EquityWare: Co-Designing Wearables With And For Low Income Communities In The U.S.

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ABSTRACT

Wearables are a potentially vital mechanism for individuals to monitor their health, track behaviors, and stay connected. Unfortunately, both price and a lack of consideration of the needs of low-SES communities have made these devices inaccessible and unusable for communities that would most substantially benefit from their affordances. To address this gap and better understand how members of low-SES communities perceive the potential benefits and barriers to using wearable devices, we conducted 19 semi-structured interviews with people from minority, high crime rate, low-SES communities. Participants emphasized a critical need for safety-related wearable devices in their communities. Still, existing tools do not yet address the specific needs of this community and are out of reach due to several barriers. We distill themes on perceived useful features and ongoing obstacles to guide a much-needed research agenda we term 'Equityware': building wearable devices based on low-SES communities' needs, comfortability, and limitations.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**.

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KEYWORDS

Wearables, Co-design, Low-socioeconomic status, Neighborhoods, Crime, Safety, interviews

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1 INTRODUCTION

Recent advancements in mobile computing have enabled the growth of wearable technologies. Wearables are electronic devices with computational capability that can be worn as accessories (smart watches, wristbands), embedded in clothing (e-textiles), implanted, used as skin patches, and even tattooed on the body. The number of wearable devices is expected to reach 1 billion by the end of 2022 [86]. Although wearable devices can improve the lives of many, low-SES and racial/ethnic minority communities that would benefit the most from the health and safety benefits that wearables provide have been largely overlooked [11, 19, 49, 101]. Low-income minorities refer to the group of people who live at or below the poverty threshold [15] and who have been disenfranchised and historically oppressed in the United States due to race, class, ability, sexual orientation or identity, or citizenship [43]. The ongoing COVID-19 pandemic crisis has further increased the divide, with poverty increasing in Black and Brown low-income communities [1, 48] and access to healthcare/insurance decreasing [8, 32]. Economic, health, and social inequities have increased significantly in recent years.

We see similar inequities in technology development. The low-SES and racial/ethnic minority population has "traditionally been

marginalized in technological design" [34]. The exclusion of these groups in technological design is not new [5, 12, 30, 34]. Recent work has shown how discrimination is perpetuated in technology among Black and Brown communities [13, 46, 59, 102]. For example, photoplethysmographic PPG sensors are embedded in popular wearables like the Apple Watch and Fitbit to measure heart rate. These sensors do not accurately read and "may not work at all" on people with darker skin tones [24, 82]. Consequently, in their current state, wearables have not been designed with/by low-SES or marginalized community members. This not only decreases their utility, but also makes them actively harmful.

We propose and coin the term "**Equityware**" as a research agenda for creating wearable technologies with and for marginalized communities in response to the harmful effects of modern wearables on low-socioeconomic (low-SES) and racial/ethnic minority individuals. As an initial step, we conducted an empirical study to understand the barriers and facilitators for equity, inclusivity, and utility in the design of wearables for minority low-SES individuals living in high crime rate neighborhoods in the United States. Through these interviews, we found that a central need and focus for community members was safety, leading us to work with participants to consider what role wearable devices could play in addressing their safety concerns. We found that participants' most prevalent safety concerns involved gang-related activity, lack of infrastructure and services, and gender-based violence. We engaged in co-design to elaborate on possible future wearable device modalities and requirements. Prior work has focused on designing software tools to mitigate the detrimental effects of crime on low-SES communities from violent neighborhoods[9, 28, 39, 74, 75]. We extend this approach by evaluating the potential benefits of co-designing wearables with these communities through a hardware perspective. Current software tools can only go so far in preventing crime, whereas hardware tools can offer capabilities such as using sensors to capture evidence of a crime or warning potential victims of possible suspicious activities before a crime takes place. To this end, we elaborate on participants' most important safety needs and ideas for using wearable tools for safety.

Our contributions include:

(1) We describe the daily safety concerns of participants living in low-SES, high-crime communities.
(2) We describe participants' perceptions of wearable devices, including existing harmful features, valuable features, and new ideas proposed by participants.
(3) We define Equityware as a research agenda for co-creating wearable devices with, by, and for members of marginalized communities.
(4) We develop a framework of Equityware design requirements, and an example hardware/software system design as a distillation of participants feedback.

2 BACKGROUND AND RELATED WORK

2.1 The Digital Divide

The COVID-19 pandemic exacerbated digital inequities. As in-person conversations became replaced by online interactions, people relied on technology to facilitate remote life and maintain connections. Thus, this period of time brought forth great technological innovations, with some characterizing this era as "the great accelerator" of digitization. However, the increased reliance on technology also exaggerated the disparity between low-SES communities and those with access to advanced devices, internet, and other digital technologies [11, 66].

In low-SES communities, many do not have access to home internet or dedicated computing devices (laptop, desktop); instead, they often have to resort to using low-end smartphones to perform complex tasks such as finding jobs or doing homework [66]. The lack of access to technology in low-SES communities can be attributed to digital redlining– the systematic denial of equal access to digital tools. Namely, internet service providers have been known to exclude low-income communities from receiving internet [67], which restricts access to online learning, safe job opportunities, and digital health services. This has contributed to a higher mortality rate from COVID-19 in low-SES communities and an educational gap in children from low-SES background [66].

Research has shown that technology– as it continues to advance– fails to address its damage to marginalized people of color. Bias has been built into systems through discriminatory machine learning algorithms based on unrepresentative data [60]; as these biased models [53] and unrepresentative data propagate through the pipeline to form the foundation for influential and high-stakes processes in society– from identifying criminal suspects to governing search engine results– AI's propensity to discriminate based on factors such as race can endanger the lives of racial minorities [4, 14, 65] and perpetuate harmful stereotypes [71]. In response, a few have explored how machine learning needs to change to protect vulnerable groups in areas such as healthcare [53] while addressing privacy concerns with sensitive data [94].

Wearables, which offer significant and important social and health information to their users, also contribute to the disparities caused by technology. Studies have shown that wearables, though helpful for physical activity tracking, are currently not serving the people who would benefit the most, such as vulnerable marginalized groups [101], and as noted, are comprised of sensors and software systems (i.e., PPG) that are less accurate on those with darker skin, limiting access to accurate health information that can be used to detect heart arrhythmia, energy expenditure, and a host of other markers [82].

It is imperative that ongoing efforts continue to carefully address each of the accessibility barriers listed above and expand the adoption of wearable devices to more closely represent the broader population. Without such actions, systemic inequities will continue to pervade the digital realm.

2.2 Designing with Marginalized Communities

In recent years, we have seen an increase in HCI research looking at the technology needs of low-SES individuals [63]. For example, a study in a major US city found that technology that satisfies several themes, including staying connected, having mobile telephony, and allowing access to information and social networks, have the potential to benefit homeless populations [63]. A co-design study on human-drone interaction in Sub-Saharan Africa indicated that integrating cultural relevance and stakeholder input could enhance

participant safety with drones while maintaining freedom of use and privacy [103].

Participatory design [69] and community-based participatory research [81, 98] have been used as methods to do work with historically marginalized communities. These collaborative research methods share the common goal of "incorporating the perspectives and needs of intended end users into technology design" [93]. Community based participatory research (CBPR) is conducted "for, with, and by communities rather than on communities [31, 37, 62], whereas traditional research uses an outsider observer that studies subjects from a distance [62]. CBPR has been used to develop health resources for pregnant and postpartum women in first-nation and Metis communities in Canada [25], to develop devices designed to aid marginalized children with prosthetic limbs walk through mud in Cambodia [55], and to expand on the possible benefits of using e-health technology in low-income Hispanic communities [40]. Harrington et al. also explored the potential of community-based design workshops that engage participants in the design process by co-designing health solutions for low-income African-American individuals. Through this process, they found that such workshops empowered their participants to take ownership over the workshopping process and their health choices and inspired more community-based activism, showing that the co-designing process is a useful and insightful tool for understanding the perspectives of people from low-SES communities [45]. Another study worked on examining the barriers that the African-American and Latinx communities face when encountering city technologies and generated solutions to these challenges but also warned that participatory design is often a White and affluent activity that can lack connection with the lived experiences of marginalized groups and even lead to unintentional harm [44], which suggests that workshops conducted by members of the same community are valuable.

Though participatory and co-design methods have been applied in mobile and computer applications [17, 25, 28, 68, 85, 88, 90, 95] and websites [40, 41, 89] to help low-SES communities, these approaches have not been widely applied to wearable devices as they relate to low-SES communities. One notable study focusing on wearables for low-SES caregivers and their children found that tracking tools for physical activity revealed the interconnectivity between community members' environment and their ability to use physical tracking applications. [79]. This work motivates the need for more research on how wearable technologies can be designed for the environmental and social contexts of low-SES communities.

2.3 Receptiveness to Wearable Devices

Approximately 30% of people in the U.S. use wearables, such as smartwatches or fitness trackers [19]. For low-SES communities, the use of wearable technologies drops to approximately 12% of those whose annual household income falls below $30,000 [97]. Past work has identified several barriers that make wearables less accessible to low-SES communities, including lack of privacy, high power demands, high cost, and an absence of nuanced cross-culture communication [19, 52].

Privacy concerns have been central to the general outlook on wearables, as users have expressed hesitation over using wearables that can record or otherwise invade their privacy [22, 100]. Research on wearables that included, but did not focus on low-SES individuals, found that people were also worried about data privacy and policies [54]. Battery life and cost are also prevalent barriers. Prior work has also found that battery life hinders the acceptability of wearables. Most wearables, especially high powered wearables [42, 73], have limited battery life and are inconvenient to charge [18, 96]. In response, a few have explored energy harvesting or increasing device efficiency [7, 51]. Further, there have been some efforts made to design cheaper wearables [64].

A final core issue limiting accessibility of wearables is a lack of nuanced cross-cultural communication surrounding wearable devices. For example, in a study that interviewed 1007 adult patients at six Federally Qualified Health Centers [52], researchers sought to better understand the perception of fitness trackers within different populations. They found that the word 'trackers' elicited concerns from many Spanish-speaking participants; such terminology generates misunderstanding of the intended use of wearables, causing distrust and active resistance among some users [52].

Thus, while several barriers limiting the acceptance of wearable devices have been identified, the current research agenda does not focus on the complex needs and challenges faced by people in low-SES neighborhoods. As we will show, community members identified additional barriers that need to be addressed to make wearable technologies usable within these neighborhoods, and further these members identified highly desirable attributes, features, and applications for future wearable devices.

3 METHODS

We conducted an exploratory study to understand the needs of low-SES communities that influence adoption and use of wearable devices. An initial round of interviews revealed a strong focus on safety concerns. This informed a second round of data collection focusing on participants perspectives, reactions, and recommendations for the design of safety-based wearable devices. This study was conducted from December 2021 to March 2022 amidst the rise of the COVID-19 Omicron variant. All interviews were conducted in English over a Zoom video call. Anonymized Institutional Review Board approved the study protocol.

3.1 Recruitment

We were interested in working with low-SES community members from metropolitan cities. We recruited participants by posting flyers on the research team's social media sites, such as Instagram and Facebook. The eligibility criteria for this study and a link to an online screening survey were posted on these flyers. Eligibility was determined if participants identified as (1) over the age of 18, (2) BIPOC,[1] and (3) low-income. Interested participants completed a screening survey that asked for basic demographic information (e.g., race, education level, household income, and the number of persons in the household) to determine eligibility. We determined that a person passed criteria three if their income levels fell below the low-income threshold according to their county's Department of

[1]The term BIPOC refers to individuals that identify as Black, Indigenous, and People of Color. As opposed to "POC" People of Color, the term BIPOC is used to acknowledge that not all people of color face equal levels of injustice. We acknowledge that this term is specific to the United States.

