural Health. 2021;37(3):667-674. 28 Naughton F, Hopewell S, Lathia N, et al. A context-sensing mobile phone app (Q sense) 42. 29 for smoking cessation: a mixed-methods study. JMIR mHealth and uHealth. 2016;4(3):e5787. 30 DeFilippis EM, Safavi K, Reyes J, Coakley L, Hickey M, Givertz MM. Mobile 43. 31 32 Geolocation Technology to Improve Multidisciplinary Care of Patients with Ventricular Assist 33 Devices: A Feasibility Study. Journal of Cardiac Failure. 2017;23(8):S84. 34 Owei L, Luks VL, Brooks KD, Kelz RR, Berns JS, Aarons CB, Smart-phone Based 44. 35 Geofencing: A Novel Approach to Monitoring Clinical Work Hours in Surgery Residency. 36 Journal of Surgical Education. 2021;78(6):e210-e217. 37 Connor CW, Herzig M. Monitoring the location of staff via mobile devices in a large 45. 38 multifacility practice group. A & A case reports. 2016;6(10):320-328. 39 40 46. Gustafson DH, McTavish FM, Chih M-Y, et al. A smartphone application to support 41 recovery from alcoholism: a randomized clinical trial. JAMA psychiatry. 2014;71(5):566-572. 42 Dorsch MP, Cornellier ML, Poggi AD, et al. Effects of a novel contextual just-in-time 47. 43 mobile app intervention (LowSalt4Life) on sodium intake in adults with hypertension: pilot 44 randomized controlled trial. JMIR mHealth and uHealth. 2020;8(8):e16696. 45 Wray TB, Pérez AE, Celio MA, Carr DJ, Adia AC, Monti PM. Exploring the Use of 48. 46 Smartphone Geofencing to Study Characteristics of Alcohol Drinking Locations in High-Risk 47 48 Gay and Bisexual Men. Alcoholism: clinical and experimental research. 2019;43(5):900-906. 49 Latkin CA, Hua W, Tobin K. Social network correlates of self-reported non-fatal 49. 50 overdose. Drug and Alcohol Dependence. 2004;73(1):61-67. 51 50. Tobin KE, Davey MA, Latkin CA. Calling emergency medical services during drug 52 overdose: an examination of individual, social and setting correlates. Addiction. 53 54 2005;100(3):397-404. 55 56 57 58

51. Tobin KE, Latkin CA. Social networks of HIV positive gay men: their role and importance in HIV prevention. *Understanding Prevention for HIV Positive Gay Men*. Springer; 2017:349-366.

52. Tobin KE, Heidari O, Winiker A, et al. Peer Approaches to Improve HIV Care Cascade Outcomes: a Scoping Review Focused on Peer Behavioral Mechanisms. *Current HIV/AIDS Reports*. 2022:1-14.

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Figure 1. Types of mechanisms of action, protective and risk factors as well as spatial scales in geofencing interventions in population health research.

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Appendix 1. Detailed search strategy across n=6 databases

PubMed

Search Terms
("Smartphone"[Mesh]) OR "Mobile Applications"[Mesh] OR smartphon*
[tiab] OR "mobile application*" [tw] OR "mobile app" [tw] OR "mobile apps"
[tw] OR "mobile phon*" [tw]
"Geographic Information Systems"[Mesh] OR "Geographic Information
System" [tw] OR "Geographical Information System" [tw] OR "Geographical
Information Systems" [tw] OR "Georeferencing" [tw] OR "Global Positioning
System" [tw] OR "Global Positioning Systems" [tw] OR "Geofenc*" [tw]
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Embase

Concert	Coorde Torme
Concept	Search Terms
Mobile	'mobile phone'/exp OR 'wireless communication'/exp OR 'mobile
applications	application'/exp OR smartphon*:ti,ab,kw OR 'mobile application*':ti,ab,kw
	OR 'mobile app':ti,ab,kw OR 'mobile apps':ti,ab,kw OR 'mobile
	phon*':ti,ab,kw
Geofencing	'geographic information system'/exp OR 'global positioning system'/exp OR
	'geographic information system':ti,ab,kw OR 'geographical information
	system':ti,ab,kw OR 'geographical information systems':ti,ab,kw OR
	'georeferencing':ti,ab,kw OR 'global positioning system':ti,ab,kw OR 'global
	positioning systems':ti,ab,kw OR 'geofenc*':ti,ab,kw
CINAHL	

CINAHL

Concept	Search Terms
Mobile	(MH "Smartphone") OR (MH "Cellular Phone+") OR (MH "Text Messaging+")
applications	OR (MH "Mobile Applications") OR smartphon* OR "mobile application*"
	OR "mobile app" OR "mobile apps" OR "mobile phon*"
Geofencing	(MH "Geographic Information Systems+") OR "Geographic Information
	System" OR "Geographical Information System" OR "Geographical
	Information Systems" OR "Georeferencing" OR "Global Positioning System"
	OR "Global Positioning Systems" OR Geofenc*

Cochrane

Concept	Search Terms
Mobile	([mh Smartphone]) OR [mh "Mobile Applications"] OR smartphon*:ti,ab OR
applications	("mobile" NEXT application*):ti,ab,kw OR "mobile app":ti,ab,kw OR "mobile
	apps":ti,ab,kw OR ("mobile" NEXT phon*):ti,ab,kw

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Geofencing	[mh "Geographic Information Systems"] OR "Geographic Information
	System":ti,ab,kw OR "Geographical Information System":ti,ab,kw OR
	"Geographical Information Systems":ti,ab,kw OR Georeferencing:ti,ab,kw
	OR "Global Positioning System":ti,ab,kw OR "Global Positioning
	Systems":ti,ab,kw OR Geofenc*:ti,ab,kw

Web of Science

Concept	Search Terms	
Mobile (ALL=((Smartphone) OR "Mobile Applications" OR smartphon* OF		
applications	application*" OR "mobile app" OR "mobile apps" OR "mobile phon*"))	
Geofencing	ALL=("Geographic Information Systems" OR "Geographic Information System" OR "Geographical Information System" OR "Geographical Information Systems" OR Georeferencing OR "Global Positioning System" OR "Global Positioning Systems" OR Geofenc*)	
APA PsychINFO		

APA PsychINFO

Concept	Search Terms
Mobile	DE "Smartphones" OR DE "Mobile Applications" OR DE "Smartphone Use"
applications	OR DE "Text Messaging" OR DE "Wireless Technologies" OR DE "Mobile
	Phones" OR smartphon* OR "mobile application*" OR "mobile app" OR
	"mobile apps" OR "mobile phon*"
Geofencing	"Geographic Information System" OR "Geographical Information System"
	OR "Geographical Information Systems" OR "Georeferencing" OR "Global
	Positioning System" OR "Global Positioning Systems" OR Geofenc*





Page	29	of	3	6
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Geofenced	Study characteristics	Development of	Results	Theory and
intervention		geofence		framework
name/citation				
Wright et al.,	Study purpose: Increase awareness and use of	User input: None	Over 60 days, 516,073	Theoretical
2021	dental services in a rural clinic		impressions were delivered,	framework:
		Mechanism of	with 475 individuals clicks on	Anderson Model of
Vendor not	Study design: Pre and post intervention	delivery: Any	the banner to get website	Health Services Use
cited	community and outcome assessments	individual with a	information, and a click	
		smartphone physically	through rate of 0.09%.	Behavioral
	Target population: Residents of a rural zip	located within the		
	code surrounding a dental clinic	boundaries of three	Increases were seen in	Social: Informational
	Co	zip codes near the	community knowledge about	support of an
	Sample size: 516,073 impressions delivered to	dental clinic received	the clinic (p=0.045) and	existing service that
	individuals crossing the geofence	a geofence message	dental visits by respondent	is place-based
	4	advertising the dental	or a family member (p=0.04)	
	Duration of follow-up: Impressions were sent	clinic with webpage	post intervention	Cognitive
	over a 60-day period	information for		
		additional information		
	Outcome of interest: Number of impressions			
	displayed to a user, clicks on the banner, click-			
	through rates on the dental website from the			
	banner, and pre/post intervention community			
Owei et al	Study purpose: Assess the impact of the ResO	User input: Nope	The mean number of	Theoretical
2021	geofencing ann on submission rates for duty	oser input. None	violations decreased	framework: None
2021	hours and number of violations reported	Mechanism of	significantly (n=0.04) and	listed
ResO		delivery: Geofences	work hour submissions did	noted
11000	Study design: Mixed methods feasibility and	were placed around	not differ with the	Behavioral
	acceptability of the ResQ app.	clinical sites where	intervention (p=0.42).	
		residents worked. The	Compared to the previous	Social
	Target population: Residents from the General	ResQ application was	year, reported violations	
	Surgery Residency Program	installed on resident's	significantly decreased	Cognitive: Sense of
		work phones and	(p<0.01).	safety in capture

	Sample size: 23	recorded work hours		and reporting of
		based on entering and	Participants found the	clinical hours
	Duration of follow-up: 60 days	exiting the geofence.	application useful for recording and reporting	
	Outcome of interest: Comparison of reported		clinical hours and eased	
	and recorded work hours submitted and work		administrative burden.	
	hour violations (80 hours per week and			
	continuous hours worked). Additionally, 13			
	participants participated in semi-structured			
	interviews to understand acceptability and			
	feasibility of ResQ.			
Gustafson et	Study purpose: Determine if a smartphone	User input: High-risk	Along with the geofenced	Theoretical
al., 2014	application to support recovery from alcohol	locations were	intervention, A-CHESS was a	framework: Self-
	use disorders reduced risky drinking days.	identified by	mobile application that	determination
A-CHESS		participants	provided monitoring,	theory
	Study design: Unmasked randomized clinical	h	information, communication,	
	trial	Mechanism of	and support services from	Behavioral: Warning
		delivery: Study team	counselors. Overall the A-	messages sent in
	Target population: People with diagnosed	geofenced user	CHESS group reported fewer	risky areas
	alcohol dependence discharged from	identified high-risk	risky drinking days at follow-	
	residential treatment	locations and sent	up (p=0.003)	Social: Informational
		alerts to the user's		support with
	Sample size: 349	smartphone asking if		counselors
		they wanted to be		
	Duration of follow-up: 8 months	there		Cognitive: Passive
				and real-time
	Outcome of interest: Risky drinking days in the			capture of
	previous 30 days			information shared
				with counselors
Nguyen et al.,	Study purpose: Evaluate the use of	<i>User input:</i> None	Remote- The application	Theoretical
2017	smartphone-based geofencing for tracking		detected 800 unique	framework: None
	hospitalizations	Mechanism of	participants in a geofenced	listed
Ginger.io		delivery: The app was	location with a positive	
		programmed with all	predictive value between 65-	

	Study design: Remote and in-person arm	U.S. hospitals	78% based on how	Behavioral
	validation of1 a mobile application that	geofenced. A	hospitalization was	
	detected hospitalizations and length of	notification was sent	confirmed. Most common	Social
	hospitalization	to within 1 hour of	error in detection was the	
		leaving the hospital	participant was a medical	Cognitive: Sense
	Target population: Remote- participants from	vicinity asking	center employee.	safety in provid
	the Health eHeart study with a smartphone	participants to		knowing your
	In-person- Patients scheduled for	confirm if they	In person- Visits were	hospitalization
	electrophysiology and cardiac catheterization	received medical care	detected in 17/22 with	status
	procedures.		confirmed hospitalization.	
			Mean visit duration was not	
	Sample size: Remote- 3,443; In person- 22		correlated with actual	
			hospital length of stay.	
	Duration of follow-up: Remote- mean of 260		,	
	days; In person- Duration of their scheduled			
	procedure	6		
	Outcome of interest: Detection of			
	hospitalization			
Naughton et	Study purpose: Feasibility and acceptability of	User input: Geofences	User engagement with the	Theoretical
al., 2016	a mobile application using geofencing to	based on user habits	application varied from 60%	framework: Lea
	deliver tailored place-based intervention	and reports of	of days pre-quit and 39%	theory and
Q Sense	messages	smoking locations	post-quit (52% excluding	taxonomy of
			outliers).	smoking behavi
	Study design: Explanatory sequential mixed	Mechanism of		change
	methods	delivery: If a smoker	Geolocation was collected on	
		reported smoking in	97% of smoking reports with	Behavioral: Cop
	Target population: Tobacco smokers willing to	the same proximity,	high accuracy. A mean of 1.5	and resilience
	set a quit date within 1 month	the device created a	geofences were created per	regarding smok
		geofence around that	participant with 87% having	triggers
	Sample size: 15 in quantitative arm and 13	area with a radius of	at least one. 5/9 participants	
	qualitative interviews	100m. When a user	eligible to receive a	Social
		entered the geofence	geofenced triggered message	
		for greater than 5	received at least one.	Coanitive

	Duration of follow-up: Pre-quit period (up to 1 month) and 2 weeks post-quit date	minutes a location- tailored support	Environmental constraints	
		messaged was	and forgetfulness were	
	Outcome of interest: 1) User engagement with	triggered	common reasons for	
	app; 2) Assess app's location-sensing accuracy;		forgetting to engage with	
	3) Feasibility of georence mechanism; 4)		app. Participants were	
	Limitations of everyday use of app		the gentlement and	
			had no privacy concerns	
Dorsch at al	Study nurness: Effectiveness of the	User input: Mixed	There was a significant	Theoretical
	LowSalt 41 if a mobile and an maintaining a low	Coofoncos woro	decrease in sodium exerction	framowork: Theory
2020	codium diat and controlling blood pressure	created based on user	(p=0.03) and decrease in	of Planned Rehavior
LowSalt/Life	sourd in diet and controlling blood pressure	input as well as from a	(p=0.03) and decrease in	of Flatified Bellavior
LOWSalt+Life	Study design: Unblinded randomized control	nredictive service	dietary recall $(p=0.01)$ and in	Rehavioral: Dietary
	trial	when a narticinant	the App group vs po App	messages sent when
		entered a grocery	groups Blood pressure	narticinant is in
	Target population: Adults diagnosed with	store restaurant or	decreased by 1.7 mmHg in	areas where they
	hypertension and taking antihypertensive	home	the App group compared to	would
	medication	nome.	0.7 in the no App, but the	purchase/consume
		Mechanism of	change was not significant	food
	Sample size: 50 randomized	delivery: Contextual	(p=0.12).	
		adaptive messages	() () () () () () () () () () () () () (Social: Informational
	Duration of follow-up: 8 weeks	were sent to	\mathbf{O} .	support regarding
		participant's phones		which products and
	<i>Outcome of interest:</i> Changes in 24-hour	when entering a		food choices had
	dietary recall and sodium intake, urine sodium	geofence, with		lower sodium in
	excretion, blood pressure	messages linked to		context of place
		content in the mobile		•
		application		Cognitive
DeFilippis et	Study purpose: Determine the feasibility of	User input: None	The system was active on 4	Theoretical
al., 2017	patients with ventricular assist devices care		occasions, each of which the	framework: None
	engagement with and feasibility of a	Mechanism of	participant confirmed they	listed
Position Health	geofencing notification system.	delivery: Geofences	were at or near the hospital	
		were drawn around	but were not seeking care. 1	Behavioral

