Speculative Vulnerability: Uncovering the Temporalities of Vulnerability in People's Experiences of the Pandemic

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Pandemic-tracking apps may form a future infrastructure for public health surveillance. Yet, there has been relatively little exploration of the potential societal implications of such an infrastructure. In semi-structured interviews with 23 participants from India, the Middle East and North Africa (MENA), and the United States, we discussed attitudes and preferences regarding the deployment of apps that support contact tracing to contain the spread of COVID-19. Through interpretive analysis, we examined the relationship between persistent discomfort and vulnerability when using such apps. Such an examination yielded three temporal forms of vulnerability: real, anticipatory, and speculative. By identifying and defining the temporalities of vulnerability through an analysis of people's pandemic-related thoughts and experiences, we develop the overlapping discourses of humanistic infrastructure studies and infrastructural speculation. In doing so, we explore the concept of vulnerability itself and present implications for the study of vulnerability in Human-Computer Interaction (HCI) and for the oversight of app-based public health surveillance.

CCS Concepts: • **Human-centered computing** → **Empirical studies in HCI**; **Empirical studies in ubiquitous and mobile computing**; *HCI theory, concepts and models*; *HCI design and evaluation methods*; • **Security and privacy** → **Social aspects of security and privacy**; • **Social and professional topics** → Privacy policies; Governmental regulations.

Additional Key Words and Phrases: COVID-19 pandemic, speculative vulnerability, persistent discomfort, privacy concerns, temporality, futuring, humanistic infrastructure studies, infrastructural speculation, pandemic-tracking apps

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1 INTRODUCTION

COVID-19 emerged in a historical period of vast digitization and connectivity. For the Internet-connected world, the ongoing pandemic is playing out in the complex sociotechnical conditions of "app culture" [84]. Apps facilitate specific actions in the form of conditional empowerment [84], thus subtly shaping people's experiences of themselves *through* the technologically-mediated activities of daily life. As such, alongside a host of digital solutions to the pandemic [108], apps designed to track the spread of the pandemic represent a speculative infrastructure of daily life [86].[1]

Yet, even amid the widespread digital connectivity of the 21st century, the very nature of the virus at the heart of the COVID-19 pandemic (i.e., its infectious danger in relation to the fundamental characteristics of human embodiment) reminds us of the *human* vulnerability that underpins the crisis. Such vulnerability requires an analytical lens that can account for people's experiences in a humanistic[2] way. In the context of the pandemic, vulnerability takes center stage. Therefore, we sought to identify and analyze the forms of vulnerability latent in the potential development of app-based, post-pandemic public health surveillance infrastructure.

We approached our goal by addressing two core research questions:

- **RQ1**: How do people from culturally heterogeneous lifeworlds understand and discuss pandemic-tracking apps?
- **RQ2**: How might people's understanding and discussion of post-pandemic futures be applied to enrich the understanding of vulnerability in Human-Computer Interaction (HCI)?

In seeking to answer these questions, we situated pandemic-tracking apps in the *lifeworlds* of their users (i.e., in the complex circumstances of people's daily lives, shaped by such factors as perception, sociotechnical norms, and politics) [109], thus attending to the overlap between infrastructure studies and HCI (e.g., [83]). In addition, we examined vulnerability through the lens of recent power-oriented discourse within HCI (e.g., [59, 61]).

To answer the research questions, we engaged in thematic analysis [12, 20, 21] of semi-structured interviews (n = 23) with eight participants from India, five from the Middle Eastern and North African (MENA) countries of Egypt, Morocco, Palestine, and Tunisia, and ten from the United States. By interviewing participants from multiple societal backgrounds about real-world artifacts belonging to the broader category of "pandemic-tracking apps" [86], we engaged in an inductive and naturalistic form of infrastructural speculation grounded in situated perceptions and expectations within heterogeneous lifeworlds [109].

We found that people's hopeful expectations about pandemic-tracking apps are, predictably, driven by the desire to mitigate the *persistent discomfort* caused by the pandemic. However, the hope expressed in the expectations of pandemic-tracking apps renders people essentially vulnerable to the disappointment of broken promises [68], perpetuation of power imbalances between users and apps [60, 84], and entrenched digital resignation [29]. Each of these vulnerabilities resides in potential app-based, post-pandemic public health surveillance infrastructures. Further, each bears a different relationship to the immediate experience of the present [83], the near futures that are the typical focus of design work [46], and the irreducible temporality of infrastructure itself [10].

[1]By "infrastructure of daily life," we refer to the *human* experiences that functionally invisible [99, 107] technological assemblages allow [83] rather than the technical infrastructure of wires and networks.
[2]We use the term "humanistic" to foreground the experiences of people as subjective human beings, rather than mere users.

Through our findings, we identified three temporal facets of vulnerability: real, anticipatory, and speculative. These facets demonstrate the need for humanistic considerations of infrastructures and their users [7, 82, 83] that move beyond the empirical cycle of present-to-proximal-future common in design-oriented HCI [27, 28, 46]. Such an approach can extend humanistic HCI [7] and respect the humans in the sociotechnical lifeworlds it helps create.