ID: Gender	Age Range	Education	Income Range	# of Persons in Household	Owns Wearables
P1: F	18-29	Bachelors	<26K	3+	No
P2: M	18-29	Two year / some college	<26K	1	No
P3: F	18-29	Two year / some college	26-50K	2	Apple Watch
P4: M	18-29	Bachelors	26-50K	2	Apple Watch
P5: F	30-44	High School	26-50K	2	Samsung Galaxy Watch
P6: F	30-44	Bachelors	<26K	1	No
P7: M	18-29	Bachelors	26-50K	1	No
P8: M	18-29	Bachelors	26-50K	1	No
P9: F	30-44	Two year / some college	26-50K	2	No
P10: F	18-29	High School	<26K	1	No
P11: F	18-29	Bachelors	26-50K	3+	Apple Watch
P12: F	18-29	Two year / some college	<26K	1	Apple Watch
P13: F	18-29	Two year / some college	<26K	2	No
P14: F	18-29	Bachelors	<26K	1	No
P15: M	30-44	Two year / some college	50-75K	2	No
P16: F	30-44	Two year / some college	50-75K	3+	No
P17: F	45-54	Two year / some college	50-75K	2	Fitbit (previously)
P18: F	30-44	Bachelors	26-50K	3+	Apple Watch
P19: F	18-29	High School	26-50K	1	Fitbit (previously)

Table 1: Participant demographics. All participants belong to Hispanic/Latinx groups.

Housing and Community Development[2]. For instance, in Los Angeles county, a household of two or more is categorized as low-income if their income is below $75,700. Eligible persons were contacted via email to participate in the study, and eligible participants then provided written consent via email.

We recruited 19 adults from low-SES communities in two metropolitan cities in the United States (see Table 1 for participant demographics). For the preliminary investigation, participants (P1-P8) were recruited from December 2021 to January 2022, and among the participants, two identified as members of the LGBTQ+ community. Participants (P9-P19) from the secondary investigation were recruited from mid to late March 2022. All participants identified as Hispanic/Latinx [3] and low income. Additionally, according to FBI crime statistics, all participants lived in communities with crime rates that are at least double the national average. It was not our intention to recruit individuals from high crime rate neighborhoods, but we felt compelled to highlight this aspect as the lived experience from these individuals have often been excluded [34, 44].

3.2 Data Collection

3.2.1 Preliminary Investigation: Understanding Community Needs. After obtaining signed consent forms, the lead author conducted 45-60 minute virtual semi-structured interviews via Zoom. Participants were compensated with a $40 gift card at the end of the study. In these initial sessions, we sought to understand if and how wearable devices might benefit members of low-SES communities and to learn about participants' opinions regarding wearable technology. Our full interview guide can be found in the appendix under A.1.

From this preliminary investigation, participants strongly emphasized a critical need for safety-related devices in their communities that have been widely overlooked by mainstream technologists and developers. The high number of safety concerns raised by participants in these low-SES neighborhoods led us to perform a second round of data collection to more meaningfully understand participants' safety concerns and the opportunities for wearable tools to help.

3.2.2 Secondary Investigation: Considering Technologies for Safety. This second phase of research focused on discussions on participants' safety concerns and perceptions of wearable devices. Interviews were again scheduled over Zoom and lasted 45-60 minutes. Participants received a $40 gift card at the end of the study.

With safety as a theme of focus, we began with a 10 to 15 minute semi-structured interview. Interview questions addressed safety concerns, participants' perceptions of wearable devices, and recommendations for safety-based wearable devices. The full interview guide can be found in the appendix under A.2.

Once we completed the semi-structured interview portion, a series of storyboards [26, 91, 105] were employed. We used storyboards because participants needed more familiarity in the preliminary investigation to understand how wearables function. For instance, a couple of participants needed help understanding the concept of a sensor or how they are utilized in a wearable system. However, once the researcher described what a sensor could do, participants then mentioned scenarios in their everyday life in which a wearable could be helpful for safety, such as when walking home or running errands alone at night.

The storyboards, therefore, allowed us to introduce the concept of safety wearables (Board 1), elicit what participants think safety wearables could or should do (Board 2), evoke feedback on current features found in safety-related wearable devices (Boards 3 and 4), and explore potential future applications/comfort with the technology (Boards 5 and 6). A limitation of this method is that we cannot incorporate every feature found in existing wearable devices. Therefore, we selected a few features based on preliminary discussions and common off-the-shelf wearable devices in the media highly commercialized around safety so that participants in the secondary investigation could then challenge, investigate, and draw on their lived experience.

The storyboards consisted of six slides, as shown in Figure 1, and were presented one at a time. Each storyboard presented a scenario related to safety and the use of a wearable device. After reading each storyboard, participants were asked if they felt positive, negative, or neutral toward each storyboard and to explain why they felt that way about the scenarios presented. We then asked participants if there was anything they would change about the scenario or the wearable device and why. We continued to do this for all six slides. As part of the data collection, we noted participants' likes, dislikes, barriers of use, and what they would add or change to the safety wearable device presented to them in each scenario.

Participants were introduced to the character Tasha in the first storyboard. Tasha feels unsafe walking to her home at night but feels safe knowing she has a safety wearable device. The second storyboard is a continuation of storyboard one, except in the second storyboard participants were explicitly asked what the device should do to help Tasha feel safe at night. Participants were then asked how they think Tasha feels after having a device that includes the features they recommended. The third storyboard introduces a device that detects motion and uses an alarm to ward off a potential threat. We refer to this device as "Locoalert" for the rest of this paper. The motion detection feature was inspired by the participants

[2]In the United States, the Department of Housing and Community development uses State Income Limits provided by the U.S. Department of Housing and Urban Development. https://www.huduser.gov/portal/datasets/il.html

[3]Latinx is a gender-neutral term that refers to individuals who identify as or relate to Latin American heritage. We acknowledge that this term is specific to the United States, and not all Latin Americans use the term Latinx to identify themselves.

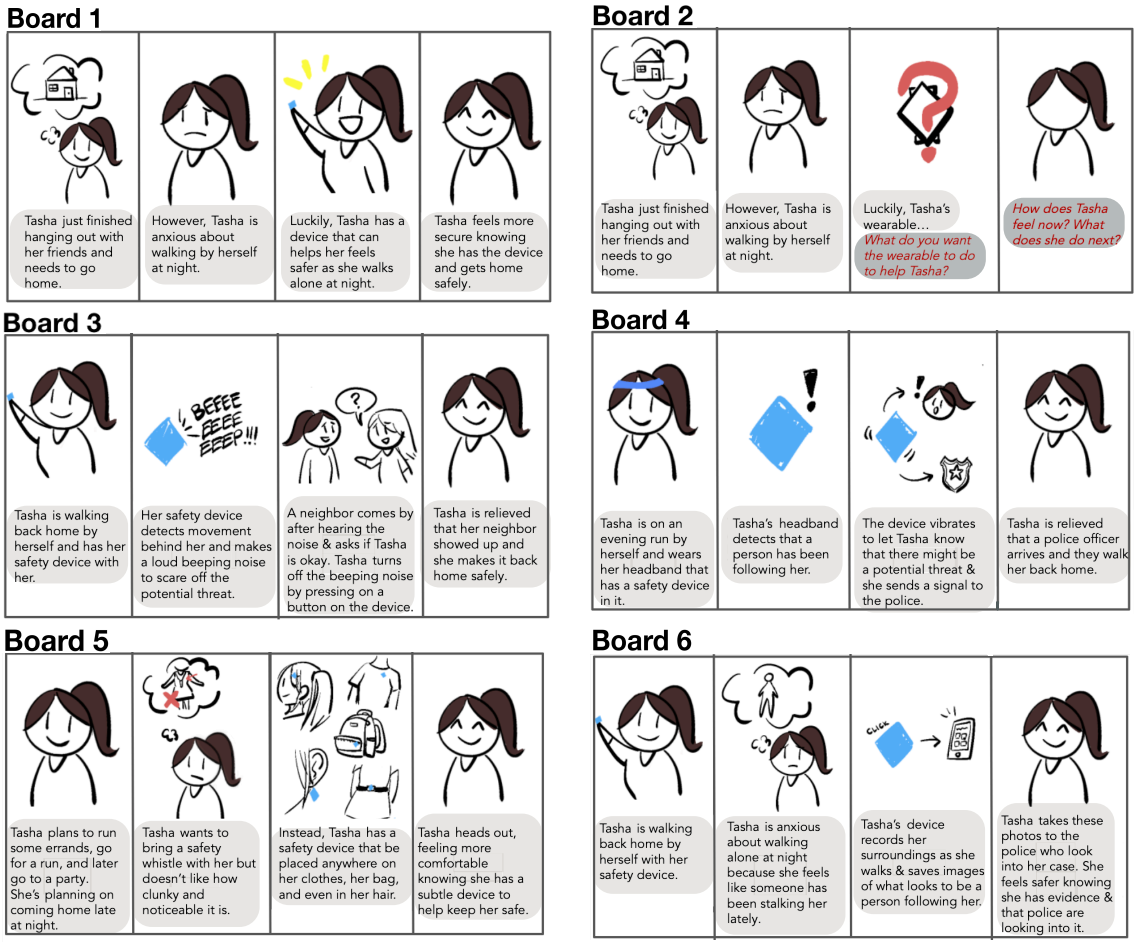

Figure 1: This figure displays the storyboards presented to participants that show *Tasha* and her use of wearable technology for safety. We used the storyboards as a starting point for discussions with participants on barriers and desirable features of wearables.

in the preliminary study who mentioned they wanted a wearable feature that senses their surroundings. The alarm function of this device was inspired by she's birdie[4]. Storyboard four uses Locoalert and is mounted on a headband. However, in this scene, Locoalert has more capabilities, such as automatically sending a signal to the police that she is in danger. This additional feature is inspired by Invisawear[5]. Storyboard five presents Locoalert as a small and versatile wearable device that can be placed on different places of a person's body. This storyboard was influenced by participants in the preliminary study who mentioned they did not want flashy and bulky devices. Lastly, in storyboard six, Tasha feels like she is being stalked. Participants were introduced to a new device that helps Tasha record her surroundings as she walks and saves images on her phone. Tasha brings evidence to the police so that they can look into her case. Postscapes[6] inspired the features in the device highlighted in this storyboard.

3.2.3 Data Analysis. Audio recordings of the interviews were transcribed, resulting in a total of 21 hours of interviews. Data from both studies were combined and analyzed together. The research team analyzed the data using a grounded theory approach [21].

Preliminary investigation: The lead author and two other co-authors performed open coding on the transcripts and identified initial themes. The research team, which consisted of two more authors, then reviewed the transcripts and collaboratively discussed associated codes to look for consistencies and differences in the data. Based on group discussions, themes were iteratively refined by the research team. After coding, the themes found in this portion of the study were: gender-based violence, lack of infrastructure and services, flashy wearable devices, powering and charging devices,

[4]she's birdie is an existing, highly commercialized wearable device aimed to be used as a safety tool by individuals https://www.shesbirdie.com/. It is designed in the form of a key-chain and when pulled it emits a loud sound to scare off a perpetrator.

[5]Invisawear is a highly commercialized wearable device that is intended to be used for safety purposes. It is designed to be fashionable and less apparent. When the button on the device is pressed it sends an alert to the ADT company, an alarm monitoring service based in the United States. https://www.invisawear.com/

[6]Postscapes is a life-logging camera designed to help capture moments in time https://www.postscapes.com/lifelogging-device/#

small and versatile design, increased awareness of surroundings, and location sharing. These codes motivated the design of the storyboards in the secondary investigation.

Secondary investigation: After the lead author and two other authors performed open coding on the transcripts and identified themes, the research team once again reviewed the transcripts and collaboratively discussed associated codes to look for consistencies and differences in the data. Once again, based on group discussions, themes were iteratively refined by the research team. Three authors then used the refined themes to code the full dataset. Two more authors from the research team then reviewed the codes to check for any discrepancies. In addition to the themes found in the preliminary investigation, the themes found in the secondary investigation are: prevalent safety concerns, critical barriers and harmful features, accepted or valuable features, and participant proposed features. In the results section, we discuss the findings in each theme more in-depth.

3.2.4 Positionality Statement. We are committed to studying how wearable technology has failed to address the needs of low-SES communities in the United States, with a focus on how wearables can harm or add value to these communities. The first author is a member of the communities examined in this study. The first and second authors identify as Latinx of Central American descent and have lived experience growing up as members of minority low-SES communities. The first author conducted all interviews and was involved in the study design, data collection, and analysis. The second author was involved in the study's data collection and analysis process. Following the concept of intersectionality, we recognize that we only capture the perspectives of a small sample of the Latinx community within the United States. We acknowledge that other groups that identify as Latinx, such as Afro-Latinx, in the United States were not represented in this study sample and may face additional challenges or have unique experiences that are not reported in this study.