	Study design: Feasibility study with	emergency	patient reported seeking ED	
	quantitative and qualitative measures	departments (ED)	care but did not receive a	Social
		across the U.S. Once	ping.	
	Target population: Adults with a ventricular	the application		Cognitive: Sense o
	assist device (VAD)	detected that a	Most patients responded	safety to
		participant	favorable to their impression	participants that
	Sample size: 21	approached an ED, a	of the application stating	emergency room
		prompt was sent to	that it "gave them peace of	and hospitalizatio
	Duration of follow-up: 6 months	their phone to confirm	mind."	could alert their V
		if they were seeking		provider regarding
	Outcome of interest: Proper detection of	care at that hospital. If		the need to
	emergency department utilization by	yes, another prompt		coordinate care
	participant and satisfaction with mobile	asked the participant		
	application.	to confirm if the app		
		could notify their VAD		
		healthcare team. If		
		'yes' to both, a		
		notification was sent		
		to the covering		
		provider's pager with		
		participant name and		
		contact.		
Connor &	Study purpose: Determine the feasibility and	User input: None	Use of the geofencing	Theoretical
Herzig, 2016	acceptability of a mobile application that allow		application showed a	framework: None
	automatic capture of work hours without	Mechanism of	significant correlation of	listed
Stat!	manual employee input	delivery: Geofences	early departures following	
		were drawn around	late departures the previous	Behavioral
	Study design: Feasibility study	hospitals where the	day (p<0.01 in 73 of 91	
		anesthesia group	occasions), and better	Social
	Target population: Anesthesia providers in a	provided services.	dispersion of working hours	
	private practice group	When the provider	(p=0.002) compared to the	Cognitive: Sense c
		enters a geofence,	previous year.	security regarding
	Sample size: 198	their time at the		equitable
		facility is continuously		distribution of wo

	Duration of follow-up: 12 months	checked and reported	Acceptance of the mobile	based on geofenced
		to a central server.	application was slow to start	data and capture of
	Outcome of interest: Equitable workload	Reports were then	but >95% in less than 1 year	time working for
	distribution, employee acceptance and uptake,	used to inform future	of roll out	billing purposes
	and reduced dispersion of the amount of	clinical responsibilities		
	overtime worked by staff	and overtime worked		
Besoain et al.,	Study purpose: Prevent sexually transmitted	User input: Mixed. Hot	All users triggered a	Theoretical
2020	infections (STIs) by sending preventive	zones were created by	geofenced hotzone during	framework:
	measures in risky situations	a system	the development phase,	Elaboration
UBESafe		administrator and	though this was not	likelihood model
	Study design: Development and feasibility	with input from users	quantified further. Hot zones	
			were seen as a necessary	Behavioral:
	Target population: Men who have sex with	Mechanism of	component from those	Contextual
	men	delivery: Geofenced	testing in the development	messages for sexual
		hot zones are areas	phase.	risk reduction sent
	Sample size: Development-5; Feasibility- 4	demines with a high		in hot spots for high-
		probability for	In the feasibility phase, users	risk intercourse
	Duration of follow-up: Development- 2 weeks;	intercourse. When	tested and rated prevention	
	Feasibility- 1 month	users enter a hot	messages as well as adding	Social: Gamification
		zone, a contextual	their own.	of preventive
	Outcome of interest: Development- functional	message to prevent		messages and
	testing to receive user feedback; Feasibility-	HIV and STIs, and	Users also contributed to hot	interaction with
	try the UBESAFE system with all its	promote testing	zones and tested existing	others using the
	functionalities		ones, contributing 65% of	application
			hot zones in the application	
			at the end of the study.	Cognitive
PRISMA 2020 Checklist

3 4	Section and Topic	ltem #	Checklist item	Location where item is reported
5	TITLE			
6 7	Title	1	Identify the report as a systematic review.	√ title
8	ABSTRACT	•		
9	Abstract	2	See the PRISMA 2020 for Abstracts checklist.	
10	INTRODUCTION	I		
11	Rationale	3	Describe the rationale for the review in the context of existing knowledge.	√ Lines 122-130,
12				133-134
14	Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	√ Lines 123-130,
15 16			í b	134-137
17	METHODS			
18	Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	√ Lines 167-171
20	Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies.	√ Lines 174-179
21 22				√ Lines 179-180
23	Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	√ Lines 174-179
24 25 26	Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	√ Lines 181-189
27 28	Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation	√Lines 182-183
29			tools used in the process.	√Lines 191-198
30 31	Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	√Lines 194-196
 32 33 34 35 36 37 38 39 40 41 42 43 44 45 		10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information. For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml	✓Lines 220-221, types of geofencing methods; 231- 232, intervention content delivery; line 242, outcomes of interest; lines 256, indirect int. outcomes; line
46 47				

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PRISMA 2020 Checklist

3	Section and Topic	ltem #	Checklist item	Location where item is reported
5 6 7 8 9 10 11				269, acceptability measures; line 280, place-based mechanisms; line 293, reporting & quality measures
12 13 14	Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	✓ Lines 182-189
15	Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NA
16 17	Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	√ lines 201-207
18 19		13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	NA
20		13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	
22 23		13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	NA
24 25		13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta- regression).	NA
26		13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NA
27 28	Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	√ Lines 295-301
29 30	Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	√Line 301
31	RESULTS			
32 33 24	Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	√Lines 201-307
35		16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	√Lines 203-206
36 37	Study characteristics	17	Cite each included study and present its characteristics.	√ Table, page 18
38 39	Risk of bias in studies	18	Present assessments of risk of bias for each included study.	√Line 301
40 41	Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	√Apprendix 1
42 43	Results of	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	√Line 221-292
44 45	synuneses	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible/interval) and intervale of statistical waterogenery. (Proving any of the direction of the	NA
46 47				

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PRISMA 2020 Checklist

Section and Topic	ltem #	Checklist item	Location where is reported	
		effect.		
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA	
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA	
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Lines 346-350; Li 301	
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Lines 346-350; Li 301	
DISCUSSION	1			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.		
	23b	Discuss any limitations of the evidence included in the review.	Lines 344-349	
	23c	Discuss any limitations of the review processes used.	346-347	
	23d	Discuss implications of the results for practice, policy, and future research.	Lines 352-362	
OTHER INFORMATION				
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Line 180	
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Line 180	
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA	
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	√Page 19	
Competing interests	26	Declare any competing interests of review authors.	√ Page 19	
Availability of data, code and	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Data sharing statement page 1	

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Location where item

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Use of Geofencing Interventions in Population Health Research: A Scoping Review

Journal:	BMJ Open
Manuscript ID	bmjopen-2022-069374.R1
Article Type:	Original research
Date Submitted by the Author:	26-Jun-2023
Complete List of Authors:	Tobin, Karin ; Johns Hopkins University Bloomberg School of Public Health, Health, Behavior and Society Heidari, Omeid; University of Washington School of Nursing, Child, Family and Population Health Nursing Volpi, Connor; Johns Hopkins University Bloomberg School of Public Health, Health, Behavior and Society Sodder, Shereen; Johns Hopkins University Bloomberg School of Public Health, Health, Behavior and Society Duncan, Dustin; Columbia University Mailman School of Public Health, Department of Epidemiology
Primary Subject Heading :	Public health
Secondary Subject Heading:	Mental health
Keywords:	EPIDEMIOLOGY, HIV & AIDS < INFECTIOUS DISEASES, MENTAL HEALTH, PUBLIC HEALTH

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Use of Geofencing Interventions in Population Health Research: A Scoping Review

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Word Count Manuscript: 3261

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Abstract

Objectives: Technological advancements that utilize global positioning system (GPS), such as geofencing, provide the opportunity to examine place-based context in population health research. To systematically identify, assess, and synthesize the existing evidence on geofencing intervention design, acceptability, feasibility, and/or impact.

Design: A scoping review using the PRISMA-ScR guidance for reporting.

Data Sources: PubMed, CINAHL, EMBASE Web of Science, Cochrane, and PsychINFO for articles in English published by December 31st, 2021.

Eligibility Criteria: Articles were included if geofencing was utilized as a mechanism for intervention delivery. Exclusion criteria: 1) a component or combination of GPS, geographic information system (GIS), or ecological momentary assessment (EMA) was utilized without delivery of an intervention; 2) did not include a health or health-related outcome from the geofencing intervention; or 3) was not a peer-reviewed study.

Data extraction and synthesis: Several researchers independently reviewed all abstracts and full-text articles for final inclusion.

Results: A total of 2171 articles were found. Nine studies were included. The majority were published in five years preceding the search (89%). Geofences in most studies (n=5) were fixed and programmed in the mobile application carried by participants without their input. Mechanisms of geofencing interventions were classified as direct or indirect with five studies (56%) utilized direct interventions. There was a variety of health outcomes (from smoking to problematic alcohol use) across the five studies that utilized an direct geofencing intervention. **Conclusions:** This review found geofencing to be an emerging technology that is an acceptable and feasible intervention applied to various populations and health outcomes. Future studies

should specify the rationale for the locations that are geofenced and user input. Moreover, attention to mechanisms of actions will enable scientists to understand not only whether geofencing is an appropriate and effective intervention but why it works to achieve the outcomes we observe.

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Strengths and Limitations

- The scoping review was comprehensive utilizing six rigorous databases.
- The review used the Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for Scoping Reviews (PRISMA-ScR) checklist.
- The review only included studies conducted in the United States which has limited generalizability to other international settings.
- L Jugh the L Jications. The review was conducted through the published literature through 2021 and therefore does • not include more recent publications.

Introduction

Population health outcomes and health disparities result from multi-level factors beyond the individual. For example, poverty can lead to a lack of access to healthy food¹ and medical care²; unstable housing can lead to inability to adhere to medications ³ and exposures to unhealthy environments⁴; homophobia and racism leads to stigma and discrimination, and mistrust and avoidance of medical systems.⁵⁻⁷

Often in behavioral research, theories or frameworks do not consider the place-based context of behavior despite literature on the consistent and enduring impact of places such as neighborhoods and communities on population health outcomes and disparities.⁸⁻¹⁰ Place-based context can be conceptualized as both geographic areas defined by boundaries or as socially constructed out of symbolic meanings *and* social relations.^{11,12} In both cases, place-based context operates to perpetuate hierarchical social structures, facilitate and constrain resources, and protect or hinder health. Moreover, place-based context may facilitate specific health-related interactions such as drug or alcohol use, experiences of violence, or engagement in healthcare. Yet behavioral interventions often conceptualize place-based context as static (e.g., place of risky sex) and do not consider how place-based contexts vary over time. Real-time geospatial methods, including the use of global positioning system (GPS) technology, are the cutting-edge, best-suited methods to overcome limitations of most neighborhoods and other environments health research because they better capture place-based contexts corresponding to individuals' lived experiences, referred to as "activity space".¹⁴⁻¹³

There are numerous types of GPS-based methods that collect data from individuals and in some cases deliver intervention content. For example, ecological momentary assessment (EMA) has been shown to be an acceptable method of data collection.¹⁴ Ecological Momentary

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Interventions (EMI) allow researchers to deliver intervention content through mobile devices.¹⁵ Just-in-time adaptive interventions (JITAI) attempt to address the changing needs of an individual where the intervention algorithm is programmed to determine if and what intervention content should be delivered to participants at set times throughout the day, whenever a participant requests one, or based on the participant's current state (e.g., stress) or environmental changes (e.g., weather).¹⁶⁻¹⁷ Finally, geofences are virtual boundaries drawn around a location and allow for monitoring and messaging when individuals enter or exits the geofenced parameter.¹⁸ Geofencing interventions are a subset of JITAI where there is continuous monitoring of the participant's location using GPS and delivery of an intervention such as text messages or links to health information or information about health services that are in the area based on a spatial context trigger. A geofence involves creating virtual predefined set of boundaries or "fences" around a geographic location, including using GPS technology. Geofencing methodology can be used in public health research – both in observational and intervention studies. Thus, geofencing can be a valuable tool in intervention research, enabling researchers to study and implement interventions in specific geographic areas. For example, geofencing allows researchers to precisely target specific areas for intervention. In addition, geofencing allows researchers to send location-based notifications (an intervention) to participants, including on their mobile devices. One example of this in the public health setting is the use of geofencing to monitor movements of individuals who tested positive for COVID-19 virus.19

Reviews of JITAI and EMI show the promising potential of this evolving technology²⁰⁻²², yet, such reviews are noted to lack the inclusion of geofencing, representing a major gap in the literature. This gap is vital to address as geofencing has the capability to address an array of

different health issues ranging from tobacco cessation to HIV medication adherence. The lack of a clear and systematic understanding of the scope of geofencing interventions undermines its potential to impact population health. The purpose of this scoping review is to describe of the state of the evidence on geofencing intervention design, acceptability, feasibility, and impact. In addition, we examine what behavioral mechanisms were targeted across the interventions assessed, as discussed below.

Conceptualizing mechanisms of action

Another limitation in the literature of EMA and JITAI interventions is the lack of attention to specific mechanisms of action that operate to achieve outcomes.²³ Therefore, we sought to develop a framework based on several complementary theories and frameworks (e.g., Turan's HIV Stigma Framework and Social Cognitive Theory²⁴⁻²⁶) to evaluate geofencing interventions included in this review. The framework posits three key mechanisms operate for place-based context to influence health outcomes (Figure 1). Each mechanism has both a protective and risk dimension. The <u>Cognitive mechanism</u> includes cognitive processes such as sense of control, knowledge, attitudes, self-efficacy, maladaptive thoughts, risk perceptions and internalized stigma.²⁷⁻³² The <u>Behavioral mechanism</u> refers to both protective behaviors such as adaptive coping as well as risky behaviors such substance use, condomless sex and non-adherence to medication and care.^{33-35 36} The <u>Social mechanism</u> refers to interactions with others in the personal social networks and broader community such as emotional or instrumental support or enacted stigma and conflict which have been shown to exacerbate or mitigate health outcomes.³⁷⁻³⁹ The framework can be applied to multiple spatial scales from a micro-level (e.g. a room in

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one's residence) to community-level (e.g. a neighborhood activity space or census tract) to macro (e.g. state, region).

[Figure 1 here]

Methods

This systematic review was conducted in accordance with the 2018 PRISMA Extension for Scoping Reviews checklist.⁴⁰

Inclusion criteria

Articles were only included if they included if geofencing was utilized as a mechanism for intervention delivery. Articles were excluded if 1) a component or combination of GPS, geographic information system (GIS), or ecological momentary assessment (EMA) was utilized without delivery of an intervention; 2) did not include a health or health-related outcome from the geofencing intervention; or 3) was not a peer-reviewed study.

Search strategy

Authors first met to develop the list of potential search terms and refined after initial searchers were conducted. Then searches were conducted in PubMed, CINAHL, EMBASE Web of Science, Cochrane, and PsychINFO for articles published through the end of 2021 (Appendix 1). Search terms were for broad concepts regarding mobile delivery of a geofencing intervention: "Geographic Information Systems"; "Georeferencing"; "Global Positioning System"; or "Geofenc*" combined with "Smartphone" or "Mobile Applications." The search was conducted on 12/1/2022 and was not registered. A protocol was not prepared.

Study selection

Screening of article titles and abstracts was conducted with two reviewers (SS, CV) in maximize scrutiny of all records. Each reviewer independently screened all articles identified from the initial search for relevance to the pre-defined inclusion criteria that was highlighted during a training session where it was emphasized that the reviewers should apply a liberal approach. Next, the same two reviewers independently reviewed each of the full texts for inclusion in the data extraction phase. Any disagreements in both phases were adjudicated by a third reviewer (OH). In all phases reviewers were not blinded to authors, funding, or information regarding publication of all the records.

Data extraction

Two reviewers (OH, KT) extracted data for details of study design, target population, sample size, duration of follow-up, theoretical framework, software or mobile application use, goal, and mechanism of geofenced intervention, and impact of the intervention of outcomes. Place-based mechanisms associated with the intervention included: 1) Behavioral, 2) Social support: Emotional, Instrumental, Informational, and Social monitoring, and 3) Cognitive. Finally, established guidance for reporting health intervention using mobile phone was utilized to evaluate the quality of each article.⁴¹

Patient and Public Involvement

None

Results

Included studies

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Using the search strategy in six identified databases, a total of 2,171 articles were found after removing duplicates. 2,039 (94%) studies were irrelevant and 132 (6%) full text studies were assessed for eligibility (Supplementary Table 1). Reasons for exclusion of the 123 articles in the full-text phases included the article not being peer reviewed (n=46, 37%), a review articles (n=19, 16%), was not the correct study design or intervention (n=14, 11%), or utilized a combination of GPS, GIS, and or Ecological Momentary Assessment, but was not a geofencing intervention (n=44, 36%). Nine studies were included in this scoping review.

Study characteristics

The majority were published in five years preceding the search (89%) (Supplemental Table 1). Most employed a pre/post study design to assess changes in measured outcome or feasibility and acceptability of the geofencing intervention (78%) with 2 unblinded randomized control trials. Sample sizes ranged from 4 to 3,443; one study's intervention quantified its reach with the geofencing intervention displaying on 516,073 mobile phones, though these impressions do not represent unique individuals receiving the intervention.⁴² Most studies (78%) were conducted in the United States, one in the United Kingdom⁴³ and one in Spain.²³

A description of studies, including the names of the mobile applications used, study design and characteristics, and place-based mechanisms are detailed in Supplemental Table 1.

The design of the geofencing interventions varied based on user input and content delivery.

Geofencing methods: User input

Geofences in most studies (n=5) were fixed and programmed in the mobile application without participant input. These included hospital emergency departments^{18,44}, hospitals where participants worked^{45,46}, and a specific rural dental clinic⁴². Two studies utilized participants

input in determining where to geofence related to smoking⁴³ or problematic alcohol use⁴⁷. Two studies utilized a mix of fixed and user input. Dorsch et al. utilized user input to geofence locations where foods were consumed or purchased as well as a cloud-based web service to predict when participants entered grocery stores or restaurants. Besoain et al., used a moderated system where participants suggested locations to geofence that were venues for high-risk sexual encounters, but these venues were moderated by the study team and locations could be added or removed.

Intervention content delivery: Direct versus Indirect

Intervention content was delivered in direct or indirect methods. Five studies (56%) sent participants intervention content directly to their phones based on triggering the geofence boundary. These interventions included informing individuals living in a rural area of a dental clinic⁴² or sending behavioral messages regarding problematic alcohol use when near a bar⁴⁷, smoking cessation in areas detected as high likelihood of smoking⁴³, making low-sodium diet choices in grocery stores, restaurants, or at home, or HIV and STI prevention messages when in venues associated with high-risk sexual activity²³. The remaining 4 studies were categorized as indirect as they collected data when participants triggered geofence boundaries and in some cases delivered content at a later time from when the fence was triggered.

Impact of the interventions

There was not a consistent health outcome across the five studies that utilized a direct intervention. Both studies that utilized a randomized control design showed improved outcomes in the group randomized to geofencing. A-CHESS sent context and place-based messages and

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included multiple other services such as a phone and data plan, access to a virtual counselor, and other interactive features (Table 1).⁴⁷ LowSalt4Life contained features including low sodium options and alternatives at grocery stores or restaurants, and the ability to scan product barcodes to find similar low sodium options. O Sense intervention participants decreased from 60% of pre-quit smoking days to 39% post-quit. UBESafe intervention reported that all participants were able to trigger a hot zone where sexual contacts often took place and received a place-based prevention message.²² Finally, Wright et al.,⁴¹ used a pre/post design, and found increases in community knowledge about the dental clinic (p=0.045) and increased number of dental visits Sec. post intervention.

Indirect intervention outcomes

Two studies used the geofence to track time working from medical practitioners or surgical residents (Supplemental Table 1). Owei et al., found the mean number of working hour violations for surgical residents' post-intervention significantly decreased (p=0.04) compared to pre-intervention and compared to the previous year (p < 0.01).⁴⁴ Connor et al., showed a significant correlation of early departures from operating room duties following late departures the previous day (p < 0.01) and better dispersion of working hours (p = 0.002) compared to the previous year.⁴⁵ Two other studies geofenced major hospitals to detect hospitalization of high priority patients. Nguyen et al., found the geofenced mobile application detected 800 unique participants who triggered a geofence, with a predictive value of true hospitalization between 65-78%.¹⁸ Similarly, from a sample size of 21, 4 of the participants activated the alert system for patients with a ventricular assist device to their on-call care team when they triggered an emergency room geofence.44

Acceptability measures

Five studies reported data regarding acceptability of the geofencing mobile application in which all participants were positive regarding the value of the intervention. Participants in two studies with indirect intervention found the application useful and described knowledge of being monitored provided a sense of security^{44,45}. Additionally, participants in two studies did not have concerns regarding the continuous geolocation tracking for intervention purpose^{43,45}, but did stress the importance of transparency regarding the use of this data⁴³. Finally, in one interactive study, participants contributed to the creation and curation of geofenced hot zones as well as the prevention messages received when hot zones were triggered, accounting for 67% of hot zones iler created and used by the study²³.

Place-based mechanisms

Four studies utilized a behavioral mechanism in their geofencing intervention.^{23,43,47,48} Four studies utilized a social mechanism which included informational support such as existence of a rural dental clinic⁴² and availability of menu grocery store items that were low in sodium.^{23,42,47,48} Additionally, participants were able to interact with counselors though the application and review their data concerning visiting high-risk locations for further intervention⁴⁷ or sharing context specific messages with other users on the application.²³ Finally, five studies utilized a cognitive mechanism that provided the participant a sense of safety, security, or knowing that their information was captured.^{46,47} These included reporting to care teams when the participants

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were hospitalized^{18,44}, capture of time and effort spent working in a clinical environment^{45,46}, and participants counselor viewing their location and interacting with their place-based data of proximity and time spent in high-risk areas for binge drinking.⁴⁷

Reporting and quality measures

From the 16-point checklist, all included studies reported on 6 items (Suplemental Table 2). Position Health⁴⁴, Statl⁴⁶, and ResQ⁴⁵ studies described how the intervention and data collected integrated into an existing health information system and described some data security procedures. A-CHESS⁴⁷ and the Wright et al.,⁴¹ intervention conducted some cost assessment regarding the delivery of the intervention or cost to the participant to utilize the participant. Finally, no study reported on compliance of the intervention or data collection mechanism compliance with national guidelines or federal statutes. We did not assess confidence in the body of evidence or risk of bias.

Discussion

The purpose of this review was to describe the use of geofencing as an intervention and mechanisms that were targeted to achieve various health outcomes. A geofence involves creating virtual predefined set of boundaries or "fences" around a geographic location, including using GPS technology. Geofencing methodology can be used in public health research – both in observational and intervention studies. Thus, geofencing can be a valuable tool in intervention research, enabling researchers to study and implement interventions in specific geographic areas. For example, geofencing allows researchers to precisely target specific areas for intervention. In addition, geofencing allows researchers to send location-based notifications (an intervention) to participants, including on their mobile devices. We identified only 9 studies that fit criteria and

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as expected, most publications were relatively recent. We found that the design of the geofencing intervention varied yet acceptability was good among study participants and impact was not assessed in all studies.

Of the studies included, only one was focused on a sexual and gender minority sample and only one with majority Black, Indigenous People of Color (BIPOC), who experience disparities on a vast number of health outcomes due to social and structural factors such as racism and homophobia.²³ Lack of inclusion of these populations is a significant gap that should be monitored as more studies are conducted. In addition, most studies were in the U.S. (North America) with no studies in developing countries, South America, Africa or Asia, which could represent an important opportunity.

The included studies described a range of user input of the geofenced locations from researcher only selection to user selection. This characteristic of an intervention merits consideration. User selection of geofenced locations may be prone to bias and recall issues.⁴⁹ Researcher selected locations may not consider the variability of their sample's place-based contexts and may under count locations that should be geofenced. The hybrid approach has the potential to address both limitations. Future studies using geofencing technology may warrant comparative studies of the user input approaches and be specific about the rationale for the type of locations that are geofenced and the user input of these so that studies can be comparable and be conducted in non-western contexts.

Some of the interventions explicitly identified a theoretical model or foundation, and all the studies described targeting at least one of the mechanisms of action from our proposed framework. The studies in which the geofencing intervention targeted the cognitive mechanism were primarily addressing surveillance of the participants and messages to cue cognitions about

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their location. Cueing is a significant component of many effective interventions as they serve as reminders to engage in behaviors of interest.⁵⁰⁻⁵² For example, wearing a bracelet that has a phrase as a reminder to take medication. Cues can focus on both the protective and risk dimensions of the mechanism. For example, if an individual triggers a geofence of a place they have identified as associated with a sense of control, a geofencing intervention could sent a text message that reminds the individual to to engage in self-care. In places where stigma is anticipated a geofencing intervention can send a text message that reminds the individual about adaptive coping behaviors.

Studies utilizing the behavioral mechanism described very specific behavioral targets such as buying lower sodium food, avoiding places of alcohol use, condom use and smoking cessation. As building self-efficacy is a well-established theoretical construct necessary for behavioral change²⁴, future studies should include opportunities to watch the desired behaviors be role-modeled and practiced to enhance the efficacy of the geofencing intervention.⁵³

Studies that utilized the social mechanism were focused on the provision of both informational and emotional support. One study included a component in which the participants could create messages for other user of the geofencing application. As there are different types of social support (e.g., emotional, appraisal, economic and informational) future studies should be specific and transparent about the types being targeted. With additional geofencing studies, a future review can be conducted using meta-analytic methods to determine the quantitative effectiveness of geofencing interventions in population health research.

Limitations

The search strategy was limited to English articles in PubMed, CINAHL, EMBASE Web of Science, Cochrane, and PsychINFO and we acknowledge other publications may not have been captured with these. There was heterogeneity in how studies reported intervention development, theoretical frameworks, and feasibility and acceptability of the intervention. This reduced the ability to properly assess the extent of behavioral mechanism utilized for the given outcome. Additionally, as geofencing is a new technology, not many peer-reviewed articles have been published and this scoping review chose to exclude conference abstracts.

Conclusions

In conclusion, this scoping review indicates that geofencing is an emerging acceptable and feasible intervention that has been applied to a variety populations and health outcomes.²³ Attention to the mechanisms of actions will enable the field to understand not only whether geofencing is an appropriate and effective intervention but why it works to achieve the outcomes we observe. There is a need for future research that includes sexual and gender minority and BIPOC populations and populations from non-Western contexts to achieve the Health People Framework objectives given the persistent findings that BIPOC and SGM populations. These studies could address those health outcomes where disparities are stark such as HIV/AIDS, cardiovascular, diabetes, COVID-related and mpox. Finally, future research can reveal place-based contexts that have not been considered which can inform resource allocation and targets for health-promoting policies.

Figure Caption: Types of mechanisms of action, protective and risk factors as well as spatial scales in geofencing interventions in population health research.

Contributorship statement

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3	Drs. Tobin and Heidari contributed equally to this manuscript.
4	KT OH and DD planned the study
5	KT, OH CV and SS acquired data and conducted the analysis for this study
6	KT, OH, CV and SS acquired data and conducted the analysis for this study.
7	KT, OH and DD equally contributed to writing and finalizing the manuscript.
8	Competing interests
9	Karin E. Tobin, Omeid Heidari, Connor Volpi, Shereen Sodder and Dustin T. Duncan declare
10	that they have no conflict of interest
11	that they have no conflict of interest.
12	
13	Funding
14	This work was supported by a grant from the National Institute of Mental Health R34MH118178
15	
15	Data sharing statement
10	All data subscriptions the data and in the estimate and in the estimate and a data successful and the second
17	All data relevant to the study are included in the article or uploaded as supplementary
18	information
19	
20	Ethics Approval
21	Ethics approval was not required as the scoping review is based on published studies
22	Ethics approval was not required as the scoping review is based on published studies,
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References:

1. Larson NI, Story MT, Nelson MC. Neighborhood environments: disparities in access to healthy foods in the US. *American journal of preventive medicine*. 2009;36(1):74-81. e10.

2. Lazar M, Davenport L. Barriers to health care access for low income families: a review of literature. *Journal of community health nursing*. 2018;35(1):28-37.

3. Kalichman SC, Kalichman MO. HIV-related stress and life chaos mediate the association between poverty and medication adherence among people living with HIV/AIDS. *Journal of clinical psychology in medical settings*. 2016;23(4):420-430.

4. Taylor SE, Repetti RL, Seeman T. Health psychology: what is an unhealthy environment and how does it get under the skin? *Annual review of psychology*. 1997;48

5. Earnshaw VA, Bogart LM, Dovidio JF, Williams DR. Stigma and racial/ethnic HIV disparities: moving toward resilience. 2015;

6. Lutete P, Matthews DW, Sabounchi NS, et al. Intersectional Stigma and Prevention Among Gay, Bisexual, and Same Gender–Loving Men in New York City, 2020: System Dynamics Models. *American journal of public health*. 2022;112(S4):S444-S451.

7. Quinn K, Dickson-Gomez J, Zarwell M, Pearson B, Lewis M. "A gay man and a doctor are just like, a recipe for destruction": How racism and homonegativity in healthcare settings influence PrEP uptake among young Black MSM. *AIDS and Behavior*. 2019;23(7):1951-1963.

8. Arcaya MC, Tucker-Seeley RD, Kim R, Schnake-Mahl A, So M, Subramanian S. Research on neighborhood effects on health in the United States: a systematic review of study characteristics. *Social Science & Medicine*. 2016;168:16-29.