4 RESULTS

In this section, we will describe how participants' experiences and personal situations color how they think about wearables. We also describe their expectations and goals for future tools. Importantly, we found that this contextual information provides the actual design space wherein any digital technology must live; as **participants' constraints and concerns remove from consideration nearly any type of commercially available wearable**.

4.1 Prevalent Safety Concerns

Every participant discussed safety issues within their community, recalling numerous instances where crime and violence affected their lives. In this section, we discuss the prevalent safety issues within these communities that have been steadily increasing each year.

4.1.1 Gang Violence. Participants (n=12) described traumatic events and concerns related to gang activity. P18 described an incident where her brother was mugged at knife-point by a gang member and said that "*luckily only his phone was stolen, better the phone than him getting hurt*". P11 recalled three instances where a direct family member was robbed at gunpoint by a gang member back when she was a student in elementary school.

Participants also mentioned that because of the gang activity in their neighborhood, they constantly need to be aware of their surroundings. P17 stated that "*even if it was daytime I felt, like, insecure… like I would have to be more mindful of my surroundings [because of gang activity]*." P17's fear was shared by twelve other participants. For example, P16 stated:

> P16: *Definitely a night was like the worst where you saw people get beat up. You know it's like very heavy with gangs around... I would always be afraid to walk to my car, like I would run.*

Thus, we found that gang-related activity was one of the most pressing safety concerns among participants. Participants expressed concern about both targeted and random violence. Participants indicated that gang violence worsens at night, and these issues have only been exacerbated due to the COVID-19 pandemic. Dickinson et al.'s violence prevention mobile application for street outreach workers and Erete's exploration of community crime-prevention technologies show the potential of using technology to reduce violence without police intervention, which we extend by exploring wearables as another form of technology to support community safety [28, 35]. It is important to highlight these issues so that wearable technology designers can be mindful of how to design future wearables for low-SES communities. We discuss the dilemma of designing wearables in neighborhoods where gang violence and theft are prevalent in section 4.2.1.

4.1.2 Lack of Infrastructure and Services. Participants also described a number of safety concerns related to the lack of safety infrastructure and services, such as street lights, and trustworthy emergency response professionals. Participants (n=13) mentioned they were scared of being out at night. Nonexistent or faulty street lights only increased their fear:

> P13: *I think the neighborhood is dark. Also, it's not very well lit, so I do feel more unsafe. Then again, I try to, like, I always look behind me to see if there's somebody walking and then [if it's] just [a] guy walking behind me I walk slower so that he gets ahead of me and so I'm the one behind him. You know, I just do little things like that.*

Here, P13 suggests the lack of proper streetlights makes them feel more unsafe in their neighborhood and mentioned that they try to take control of the situation by making sure they walk behind a person. Even though participants feel unsafe due to the lack of proper lighting in their neighborhoods and increased criminal activity, they do not feel compelled to alert authorities. All participants are from neighborhoods predominantly comprised of people of color, and there is a history of mistrust between people in these neighborhoods and the police. P18 talked about why they don't go to authorities after a crime:

> P18: *We just didn't notify them [(the police)] because they just never come. They never show up. My sister has called. We have some neighbors who, I don't know, for some reason this house attracts people who get involved in domestic violence. And my sister called the police*

> *once and they never showed up. Then we recently had another event. Well, I shouldn't say event, but another incident like a domestic violence incident and then the police asked me like why didn't you call? I was like well because the last time we called, nobody showed up.*

Similarly, P14 expressed her frustration with authorities and said "*I mean, come on, [in] places where it's not safe. Like for instance in [redacted], the police doesn't show up and if they show up, instead they'll arrest you*". In these quotes, P18 and P14 share that alerting police and other first responders is useless. Participants indicated that the police have a history of not showing up to incidents in low-SES neighborhoods. P14 also expressed their concern that if they were to alert the police about a crime, the police would just come and arrest the innocent victims or bystanders.

In situations where authorities do show up, participants stated that authorities should be able to do more to ensure the safety of victims. As P15 shared:

> P15: *I drive for Uber so I had a passenger who had, who told me they just got raped and she was surrounded by like 6 different sheriffs and not one of them took her home.*

In this quote, P15 shares their frustration towards authorities. They felt that the sheriffs were very insensitive towards a woman who experienced a horrific crime and felt more care should have been taken. P13 expanded on this issue, describing a more systematic concern with authorities.

> P13: *Well, there's just a lot of racism and issues that's systemic that need to be, you know, dealt with... At the same time do you really want a police force in a neighborhood where it's like, people of color? Not really, because of the way that they treat people of color, you know, like the people don't trust police, you know.*

Here, P13 relates mistrust of police with the way police have historically mistreated people of color. People from these communities feel scared because they feel they cannot turn to anyone.

The lack of street lights and police mistrust were the most common infrastructural issues impacting participants' communities. Previous research has shown that unlit places increase women's fear, especially in areas that are known to be unsafe [2, 10, 58]. While other work in the literature report how people from communities of color avoid reporting incidents to law enforcement due to mistrust and power imbalance [27, 77, 84]. Dickinson similarly noted the insufficiencies in infrastructure and absence of police support in low-SES communities but focused on the possibility of developing civic technologies for community advancement rather than the development of devices to support personal safety [29]. As people from low-SES communities continue to face systemic issues that prevent them from feeling safe and protected in their environments, targeted solutions that can help increase personal safety are needed. As we will discuss later, wearable technologies may be able to help individuals circumvent some of these infrastructural limitations, but thus far have failed to consider such community needs directly.

4.1.3 Gender based violence. Amongst the female participants (n = 14), gender-based violence was a common experience. Gender-Based violence refers to "harmful acts directed at an individual based on their gender. It is rooted in gender inequality, the abuse of power and harmful norms" [36]. Nine participants said they experienced instances of harassment and stalking. All female participants (n=14) shared concerns about "*getting raped, mugged, or kidnapped.*" P14 reported:

> P14: *Being raped is [a concern] as a female. Another one would be getting attacked or robbed for the things that you have on you. There are a lot of people out here who still carry— who carry guns and they carry knives too. So then for them to be able to assault you is very, very easy, especially if you're not someone who is like, I guess big in stature or in height, or like in weight or mass. Whatever, you wouldn't be able to protect yourself alone if you're female.*

Getting kidnapped was a common concern amongst the female participants. P16 had the courage to share their experience of surviving an attempted kidnapping:

> P16: *I was once, this is in the daytime too in [redacted], and there was like these two guys that wanted to kidnap my cousin and I. For me, I think it's very traumatic. And I do not like, I just, I'm just afraid at night, like, you just never know what could happen.*

P16 explicitly mentioned that this experience traumatized her for life. She mentions later in her interview that she shouted for help but no one came to her rescue. Even though she is older now and thinks she might be able to put up a fight, she fears it wouldn't be enough to help her survive if such a situation repeated itself. Another participant, P19, shares her own experience and feelings of helplessness:

> P19: *I used to come home from work like at like 4:00 PM and like a guy on a bike would be following me and I'd be like really? [L]ike in the afternoon? Or [there are] people on like a curb and they're just like hey, hey, hey. ... Luckily nothing has ever happened to me. Knock on wood, but I mean I know people that are like 'oh yeah, like the other day I got stopped,' or like, or you know, 'they try to rob me' and I'm like God like that really sucks because like,* ***it's like we really can't do anything, especially as girls. We really can't go out in the day or the night, like, we live in fear forever****.*

In this quote P19 talks about situations where she was stalked and catcalled. Day and night women feel unsafe in their neighborhoods, and as a woman, she feels she lives in constant fear that something worse might happen to her.

Gender-based violence is a major issue that significantly worsens the quality of life of individuals from low-SES communities. The ubiquity of this issue forces those most vulnerable to operate under continuous fear and vigilance. Blom et al. report similar findings in their work with females in urban cities located in India and the United States[10].

Overall, these safety issues cause extreme distress in individuals from low-SES communities that lead to the reduction of quality of life. Gang-related activities, such as robbery and assaults, cause participants to feel insecure in their neighborhoods and force them to remain constantly vigilant. The lack of infrastructure and services, such as faulty street lighting and mistrust in authorities, perpetuate dangerous living conditions in their communities. Finally, gender-based violence was often brought up by participants due to its propensity to adversely affect women's ability to recreate and live their lives. Safety is all too time-consuming; they cannot focus on anything else. There is a clear need for safety tools that are tailored to them and their communities. Yet, while safety tools are of utmost importance, there is a lack of research understanding and designing for the safety concerns of these communities.

4.2 Perceptions and Reactions to Wearable Devices

While most participants did not own a wearable device, an aim of this research was to understand perceptions and reactions toward these types of technologies. Participants' perceptions and reactions toward wearable devices were surprisingly positive. All participants mentioned that they were aware of wearable devices. A few participants already owned wearables, see Table 1, but only one participant (P18) mentioned specifically using the device for safety purposes. P18 mentioned that they press the SOS alarm button on their Apple Watch if they felt they were in danger. All other participants (n= 11) revealed that they would consider owning a wearable device if they were not too expensive. Interestingly P3, who works at a cellular service provider in a predominantly Latinx low-SES neighborhood said:

> P3: *Working at T-Mobile (I've worked there for four years), I would sell wearables, and honestly, even if people can't afford it, they still buy it… it's kind of a symbol.*

This quote displays a growing interest in wearable technology amongst the low- SES communities in this study. As P3 mentioned, having a wearable device is akin to a status symbol, despite the financial burden. In the following sections, we dive deeper into the critical barriers, accepted features, and participants' proposed new features for safety wearables.

4.2.1 Critical Barriers and Harmful features. We found that existing wearable tools often created conflict by incorporating features that were considered both acceptable and unacceptable by community members. In this section, we discuss the unacceptable features that were seen as either barriers to adoption or actively harmful. We will review the features perceived more positively by participants in the section 5.2.2.

Invasion of Privacy: Storyboards were at times met with concern and criticism, guiding rich discussion on wearable features that would serve as barriers to adoption and use in the community. The most controversial feature was the use of cameras. Participants (n=11) felt cameras were too privacy invasive, but only two participants were completely against using cameras. In the following quote, P18 shares how she feels about the use of cameras:

> P18: *I mean. It is and it isn't right. I mean one thing is because it's like for your safety. But also, I mean I, if it's for my safety, I wouldn't mind having someone like record me unless I'm like doing some other stuff you know... I guess like an invasion of privacy, just because, you know if it detects someone who's just walking by you and not like essentially a predator, uhm, you know those people might be upset or I don't know like. You know they might say something like hey, why is your wearable device taking a picture of me or something like that?*

This quote shows P18's concerns around a camera focused wearable. P18 mentions that a camera actively filming them can violate the privacy of the people around them. Though the cameras made several participants feel uncomfortable, they did see the benefits of using the camera as a tool to gather evidence from a perpetrator.

Potential Discrimination: In addition to privacy concerns, participants discussed that cameras can be used to perpetuate discrimination against people of color.

> P15: *It [the camera] might discriminate against people, like, people of color. So it might send out the wrong signal and cause... cause something to be more than it needs to be. So instead of diffusing the situation, it just enhances it and might end somebody's life.*

P15 expressed concern over having cameras on wearable devices. Even though having a camera might be used for good intentions, cameras can reinforce discrimination against innocent people of color [4, 14, 65]. If authorities were wrongly notified and drastic actions were taken, it could potentially lead to the arrest of an innocent person or worse, an end to that innocent person's life. It is important that wearable tech designers and researchers keep in mind there are many ways that this technology can negatively affect the people it's supposed to serve.

Lack of control over device features: Participants (n=10) felt uncomfortable due to the lack of control over the device features we presented in the storyboards. When referring to Locoalert, the device introduced in the storyboards, participants felt they would not use the device unless they had more control over it. P11 said the following about Locoalert:

> P11: *You know, if it's not that loud, it's not really gonna scare anyone. If anything, they'll probably do it [violence] faster before, you know, it actually calls out for help or something. I'd like for it to vibrate because then it's at your discretion and you can decide what to do discreetly without letting the other person know that you know.*

This quote illustrates P11's disinterest in Locoalert unless it allows the user to fine tune the control of the device. All participants in the second group (n=11) felt they liked Locoalert's intention but would prefer additional controls.