9. Duncan DT, Kawachi I. *Neighborhoods and health.* vol 10. Oxford University Press New York; 2018.

10. Rifkin SB. Examining the links between community participation and health outcomes: a review of the literature. *Health policy and planning*. 2014;29(suppl_2):ii98-ii106.

11. Gesler WM. Therapeutic landscapes: medical issues in light of the new cultural geography. *Social science & medicine*. 1992;34(7):735-746.

12. Keene DE, Padilla MB. Spatial stigma and health inequality. *Critical public health*. 2014;24(4):392-404.

13. Duncan DT, Kawachi I, Subramanian S, Aldstadt J, Melly SJ, Williams DR. Examination of how neighborhood definition influences measurements of youths' access to tobacco retailers: a methodological note on spatial misclassification. *American journal of epidemiology*. 2014;179(3):373-381.

14. Palmer JR, Espenshade TJ, Bartumeus F, Chung CY, Ozgencil NE, Li K. New approaches to human mobility: Using mobile phones for demographic research. *Demography*. 2013;50(3):1105-1128.

15. Heron KE, Smyth JM. Ecological momentary interventions: incorporating mobile technology into psychosocial and health behaviour treatments. *British journal of health psychology*. 2010;15(1):1-39.

16. Wang L, Miller LC. Just-in-the-moment adaptive interventions (JITAI): A metaanalytical review. *Health Communication*. 2020;35(12):1531-1544.

17. Nahum-Shani I, Smith SN, Spring BJ, et al. Just-in-time adaptive interventions (JITAIs) in mobile health: key components and design principles for ongoing health behavior support. *Annals of Behavioral Medicine*. 2018;52(6):446-462.

BMJ Open

3	18 Nguyen KT Olgin JE Pletcher MJ et al Smartphone-based geofencing to ascertain
4	hospitalizations Circulation: Cardiovascular Quality and Qutcomes 2017:10(3):e003326
5	10 Abmed N Michelin RA Yue W at al A survey of COVID 10 contact tracing apps
6	IFEE = 2020.9.124577 + 124(0)
7	<i>IEEE access</i> . 2020;8:134577-134601.
8	20. Carpenter SM, Menictas M, Nahum-Shani I, Wetter DW, Murphy SA. Developments in
9	mobile health just-in-time adaptive interventions for addiction science. <i>Current addiction</i>
10	reports, 2020;7(3):280-290.
11	21 Naughton F. Delivering "Just-In-Time" smoking cessation support via mobile phones:
12	aurrent knowledge and future directions. <i>Nicoting & Tobacco Research</i> 2017:10(2):270-282
13	current knowledge and future directions. <i>Nicotine & Tobacco Research</i> . 2017,19(5).579-585.
14	22. Thomas JG, Bond DS. Review of innovations in digital health technology to promote
15	weight control. Current diabetes reports. 2014;14(5):1-10.
16	23. Besoain F, Perez-Navarro A, Aviñó CJ, Caylà JA, Barriga NA, de Olalla PG. Prevention
17	of HIV and other sexually transmitted infections by geofencing and contextualized messages
18	with a gamified app UBESAFE: design and creation study <i>JMIR mHealth and uHealth</i>
19	$2020.8(3) \cdot 14568$
20	2020,6(5).014508.
21	24. Bandura A. Social cognitive theory. An agenic perspective. Asian journal of social
22	psychology. 1999;2(1):21-41.
23	25. Turan B, Hatcher AM, Weiser SD, Johnson MO, Rice WS, Turan JM. Framing
24	mechanisms linking HIV-related stigma, adherence to treatment, and health outcomes. American
25	<i>journal of public health</i> . 2017:107(6):863-869.
26	26 Macintyre S Ellaway A Cummins S Place effects on health: how can we concentualise
27	20. Inductive 5, Endway A, Cammins 5. Frace creces on nearly now can we conceptualise,
28	27 Khowahana and T. Man alkally a surply C. Mannhiam W. Anisamthananaly A.
29	27. Knawcharoenporn I, Mongkolkaewsub S, Naljitra C, Knonphiern W, Apisarntnanarak A,
30	Phanuphak N. HIV risk, risk perception and uptake of HIV testing and counseling among youth
31	men who have sex with men attending a gay sauna. <i>AIDS research and therapy</i> . 2019;16(1):1-
32	11.
33	28. Machowska A, Bamboria BL, Bercan C, Sharma M, Impact of 'HIV-related stigma-
34	reduction workshops' on knowledge and attitude of healthcare providers and students in Central
35	India: a pro-test and post test intervention study <i>BML anen</i> 2020:10(4):e033612
36	Minuta. a pre-test and post-test intervention study. <i>DND open.</i> 2020,10(4):0055012.
37	29. MI 1, LI X, Zhou G, Qiao S, Shen Z, Zhou Y. HIV disclosure to family members and
38	medication adherence: role of social support and self-efficacy. AIDS and Behavior.
39	2020;24(1):45-54.
40	30. SeyedAlinaghi S, MohsseniPour M, Aghaei E, Zarani F, Fathabadi J,
41	Mohammadifirouzeh M. The Relationships Between Early Maladaptive Schemas. Quality of
42	Life and Self-care Behaviors in a Sample of Persons Living with HIV. The Potential Mediating
43	Polo of Cognitive Emotion Population Strategies. The Onen AIDS Journal 2020:14(1)
44	21 Stantas A. Jashaan SE. The life shills of alder Americana according with a communic
45	31. Steptoe A, Jackson SE. The file skills of older Americans: association with economic,
46	psychological, social, and health outcomes. Scientific Reports. 2018;8(1):1-10.
47	32. Yıgıt I, Bayramoglu Y, Weiser SD, et al. Changes in internalized stigma and HIV health
48	outcomes in individuals new to HIV care: The mediating roles of depression and treatment self-
49	efficacy. AIDS Patient Care and STDs. 2020;34(11):491-497.
50	Gonzalez A Barinas I O'Cleirigh C Substance use: impact on adherence and HIV
51	medical treatment Current HIV/AIDS Reports 2011.8(A):223-23A
52	24 Logio CH Williams CC Wong V at al Adapting stigms machanism from surveying to
53	54. Logie UII, winnams UU, wang 1, et al. Adapting sugma mechanism frameworks to
54	explore complex pathways between intersectional stigma and HIV-related health outcomes
55	among women living with HIV in Canada. Soc Sci Med. 2019;232:129-38.
56	
57	
58	20
59	For near raview only, http://bmianen.hmi.com/site/about/quidelines.yhtml
60	For peer review only - http://binjopen.binj.com/site/about/guidelines.xittini

35. Safren SA, Blashill AJ, Lee JS, et al. Condom-use self-efficacy as a mediator between syndemics and condomless sex in men who have sex with men (MSM). *Health psychology*. 2018;37(9):820.

36. Weinstein ER, Harkness A, Ironson G, Shrader C-H, Duncan DT, Safren SA. Life instability associated with lower ART adherence and other poor HIV-related care outcomes in older adults with HIV. *International journal of behavioral medicine*. 2022:1-11.

37. Bekele T, Rourke SB, Tucker R, et al. Direct and indirect effects of perceived social support on health-related quality of life in persons living with HIV/AIDS. *AIDS care*. 2013;25(3):337-346.

38. Koegler E, Kennedy CE. A scoping review of the associations between mental health and factors related to HIV acquisition and disease progression in conflict-affected populations. *Conflict and health.* 2018;12(1):1-22.

39. Vaughan E, Power M, Sixsmith J. Experiences of stigma in healthcare settings by people living with HIV in Ireland: a qualitative study. *AIDS care*. 2020;32(9):1162-1167.

40. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Annals of internal medicine*. 2018;169(7):467-473.

41. Agarwal S, LeFevre AE, Lee J, et al. Guidelines for reporting of health interventions using mobile phones: mobile health (mHealth) evidence reporting and assessment (mERA) checklist. *bmj*. 2016;352

42. Wright WG, Rafferty AP, Winterbauer N, Locklear K, Tucker-McLaughlin M. Geofencing: Mobile Technology as a Health Promotion Tool to Raise Awareness of a Dental Clinic in Rural North Carolina. *The Journal of Rural Health*. 2021;37(3):667-674.

43. Naughton F, Hopewell S, Lathia N, et al. A context-sensing mobile phone app (Q sense) for smoking cessation: a mixed-methods study. *JMIR mHealth and uHealth*. 2016;4(3):e5787.

44. DeFilippis EM, Safavi K, Reyes J, Coakley L, Hickey M, Givertz MM. Mobile Geolocation Technology to Improve Multidisciplinary Care of Patients with Ventricular Assist Devices: A Feasibility Study. *Journal of Cardiac Failure*. 2017;23(8):S84.

45. Owei L, Luks VL, Brooks KD, Kelz RR, Berns JS, Aarons CB. Smart-phone Based Geofencing: A Novel Approach to Monitoring Clinical Work Hours in Surgery Residency. *Journal of Surgical Education*. 2021;78(6):e210-e217.

46. Connor CW, Herzig M. Monitoring the location of staff via mobile devices in a large multifacility practice group. *A & A case reports*. 2016;6(10):320-328.

47. Gustafson DH, McTavish FM, Chih M-Y, et al. A smartphone application to support recovery from alcoholism: a randomized clinical trial. *JAMA psychiatry*. 2014;71(5):566-572.

48. Dorsch MP, Cornellier ML, Poggi AD, et al. Effects of a novel contextual just-in-time mobile app intervention (LowSalt4Life) on sodium intake in adults with hypertension: pilot randomized controlled trial. *JMIR mHealth and uHealth*. 2020;8(8):e16696.

49. Wray TB, Pérez AE, Celio MA, Carr DJ, Adia AC, Monti PM. Exploring the Use of Smartphone Geofencing to Study Characteristics of Alcohol Drinking Locations in High-Risk Gay and Bisexual Men. *Alcoholism: clinical and experimental research*. 2019;43(5):900-906.

50. Latkin CA, Hua W, Tobin K. Social network correlates of self-reported non-fatal overdose. *Drug and Alcohol Dependence*. 2004;73(1):61-67.

51. Tobin KE, Davey MA, Latkin CA. Calling emergency medical services during drug overdose: an examination of individual, social and setting correlates. *Addiction*. 2005;100(3):397-404.

52. Tobin KE, Latkin CA. Social networks of HIV positive gay men: their role and importance in HIV prevention. *Understanding Prevention for HIV Positive Gay Men*. Springer; 2017:349-366.

53. Tobin KE, Heidari O, Winiker A, et al. Peer Approaches to Improve HIV Care Cascade Outcomes: a Scoping Review Focused on Peer Behavioral Mechanisms. *Current HIV/AIDS Reports*. 2022:1-14.

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Figure 1. Types of mechanisms of action, protective and risk factors as well as spatial scales in geofencing interventions in population health research.

Mechanisms of Action	Protective	Risk	Spatial Scales
Cognitive	Sense of control Self-efficacy	Internalized & anticipated stigma Risk perceptions	Room Home Block Neighborhood City
Behavioral	Adaptive Coping Self-care	Substance use Non-adherence to medication	County State Region
Social	Instrumental & Emotional support	Enacted stigma Conflict	Nation Globe

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Name/citation	Study characteristics	Development of	Results	Theory and
Geofenced		geofence		framework
intervention				
Refernce				
number				
Wright et al.,	Study purpose: Increase awareness and	User input: None	Over 60 days, 516,073	Theoretical
2021	use of dental services in a rural clinic		impressions were	framework:
	6	Mechanism of	delivered, with 475	Anderson Model
Vendor not	Study design: Pre and post intervention	delivery: Any	individuals clicks on the	of Health Services
cited	community and outcome assessments	individual with a	banner to get website	Use
		smartphone	information, and a click	
41	Target population: Residents of a rural zip	physically located	through rate of 0.09%.	Behavioral
	code surrounding a dental clinic	within the		
		boundaries of three	Increases were seen in	Social:
	Sample size: 516,073 impressions	zip codes near the	community knowledge	Informational
	delivered to individuals crossing the	dental clinic	about the clinic (p=0.045)	support of an
	geofence	received a geofence	and dental visits by	existing service
		message advertising	respondent or a family	that is place-based
	Duration of follow-up: Impressions were	the dental clinic	member (p=0.04) post	
	sent over a 60-day period	with webpage	intervention	Cognitive
		information for		
	Outcome of interest: Number of	additional		
	impressions displayed to a user, clicks on	information		
	the banner, click-through rates on the			
	dental website from the banner, and			
	pre/post intervention community			
	knowledge of the dental clinic			

Owei et al.,	Study purpose: Assess the impact of the	User input: None	The mean number of	Theoretical
2021	ResQ geofencing app on submission rates		violations decreased	framework: None
	for duty hours and number of violations	Mechanism of	significantly (p=0.04) and	listed
ResQ	reported	delivery: Geofences	work hour submissions did	
		were placed around	not differ with the	Behavioral
44	Study design: Mixed methods feasibility	clinical sites where	intervention (p=0.42).	
	and acceptability of the ResQ app.	residents worked.	Compared to the previous	Social
		The ResQ	year, reported violations	
	Target population: Residents from the	application was	significantly decreased	Cognitive: Sense of
	General Surgery Residency Program	installed on	(p<0.01).	safety in capture
	· ·	resident's work		and reporting of
	Sample size: 23	phones and	Participants found the	clinical hours
		recorded work	application useful for	
	Duration of follow-up: 60 days	hours based on	recording and reporting	
		entering and exiting	clinical hours and eased	
	Outcome of interest: Comparison of	the geofence.	administrative burden.	
	reported and recorded work hours			
	submitted and work hour violations (80			
	hours per week and continuous hours			
	worked). Additionally, 13 participants			
	participated in semi-structured interviews			
	to understand acceptability and feasibility		$\sim n$	
	of ResQ.			
Gustafson et	Study purpose: Determine if a	User input: High-risk	Along with the geofenced	Theoretical
al., 2014	smartphone application to support	locations were	intervention, A-CHESS was	framework: Self-
	recovery from alcohol use disorders	identified by	a mobile application that	determination
A-CHESS	reduced risky drinking days.	participants	provided monitoring,	theory
			information,	
46	Study design: Unmasked randomized	Mechanism of	communication, and	Behavioral:
	clinical trial	delivery: Study team	support services from	Warning messages
		geofenced user	counselors. Overall the A-	sent in risky areas

	<i>Target population:</i> People with diagnosed alcohol dependence discharged from	identified high-risk locations and sent	CHESS group reported fewer risky drinking days	Social:
	residential treatment	alerts to the user's smartphone asking	at follow-up (p=0.003)	Informational support with
	Sample size: 349	if they wanted to be there		counselors
	Duration of follow-up: 8 months			<i>Cognitive:</i> Passive and real-time
	Outcome of interest: Risky drinking days in			capture of
	the previous 30 days			information
				shared with
				counselors
Nguyen et al.,	Study purpose: Evaluate the use of	<i>User input:</i> None	Remote- The application	Theoretical
2017	smartphone-based geofencing for tracking		detected 800 unique	framework: None
	hospitalizations	Mechanism of	participants in a	listed
Ginger.io		delivery: The app	geofenced location with a	
	Study design: Remote and in-person arm	was programmed	positive predictive value	
18	validation of1 a mobile application that	with all U.S.	between 65-78% based on	Behavioral
	detected hospitalizations and length of	hospitals geofenced.	how hospitalization was	
	hospitalization	A notification was	confirmed. Most common	Social
		sent to within 1	error in detection was the	
	Target population: Remote- participants	hour of leaving the	participant was a medical	<i>Cognitive:</i> Sense of
	from the Health eHeart study with a	hospital vicinity	center employee.	safety in provider
	smartphone	asking participants		knowing your
	In-person- Patients scheduled for	to confirm if they	In person- Visits were	hospitalization
	electrophysiology and cardiac	received medical	detected in 17/22 with	status
	catheterization procedures.	care	confirmed hospitalization.	
			Mean visit duration was	
	Sample size: Remote- 3,443; In person- 22		not correlated with actual	
			hospital length of stay.	