In storyboard 4, Locoalert is attached to a headband and Tasha, the character in the storyboard, signals the police for help. All participants in the second group felt that signaling to the police was too excessive, misused resources, and felt the police had better things to do. However, participants liked the idea of a device to

help increase their awareness of their surroundings. We discuss participants' positive reactions toward Locoalert in section 4.2.2.

Flashy Wearable Devices: Having an expensive looking device in a high-crime area may put the wearer at risk. A device that is too "flashy" can easily make them a target for getting robbed. All participants articulated that if they would use a wearable device, they would rather it be small and inconspicuous as possible. P1 explains their reasoning on not wanting a flashy wearable device:

> P1: *I don't like something very flashy, expensive [that] I'm gonna get jumped with. Of course some people like showing off… If you go for younger generations, they're like 'I'll wear that. Even if I get mugged, I'm ready to survive.' So whether we want to be really scientific, we can't be really scientific when we're living our lives. You know in the streets, we gotta be ready, we gotta be aware.*

Even though P1 expresses interest in a wearable device, if they had to choose, they would rather have a wearable device that is not too "*flashy*". If the device is too flashy, a wearer is putting themselves at risk for getting "*jumped*" or "*mugged*" . P1 mentions that younger generations in her neighborhood might be willing to wear a conspicuous wearable device, but they will always have to be "*ready*" and "*aware*" of their surroundings. It is important that wearable tech designers keep in mind that the more concealed a wearable device can be, the better it would be for members of a low-SES community to use. Members from these communities should not have to sacrifice their safety by trying to wear a piece of technology that they feel they can benefit from.

Additionally, P6 mentions their fear of having a wearable get stolen and the further concern that their personal digital information would also be lost along with the device.

> P6: *I wouldn't wanna get it stolen huh? 'cause then I would need my information and my information would get lost with the device. Yeah, then I had to get a whole new sensor and retrain it again.*

Powering and Charging Devices: The ability to power a device is another barrier for people from low- SES communities. Batteries are generally the most expensive part of a wearable device, the most expensive to maintain due to their short lifespan, and the most burdensome since they have to constantly be recharged. Having to constantly recharge a wearable device is a hindrance to many members from low-SES communities because power is not always available to them. Participants mentioned that their neighborhoods are prone to frequent power outages. P1 explains how they respond to this predicament.

> P1: *I have portable chargers for the fear of power outages…So [I] charge my phone just in case because of blackouts and things like that so you never know. And then I have like five portable batteries.*

P1 revealed that due to the frequent blackouts their neighborhoods face, they have to rely on portable battery chargers for their home. Power outages are a common concern in low-SES households [80]. Though we did not directly ask participants if they faced power outages in their neighborhoods, participants (n=5) mentioned power outages in conversation. P1 also mentioned in their interview that they live in a household of six people, so charging their technologies is all the more difficult. Participants who owned a wearable device (n=6) described charging their devices as a nuisance.

Charging a wearable device is not just burdensome; the battery life of a wearable is directly tied to people's well-being when it comes to safety-related technologies. A safety wearable device would render itself useless if it had poor battery life. Wearable devices need a fundamental rethinking of the way they are currently built. It is imperative that future wearables are able to function on ultra-low power platforms or even be batteryless.

4.2.2 Accepted or Valuable features. Though participants identified critical barriers that would impede them from obtaining a wearable device, there were also features that participants viewed as important. In this section, we describe the features participants liked and how these features could help members in their communities.

Automatic evidence capture: Though most participants felt uncomfortable wearing cameras, participants acknowledged that cameras could be a valuable tool to help capture evidence in case they were in a situation where they felt unsafe. P19 explains:

> P19: *It's good to have as a feature because, you know, if you don't have proof— like let's say you go to the police and you're like "oh somebody's stalking me", they really wouldn't, uhm, I think they wouldn't feel, like, OK, it's a valid story or anything. But if you have proof then, you know, it's more likely to become a case where they can assist you.*

A camera would facilitate the capture of evidence that a victim could present to authorities to establish a case against the stalker. Without evidence, P19 feels that authorities would not be willing or able to assist or protect the stalking victims. Participants also noted that it would be helpful to include a camera in a wearable so that they can have the ability to capture any wrongdoing authorities inflict on innocent people of color. Police brutality occurs frequently in low-SES communities. As technology has advanced, more people of color have used the cameras on their phones to capture incidents of police brutality.

Interestingly, P9 shares that the use of a camera would be helpful in providing additional evidence for people who experience a traumatic event. P9 says the following:

> P9: *OK, I'm definitely a lot more positive on this one because they actually have evidence that you can use. Cause for the most part I feel like when something happens I guess your brain automatically triggers like a blackout where they don't want you to remember those traumatic experiences. So having something that can do that for you is a little bit more reassuring.*

P9's comment highlights an interesting perspective. While the way in which an individual processes and is affected by a stressful event is unpredictable, extensive research has deduced that the hippocampus, the brain's learning and memory epicenter, is particularly sensitive to trauma. In some cases, such events may induce heightened retention and uncontrolled flashbacks, other times individuals experience dissociative amnesia [87]. In the latter, victims are often left with feelings of anxiety and depression associated

with the trauma but are unable to remember exact details from the event [78]. In situations such as this, P9 feels that having a wearable camera would be helpful because it can serve as a tool for reassurance.

For the most part, participants (n=9) said they would like a wearable device with a camera on board so long as it was small and gave the user control of when to turn it on and off. They also agreed with P19 and P14 that having a camera can help prove that someone has been stalked, experienced an assault, or as proof of police brutality towards people of color. Seventeen participants liked this feature and found it valuable. All of these participants were also aware that a camera feature can pose an invasion of privacy towards themselves and others. Participants agreed that due to the privacy issue, the user needs to have easy control of when the camera is on or off. In addition, participants who accepted the camera feature all mentioned that it could possibly be misused, as it can also perpetuate discrimination towards people of color. If cameras were to be integrated into a safety-based wearable device, designers should be aware that though cameras can be helpful, they can also cause harm in low- SES communities that people of color predominantly represent.

SOS alarm/ Sensing Surroundings/motion detection: In subsection 4.2.1, we learned that participants were reluctant toward Locoalert, the device we presented in the storyboards that consisted of a motion detection sensor, an alarm to ward off perpetrators, and that automatically sends a signal to authorities. Though they did not like that Locoalert automatically sends a signal to the police and is constantly on, participants mentioned they would be willing to use Locoalert if the user could control when the feature was active, the mechanisms of feedback and alert, and if they could re-purpose Locoalert to make them more aware of their surroundings.

P19 and P17 said they would like the device to have a setting that lets them choose whether they want Locoalert to vibrate or emit a loud noise. P14 mentioned "*if we were given the opportunity to just, I guess, choose our own beep or our own alarm that would be another [helpful feature]*". Give us the option to do so and also how loud we want it to be". Participants (n=11) agreed with P19 and P17 that it was important for them to have control over the device (vibration, volume) so they can turn it on or off when needed and not make a spectacle out of the situation. If they feel unsafe, they can use the loud sound for help, or else they can take control of the situation and keep on going with their day.

Participants (n=11) said that Localert is a valuable tool because it would help increase their awareness of their surroundings and potentially catch a perpetrator off guard in the event they are in danger, a feature not seen in current wearables.

Small and versatile: Participants (n=19) mentioned that they would want a wearable device that was small enough to be hidden. We presented participants with a versatile wearable device that can be placed anywhere on the body in board 5. Participants 11 and 12 were the only ones who opposed having a wearable device that can be placed anywhere, and they preferred something more stationary that can stay in one place on your body. Interestingly, both P11 and P12 already owned an Apple watch, so they preferred to use a wearable device that is always on their wrist like the Apple watch. All other participants in the second group liked having a non-flashy, small, versatile device that can be put anywhere on your body and would buy a device like this, if affordable.

Removing dependance on power: Ultra Low Power or Batteryless device: As mentioned in the previous section, charging a wearable device can be a hindrance for members of low-SES communities that were examined in this study. This issue leads to less adoption of wearable devices amongst individuals from these communities. We asked participants about acceptance if charging were not an issue. Participants seemed excited and interested when asked what their thoughts were on batteryless wearables, which would require no charging (but could have other usability considerations). We asked if a hypothetical batteryless wearable device existed that relied on motion to harness energy to power the device itself but was prone to power failures, would they still be interested in purchasing a device? Would they instead wait until the technology got better and was not prone to power failures? Or were they not interested at all?

From the first group, all participants, including P7 and P8, were interested in using a low-power or batteryless energy harvesting device because they felt it would encourage them to be more active throughout the day since the device's function would rely on their motion. In the second study, six participants brought this up when asked what their thoughts were on the current state of wearable devices. Amongst the previously mentioned participants (n=6), we asked them the same questions since they brought up the nuisance of charging a device. P15 said the following:

> P15: *Oh yeah of course, so it runs on kinetic energy? Using the energy to charge the battery? Yeah, yeah, for sure I would definitely buy it just because I don't have to worry about charging it.*

Participants said they liked the idea of having a low power or batteryless device because it would encourage them to be more active and would not have to worry about charging their device. However, participants mentioned that a lot of people, particularly older generations who do not have much experience with technology, would probably not be interested in a batteryless wearable device. As P19 said "*It would be a hard sell for older people in this community*". Other participants mentioned that older folks, particularly in the communities examined, do not like interacting with *current* technology because the user interfaces are hard for them to use. Past literature has shown that older adult populations have similar complaints (i.e. unreadable screens) when using wearable technology [50, 92].

In summary, participants identified several features that they perceived as useful and/or necessary that they would want integrated into a wearable device. Namely, participants found that automatic evidence capture could help them collect evidence in unsafe situations and that motion detection could be valuable if they had control over appropriate responses. Further, the majority of participants preferred small, versatile, and discreet wearables, and younger participants were interested in ultra low power/batteryless devices. All of these preferences should be taken into consideration when developing wearables for low-SES communities, as their unique needs translate to specific features and design elements that can be implemented into wearable devices.

4.2.3 Participant Proposed Features. Participants also added new ideas in response to the storyboards– technologies not proposed by researchers. In this section we discuss the tools/features participants independently came up with and identified as useful, helping to show their values.

Locations Sharing: When asked what is an essential feature that should be included in a safety wearable device, thirteen participants said they wanted the ability to share their location with a friend or a family member so that they can have the reassurance that someone is looking out for them or have someone know what their last location was. For example, P14 shared:

> P14: *I would like her device to notify a friend of hers or a family member saying that she's walking home. So when she arrives home or like to show her on some type of map showing her route.*

P14 takes their idea a little further by saying that having a map to share with a family member would be beneficial so that their family member or whom she chooses to share her location can track her route.

A total of 13 participants proposed that a location-sharing solution feature would be essential in a safety-based wearable device. Participants mentioned that sharing their location provides reassurance that someone was looking out for them on the way home. Participants also indicated their desire to have their device inform their loved ones when they begin their commute home and arrive home safely.

Microphone/ Voice Recognition: Participants (n=7) proposed the use of microphones for voice recognition. Participants were aware of the potential harms that using a microphone can bring, but said they can be useful in case you need to call in an emergency. For instance, P11 said:

> P11: *Voice recognition is a good one. In case there's an emergency, you know OK, help me call 911 or something. Like emergency contacts [or]emergency services.*

Further, P10 elaborates on how voice recognition might help in providing evidence that someone has been stalking or following them:

> P10: *In terms of stalking, maybe if the person has had a conversation with you before I guess [the device] could analyze their voice in different situations. It [could] also show that you aren't making it up. Maybe you've told people like 'oh, I feel like someone is following me'. You've had these thoughts [of feeling stalked] for a while and [you are] not making it up.*

This quote illustrates P10's concern about people not understanding or believing her claims about being stalked. P10 mentions that having a microphone would be beneficial to have on a wearable device so that it can help analyze the voice of a stalker, and having that evidence would help her convince people to believe her.

Night Vision: Due to the lack of lighting in their neighborhoods, participants (n=7) explicitly mentioned that if cameras were to be used in a wearable device, having night vision would be extremely beneficial. P14 exclaimed "*You know what would also be a very good idea to have [the camera] have some type of night vision*". Similarly P18 reported the following:

> P18: *Is [the camera]gonna be good enough to [record] like in the dark, 'cause you know how sometimes like in some areas there's no lighting. Like you know if you go to like [anonymized neighborhood], they don't have any streetlights. Is it going to take a good picture of the predator if it's just like dark?*

As highlighted earlier, lack of street lights or faulty street lights are a prevalent concern amongst participants. Since most crimes happen at night, participants who said they would like the camera to have night vision capabilities to help capture evidence of perpetrators. A camera's usefulness would be severely handicapped without the ability to record usable footage at night.