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	Duration of follow-up: Remote- mean of			
	260 days; In person- Duration of their			
	scheduled procedure			
	Outcome of interest: Detection of			
	hospitalization			
Naughton et	Study purpose: Feasibility and acceptability	User input:	User engagement with the	Theoretical
al., 2016	of a mobile application using geofencing	Geofences based on	application varied from	framework:
	to deliver tailored place-based	user habits and	60% of days pre-quit and	Learning theory
Q Sense	intervention messages	reports of smoking	39% post-quit (52%	and taxonomy of
	· A	locations	excluding outliers).	smoking behavior
20	Study design: Explanatory sequential			change
	mixed methods	Mechanism of	Geolocation was collected	
		delivery: If a smoker	on 97% of smoking reports	Behavioral: Coping
	Target population: Tobacco smokers	reported smoking in	with high accuracy. A	and resilience
	willing to set a quit date within 1 month	the same proximity,	mean of 1.5 geofences	regarding smoking
		the device created a	were created per	triggers
	Sample size: 15 in quantitative arm and 13	geofence around	participant with 87%	
	qualitative interviews	that area with a	having at least one. 5/9	Social
		radius of 100m.	participants eligible to	
	Duration of follow-up: Pre-quit period (up	When a user	receive a geofenced	Cognitive
	to 1 month) and 2 weeks post-quit date	entered the	triggered message	
		geofence for greater	received at least one.	
	Outcome of interest: 1) User engagement	than 5 minutes a		
	with app; 2) Assess app's location-sensing	location-tailored	Environmental constraints	
	accuracy; 3) Feasibility of geofence	support messaged	and forgetfulness were	
	mechanism; 4) Limitations of everyday use	was triggered	common reasons for	
	of app		forgetting to engage with	
			app. Participants were	
			positive about the value of	
			the geofenced support	

			and had no privacy	
			concerns.	
Dorsch et al.,	Study purpose: Effectiveness of the	User input: Mixed.	There was a significant	Theoretical
2020	LowSalt4Life mobile app on maintaining a	Geofences were	decrease in sodium	<i>framework:</i> Theory
	low sodium diet and controlling blood	created based on	excretion (p=0.03) and	of Planned
LowSalt4Life	pressure	user input as well as	decrease in sodium intake	Behavior
	\wedge	from a predictive	via 24 hour dietary recall	
47	Study design: Unblinded randomized	service when a	(p=0.01) and in the App	Behavioral: Dietary
	control trial	participant entered	group vs no App groups.	messages sent
		a grocery store,	Blood pressure decreased	when participant is
	Target population: Adults diagnosed with	restaurant, or home.	by 1.7 mmHg in the App	in areas where
	hypertension and taking antihypertensive		group compared to 0.7 in	they would
	medication	Mechanism of	the no App, but the	purchase/consume
		delivery: Contextual	change was not significant	food
	Sample size: 50 randomized	adaptive messages	(p=0.12).	
		were sent to		Social:
	Duration of follow-up: 8 weeks	participant's phones		Informational
		when entering a		support regarding
	Outcome of interest: Changes in 24-hour	geofence, with		which products
	dietary recall and sodium intake, urine	messages linked to		and food choices
	sodium excretion, blood pressure	content in the	\mathbf{O}	had lower sodium
		mobile application	$\sim n$	in context of place
				Cognitive
DeFilippis et	Study purpose: Determine the feasibility of	<i>User input:</i> None	The system was active on	Theoretical
al. <i>,</i> 2017	patients with ventricular assist devices		4 occasions, each of which	framework: None
	care engagement with and feasibility of a	Mechanism of	the participant confirmed	listed
Position	geofencing notification system.	delivery: Geofences	they were at or near the	
Health		were drawn around	hospital but were not	Behavioral
	Study design: Feasibility study with	emergency	seeking care. 1 patient	
43	quantitative and qualitative measures	departments (ED)		Social

				1
		across the U.S. Once	reported seeking ED care	
	Target population: Adults with a	the application	but did not receive a ping.	Cognitive: Sense of
	ventricular assist device (VAD)	detected that a		safety to
		participant	Most patients responded	participants that
	Sample size: 21	approached an ED, a	favorable to their	emergency room
		prompt was sent to	impression of the	and
	Duration of follow-up: 6 months	their phone to	application stating that it	hospitalizations
		confirm if they were	"gave them peace of	could alert their
	Outcome of interest: Proper detection of	seeking care at that	mind."	VAD provider
	emergency department utilization by	hospital. If yes,		regarding the need
	participant and satisfaction with mobile	another prompt		to coordinate care
	application.	asked the		
		participant to		
		confirm if the app		
		could notify their		
		VAD healthcare		
		team. If 'yes' to		
		both, a notification		
		was sent to the		
		covering provider's		
		pager with		
		participant name		
		and contact.		
Connor &	Study purpose: Determine the feasibility	User input: None	Use of the geofencing	Theoretical
Herzig, 2016	and acceptability of a mobile application		application showed a	framework: None
	that allow automatic capture of work	Mechanism of	significant correlation of	listed
Stat!	hours without manual employee input	delivery: Geofences	early departures following	
		were drawn around	late departures the	Behavioral
45	Study design: Feasibility study	hospitals where the	previous day (p<0.01 in 73	
		anesthesia group	of 91 occasions), and	Social
		provided services.	better dispersion of	
		•		

	Target population: Anesthesia providers in	When the provider	working hours (p=0.002)	Cognitive: Sense of
	a private practice group	enters a geofence,	compared to the previous	security regarding
		their time at the	year.	equitable
	Sample size: 198	facility is		distribution of
		continuously	Acceptance of the mobile	work based on
	Duration of follow-up: 12 months	checked and	application was slow to	geofenced data
	\wedge	reported to a	start but >95% in less than	and capture of
	Outcome of interest: Equitable workload	central server.	1 year of roll out	time working for
	distribution, employee acceptance and	Reports were then		billing purposes
	uptake, and reduced dispersion of the	used to inform		
	amount of overtime worked by staff	future clinical		
		responsibilities and		
		overtime worked		
Besoain et al.,	Study purpose: Prevent sexually	User input: Mixed.	All users triggered a	Theoretical
2020	transmitted infections (STIs) by sending	Hot zones were	geofenced hotzone during	framework:
	preventive measures in risky situations	created by a system	the development phase,	Elaboration
UBESafe		administrator and	though this was not	likelihood model
	Study design: Development and feasibility	with input from	quantified further. Hot	
22		users	zones were seen as a	Behavioral:
	Target population: Men who have sex with		necessary component	Contextual
	men	Mechanism of	from those testing in the	messages for
		delivery: Geofenced	development phase.	sexual risk
	Sample size: Development-5; Feasibility- 4	hot zones are areas		reduction sent in
		demines with a high	In the feasibility phase,	hot spots for high-
	Duration of follow-up: Development- 2	probability for	users tested and rated	risk intercourse
	weeks; Feasibility- 1 month	intercourse. When	prevention messages as	
		users enter a hot	well as adding their own.	Social:
	Outcome of interest: Development-	zone, a contextual		Gamification of
	functional testing to receive user	message to prevent	Users also contributed to	preventive
	feedback; Feasibility- try the UBESAFE	HIV and STIs, and	hot zones and tested	messages and
	system with all its functionalities	promote testing	existing ones, contributing	interaction with

65% of hot zones in the application at the end of the study.	others using the application
	Cognitive

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	2021	2021	2014	2017	2016	2020	al., 2017	Q Horzia	2020
	2021	2021	2014	2017	2010	2020		2016	2020
Infrastructure								2010	
Technology platform									
Interpretability/Health information									
systems context									
Intervention delivery									
Intervention content									
Usability/content testing									
User feedback									
Access of individual participants									
Cost assessment									
Adoption inputs/program entry									
Limitations for delivery at scale									
Contextual adaptability			-	2					
Replicability				N					
Data security				l l					
Compliance with national guidelines									
or regulatory statutes									

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	



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SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE <u>#</u>
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	
Results of		For each included source of evidence, present the	
individual sources	17	relevant data that were charted that relate to the review	
of evidence		questions and objectives.	
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	
Limitations	20	Discuss the limitations of the scoping review process.	
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

[‡] The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.



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Use of geofencing interventions in population health research: a scoping review

Journal:	BMJ Open
Manuscript ID	bmjopen-2022-069374.R2
Article Type:	Original research
Date Submitted by the Author:	14-Jul-2023
Complete List of Authors:	Tobin, Karin ; Johns Hopkins University Bloomberg School of Public Health, Health, Behavior and Society Heidari, Omeid; University of Washington School of Nursing, Child, Family and Population Health Nursing Volpi, Connor; Johns Hopkins University Bloomberg School of Public Health, Health, Behavior and Society Sodder, Shereen; Johns Hopkins University Bloomberg School of Public Health, Health, Behavior and Society Duncan, Dustin; Columbia University Mailman School of Public Health, Department of Epidemiology
Primary Subject Heading :	Public health
Secondary Subject Heading:	Mental health
Keywords:	EPIDEMIOLOGY, HIV & AIDS < INFECTIOUS DISEASES, MENTAL HEALTH, PUBLIC HEALTH

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Use of geofencing interventions in population health research: a scoping review

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Word count: 3261

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Abstract

Objectives: Technological advancements that utilize global positioning system (GPS), such as geofencing, provide the opportunity to examine place-based context in population health research. This review aimed to systematically identify, assess, and synthesize the existing evidence on geofencing intervention design, acceptability, feasibility, and/or impact. **Design:** Scoping review, using the PRISMA-ScR guidance for reporting.

Data sources: PubMed, CINAHL, EMBASE Web of Science, Cochrane, and PsychINFO for articles in English published up to December 31st, 2021.

Eligibility criteria: Articles were included if geofencing was utilized as a mechanism for intervention delivery. Exclusion criteria: 1) a component or combination of GPS, geographic information system (GIS), or ecological momentary assessment (EMA) was utilized without delivery of an intervention; 2) did not include a health or health-related outcome from the geofencing intervention; or 3) was not a peer-reviewed study.

Data extraction and synthesis: Several researchers independently reviewed all abstracts and full-text articles for final inclusion.

Results: A total of 2,171 articles were found; after exclusions, nine studies were included in the review. The majority were published in five years preceding the search (89%). Geofences in most studies (n=5) were fixed and programmed in the mobile application carried by participants without their input. Mechanisms of geofencing interventions were classified as direct or indirect, with five studies (56%) utilizing direct interventions. There were several different health outcomes (from smoking to problematic alcohol use) across the five studies that utilized a direct geofencing intervention.

Conclusions: This scoping review found geofencing to be an emerging technology that is an acceptable and feasible intervention applied to several different populations and health outcomes. Future studies should specify the rationale for the locations that are geofenced and user input. Moreover, attention to mechanisms of actions will enable scientists to understand not only whether geofencing is an appropriate and effective intervention but why it works to achieve the outcomes observed.

Strengths and limitations of this study

- The scoping review was comprehensive, utilizing rigorous searches of six databases.
- The review used the Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for Scoping Reviews (PRISMA-ScR) checklist to guide reporting.
- Most of the eligible studies were conducted in the United States, limiting generalizability to other international settings.
- The review was conducted through the published literature through 2021 and therefore does not include more recent publications.

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Introduction

Population health outcomes and health disparities result from multi-level factors beyond the individual. For example, poverty can lead to a lack of access to healthy food¹ and medical care²; unstable housing can lead to inability to adhere to medications³ and exposures to unhealthy environments;⁴ homophobia and racism leads to stigma and discrimination, and mistrust and avoidance of medical systems.⁵⁻⁷

Often in behavioral research, theories or frameworks do not consider the place-based context of behavior despite literature on the consistent and enduring impact of places such as neighborhoods and communities on population health outcomes and disparities.⁸⁻¹⁰ Place-based context can be conceptualized as both geographic areas defined by boundaries or as socially constructed out of symbolic meanings *and* social relations.^{11,12} In both cases, place-based context operates to perpetuate hierarchical social structures, facilitate and constrain resources, and protect or hinder health. Moreover, place-based context may facilitate specific health-related interactions such as drug or alcohol use, experiences of violence, or engagement in healthcare. Yet behavioral interventions often conceptualize place-based context as static (e.g., place of risky sex) and do not consider how place-based contexts vary over time. Real-time geospatial methods, including the use of global positioning system (GPS) technology, are the cutting-edge, best-suited methods to overcome limitations of most neighborhoods and other environments health research because they better capture place-based contexts corresponding to individuals' lived experiences, referred to as "activity space".¹³

There are numerous types of GPS-based methods that collect data from individuals and in some cases deliver intervention content. For example, ecological momentary assessment (EMA) has been shown to be an acceptable method of data collection.¹⁴ Ecological Momentary

Interventions (EMI) allow researchers to deliver intervention content through mobile devices.¹⁵ Just-in-time adaptive interventions (JITAI) attempt to address the changing needs of an individual where the intervention algorithm is programmed to determine if and what intervention content should be delivered to participants at set times throughout the day, whenever a participant requests one, or based on the participant's current state (e.g., stress) or environmental changes (e.g., weather).¹⁶⁻¹⁷ Finally, geofences are virtual boundaries drawn around a location and allow for monitoring and messaging when individuals enter or exits the geofenced parameter.¹⁸ Geofencing interventions are a subset of JITAI where there is continuous monitoring of the participant's location using GPS and delivery of an intervention such as text messages or links to health information or information about health services that are in the area based on a spatial context trigger. A geofence involves creating virtual predefined set of boundaries or "fences" around a geographic location, including using GPS technology. Geofencing methodology can be used in public health research – both in observational and intervention studies. Thus, geofencing can be a valuable tool in intervention research, enabling researchers to study and implement interventions in specific geographic areas. For example, geofencing allows researchers to precisely target specific areas for intervention. In addition, geofencing allows researchers to send location-based notifications (an intervention) to participants, including on their mobile devices. One example of this in the public health setting is the use of geofencing to monitor movements of individuals who tested positive for COVID-19 virus.19

Reviews of JITAI and EMI show the promising potential of this evolving technology,²⁰⁻²² yet, such reviews are noted to lack the inclusion of geofencing, representing a major gap in the literature. This gap is vital to address as geofencing has the capability to address an array of

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different health issues ranging from tobacco cessation to HIV medication adherence. The lack of a clear and systematic understanding of the scope of geofencing interventions undermines its potential to impact population health. The purpose of this scoping review is to describe of the state of the evidence on geofencing intervention design, acceptability, feasibility, and impact. In addition, we examine what behavioral mechanisms were targeted across the interventions assessed.