Ethics Acknowledgment: We acknowledge that using microphones and cameras brings ethical concerns, especially when concerning children and tracking. We discuss these issues in section 5.2 as a tension in technical literacy of the population.

5 DISCUSSION

The findings presented in this paper help describe the perceptions of wearable devices amongst individuals from low-SES neighborhoods. We found that there was a strong interest in using wearables for safety amongst members from low-SES communities. We learned that participants experience daily safety concerns such as gang violence, lack of infrastructure and services, and gender-based violence. Despite these fears, participants must continue to live their daily lives. Participants expressed interest in having wearable devices that can help mitigate their sense of fear.

5.1 Barriers Needed to be Addressed by Equityware Technology

Prior work aims to understand the perceptions of wearables in other low-SES areas, especially internationally [6, 70, 72]. However, these works primarily focused on wearables for healthcare purposes. By conducting more exploratory research, the issues of crime and safety became central to this research. In this research, participants living in low-SES communities shared critical barriers that limited their use of wearables, features of wearable technologies that they found acceptable, and proposed new ideas for wearable safety devices. We summarize these findings in Table 2. Participants described significant barriers that make wearable devices unusable and even harmful, which were concerns we did not find in prior research. These included access to power, the harms that can arise from flashy, conspicuous, and expensive-looking wearables, lack of control over device features, and a nuanced understanding of privacy regarding cameras. We discuss these new findings that motivate new research in critical areas:

Access to power. In our work, we discovered that access to power limits wearable adoption for individuals from low-SES communities in developed countries. Our work supports some conclusions of previous work that found that wearables are annoying to recharge. We found that participants were more willing to adopt wearables that needed to be recharged less by harvesting energy or operating with less power. However, participants mentioned that access to

Safety Concerns	Helpful Features	Harmful features & Critical Barriers	Proposed Features
Gang violence	Camera (automatic evidence capture)	Privacy invasive cameras	Location Sharing
Lack of infrastructure	SOS alarm + Surround sensing	Racial Discrimination	Microphone\Voice recognition
Gender-based violence	Small size	Lack of design control	Flashlight
	Versatility	Affordability	Night vision camera
	Ultra-low power or batteryless	Flashiness	
		Short battery-life	

Table 2: This table presents participants' safety concerns, the critical barriers/harmful features of wearable devices we presented to them in the storyboards, the accepted and valuable features, and participants' proposed features.

power was an issue that went beyond annoyance, as they face infrastructural barriers in the form of frequent neighborhood/home power outages, which is a concern not addressed in prior work.

This second concern is even more pervasive in developing countries, where power outages are widespread. Previous work has measured this unreliability and how it affects residents: [61] deployed large sensor networks to measure power outages and quality in Ghana; [57] measured power unreliability in Tanzania; [23] asked participants to measure power usage; and [104] reported on how power unreliability affects the utility of mobile phones in Kenya. Our work builds on these by investigating how power access affects the safety benefits of wearables. Just as our participants experienced disproportionately high power outages, we argue that individuals in developing countries without access to stable power would have difficulty recharging wearable devices. While our approach and setting is unique — we work with a marginalized community living in a highly developed country — technology improvements which benefit these communities may also help communities in developing countries.

"Flashy" wearable devices. Wearing conspicuous, expensive looking wearables was another concern amongst participants. All participants mentioned that they would choose to use a wearable device that was more subtle to not attract the attention of potential muggers. Current wearables in the market such as smartwatches have big screens and are expensive and bulky, making them too conspicuous for individuals in low-SES communities to use in their neighborhoods. We propose making future wearables smaller and more modular as seen in Figure 2.

Lack of contextual reconfigurability of device features. Participants noted multiple times that if they could only change one thing about general-purpose wearables, the devices might be perfect. However, the "one thing" often would need to be updated depending on the context, such as when a tool should connect with authorities or record to capture evidence. Because these devices cannot be changed instantly, a user from this community would have to use multiple wearables and switch them out as needed, which is a high burden, high cost non-option. Future wearable devices must therefore be multi-purpose but also reconfigurable on the go to provide high amounts of contextual usage.

Nuanced understanding of cameras and privacy. Cameras raised privacy concerns about perpetuating the discrimination of people of color, which has been studied in related work [4, 14, 65]. However, we found that this population had a nuanced, and at times conflicting viewpoints on privacy, as technologies like cameras were seen as helpful at times, especially in extreme, violent circumstances. While other populations might view the cameras' invasion of privacy as the main motivating factor to not use a surveillance device, fear and safety were the overriding concerns we found that motivated participants to wear a camera due to its utility for evidence capture. Despite adverse reactions towards cameras as in other populations, we found that participants were willing to accept the use of cameras as they relate to safety to help capture evidence of a bad situation.

These tensions show how wearables do not currently address the needs and barriers of the community and present opportunities forward. Based on these findings, we introduce Equityware as a field of research focused on co-designing inclusive wearable technology that can benefit the lives of those who have been left on the margins.

5.2 Where do we go from here? Setting an Equityware Agenda

To date, most HCI research has focused on co-designing software systems with low-SES communities. We see an important opportunity, and even a mandate, to co-design hardware/software systems with low-SES communities. The barriers we discussed above necessitate techniques beyond what is possible with software, especially regarding safety, as the capabilities, features, and context require rethinking the physical capabilities of wearables. Collaborations between HCI and systems researchers can bridge this gap. For instance, as systems researchers make hardware advancements that overcome physical barriers of current devices, HCI methods can be used to understand how low-SES community members want to interact with these devices. Now that low-cost, custom designed hardware has become more available in the past decade, this type of iterative hardware/software co-design is much more feasible for academic-led research. Based on the findings laid out in this paper, we believe these community-focused collaborations can greatly change the landscape of wearable devices for low-SES communities. We therefore term the phrase Equityware to refer to the equitable democratization of computing technologies. The Equityware research agenda aims to create wearable technologies, with and for marginalized communities in response to the harmful effects of modern wearables on low-socioeconomic (low-SES) and racial/ethnic minority individuals. We present an exemplar system co-design distilled from our discussions with participants in Figure 2 and

our recommendations for the field of Equityware below. While the authors intend to focus their research on wearable technologies, the principles and concepts of Equityware must broadly expand to other branches of computing research to ensure an equitable future.

We designed a prototype system (shown in Figure 2) that could integrate the major themes and features participants suggested and overcome many barriers to usage participants presented. The core of the design embraces the idea of **contextual reconfigurability** in hardware and software. Participants can mix and match various types of single feature devices and connect them in ways that can be unobtrusive and hidden or highly visible. The concept could be further enhanced by a coordinating smartphone application that helps users to understand what they are combining and give insight on utility. Below, we discuss our recommendations alongside this new concept.

At the Hardware Level: Recent work has shown the glaring need to design wearable and ubiquitous technology from the ground up that co-designs for minority populations– the most notable being studies on SPO2 and optical heart rate sensors that are less accurate for darker skin pigmentation [11, 24, 82]. While this example is compelling, fixing individual sensors or components to be less biased is not enough. We must focus on full hardware systems and the features that (as we have shown) do not consider minority or HRCM low-SES communities– for example, lack of audio alerts, location-based sharing, or a hidden camera. As researchers, we must make sure that the technology we develop, even in the hardware components that make up a full system, is equitable and does not perpetuate discrimination towards people of color, especially as wearables are emerging as critical care and telehealth devices [33, 83].

Involving marginalized groups in the design process of future computing technologies, such as wearables, helps highlight diverse perspectives and specific needs. For instance, our study found that participants face multiple power outages in their neighborhoods throughout the year, leading to much lower adoption of wearable technology due to the inability to charge a wearable device consistently. Even when power is available, outlets and charging may not be available due to crowded housing. Hence a question to the research field is, **how do we design around the environmental constraints that individuals from low- SES communities face?** Designing around these resource constraints, such as limited power availability, requires a fundamental rethinking of how wearables are developed. Possible solutions to address these resource constraints include developing computing techniques and hardware systems that require little or no power. Instead of building expensive, high-performance wearable devices with multi-core CPUs and graphics processors (and short battery lifetime), we could instead use low-performance (but still capable) MCUs that may not offer bleeding edge performance to play the newest games but would provide small, discreet, and capable computation on-body for long periods without charging. This approach repurposes hardware that focuses on performance above all else to now be applied to users' concerns above all.

Additionally, this approach will help reduce the power consumption in future wearable technologies and open the door for energy harvesting applications that may lead to batteryless technologies—implementing environmental sensing capabilities that are not as invasive as cameras can be another solution. For instance, acoustic sensing can help with localizing and environmental sensing and help address safety issues as Locoalert does.

There is very little research in the HCI community that involves co-designing with low-SES communities at the hardware level, let alone studies that involve co-designing a wearable device with members of these communities. We call the HCI community to take part in helping to democratize wearables and find different ways that hardware systems can help address resource constraints in low-SES communities.

At the Software Level: For wearable devices, designing the software and hardware must take place in parallel. We see a clear lack of research that includes the input of low-SES individuals from the start of the ideation and creation stage and considers both the form factor and the ways individuals want to interact with these form factors. Rather, most research in this area either asks for input from low-SES communities retrospectively on finished devices or simply highlights the issues that low-SES communities have with existing wearables, which overlooks the specific problems or needs that these groups may have. As a result, the potential for wearables for low-SES groups is not fully understood and explored.

Prior work on safety interfaces offers useful guidance for Equityware research. For example, Right to Be, [7] allows people to report harassment encounters. The Citizen App[8] allows communities to share real-time information about criminal activity in their neighborhoods. We see an opportunity to consider integrating wearable devices with these applications. For example, a person could use one of the modular features shown in Figure 2) to enable the Citizen App automatically and capture evidence or even integrate a hidden camera module in a button or earring that the Citizen App could trigger. Alternatively, functions of the Hollaback application could be enhanced by location sharing, evidence capture, and even wearable physiologic data for memory recall. This is one way we can fuse HCI, software, and hardware systems research to help support the safety needs of low-SES communities.

As new capabilities are added to hardware, software systems must adapt to make use of them. For example, developers responded by creating richer touch interfaces and denser information displays when enhanced graphical abilities emerged in smartwatches (i.e., high-resolution, bright displays). Similarly, we expect software systems to respond to the Equityware research agenda and hardware proposals by embracing **contextual reconfigurability**, which participants often discussed: essentially, how can software systems enable fast reconfigurability and response as context and situations change for the wearable user? Other issues include how to encapsulate nuanced notions of **privacy with cameras** in software while allowing for **evidence capture**; can the users navigate this tension while also keeping in mind the other constraints identified? For

[7] Right to be, previously known as Hollaback! is a non-profit organization that raises awareness on harassment both online and in-person, and trains people to respond, intervene, and heal from harassment.
[8] https://citizen.com/

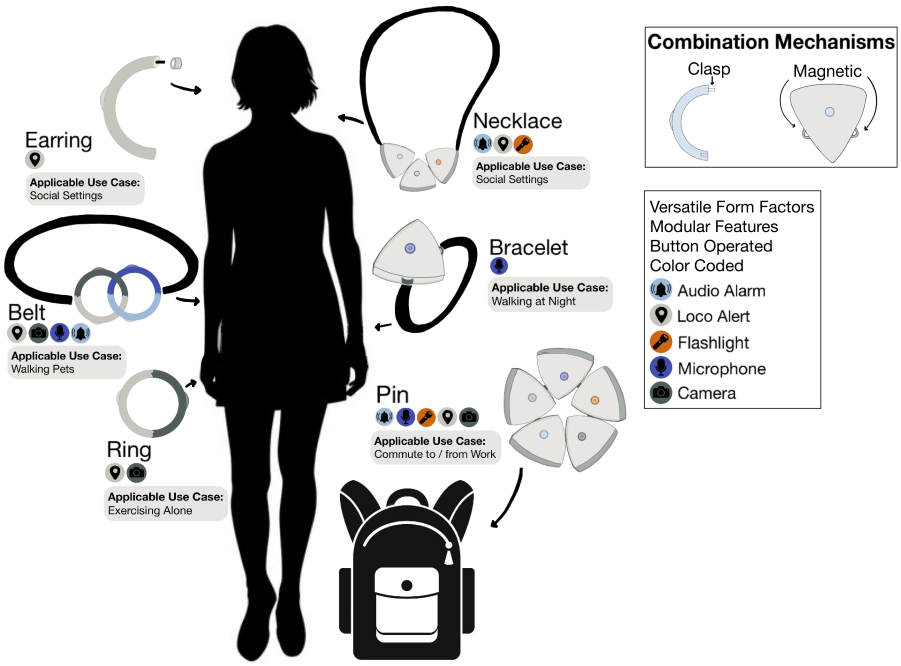

Figure 2: This figure shows the outcomes from the storyboards, and the paper authors attempt to distill the design requirements, context, and conversations over the course of the study into a cohesive wearable system for multi-faceted safety in HRCM low-SES communities. By providing a mechanism that affords wearing in different forms and on varied body parts (i.e., necklace versus ring versus backpack), a user can have the ability to reconfigure their device at will, to adjust and navigate tensions around stigma, visibility, and pride/fashion, as well as adapt to requirements for various situations (i.e., going to the club versus walking alone outside). We expect that each "feature" device can be attached to each other and put on the body at will and that these devices could be made low power with long battery life, without a need for connectivity, to ease burden.

example, long battery life is essential, so how does one minimize the energy usage of always-on camera systems? Potentially this could be via triggering mechanisms or user-initiated actions (i.e., an alert gesture or voice command), but these options must be explored and validated within the community.

We encourage researchers to develop software intervention tools that closely embrace new capabilities for wearables discussed that require minimal interface interaction. For instance, known machine learning models/algorithms for motion/activity sensing can be combined with sensors that measure a user's predetermined distinctive gesture that signals the user's distress and notifies those with whom they share their location. Similarly, activity/motion sensing can activate cameras, turn on SOS alarms, and trigger a light source emanating from a wearable device. Regardless of the mode by which features are activated, the interactive gesture should be easy to learn and intuitive so that a user can utilize the safety features reliably in response to criminal activity.

At the Research Level: The findings from this work point to interesting research questions and open research opportunities for the field. Recent studies have shown that technology can be utilized as safety tools to prevent and deescalate violent crime. Dickinson et al co-designed a mobile application to help street outreach workers prevent violence in their communities [28]. Patton et al built a tool that uses NLP to detect the nuances and complexities of language within social media posts of Black youth in Chicago in hopes of violence prevention efforts [76]. Blandfort et al used machine learning models to build a tool that contextualizes social media posts to detect and prevent gang-involved crime [20]. Our research expands on this work by investigating the potential of wearables as a safety tool by determining the hardware features that low-SES community members feel they need to protect themselves from crimes and violence.

Participants in our study were strongly focused on addressing their immediate safety needs within their communities. More

broadly, there may be opportunities to engage people in addressing these systemic injustices in other ways. For example, in our findings, people mentioned wanting to capture evidence of crime and police brutality.

Evidence gathering by individuals, when captured at scale, gives grassroots community-driven advocates crucial data to push for accountability of law enforcement and other public officials. Additionally, this evidence gathering may be useful for community domestic violence prevention organizations to build cases on behalf of domestic violence victims. These are only two examples; we expect researchers to further explore ways that wearables can not only address immediate safety needs but also allow community members to voice the kind of problems and changes they want to see within the community.

This research is a first step in developing Equityware as a long-term research agenda. We acknowledge that our work is executed through a U.S. centric perspective. However, we recognize the international need for Equityware, especially given the HCI4D and ICT4D work around safety technologies targeted to increase women's safety [2, 3, 10, 58] that parallels our findings. For instance, fear of being in unlit areas [10, 58], feeling unsafe in areas that are known to be dangerous [10, 58], women feeling unsafe walking alone or being around unfamiliar men [2, 10, 58], and avoiding calling the police to report incidents due to mistrust and power imbalances [56, 58] have been reported. We see opportunities to consider how wearable technology needs may be different for low-income communities in other countries and cultures.

Lastly, due to the limitations of the methods we incorporated, we see the opportunity for researchers to develop new methods to engage community members in co-designing wearable technologies. Storyboards can be a limiting method [26, 91, 105]; we can only show so many ideas and bias participants. We need new methods to help engage community members from low-SES communities in brainstorming on how wearables and hardware can support them when they have limited experience with them.

Education: Participants brought up ideas that at times overlooked the known negative impacts of these features on marginalized communities. For example, some participants proposed having microphones on a safety wearable device. While microphones may potentially help benefit the community, there are potential criminal consequences for recording conversations without consent. Participants also proposed location-sharing features in a wearable device, but prior work shows [38] how these technologies can cause harm. As we work on creating tech for communities, we need to make sure they have the opportunity and resources to educate themselves on these potential harms, similar to recent work developing clinical computer security education [38, 47].

6 LIMITATIONS

We acknowledge that this study has sampling limitations, and our report only focuses on low-SES neighborhoods that are predominantly Latinx from two metropolitan cities in the United States. Further, we acknowledge that the Latinx community is not a monolith [99]. Participants were predominantly of Mexican and Central American descent; therefore, this study looks at a small sample of a larger group with different heritages and cultural practices [16]. Lastly, we acknowledge that safety concerns affect all women regardless of race or class, not just Latinas from low-SES neighborhoods. Further research on how women from different races and classes affect their experience and access to safety tools and their limitations would be an interesting topic for future work.

Further, we acknowledge that safety concerns affect all genders, and members of the LGBTQ+ community may experience additional challenges and concerns. Understanding how members of the LGBTQ+ community use current tools as they relate to safety also poses an interesting topic for future work.

7 CONCLUSION

Current wearable devices fail to address the safety needs of the low-SES participants we interviewed. This paper discusses the increasing need to develop wearable technologies for low-socioeconomic status communities. We found that there are prevalent safety concerns and barriers that prevent the adoption of wearables in low-SES communities. The prevalent safety concerns amongst participants were gang violence, lack of infrastructure and services, and gender-based violence. The barriers to adopting wearables among participants were access to power, the conspicuousness of a wearable device and the harms that emerge from using them, lack of control over device features, and a nuanced understanding of privacy regarding cameras. We introduced the Equityware research agenda to highlight opportunities for HCI and systems researchers to collaborate at three levels: hardware, software, and education. Interdisciplinary research and development will be key to addressing these communities' complex safety concerns and limitations. This study is the first of its kind to work on co-designing safety wearables directly with individuals living in low-SES, high crime neighborhoods.

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REFERENCES

[1] 2022. Tracking the COVID-19 economy's effects on food, housing, and employment hardships. https://www.cbpp.org/research/poverty-and-inequality/tracking-the-covid-19-economys-effects-on-food-housing-and

[2] Syed Ishtiaque Ahmed, Steven J Jackson, Nova Ahmed, Hasan Shahid Ferdous, Md Rashidujjaman Rifat, ASM Rizvi, Shamir Ahmed, and Rifat Sabbir Mansur. 2014. Protibadi: A platform for fighting sexual harassment in urban Bangladesh. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 2695–2704.

[3] Mohammed Eunus Ali, Shabnam Basera Rishta, Lazima Ansari, Tanzima Hashem, and Ahamad Imtiaz Khan. 2015. SafeStreet: empowering women against street harassment using a privacy-aware location based application. In *Proceedings of the Seventh International Conference on Information and Communication Technologies and Development*. 1–4.

[4] Fabio Bacchini and Ludovica Lorusso. 2019. Race, again: how face recognition technology reinforces racial discrimination. *Journal of information, communication and ethics in society* (2019).

[5] Laura Benton, Asimina Vasalou, Rilla Khaled, Hilary Johnson, and Daniel Gooch. 2014. Diversity for design: a framework for involving neurodiverse children in the technology design process. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*. 3747–3756.

[6] Constanza Bianchi, Sven Tuzovic, and Volker G Kuppelwieser. 2022. Investigating the drivers of wearable technology adoption for healthcare in South America. *Information Technology & People* (2022).

[7] Waleed Bin Qaim, Aleksandr Ometov, Antonella Molinaro, Ilaria Lener, Claudia Campolo, Elena Simona Lohan, and Jari Nurmi. 2020. Towards Energy Efficiency in the Internet of Wearable Things: A Systematic Review. *IEEE Access* 8 (09 2020), 175412–175435. https://doi.org/10.1109/ACCESS.2020.3025270

[8] Josh Bivens and Ben Zipperer. [n.d.]. *Health insurance and the COVID-19 shock*. https://www.epi.org/publication/health-insurance-and-the-covid-19-shock/

[9] Terra Blevins, Robert Kwiatkowski, Jamie C Macbeth, Kathleen McKeown, Desmond Patton, and Owen Rambow. 2016. Automatically processing tweets from gang-involved youth: towards detecting loss and aggression. (2016).

[10] Jan Blom, Divya Viswanathan, Mirjana Spasojevic, Janet Go, Karthik Acharya, and Robert Ahonius. 2010. Fear and the city: role of mobile services in harnessing safety and security in urban use contexts. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 1841–1850.

[11] LaPrincess C Brewer, Karen L Fortuna, Clarence Jones, Robert Walker, Sharonne N Hayes, Christi A Patten, and Lisa A Cooper. 2020. Back to the future: Achieving Health Equity Through Health Informatics and Digital Health. *JMIR mHealth and uHealth* 8, 1 (2020). https://doi.org/10.2196/14512

[12] Diana Budds and Diana Budds. 2018. How Urban Design Perpetuates Racial Inequality–And What We Can Do About It. *Fast Company* (2018).

[13] Joy Buolamwini and Timnit Gebru. 2018. Gender shades: Intersectional accuracy disparities in commercial gender classification. In *Conference on fairness, accountability and transparency*. PMLR, 77–91.

[14] Joy Buolamwini and Timnit Gebru. 2018. Gender Shades: Intersectional Accuracy Disparities in Commercial Gender Classification. In *Proceedings of the 1st Conference on Fairness, Accountability and Transparency (Proceedings of Machine Learning Research, Vol. 81)*, Sorelle A. Friedler and Christo Wilson (Eds.). PMLR, 77–91. https://proceedings.mlr.press/v81/buolamwini18a.html

[15] US Census Bureau. 2022. Income and poverty. https://www.census.gov/topics/income-poverty.html

[16] Christopher L Busey and Carolyn Silva. 2021. Troubling the essentialist discourse of Brown in education: The anti-Black sociopolitical and sociohistorical etymology of Latinxs as a Brown monolith. *Educational Researcher* 50, 3 (2021), 176–186.

[17] AM Bustamante, N Brendel, A Degbelo, and C Kray. 2018. Participatory Design and Participatory Research: An HCI Case Study. (2018).

[18] Paul Cain. 2015. Unlock the full potential of wearables with organic TFTs. *Information Display* 31, 1 (Jan 2015), 22–26. https://doi.org/10.1002/j.2637-496x.2015.tb00782.x

[19] Ranganathan Chandrasekaran, Vipanchi Katthula, and Evangelos Moustakas. 2020. Patterns of Use and Key Predictors for the Use of Wearable Health Care Devices by US Adults: Insights from a National Survey. *J Med Internet Res* 22, 10 (16 Oct 2020), e22443. https://doi.org/10.2196/22443

[20] Serina Chang, Ruiqi Zhong, Ethan Adams, Fei-Tzin Lee, Siddharth Varia, Desmond Patton, William Frey, Chris Kedzie, and Kathleen McKeown. 2018. Detecting gang-involved escalation on social media using context. *arXiv preprint arXiv:1809.03632* (2018).

[21] Kathy Charmaz, Liska Belgrave, et al. 2012. Qualitative interviewing and grounded theory analysis. *The SAGE handbook of interview research: The complexity of the craft* 2 (2012), 347–365.

[22] John W. Cheng and Hitoshi Mitomo. 2017. The underlying factors of the perceived usefulness of using smart wearable devices for disaster applications. *Telematics and Informatics* 34, 2 (2017), 528–539. https://doi.org/10.1016/j.tele.2016.09.010

[23] George Hope Chidziwisano, Susan Wyche, and Erick Oduor. 2020. GridAlert: Using a Sensor-Based Technology to Monitor Power Blackouts in Kenyan Homes. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376500

[24] Peter J Colvonen, Pamela N DeYoung, Naa-Oye A Bosompra, and Robert L Owens. 2020. Limiting racial disparities and bias for wearable devices in health science research.