Conceptualizing mechanisms of action

Another limitation in the literature of EMA and JITAI interventions is the lack of attention to specific mechanisms of action that operate to achieve outcomes.²³ Therefore, we sought to develop a framework based on several complementary theories and frameworks (e.g., Turan's HIV Stigma Framework and Social Cognitive Theory²⁴⁻²⁶) to evaluate geofencing interventions included in this review. The framework posits three key mechanisms operate for place-based context to influence health outcomes (Figure 1). Each mechanism has both a protective and risk dimension. The <u>Cognitive mechanism</u> includes cognitive processes such as sense of control, knowledge, attitudes, self-efficacy, maladaptive thoughts, risk perceptions and internalized stigma.²⁷⁻³² The <u>Behavioral mechanism</u> refers to both protective behaviors such as adaptive coping as well as risky behaviors such substance use, condomless sex and non-adherence to medication and care.³³⁻³⁵ The <u>Social mechanism</u> refers to interactions with others in the personal social networks and broader community such as emotional or instrumental support or enacted stigma and conflict which have been shown to exacerbate or mitigate health outcomes.³⁶⁻³⁸ The framework can be applied to multiple spatial scales from a micro-level (e.g. a room in one's

residence) to community-level (e.g. a neighborhood activity space or census tract) to macro (e.g. state, region).

Methods

Study design

This scoping review is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) extension for Scoping Reviews checklist.³⁹

Inclusion criteria

Articles were only included if they utilized geofencing as a mechanism for intervention delivery. Articles were excluded if 1) a component or combination of GPS, geographic information system (GIS), or ecological momentary assessment (EMA) was utilized without delivery of an intervention; 2) did not include a health or health-related outcome from the geofencing intervention; or 3) was not a peer-reviewed study.

Search strategy

Authors first met to develop the list of potential search terms and refined after initial searchers were conducted. Then searches were conducted in PubMed, CINAHL, EMBASE Web of Science, Cochrane, and PsychINFO for articles published through the end of 2021 (Appendix 1, detailed search strategy across n=6 databases). Search terms were for broad concepts regarding mobile delivery of a geofencing intervention: "Geographic Information Systems"; "Georeferencing"; "Global Positioning System"; or "Geofenc*" combined with "Smartphone" or

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"Mobile Applications." The search was conducted on 12/1/2021 and was not registered. A protocol was not prepared.

Study selection

Screening of article titles and abstracts was conducted with two reviewers (SS, CV) to maximize scrutiny of all records. Each reviewer independently screened all articles identified from the initial search for relevance to the pre-defined inclusion criteria that was highlighted during a training session where it was emphasized that the reviewers should apply a liberal approach. Next, the same two reviewers independently reviewed each of the full texts for inclusion in the data extraction phase. Any disagreements in both phases were adjudicated by a third reviewer (OH). In all phases reviewers were not blinded to authors, funding, or information regarding publication of all the records. ez.e

Data extraction

Two reviewers (OH, KT) extracted data for details of study design, target population, sample size, duration of follow-up, theoretical framework, software or mobile application use, goal, and mechanism of geofenced intervention, and impact of the intervention of outcomes. Place-based mechanisms associated with the intervention included: 1) Behavioral, 2) Social support: Emotional, Instrumental, Informational, and Social monitoring, and 3) Cognitive. Finally, established guidance for reporting health intervention using mobile phone was utilized to evaluate the quality of each article.⁴⁰

Patient and Public Involvement

None.

Results

Included studies

Using the search strategy in six identified databases, a total of 2,171 articles were found after removing duplicates. 2,039 (94%) studies were irrelevant and 132 (6%) full text studies were assessed for eligibility. Reasons for exclusion of the 123 articles in the full-text phase included the article not being peer reviewed (n=46, 37%), review articles (n=19, 16%), was not the correct study design or intervention (n=14, 11%), or utilized a combination of GPS, GIS, and or Ecological Momentary Assessment, but was not a geofencing intervention (n=44, 36%). Nine eligible studies were ultimately included in this scoping review (Figure 2; Appendix 2, Details of nine studies that met inclusion for the scoping review).

Study characteristics

The majority were published in five years preceding the search (n=8; 89%). Most employed a pre/post study design to assess changes in measured outcome or feasibility and acceptability of the geofencing intervention (n=7; 78%) with two unblinded randomized control trials. Sample sizes ranged from 4 to 3,443; one study's intervention quantified its reach with the geofencing intervention displaying on 516,073 mobile phones, though these impressions do not represent unique individuals receiving the intervention.⁴¹ Most studies (n=7; 78%) were conducted in the United States, one in the United Kingdom⁴² and one in Spain.²³ A description of studies, including the names of the mobile applications used, study design and characteristics, and place-based mechanisms are detailed in Appendix 2. The design of the geofencing interventions varied

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based on user input and content delivery (Appendix 3, Components of mobile health evidence reporting and assessment).

Geofencing methods: user input

Geofences in most studies (n=5) were fixed and programmed in the mobile application without participant input. These included hospital emergency departments,^{18,43} hospitals where participants worked.^{44,45} and a specific rural dental clinic.⁴¹ Two studies utilized participants input in determining where to geofence related to smoking⁴² or problematic alcohol use.⁴⁶ Two studies utilized a mix of fixed and user input. Dorsch et al. utilized user input to geofence locations where foods were consumed or purchased as well as a cloud-based web service to predict when participants entered grocery stores or restaurants. Besoain et al., used a moderated system where participants suggested locations to geofence that were venues for high-risk sexual encounters, but these venues were moderated by the study team and locations could be added or removed.

Intervention content delivery: direct versus indirect

Intervention content was delivered in direct or indirect methods. Five studies (56%) sent participants intervention content directly to their phones based on triggering the geofence boundary. These interventions included informing individuals living in a rural area of a dental clinic⁴¹ or sending behavioral messages regarding problematic alcohol use when near a bar,⁴⁶ smoking cessation in areas detected as high likelihood of smoking,⁴² making low-sodium diet choices in grocery stores, restaurants, or at home, or HIV and STI prevention messages when in venues associated with high-risk sexual activity.²³ The remaining 4 studies were categorized as

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indirect as they collected data when participants triggered geofence boundaries and in some cases delivered content at a later time from when the fence was triggered.

Impact of the interventions

There was not a consistent health outcome across the five studies that utilized a direct intervention. Both studies that utilized a randomized control design showed improved outcomes in the group randomized to geofencing. A-CHESS sent context and place-based messages and included multiple other services such as a phone and data plan, access to a virtual counselor, and other interactive features.⁴⁶ LowSalt4Life contained features including low sodium options and alternatives at grocery stores or restaurants, and the ability to scan product barcodes to find similar low sodium options. Q Sense intervention participants decreased from 60% of pre-quit smoking days to 39% post-quit. UBESafe intervention reported that all participants were able to trigger a hot zone where sexual contacts often took place and received a place-based prevention message.²² Finally, Wright et al.,⁴¹ used a pre/post design, and found increases in community knowledge about the dental clinic (p=0.045) and increased number of dental visits post intervention.

Indirect intervention outcomes

Two studies used the geofence to track time working from medical practitioners or surgical residents. Owei et al., found the mean number of working hour violations for surgical residents' post-intervention significantly decreased (p=0.04) compared to pre-intervention and compared to the previous year (p<0.01).⁴⁴ Connor et al., showed a significant correlation of early departures from operating room duties following late departures the previous day (p<0.01) and better

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dispersion of working hours (p=0.002) compared to the previous year.⁴⁵ Two other studies geofenced major hospitals to detect hospitalization of high priority patients. Nguyen et al., found the geofenced mobile application detected 800 unique participants who triggered a geofence, with a predictive value of true hospitalization between 65-78%.¹⁸ Similarly, from a sample size of 21, 4 of the participants activated the alert system for patients with a ventricular assist device to their on-call care team when they triggered an emergency room geofence.⁴³

Acceptability measures

Five studies reported data regarding acceptability of the geofencing mobile application in which all participants were positive regarding the value of the intervention. Participants in two studies with indirect intervention found the application useful and described knowledge of being monitored provided a sense of security.^{43,44} Additionally, participants in two studies did not have concerns regarding the continuous geolocation tracking for intervention purpose,^{42,44} but did stress the importance of transparency regarding the use of this data.⁴² Finally, in one interactive study, participants contributed to the creation and curation of geofenced hot zones as well as the prevention messages received when hot zones were triggered, accounting for 67% of hot zones created and used by the study.²³

Place-based mechanisms

Four studies utilized a behavioral mechanism in their geofencing intervention.^{23,42,46,47} Four studies utilized a social mechanism which included informational support such as existence of a rural dental clinic⁴¹ and availability of menu grocery store items that were low in sodium.^{23,41,46,47} Additionally, participants were able to interact with counselors though the application and

review their data concerning visiting high-risk locations for further intervention⁴⁶ or sharing context specific messages with other users on the application.²³ Finally, five studies utilized a cognitive mechanism that provided the participant a sense of safety, security, or knowing that their information was captured.^{45,46} These included reporting to care teams when the participants were hospitalized,^{18,43} capture of time and effort spent working in a clinical environment,^{44,45} and participants counselor viewing their location and interacting with their place-based data of proximity and time spent in high-risk areas for binge drinking.⁴⁶

Reporting and quality measures

All included studies reported on at least six items (Appendix 3). Position Health,⁴³ Stat!,⁴⁵ and ResQ⁴⁴ reported on how the intervention and data collected integrated into an existing health information system and described some data security procedures. CHESS⁴⁶ and the Wright et al.⁴¹ intervention conducted some cost assessment regarding the delivery of the intervention or cost to the participant to utilize the participant. No study reported on compliance of the intervention or data collection mechanism compliance with national guidelines or federal statutes. We did not assess confidence in the body of evidence or risk of bias.

Discussion

The purpose of this scoping review was to describe the use of geofencing as an intervention and mechanisms that were targeted to achieve various health outcomes. A geofence involves creating virtual predefined set of boundaries or "fences" around a geographic location, including using GPS technology. Geofencing methodology can be used in public health research – both in observational and intervention studies. Thus, geofencing can be a valuable tool in intervention

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research, enabling researchers to study and implement interventions in specific geographic areas. For example, geofencing allows researchers to precisely target specific areas for intervention. In addition, geofencing allows researchers to send location-based notifications (an intervention) to participants, including on their mobile devices. We identified only nine studies that fitted the criteria and, as expected, most publications were relatively recent. We found that the design of the geofencing intervention varied yet acceptability was good among study participants and impact was not assessed in all studies.

Of the studies included, only one was focused on a sexual and gender minority sample and only one with majority Black, Indigenous People of Color (BIPOC), who experience disparities on a vast number of health outcomes due to social and structural factors such as racism and homophobia.²³ Lack of inclusion of these populations is a significant gap that should be monitored as more studies are conducted. In addition, most studies were conducted in the United States, with no studies in developing countries, South America, Africa or Asia, which could represent an important opportunity.

The included studies described a range of user input of the geofenced locations from researcher only selection to user selection. This characteristic of an intervention merits consideration. User selection of geofenced locations may be prone to bias and recall issues.⁴⁸ Researcher selected locations may not consider the variability of their sample's place-based contexts and may under count locations that should be geofenced. The hybrid approach has the potential to address both limitations. Future studies using geofencing technology may warrant comparative studies of the user input approaches and be specific about the rationale for the type of locations that are geofenced and the user input of these so that studies can be comparable and be conducted in non-western contexts.

Some of the interventions explicitly identified a theoretical model or foundation, and all the studies described targeting at least one of the mechanisms of action from our proposed framework. The studies in which the geofencing intervention targeted the cognitive mechanism were primarily addressing surveillance of the participants and messages to cue cognitions about their location. Cueing is a significant component of many effective interventions as they serve as reminders to engage in behaviors of interest.⁴⁹⁻⁵¹ For example, wearing a bracelet that has a phrase as a reminder to take medication. Cues can focus on both the protective and risk dimensions of the mechanism. For example, if an individual triggers a geofence of a place they have identified as associated with a sense of control, a geofencing intervention could sent a text message that reminds the individual to engage in self-care. In places where stigma is anticipated a geofencing intervention can send a text message that reminds the individual about adaptive coping behaviors.

Studies utilizing the behavioral mechanism described very specific behavioral targets such as buying lower sodium food, avoiding places of alcohol use, condom use and smoking cessation. As building self-efficacy is a well-established theoretical construct necessary for behavioral change,²⁴ future studies should include opportunities to watch the desired behaviors be role-modeled and practiced to enhance the efficacy of the geofencing intervention.⁵²

Studies that utilized the social mechanism were focused on the provision of both informational and emotional support. One study included a component in which the participants could create messages for other user of the geofencing application. As there are different types of social support (e.g., emotional, appraisal, economic and informational) future studies should be specific and transparent about the types being targeted. With additional geofencing studies, a

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future review can be conducted using meta-analytic methods to determine the quantitative effectiveness of geofencing interventions in population health research.

Limitations

The search strategy was limited to English articles in PubMed, CINAHL, EMBASE Web of Science, Cochrane, and PsychINFO and we acknowledge other publications may not have been captured with these. There was heterogeneity in how studies reported intervention development, theoretical frameworks, and feasibility and acceptability of the intervention. This reduced the ability to properly assess the extent of behavioral mechanism utilized for the given outcome. Additionally, as geofencing is a new technology, not many peer-reviewed articles have been published and this scoping review chose to exclude conference abstracts.

Conclusions

This scoping review found geofencing to be an emerging technology that is an acceptable and feasible intervention applied to several different populations and health outcomes.²³ Attention to the mechanisms of actions will enable the field to understand not only whether geofencing is an appropriate and effective intervention but why it works to achieve the outcomes we observe. There is a need for future research that includes sexual and gender minority and BIPOC populations and populations from non-Western contexts to achieve the Health People Framework objectives given the persistent findings that BIPOC and SGM populations. These studies could address those health outcomes where disparities are stark such as HIV/AIDS, cardiovascular, diabetes, COVID-related and mpox. Finally, future research can reveal place-

based contexts that have not been considered which can inform resource allocation and targets

for health-promoting policies.

Contributors

Drs. Tobin and Heidari contributed equally to this manuscript. KT, OH and DD planned the study. KT, OH, CV and SS acquired data and conducted the analysis for this study. KT, OH and DD equally contributed to writing and finalizing the manuscript.

Competing interests

We declare that we have no competing interests.

Funding

This work was supported by a grant from the National Institute of Mental Health (R34MH118178).