[25] Francine E Darroch and Audrey R Giles. 2017. Conception of a resource: Development of a physical activity and healthy living resource with and for pregnant urban First Nations and Métis women in Ottawa, Canada. *Qualitative Research in Sport, Exercise and Health* 9, 2 (2017), 157–169.

[26] Scott Davidoff, Min Kyung Lee, Anind K Dey, and John Zimmerman. 2007. Rapidly exploring application design through speed dating. In *International conference on ubiquitous computing*. Springer, 429–446.

[27] Matthew Desmond, Andrew V Papachristos, and David S Kirk. 2016. Police violence and citizen crime reporting in the black community. *American sociological review* 81, 5 (2016), 857–876.

[28] Jessa Dickinson, Jalon Arthur, Maddie Shiparski, Angalia Bianca, Alejandra Gonzalez, and Sheena Erete. 2021. Amplifying community-led violence prevention as a counter to structural oppression. *Proceedings of the ACM on Human-Computer Interaction* 5, CSCW1 (2021), 1–28.

[29] Jessa Dickinson, Mark Díaz, Christopher A Le Dantec, and Sheena Erete. 2019. " The cavalry ain't coming in to save us" Supporting Capacities and Relationships through Civic Tech. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (2019), 1–21.

[30] Tawanna R Dillahunt, Sheena Erete, Roxana Galusca, Aarti Israni, Denise Nacu, and Phoebe Sengers. 2017. Reflections on design methods for underserved communities. In *Companion of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*. 409–413.

[31] Carl DiSalvo, Andrew Clement, and Volkmar Pipek. 2012. Communities: Participatory Design for, with and by communities. In *Routledge international handbook of participatory design*. Routledge, 202–230.

[32] Stan Dorn. [n.d.]. *THE COVID-19 PANDEMIC AND RESULTING ECONOMIC CRASH HAVE CAUSED THE GREATEST HEALTH INSURANCE LOSSES IN AMERICAN HISTORY*. https://familiesusa.org/resources/the-covid-19-pandemic-and-resulting-economic-crash-have-caused-the-greatest-health-insurance-losses-in-american-history/

[33] Jessilyn Dunn, Ryan Runge, and Michael Snyder. 2018. Wearables and the medical revolution. *Personalized medicine* 15, 5 (2018), 429–448.

[34] Sheena Erete, Aarti Israni, and Tawanna Dillahunt. 2018. An intersectional approach to designing in the margins. *Interactions* 25, 3 (2018), 66–69.

[35] Sheena Lewis Erete. 2013. Empowerment through community crime-prevention technologies. *Interactions* 20, 6 (2013), 27–31.

[36] United Nations High Commissioner for Refugees. [n.d.]. Gender-based violence. https://www.unhcr.org/en-us/gender-based-violence.html

[37] Sarah Fox, Jill Dimond, Lilly Irani, Tad Hirsch, Michael Muller, and Shaowen Bardzell. 2017. Social Justice and Design: Power and oppression in collaborative systems. In *Companion of the 2017 acm conference on computer supported cooperative work and social computing*. 117–122.

[38] Diana Freed, Jackeline Palmer, Diana Minchala, Karen Levy, Thomas Ristenpart, and Nicola Dell. 2018. "A Stalker's Paradise" How Intimate Partner Abusers Exploit Technology. In *Proceedings of the 2018 CHI conference on human factors in computing systems*. 1–13.

[39] William R Frey, Desmond U Patton, Michael B Gaskell, and Kyle A McGregor. 2020. Artificial intelligence and inclusion: Formerly gang-involved youth as domain experts for analyzing unstructured twitter data. *Social Science Computer Review* 38, 1 (2020), 42–56.

[40] Tamar Ginossar and Sara Nelson. 2010. Reducing the health and digital divides: a model for using community-based participatory research approach to e-health interventions in low-income Hispanic communities. *Journal of Computer-Mediated Communication* 15, 4 (2010), 530–551.

[41] Jeffrey T Grabill. 2003. Community computing and citizen productivity. *Computers and Composition* 20, 2 (2003), 131–150.

[42] Abdolrasoul Habibipour, Ali Mohammad Padyab, and Anna Ståhlbröst. 2017. Social, Ethical and Ecological Issues in Wearable Technologies. *AMCIS 2019 Proceedings, Association for Information Systems* (Jul 2017).

[43] Christina Harrington and Tawanna R Dillahunt. 2021. Eliciting Tech Futures Among Black Young Adults: A Case Study of Remote Speculative Co-Design. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–15.

[44] Christina Harrington, Sheena Erete, and Anne Marie Piper. 2019. Deconstructing community-based collaborative design: Towards more equitable participatory design engagements. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (2019), 1–25.

[45] Christina N Harrington, Katya Borgos-Rodriguez, and Anne Marie Piper. 2019. Engaging low-income African American older adults in health discussions through community-based design workshops. In *Proceedings of the 2019 chi conference on human factors in computing systems*. 1–15.

[46] Drew Harwell. 2019. Oregon became a testing ground for Amazon's facial-recognition policing. But what if Rekognition gets it wrong. *Washington Post* 30 (2019).

[47] Sam Havron, Diana Freed, Rahul Chatterjee, Damon McCoy, Nicola Dell, and Thomas Ristenpart. 2019. Clinical computer security for victims of intimate partner violence. In *28th USENIX Security Symposium (USENIX Security 19)*. 105–122.

[48] Alyssa Fowers Heather Long, Andrew Van Dam and Leslie Shapiro. [n.d.]. *The covid-19 recession is the most unequal in modern U.S. history*. https://www.washingtonpost.com/graphics/2020/business/coronavirus-recession-equality/

[49] J. C. Herz. [n.d.]. *Wearables Are Totally Failing the People Who Need Them Most*. https://www.wired.com/2014/11/where-fitness-trackers-fail/

[50] Josiah Hester, Travis Peters, Tianlong Yun, Ronald Peterson, Joseph Skinner, Bhargav Golla, Kevin Storer, Steven Hearndon, Kevin Freeman, Sarah Lord,

et al. 2016. Amulet: An energy-efficient, multi-application wearable platform. In *Proceedings of the 14th ACM Conference on Embedded Network Sensor Systems CD-ROM*. 216–229.

[51] Josiah Hester, Travis Peters, Tianlong Yun, Ronald Peterson, Joseph Skinner, Bhargav Golla, Kevin Storer, Steven Hearndon, Kevin Freeman, Sarah Lord, and et al. 2016. Amulet: An Energy-Efficient, Multi-Application Wearable Platform. *Proceedings of the 14th ACM Conference on Embedded Network Sensor Systems CD-ROM* (2016). https://doi.org/10.1145/2994551.2994554

[52] Michelle Holko, Tamara R. Litwin, Fatima Munoz, Katrina I. Theisz, Linda Salgin, Nancy Piper Jenks, Beverly W. Holmes, Pamelia Watson-McGee, Eboni Winford, Yashoda Sharma, and et al. 2022. Wearable Fitness Tracker use in Federally Qualified Health Center Patients: Strategies to improve the health of all of US using Digital Health Devices. *npj Digital Medicine* 5, 1 (2022). https://doi.org/10.1038/s41746-022-00593-x

[53] Sara Hooker. 2021. Moving beyond "algorithmic bias is a data problem". *Patterns* 2, 4 (2021), 100241. https://doi.org/10.1016/j.patter.2021.100241

[54] Hugh Hunkin, Daniel L. King, and Ian T. Zajac. 2020. Perceived acceptability of wearable devices for the treatment of mental health problems. *Journal of Clinical Psychology* 76, 6 (2020), 987–1003. https://doi.org/10.1002/jclp.22934 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1002/jclp.22934

[55] Sofia Hussain, Elizabeth B-N Sanders, and Martin Steinert. 2012. Participatory design with marginalized people in developing countries: Challenges and opportunities experienced in a field study in Cambodia. *International Journal of Design* 6, 2 (2012).

[56] Nadia Ilahi. 2009. Gendered contestations: An analysis of street harassment in Cairo and its implications for women's access to public spaces. *Surfacing: An Interdisciplinary Journal for Gender in the Global South* 2, 1 (2009), 56–69.

[57] Veronica Jacome, Noah Klugman, Catherine Wolfram, Belinda Grunfeld, Duncan Callaway, and Isha Ray. 2019. Power quality and modern energy for all. *Proceedings of the National Academy of Sciences* 116, 33 (2019), 16308–16313.

[58] Naveena Karusala and Neha Kumar. 2017. Women's safety in public spaces: Examining the efficacy of panic buttons in New Delhi. In *Proceedings of the 2017 CHI conference on human factors in computing systems*. 3340–3351.

[59] Maximilian Kasy and Rediet Abebe. 2021. Fairness, equality, and power in algorithmic decision-making. In *Proceedings of the 2021 ACM Conference on Fairness, Accountability, and Transparency*. 576–586.

[60] Zaid Khan and Yun Fu. 2021. One Label, One Billion Faces: Usage and Consistency of Racial Categories in Computer Vision. In *Proceedings of the 2021 ACM Conference on Fairness, Accountability, and Transparency* (Virtual Event, Canada) *(FAccT '21)*. Association for Computing Machinery, New York, NY, USA, 587–597. https://doi.org/10.1145/3442188.3445920

[61] Noah Klugman, Joshua Adkins, Susanna Berkouwer, Kwame Abrokwah, Ivan Bobashev, Pat Pannuto, Matthew Podolsky, Aldo Suseno, Revati Thatte, Catherine Wolfram, et al. 2019. Hardware, apps, and surveys at scale: insights from measuring grid reliability in Accra, Ghana. In *Proceedings of the 2nd ACM SIGCAS Conference on Computing and Sustainable Societies*. 134–144.

[62] Rhonda Koster, Kirstine Baccar, and R Harvey Lemelin. 2012. Moving from research ON, to research WITH and FOR Indigenous communities: A critical reflection on community-based participatory research. *The Canadian Geographer/Le Géographe canadien* 56, 2 (2012), 195–210.

[63] Christopher A Le Dantec and W Keith Edwards. 2008. Designs on dignity: perceptions of technology among the homeless. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 627–636.

[64] Sang M. Lee and DonHee Lee. 2020. Healthcare wearable devices: An analysis of key factors for continuous use intention. *Service Business* 14, 4 (2020), 503–531. https://doi.org/10.1007/s11628-020-00428-3

[65] Jennifer Lynch. 2020. Face off: Law enforcement use of face recognition technology. *Available at SSRN 3909038* (2020).

[66] Terika McCall, Kammarauche Asuzu, Carol R. Oladele, Tiffany I. Leung, and Karen H. Wang. 2022. A socio-ecological approach to addressing digital redlining in the United States: A call to action for health equity. *Frontiers in Digital Health* 4 (2022). https://doi.org/10.3389/fdgth.2022.897250

[67] Beza Merid, Maria Cielito Robles, and Brahmajee K. Nallamothu. 2021. Digital Redlining and Cardiovascular Innovation. *Circulation* 144, 12 (2021), 913–915. https://doi.org/10.1161/circulationaha.121.056532

[68] Maletsabisa Molapo, Melissa Densmore, and Limpho Morie. 2016. Designing with community health workers: enabling productive participation through exploration. In *Proceedings of the First African Conference on Human Computer Interaction*. 58–68.

[69] Michael J Muller and Sarah Kuhn. 1993. Participatory design. *Commun. ACM* 36, 6 (1993), 24–28.

[70] Bishwajit Nayak, Som Sekhar Bhattacharyya, Saurabh Kumar, and Rohan Kumar Jumnani. 2021. Exploring the factors influencing adoption of health-care wearables among generation Z consumers in India. *Journal of Information, Communication and Ethics in Society* (2021).

[71] Safiya Umoja Noble. 2018. *Algorithms of Oppression: How Search Engines Reinforce Racism*. New York University Press, New York, USA. https://doi.org/doi:10.18574/nyu/9781479833641.001.0001

[72] Janet Mayowa Nwaogu, Albert PC Chan, John A Naslund, Carol KH Hon, Christopher Belonwu, and Jackie Yang. 2021. Exploring the barriers to and motivators for using digital mental health interventions among construction personnel in Nigeria: qualitative study. *JMIR formative research* 5, 11 (2021), e18969.