Data availability statement

No additional data available.

Ethics approval

Ethics approval was not required as the scoping review is based on published studies.

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References

Larson NI, Story MT, Nelson MC. Neighborhood environments: disparities in access to 1. healthy foods in the US. American journal of preventive medicine. 2009;36(1):74-81. e10. Lazar M, Davenport L. Barriers to health care access for low income families: a review 2. of literature. Journal of community health nursing. 2018;35(1):28-37. Kalichman SC, Kalichman MO. HIV-related stress and life chaos mediate the association 3. between poverty and medication adherence among people living with HIV/AIDS. Journal of clinical psychology in medical settings. 2016;23(4):420-430. Taylor SE, Repetti RL, Seeman T. Health psychology: what is an unhealthy environment 4. and how does it get under the skin? Annual review of psychology. 1997;48 Earnshaw VA, Bogart LM, Dovidio JF, Williams DR. Stigma and racial/ethnic HIV 5. disparities: moving toward resilience. 2015; Lutete P, Matthews DW, Sabounchi NS, et al. Intersectional Stigma and Prevention 6. Among Gay, Bisexual, and Same Gender-Loving Men in New York City, 2020: System Dynamics Models. American journal of public health. 2022;112(S4):S444-S451. 7. Ouinn K, Dickson-Gomez J, Zarwell M, Pearson B, Lewis M, "A gay man and a doctor are just like, a recipe for destruction": How racism and homonegativity in healthcare settings influence PrEP uptake among young Black MSM. AIDS and Behavior. 2019;23(7):1951-1963. 8. Arcaya MC, Tucker-Seeley RD, Kim R, Schnake-Mahl A, So M, Subramanian S. Research on neighborhood effects on health in the United States: a systematic review of study characteristics. Social Science & Medicine. 2016;168:16-29. Duncan DT, Kawachi I. Neighborhoods and health. vol 10. Oxford University Press New 9. York; 2018. Rifkin SB. Examining the links between community participation and health outcomes: a 10. review of the literature. *Health policy and planning*. 2014;29(suppl 2):ii98-ii106. Gesler WM. Therapeutic landscapes: medical issues in light of the new cultural 11. geography. Social science & medicine. 1992;34(7):735-746. Keene DE, Padilla MB. Spatial stigma and health inequality. Critical public health. 12. 2014;24(4):392-404. Duncan DT, Kawachi I, Subramanian S, Aldstadt J, Melly SJ, Williams DR. Examination 13. of how neighborhood definition influences measurements of youths' access to tobacco retailers: a methodological note on spatial misclassification. American journal of epidemiology. 2014;179(3):373-381. Palmer JR, Espenshade TJ, Bartumeus F, Chung CY, Ozgencil NE, Li K. New 14. approaches to human mobility: Using mobile phones for demographic research. *Demography*. 2013;50(3):1105-1128. Heron KE, Smyth JM, Ecological momentary interventions: incorporating mobile 15. technology into psychosocial and health behaviour treatments. British journal of health psychology. 2010;15(1):1-39. Wang L, Miller LC. Just-in-the-moment adaptive interventions (JITAI): A meta-16. analytical review. Health Communication. 2020;35(12):1531-1544. Nahum-Shani I, Smith SN, Spring BJ, et al. Just-in-time adaptive interventions (JITAIs) 17. in mobile health: key components and design principles for ongoing health behavior support. 54 Annals of Behavioral Medicine. 2018;52(6):446-462. 18 For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml

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Nguyen KT, Olgin JE, Pletcher MJ, et al. Smartphone-based geofencing to ascertain 18. hospitalizations. Circulation: Cardiovascular Quality and Outcomes. 2017;10(3):e003326. Ahmed N, Michelin RA, Xue W, et al. A survey of COVID-19 contact tracing apps. 19. IEEE access. 2020;8:134577-134601. Carpenter SM, Menictas M, Nahum-Shani I, Wetter DW, Murphy SA. Developments in 20. mobile health just-in-time adaptive interventions for addiction science. Current addiction reports. 2020;7(3):280-290. Naughton F. Delivering "Just-In-Time" smoking cessation support via mobile phones: 21. current knowledge and future directions. Nicotine & Tobacco Research. 2017;19(3):379-383. Thomas JG, Bond DS. Review of innovations in digital health technology to promote 22. weight control. Current diabetes reports. 2014;14(5):1-10. Besoain F, Perez-Navarro A, Aviñó CJ, Caylà JA, Barriga NA, de Olalla PG. Prevention 23. of HIV and other sexually transmitted infections by geofencing and contextualized messages with a gamified app, UBESAFE: design and creation study. JMIR mHealth and uHealth. 2020;8(3):e14568. 24. Bandura A. Social cognitive theory: An agentic perspective. Asian journal of social psychology. 1999;2(1):21-41. Turan B, Hatcher AM, Weiser SD, Johnson MO, Rice WS, Turan JM. Framing 25. mechanisms linking HIV-related stigma, adherence to treatment, and health outcomes. American journal of public health. 2017;107(6):863-869. Macintyre S, Ellaway A, Cummins S. Place effects on health: how can we conceptualise, 26. operationalise and measure them? Social science & medicine. 2002;55(1):125-139. Khawcharoenporn T, Mongkolkaewsub S, Naijitra C, Khonphiern W, Apisarnthanarak A, 27. Phanuphak N. HIV risk, risk perception and uptake of HIV testing and counseling among youth men who have sex with men attending a gay sauna. AIDS research and therapy. 2019;16(1):1-11. Machowska A, Bamboria BL, Bercan C, Sharma M. Impact of 'HIV-related stigma-28. reduction workshops' on knowledge and attitude of healthcare providers and students in Central India: a pre-test and post-test intervention study. *BMJ open*. 2020;10(4):e033612. Mi T, Li X, Zhou G, Oiao S, Shen Z, Zhou Y, HIV disclosure to family members and 29. medication adherence: role of social support and self-efficacy. AIDS and Behavior. 2020;24(1):45-54. 30. SeyedAlinaghi S, MohsseniPour M, Aghaei E, Zarani F, Fathabadi J, Mohammadifirouzeh M. The Relationships Between Early Maladaptive Schemas, Quality of Life and Self-care Behaviors in a Sample of Persons Living with HIV: The Potential Mediating Role of Cognitive Emotion Regulation Strategies. *The Open AIDS Journal*. 2020;14(1) Steptoe A, Jackson SE. The life skills of older Americans: association with economic, 31. psychological, social, and health outcomes. Scientific Reports. 2018;8(1):1-10. 32. Yigit I, Bayramoglu Y, Weiser SD, et al. Changes in internalized stigma and HIV health outcomes in individuals new to HIV care: The mediating roles of depression and treatment selfefficacy. AIDS Patient Care and STDs. 2020;34(11):491-497. 33. Gonzalez A, Barinas J, O'Cleirigh C. Substance use: impact on adherence and HIV medical treatment. Current HIV/AIDS Reports. 2011;8(4):223-234. Logie CH, Williams CC, Wang Y, et al. Adapting stigma mechanism frameworks to 34. explore complex pathways between intersectional stigma and HIV-related health outcomes among women living with HIV in Canada. Soc Sci Med. 2019;232:129-38. 19 For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml

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3	35 Safren SA Blashill AL Lee IS et al Condom-use self-efficacy as a mediator between
4	syndemics and condomless sex in men who have sex with men (MSM) Health nsychology
5	$2018 \cdot 37(0) \cdot 820$
6	26 Bakala T. Rourka S.B. Tuckar R. at al. Diract and indiract affects of perceived social
/	support on boolth related quality of life in persona living with UIV/AIDS AIDS ages
8	support on health-related quarty of the in persons fiving with HTV/AIDS. AIDS cure.
9	2013;25(3):337-346.
10	37. Koegler E, Kennedy CE. A scoping review of the associations between mental health and
11	factors related to HIV acquisition and disease progression in conflict-affected populations.
12	<i>Conflict and health</i> . 2018;12(1):1-22.
14	38. Vaughan E, Power M, Sixsmith J. Experiences of stigma in healthcare settings by people
15	living with HIV in Ireland: a qualitative study. AIDS care. 2020;32(9):1162-1167.
16	39. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-
17	ScR): checklist and explanation <i>Annals of internal medicine</i> 2018:169(7):467-473
18	40 A garwal S LeFevre AF Lee L et al Guidelines for reporting of health interventions
19	using mabile phonons: mabile health (mHealth) evidence reporting and assessment (mEDA)
20	using mobile phones. mobile hearth (infrearth) evidence reporting and assessment (inEKA)
21	checklist. <i>bmj</i> . 2016;352
22	41. Wright WG, Rafferty AP, Winterbauer N, Locklear K, Tucker-McLaughlin M.
23	Geofencing: Mobile Technology as a Health Promotion Tool to Raise Awareness of a Dental
24	Clinic in Rural North Carolina. <i>The Journal of Rural Health</i> . 2021;37(3):667-674.
25	42. Naughton F, Hopewell S, Lathia N, et al. A context-sensing mobile phone app (Q sense)
26	for smoking cessation: a mixed-methods study. JMIR mHealth and uHealth. 2016;4(3):e5787.
27	43 DeFilippis EM Safavi K Reves J Coakley L Hickey M Givertz MM Mobile
28	Geolocation Technology to Improve Multidisciplinary Care of Patients with Ventricular Assist
29	Devices: A Feasibility Study Journal of Cardiac Failure 2017:23(8):S84
30	44 Owei L. Luka VI. Drooks VD. Kolz DD. Dorna IS. Aarona CD. Smart phone Deced
31	44. Ower L, Luks VL, Diooks KD, Keiz KK, Beins JS, Aarons CB. Sinart-phone based
3Z 22	Geotencing: A Novel Approach to Monitoring Clinical work Hours in Surgery Residency.
34	Journal of Surgical Education. 2021;78(6):e210-e217.
35	45. Connor CW, Herzig M. Monitoring the location of staff via mobile devices in a large
36	multifacility practice group. A & A case reports. 2016;6(10):320-328.
37	46. Gustafson DH, McTavish FM, Chih M-Y, et al. A smartphone application to support
38	recovery from alcoholism: a randomized clinical trial. JAMA psychiatry. 2014;71(5):566-572.
39	47. Dorsch MP. Cornellier ML. Poggi AD. et al. Effects of a novel contextual just-in-time
40	mobile app intervention (LowSalt4Life) on sodium intake in adults with hypertension pilot
41	randomized controlled trial <i>IMIR mHealth and uHealth</i> 2020.8(8):e16696
42	18 Wray TB Dáraz AE Calio MA Carr DI Adia AC Monti PM Exploring the Use of
43	Smorth hone Caefonning to Study Characteristics of Alashal Drinking Lasotions in Uich Dick
44	Sinarphone Geolencing to Study Characteristics of Alcohof Diffiking Locations in High-Kisk
45	Gay and Bisexual Men. Alcoholism: clinical and experimental research. 2019;43(5):900-906.
46	49. Latkin CA, Hua W, Tobin K. Social network correlates of self-reported non-fatal
47	overdose. <i>Drug and Alcohol Dependence</i> . 2004;73(1):61-67.
48	50. Tobin KE, Davey MA, Latkin CA. Calling emergency medical services during drug
49	overdose: an examination of individual, social and setting correlates. Addiction.
50	2005;100(3):397-404.
51 52	51. Tobin KE, Latkin CA. Social networks of HIV positive gay men: their role and
52 53	importance in HIV prevention. Understanding Prevention for HIV Positive Gav Men Springer
55	2017·349-366
55	
56	
57	
58	20
59	20
60	For peer review only - http://bmjopen.bmj.com/site/about/guidelines.xhtml

52. Tobin KE, Heidari O, Winiker A, et al. Peer Approaches to Improve HIV Care Cascade Outcomes: a Scoping Review Focused on Peer Behavioral Mechanisms. *Current HIV/AIDS Reports*. 2022:1-14.

Figure 1. Types and mechansims of action, protective and risk factors as well as spatial scales in geofencing intrerventions in population health research.

Figure 2. PRISMA flow diagram

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Figure 1. Types of mechanisms of action, protective and risk factors as well as spatial scales in geofencing interventions in population health research.

Mechanisms of Action	Protective	Risk	Spatial Scales
Cognitive	Sense of control	Internalized &	Room
	Self-efficacy	anticipated	Home
		stigma	Block
		Risk	Neighborhood
		perceptions	City
Behavioral	Adaptive	Substance use	County
	Coping	Non-adherence	State
	Self-care	to medication	Region
Social	Instrumental &	Enacted stigma	Nation
	Emotional	Conflict	Globe

215x279mm (200 x 200 DPI)

Figure 2. PRISMA diagram of selected studies



210x297mm (200 x 200 DPI)

Appendix 1. Detailed search strategy across n=6 databases

PubMed

Concept	Search Terms
Mobile	("Smartphone"[Mesh]) OR "Mobile Applications"[Mesh] OR smartphon*
applications	[tiab] OR "mobile application*" [tw] OR "mobile app" [tw] OR "mobile apps"
	[tw] OR "mobile phon*" [tw]
Geofencing	"Geographic Information Systems"[Mesh] OR "Geographic Information
	System" [tw] OR "Geographical Information System" [tw] OR "Geographical
	Information Systems" [tw] OR "Georeferencing" [tw] OR "Global Positioning
	System" [tw] OR "Global Positioning Systems" [tw] OR "Geofenc*" [tw]
Embase	0

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Search Terms
'mobile phone'/exp OR 'wireless communication'/exp OR 'mobile
application'/exp OR smartphon*:ti,ab,kw OR 'mobile application*':ti,ab,kw
OR 'mobile app':ti,ab,kw OR 'mobile apps':ti,ab,kw OR 'mobile
phon*':ti,ab,kw
'geographic information system'/exp OR 'global positioning system'/exp OR
'geographic information system':ti,ab,kw OR 'geographical information
system':ti,ab,kw OR 'geographical information systems':ti,ab,kw OR
'georeferencing':ti,ab,kw OR 'global positioning system':ti,ab,kw OR 'global
positioning systems':ti,ab,kw OR 'geofenc*':ti,ab,kw

CINAHL

Concept	Search Terms
Mobile	(MH "Smartphone") OR (MH "Cellular Phone+") OR (MH "Text Messaging+")
applications	OR (MH "Mobile Applications") OR smartphon* OR "mobile application*"
	OR "mobile app" OR "mobile apps" OR "mobile phon*"
Geofencing	(MH "Geographic Information Systems+") OR "Geographic Information
	System" OR "Geographical Information System" OR "Geographical
	Information Systems" OR "Georeferencing" OR "Global Positioning System"
	OR "Global Positioning Systems" OR Geofenc*

Cochrane

Concept	Search Terms
Mobile	([mh Smartphone]) OR [mh "Mobile Applications"] OR smartphon*:ti,ab OR
applications	("mobile" NEXT application*):ti,ab,kw OR "mobile app":ti,ab,kw OR "mobile
	apps":ti,ab,kw OR ("mobile" NEXT phon*):ti,ab,kw

Geofencing	[mh "Geographic Information Systems"] OR "Geographic Information
	System":ti,ab,kw OR "Geographical Information System":ti,ab,kw OR
	"Geographical Information Systems":ti,ab,kw OR Georeferencing:ti,ab,kw
	OR "Global Positioning System":ti,ab,kw OR "Global Positioning
	Systems":ti,ab,kw OR Geofenc*:ti,ab,kw

Web of Science

Concept	Search Terms				
Mobile	(ALL=((Smartphone) OR "Mobile Applications" OR smartphon* OR "mobile				
applications	application*" OR "mobile app" OR "mobile apps" OR "mobile phon*"))				
Geofencing ALL=("Geographic Information Systems" OR "Geographic Information					
	System" OR "Geographical Information System" OR "Geographical				
	Information Systems" OR Georeferencing OR "Global Positioning System"				
	OR "Global Positioning Systems" OR Geofenc*)				
APA PsychINFO					

APA PsychINFO

Concept	Search Terms
Mobile	DE "Smartphones" OR DE "Mobile Applications" OR DE "Smartphone Use"
applications	OR DE "Text Messaging" OR DE "Wireless Technologies" OR DE "Mobile
	Phones" OR smartphon* OR "mobile application*" OR "mobile app" OR
	"mobile apps" OR "mobile phon*"
Geofencing	"Geographic Information System" OR "Geographical Information System"
	OR "Geographical Information Systems" OR "Georeferencing" OR "Global
	Positioning System" OR "Global Positioning Systems" OR Geofenc*

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Name/citation	Study characteristics	Development of	Results	Theory and
Geofenced		geofence		framework
intervention				
Refernce				
number				
Wright et al.,	Study purpose: Increase awareness and	User input: None	Over 60 days, 516,073	Theoretical
2021	use of dental services in a rural clinic		impressions were	framework:
	6	Mechanism of	delivered, with 475	Anderson Model
Vendor not	Study design: Pre and post intervention	delivery: Any	individuals clicks on the	of Health Services
cited	community and outcome assessments	individual with a	banner to get website	Use
	C.	smartphone	information, and a click	
41	Target population: Residents of a rural zip	physically located	through rate of 0.09%.	Behavioral
	code surrounding a dental clinic	within the		
		boundaries of three	Increases were seen in	Social:
	Sample size: 516,073 impressions	zip codes near the	community knowledge	Informational
	delivered to individuals crossing the	dental clinic	about the clinic (p=0.045)	support of an
	geofence	received a geofence	and dental visits by	existing service
		message advertising	respondent or a family	that is place-based
	Duration of follow-up: Impressions were	the dental clinic	member (p=0.04) post	
	sent over a 60-day period	with webpage	intervention	Cognitive
		information for		
	Outcome of interest: Number of	additional		
	impressions displayed to a user, clicks on	information		
	the banner, click-through rates on the			
	dental website from the banner, and			
	pre/post intervention community			
	knowledge of the dental clinic			

Owei et al.,	Study purpose: Assess the impact of the	User input: None	The mean number of	Theoretical
2021	ResQ geofencing app on submission rates		violations decreased	framework: None
	for duty hours and number of violations	Mechanism of	significantly (p=0.04) and	listed
ResQ	reported	delivery: Geofences	work hour submissions did	
		were placed around	not differ with the	Behavioral
44	Study design: Mixed methods feasibility	clinical sites where	intervention (p=0.42).	
	and acceptability of the ResQ app.	residents worked.	Compared to the previous	Social
		The ResQ	year, reported violations	
	Target population: Residents from the	application was	significantly decreased	Cognitive: Sense of
	General Surgery Residency Program	installed on	(p<0.01).	safety in capture
	· A	resident's work		and reporting of
	Sample size: 23	phones and	Participants found the	clinical hours
		recorded work	application useful for	
	Duration of follow-up: 60 days	hours based on	recording and reporting	
		entering and exiting	clinical hours and eased	
	Outcome of interest: Comparison of	the geofence.	administrative burden.	
	reported and recorded work hours			
	submitted and work hour violations (80			
	hours per week and continuous hours			
	worked). Additionally, 13 participants			
	participated in semi-structured interviews			
	to understand acceptability and feasibility		$\sim n$	
	of ResQ.			
Gustafson et	Study purpose: Determine if a	User input: High-risk	Along with the geofenced	Theoretical
al., 2014	smartphone application to support	locations were	intervention, A-CHESS was	framework: Self-
	recovery from alcohol use disorders	identified by	a mobile application that	determination
A-CHESS	reduced risky drinking days.	participants	provided monitoring,	theory
			information,	
46	Study design: Unmasked randomized	Mechanism of	communication, and	Behavioral:
	clinical trial	delivery: Study team	support services from	Warning messages
		geofenced user	counselors. Overall the A-	sent in risky areas

	<i>Target population:</i> People with diagnosed alcohol dependence discharged from residential treatment	identified high-risk locations and sent	CHESS group reported fewer risky drinking days	Social:
	Sampla siza: 240	smartphone asking	at 10110w-up (p=0.005)	support with
	Sumple size. 549	there		courseiors
	Duration of follow-up: 8 months			<i>Cognitive:</i> Passive and real-time
	Outcome of interest: Risky drinking days in			capture of
	the previous 30 days			information
	$\rho_{\rm O}$			shared with counselors
Nguyen et al.,	Study purpose: Evaluate the use of	<i>User input:</i> None	Remote- The application	Theoretical
2017	smartphone-based geofencing for tracking		detected 800 unique	framework: None
	hospitalizations	Mechanism of	participants in a	listed
Ginger.io		delivery: The app	geofenced location with a	
	Study design: Remote and in-person arm	was programmed	positive predictive value	
18	validation of 1 a mobile application that	with all U.S.	between 65-78% based on	Behavioral
	detected hospitalizations and length of	hospitals geofenced.	how hospitalization was	
	nospitalization	A notification was	confirmed. Most common	Social
	Target population: Pomoto- participants	bour of loaving the	participant was a modical	Cognitive: Sonso of
	from the Health eHeart study with a	hospital vicinity	center employee	safety in provider
	smartphone	asking participants	center employee.	knowing your
	In-person- Patients scheduled for	to confirm if they	In person-Visits were	hospitalization
	electrophysiology and cardiac	received medical	detected in 17/22 with	status
	catheterization procedures.	care	confirmed hospitalization.	
			Mean visit duration was	
	Sample size: Remote- 3,443; In person- 22		not correlated with actual	
			hospital length of stay.	

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			Γ	l
	Duration of follow-up: Remote- mean of			
	260 days; In person- Duration of their			
	scheduled procedure			
	Outcome of interest: Detection of			
	hospitalization			
Naughton et	Study purpose: Feasibility and acceptability	User input:	User engagement with the	Theoretical
al., 2016	of a mobile application using geofencing	Geofences based on	application varied from	framework:
	to deliver tailored place-based	user habits and	60% of days pre-quit and	Learning theory
Q Sense	intervention messages	reports of smoking	39% post-quit (52%	and taxonomy of
	· A	locations	excluding outliers).	smoking behavior
20	Study design: Explanatory sequential			change
	mixed methods	Mechanism of	Geolocation was collected	
		delivery: If a smoker	on 97% of smoking reports	Behavioral: Coping
	Target population: Tobacco smokers	reported smoking in	with high accuracy. A	and resilience
	willing to set a quit date within 1 month	the same proximity,	mean of 1.5 geofences	regarding smoking
		the device created a	were created per	triggers
	Sample size: 15 in quantitative arm and 13	geofence around	participant with 87%	
	qualitative interviews	that area with a	having at least one. 5/9	Social
		radius of 100m.	participants eligible to	
	<i>Duration of follow-up:</i> Pre-quit period (up	When a user	receive a geofenced	Cognitive
	to 1 month) and 2 weeks post-quit date	entered the	triggered message	
		geofence for greater	received at least one.	
	Outcome of interest: 1) User engagement	than 5 minutes a		
	with app; 2) Assess app's location-sensing	location-tailored	Environmental constraints	
	accuracy; 3) Feasibility of geofence	support messaged	and forgetfulness were	
	mechanism; 4) Limitations of everyday use	was triggered	common reasons for	
	of app		forgetting to engage with	
			app. Participants were	
			positive about the value of	
			the geofenced support	

			and had no privacy	
			concerns.	
Dorsch et al.,	Study purpose: Effectiveness of the	User input: Mixed.	There was a significant	Theoretical
2020	LowSalt4Life mobile app on maintaining a	Geofences were	decrease in sodium	framework: Theory
	low sodium diet and controlling blood	created based on	excretion (p=0.03) and	of Planned
LowSalt4Life	pressure	user input as well as	decrease in sodium intake	Behavior
	\sim	from a predictive	via 24 hour dietary recall	
47	Study design: Unblinded randomized	service when a	(p=0.01) and in the App	Behavioral: Dietary
	control trial	participant entered	group vs no App groups.	messages sent
		a grocery store,	Blood pressure decreased	when participant is
	Target population: Adults diagnosed with	restaurant, or home.	by 1.7 mmHg in the App	in areas where
	hypertension and taking antihypertensive		group compared to 0.7 in	they would
	medication	Mechanism of	the no App, but the	purchase/consume
		delivery: Contextual	change was not significant	food
	Sample size: 50 randomized	adaptive messages	(p=0.12).	
	•	were sent to		Social:
	Duration of follow-up: 8 weeks	participant's phones		Informational
		when entering a		support regarding
	Outcome of interest: Changes in 24-hour	geofence, with		which products
	dietary recall and sodium intake, urine	messages linked to		and food choices
	sodium excretion, blood pressure	content in the		had lower sodium
		mobile application	\sim h	in context of place
				Cognitive
DeFilippis et	Study purpose: Determine the feasibility of	User input: None	The system was active on	Theoretical
al., 2017	patients with ventricular assist devices		4 occasions, each of which	framework: None
	care engagement with and feasibility of a	Mechanism of	the participant confirmed	listed
Position	geofencing notification system.	delivery: Geofences	they were at or near the	
Health		were drawn around	hospital but were not	Behavioral
	Study design: Feasibility study with	emergency	seeking care. 1 patient	
43	quantitative and qualitative measures	departments (ED)		Social
		across the U.S. Once	reported seeking ED care	
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	larget population: Adults with a	the application	but did not receive a ping.	Cognitive: Sense of
	ventricular assist device (VAD)	detected that a		safety to
		participant	Most patients responded	participants that
	Sample size: 21	approached an ED, a	favorable to their	emergency room
		prompt was sent to	impression of the	and
	Duration of follow-up: 6 months	their phone to	application stating that it	hospitalizations
		confirm if they were	"gave them peace of	could alert their
	Outcome of interest: Proper detection of	seeking care at that	mind."	VAD provider
	emergency department utilization by	hospital. If yes,		regarding the need
	participant and satisfaction with mobile	another prompt		to coordinate care
	application.	asked the		
	CO.	participant to		
		confirm if the app		
		could notify their		
		VAD healthcare		
		team. If 'yes' to		
		both, a notification		
		was sent to the		
		covering provider's		
		pager with		
		participant name		
		and contact.		
Connor &	Study purpose: Determine the feasibility	User input: None	Use of the geofencing	Theoretical
Herzig, 2016	and acceptability of a mobile application		application showed a	framework: None
	that allow automatic capture of work	Mechanism of	significant correlation of	listed
Stat!	hours without manual employee input	delivery: Geofences	early departures following	
		were drawn around	late departures the	Behavioral
45	Study design: Feasibility study	hospitals where the	previous day (p<0.01 in 73	
		anesthesia group	of 91 occasions), and	Social
		provided services.	better dispersion of	-

	Target population: Anesthesia providers in	When the provider	working hours (p=0.002)	Cognitive: Sense of
	a private practice group	enters a geofence,	compared to the previous	security regarding
		their time at the	year.	equitable
	Sample size: 198	facility is		distribution of
		continuously	Acceptance of the mobile	work based on
	Duration of follow-up: 12 months	checked and	application was slow to	geofenced data
	\sim	reported to a	start but >95% in less than	and capture of
	Outcome of interest: Equitable workload	central server.	1 year of roll out	time working for
	distribution, employee acceptance and	Reports were then		billing purposes
	uptake, and reduced dispersion of the	used to inform		
	amount of overtime worked by staff	future clinical		
		responsibilities and		
		overtime worked		
Besoain et al.,	Study purpose: Prevent sexually	User input: Mixed.	All users triggered a	Theoretical
2020	transmitted infections (STIs) by sending	Hot zones were	geofenced hotzone during	framework:
	preventive measures in risky situations	created by a system	the development phase,	Elaboration
UBESafe		administrator and	though this was not	likelihood model
	Study design: Development and feasibility	with input from	quantified further. Hot	
22		users	zones were seen as a	Behavioral:
	Target population: Men who have sex with		necessary component	Contextual
	men	Mechanism of	from those testing in the	messages for
		delivery: Geofenced	development phase.	sexual risk
	Sample size: Development-5; Feasibility- 4	hot zones are areas		reduction sent in
		demines with a high	In the feasibility phase,	hot spots for high-
	Duration of follow-up: Development- 2	probability for	users tested and rated	risk intercourse
	weeks; Feasibility- 1 month	intercourse. When	prevention messages as	
		users enter a hot	well as adding their own.	Social:
	Outcome of interest: Development-	zone, a contextual		Gamification of
	functional testing to receive user	message to prevent	Users also contributed to	preventive
	feedback; Feasibility- try the UBESAFE	HIV and STIs, and	hot zones and tested	messages and
	system with all its functionalities	promote testing	existing ones, contributing	interaction with

	65% of hot zones in the	others using the
	application at the end of	application
	the study.	
		Cognitive

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	Wright	Owei	Gustafson	Nguyen	Naughto	Dorsch	DeFilippis et	Connor	Besoair
	et al.,	et al.,	et al.,	et al.,	n et al.,	et al.,	al., 2017	&	et al.,
	2021	2021	2014	2017	2016	2020		Herzig,	2020
								2016	
Infrastructure									
Technology platform									
Interpretability/Health information									
systems context									
Intervention delivery									
Intervention content									
Usability/content testing		NO.							
User feedback									
Access of individual participants									
Cost assessment									
Adoption inputs/program entry									
Limitations for delivery at scale									
Contextual adaptability									
Replicability				l l					
Data security					UA				
Compliance with national guidelines									
or regulatory statutes									

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM PRISMA-ScR CHECKLIST ITEM			
TITLE				
Title	1	Identify the report as a scoping review.		
ABSTRACT				
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.		
INTRODUCTION			1	
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.		
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.		
METHODS				
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.		
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.		
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.		
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.		
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.		
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.		
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.		
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).		
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.		



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SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	
Results of		For each included source of evidence, present the	
individual sources	17	relevant data that were charted that relate to the review	
of evidence		questions and objectives.	
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	
Limitations	20	Discuss the limitations of the scoping review process.	
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

[‡] The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