[73] Aleksandr Ometov, Viktoriia Shubina, Lucie Klus, Justyna Skibińska, Salwa Saafi, Pavel Pascacio, Laura Flueratoru, Darwin Quezada Gaibor, Nadezhda Chukhno, Olga Chukhno, Asad Ali, Asma Channa, Ekaterina Svertoka, Waleed Bin Qaim, Raúl Casanova-Marqués, Sylvia Holcer, Joaquín Torres-Sospedra, Sven Casteleyn, Giuseppe Ruggeri, Giuseppe Araniti, Radim Burget, Jiri Hosek, and Elena Simona Lohan. 2021. A Survey on Wearable Technology: History, State-of-the-Art and Current Challenges. *Computer Networks* 193 (2021), 108074. https://doi.org/10.1016/j.comnet.2021.108074

[74] Desmond U Patton, Philipp Blandfort, William R Frey, Rossano Schifanella, Kyle McGregor, and Shih-Fu U Chang. 2020. Vatas: An open-source web platform for visual and textual analysis of social media. *Journal of the Society for Social Work and Research* 11, 1 (2020), 133–155.

[75] Desmond Upton Patton, Robert D Eschmann, Caitlin Elsaesser, and Eddie Bocanegra. 2016. Sticks, stones and Facebook accounts: What violence outreach workers know about social media and urban-based gang violence in Chicago. *Computers in human behavior* 65 (2016), 591–600.

[76] Desmond U Patton, William R Frey, Kyle A McGregor, Fei-Tzin Lee, Kathleen McKeown, and Emanuel Moss. 2020. Contextual analysis of social media: The promise and challenge of eliciting context in social media posts with natural language processing. In *Proceedings of the AAAI/ACM Conference on AI, Ethics, and Society*. 337–342.

[77] Desmond Upton Patton, Patrick Leonard, Loren Cahill, Jamie Macbeth, Shantel Crosby, and Douglas-Wade Brunton. 2016. "Police took my homie I dedicate my life 2 his revenge": Twitter tensions between gang-involved youth and police in Chicago. *Journal of Human Behavior in the Social Environment* 26, 3-4 (2016), 310–324.

[78] Jelena Radulovic, Royce Lee, and Andrew Ortony. 2018. State-dependent memory: neurobiological advances and prospects for translation to dissociative amnesia. *Frontiers in Behavioral Neuroscience* 12 (2018), 259.

[79] Herman Saksono, Carmen Castaneda-Sceppa, Jessica Hoffman, Magy Seif El-Nasr, Vivien Morris, and Andrea G Parker. 2018. Family health promotion in low-SES neighborhoods: A two-month study of wearable activity tracking. In *Proceedings of the 2018 chi conference on human factors in computing systems*. 1–13.

[80] Mat Santamouris, K Pavlou, A Synnefa, K Niachou, and D Kolokotsa. 2007. Recent progress on passive cooling techniques: Advanced technological developments to improve survivability levels in low-income households. *Energy and Buildings* 39, 7 (2007), 859–866.

[81] David Satcher. 2005. *Methods in community-based participatory research for health*. John Wiley & Sons.

[82] Anna Shcherbina, C. Mattsson, Daryl Waggott, Heidi Salisbury, Jeffrey Christle, Trevor Hastie, Matthew Wheeler, and Euan Ashley. 2017. Accuracy in wrist-worn, sensor-based measurements of heart rate and energy expenditure in a diverse cohort. *Journal of Personalized Medicine* 7, 2 (2017), 3. https://doi.org/10.3390/jpm7020003

[83] Matthew Smuck, Charles A Odonkor, Jonathan K Wilt, Nicolas Schmidt, and Michael A Swiernik. 2021. The emerging clinical role of wearables: factors for successful implementation in healthcare. *NPJ Digital Medicine* 4, 1 (2021), 1–8.

[84] Aparna Sodhi, Nathan Aguilar, Deanna E Choma, Jackie Marie Steve, Desmond Patton, and Marie Crandall. 2020. Social media representations of law enforcement within four diverse Chicago neighborhoods. *Journal of Contemporary Ethnography* 49, 6 (2020), 832–852.

[85] Fiona Ssozi-Mugarura, Edwin Blake, and Ulrike Rivett. 2016. Supporting community needs for rural water management through community-based co-design. In *Proceedings of the 14th Participatory Design Conference: Full papers-Volume 1*. 91–100.

[86] Statista. [n.d.]. *Number of connected wearable devices worldwide from 2016 to 2022*. https://www.statista.com/statistics/487291/global-connected-wearable-devices/

[87] Jennifer S. Stevens, Renuka Reddy, Ye Ji Kim, Sanne J.H. van Rooij, Timothy D. Ely, Stephan Hamann, Kerry J. Ressler, and Tanja Jovanovic. 2018. Episodic memory after trauma exposure: Medial temporal lobe function is positively related to re-experiencing and inversely related to negative affect symptoms. *NeuroImage: Clinical* 17 (2018), 650–658. https://doi.org/10.1016/j.nicl.2017.11.016

[88] Elizabeth Stowell, Teresa K O'Leary, Everlyne Kimani, Michael K Paasche-Orlow, Timothy Bickmore, and Andrea G Parker. 2020. Investigating Opportunities for Crowdsourcing in Church-Based Health Interventions: A Participatory Design Study. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–12.

[89] Barsa Tandukar, Pooja Vazirani, and Aqueasha Martin-Hammond. 2021. Advocacy Through Design: Partnering to Improve Online Communications and

Connections in a Life Plan Community. In *Designing Interactive Systems Conference 2021*. 1695–1709.
[90] Mamello Thinyane, Karthik Bhat, Lauri Goldkind, and Vikram Kamath Cannanure. 2018. Critical participatory design: reflections on engagement and empowerment in a case of a community based organization. In *Proceedings of the 15th Participatory Design Conference: Full Papers-Volume 1*. 1–10.
[91] Khai N. Truong, Gillian R. Hayes, and Gregory D. Abowd. 2006. Storyboarding: An Empirical Determination of Best Practices and Effective Guidelines. In *Proceedings of the 6th Conference on Designing Interactive Systems* (University Park, PA, USA) *(DIS '06)*. Association for Computing Machinery, New York, NY, USA, 12–21. https://doi.org/10.1145/1142405.1142410
[92] Tsai-Hsuan Tsai, Kevin C Tseng, and Yung-Sheng Chang. 2017. Testing the usability of smartphone surface gestures on different sizes of smartphones by different age groups of users. *Computers in Human Behavior* 75 (2017), 103–116.
[93] Kim M Unertl, Chris L Schaefbauer, Terrance R Campbell, Charles Senteio, Katie A Siek, Suzanne Bakken, and Tiffany C Veinot. 2016. Integrating community-based participatory research and informatics approaches to improve the engagement and health of underserved populations. *Journal of the American Medical Informatics Association* 23, 1 (2016), 60–73.
[94] Michael Veale and Reuben Binns. 2017. Fairer machine learning in the real world: Mitigating discrimination without collecting sensitive data. *Big Data and Society* 4, 2 (2017), 205395171774353. https://doi.org/10.1177/2053951717743530
[95] Morgan Vigil-Hayes, Ann Futterman Collier, Shelby Hagemann, Giovanni Castillo, Keller Mikkelson, Joshua Dingman, Andrew Muñoz, Jade Luther, and Alexandra McLaughlin. 2021. Integrating cultural relevance into a behavioral mHealth intervention for Native American youth. *Proceedings of the ACM on human-computer interaction* 5, CSCW1 (2021), 1–29.
[96] Vini Vijayan, James P. Connolly, Joan Condell, Nigel McKelvey, and Philip Gardiner. 2021. Review of Wearable Devices and Data Collection Considerations for Connected Health. *Sensors* 21, 16 (2021). https://doi.org/10.3390/s21165589
[97] Emily A. Vogels. 2020. About one-in-five Americans use a smart watch or fitness tracker. https://www.pewresearch.org/fact-tank/2020/01/09/about-one-in-five-americans-use-a-smart-watch-or-fitness-tracker/
[98] Nina B Wallerstein and Bonnie Duran. 2006. Using community-based participatory research to address health disparities. *Health promotion practice* 7, 3 (2006), 312–323.
[99] Robin M Weinick, Elizabeth A Jacobs, Lisa Cacari Stone, Alexander N Ortega, and Helen Burstin. 2004. Hispanic healthcare disparities: challenging the myth of a monolithic Hispanic population. *Medical care* (2004), 313–320.
[100] Daniel Weiz, Gagat Anand, and Claus-Peter H. Ernst. 2016. The influence of subjective norm on the usage of smartglasses. *Progress in IS* (Feb 2016), 1–11. https://doi.org/10.1007/978-3-319-30376-5_1
[101] Max J. Western, Miranda E. Armstrong, Ishrat Islam, Kelly Morgan, Una F. Jones, and Mark J. Kelson. 2021. The effectiveness of digital interventions for increasing physical activity in individuals of low socioeconomic status: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity* 18, 1 (2021). https://doi.org/10.1186/s12966-021-01218-4
[102] Meredith Whittaker, Meryl Alper, Cynthia L Bennett, Sara Hendren, Liz Kaziunas, Mara Mills, Meredith Ringel Morris, Joy Rankin, Emily Rogers, Marcel Salas, et al. 2019. Disability, bias, and AI. *AI Now Institute* (2019).
[103] Anna Wojciechowska, Foad Hamidi, Andrés Lucero, and Jessica R Cauchard. 2020. Chasing Lions: Co-designing human-drone interaction in sub-saharan Africa. *arXiv preprint arXiv:2005.02022* (2020).
[104] Susan P Wyche and Laura L Murphy. 2013. Powering the cellphone revolution: findings from mobile phone charging trials in off-grid Kenya. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 1959–1968.
[105] John Zimmerman and Jodi Forlizzi. 2017. Speed dating: providing a menu of possible futures. *She Ji: The Journal of Design, Economics, and Innovation* 3, 1 (2017), 30–50.

A INTERVIEW QUESTIONS

A.1 Preliminary Investigation Questions: Understanding Community needs

(1) Do you own a mobile phone?
(2) Do you rely on other facilities to have access to Wi-Fi (ex. coffee shop, school, library? If Wi-Fi is not available, what are other wireless connectivities do you have access to (e.g., cellular data?)
(3) Are you able to charge your phone in your home or do you rely on other facilities to charge your phone?
(4) What are your resource constraints if you have any?
(5) What are your thoughts on wearable technology? Are people willing to adopt this technology or is it frowned upon?
(6) Do you own a wearable device? If so, what is it? How often do you use it? What applications do you use it for?
(7) Would you be comfortable using wearable technology?
(8) What would make a wearable device feel uncomfortable for you? How would the size and/or weight of a wearable device impact your decision on whether you find it comfortable or not? What about the cost of a wearable device? Would you find expensive wearable devices too intimidating to use? What about appearance?
(9) If you could design a wearable device that would fit your needs, what functionalities would you want it to have? How would you want it to look like?
(10) Do you think people in your community would benefit from this wearable device?

A.2 Secondary Investigation Questions: Considering technologies for safety

(1) Can you tell me a bit about the neighborhood or area you live in? Are there things you like and dislike about it?
(2) What activities do you feel safe doing in your neighborhood? (Like going for a walk, hanging out at a park, etc.) Are there activities you don't feel safe doing in your neighborhood area?
(3) How do you feel about walking alone around your neighborhood? What about when you're walking alone at night versus during the day? What concerns do you have, if any, about what could happen to you or someone you know when walking alone?
(4) Have you ever felt unsafe in your area or in unfamiliar places (like other neighborhoods, stores, bars, or when doing things like going shopping, visiting other people, etc.)? What do you do when you're feeling unsafe? Do you carry anything with you to help you feel more safe?
(5) Have you or someone you know ever been harassed or attacked in your neighborhood or unfamiliar area? If you're comfortable sharing, could you tell me a bit more about what happened?
(6) Were authorities like police or some other 3rd party notified? How did you feel about that experience or hearing about what happened?
(7) What advice do you or would you give to a loved one who was going to be walking alone in an unfamiliar or unsafe area?