This paper makes the following contributions:

- theorizes the relationship between persistent discomfort and vulnerability, allowing for a more nuanced discussion of vulnerability within HCI;
- identifies the distinctions between real, anticipatory, and speculative vulnerabilities;
- explains the need to adopt humanistic approaches to the development and deployment of technical solutions for public health; and
- demonstrates the suitability of infrastructural speculation for identifying vectors of speculative vulnerability latent within possible future infrastructures.

In the sections that follow, we ground our work in the literature about vulnerability, infrastructure, and design futures. Since privacy is a common form of vulnerability in the connected world, we provide connections with the literature about privacy and pandemic-tracking apps. We then describe our method and analytical framework and present the findings. We proceed to discuss the temporal differences in vulnerability that we uncovered and provide implications for the study of vulnerability in HCI and for the deployment and oversight of pandemic-tracking apps as a form of post-pandemic, public health surveillance infrastructure. We conclude with a call to develop additional modes of inquiry that focus on societal implications within longer-term futures.

2 RELATED WORK

We lay the foundations for our work by introducing the HCI literature about vulnerability. We then ground our discussion of vulnerability within the privacy literature, followed by an overview of research about pandemic-tracking apps in the geographical regions in which the participants of our study reside.

2.1 Vulnerability

Vulnerable populations are of increasing interest in HCI (e.g., [6, 31, 59, 60, 80]). Research about vulnerable populations has yielded important insight about the effects of characterizing populations as "vulnerable" [66] and the broader risks of harm created by novel technology [6, 31]. Such research contextualizes the work on the resilience of vulnerable people when managing disruptions to life (e.g., [89]). Empirical engagement with vulnerable populations constitutes a meaningful opportunity to advance social justice (e.g., [30, 67]), equality (e.g., [16]), and quality of life (e.g., [95]).

Despite the focus on vulnerable populations, the concept of vulnerability has received comparatively little attention. In particular, the temporality of vulnerability remains unexplored. Recent work has acknowledged that vulnerability is partially constructed through the normativity of power relationships instantiated in digital technology [61], implying that vulnerability is subject to change over time. Yet, vulnerability is typically framed in terms of harm reduction based on stable levels of risk faced by certain communities or categories of living beings [80]. McDonald et al. [59] defined vulnerable populations as "those whose race, class, gender or sexual identity, and other intersectional characteristics or circumstances put them at particular risk in the society at large." It is worth noting that this definition is closely related to that of social vulnerability which "identifies sensitive populations that may be less likely to respond to, cope with, and recover from a natural disaster" [22].

Given its commitment to improving daily life through computing, HCI research about vulnerability tends to emerge from a concern for mitigating *known* forms of vulnerability (i.e., the observable propensity toward harm that characterizes a known sub-population). However, in the case of COVID-19, the affected population is necessarily everyone in the world.[3] The global nature of the pandemic relative to existing definitions of vulnerability poses problems of scale and framing and highlights the need to consider potential vulnerabilities (cf. [45, 101]) that *may arise* as a result of pandemic-mitigation technologies. The computer not only reaches out [38], but computing researchers and practitioners are responsible for "pushing" it out [7]. Those who design and deploy pandemic-tracking technology are obligated to account for the future forms of vulnerability it may unintentionally create [45, 101]. Therefore, we approach vulnerability through the lens of its temporalities.

2.1.1 Filtering Vulnerability Through Infrastructure and Futuring. Our interest in the temporality of vulnerability bears a relationship to a host of HCI literature that describes and analyzes methods of futuring. Of particular note is the concept of the *proximal future* found in design-oriented futuring (e.g., [9, 28, 46, 52]). Calls for increased work toward understanding the future social implications of designed technologies are increasingly common (e.g., [32, 57, 72, 90]).

As potential infrastructures of daily life, pandemic-tracking apps are simultaneously real and speculative. The apps are real in the present, but their trajectory toward the status of invisible infrastructure [99, 107] is yet to be achieved. On the one hand, pandemic-tracking apps reside in the ongoing transition from the present to the near future. On the other hand, their potential alludes to futures in which such apps will have become part of the public health infrastructure. Therefore, we consider the potential infrastructures formed by pandemic-tracking apps from the temporal perspective of the *future perfect tense* (i.e., implied futures in which pandemic-tracking apps *will have been* routinized as infrastructure [11, 83, 99, 107]). Such a framing allows accounting for the ultimately *received* nature of successful infrastructures [99], thus escaping, however temporarily, the design cycle located in the relationship between the observable present and the proximal future.

Within the overlapping areas of infrastructure studies, design, and futuring, the concept of "infrastructuring" has been prominent in situating infrastructures and their development in the present [51, 71]. As such, it is possible that speculative design work that analyzes how proximal futures are achieved is blinded to the future experience of *being* within a received infrastructure that has already been developed [87]. Because pandemic-tracking apps may slowly coalesce as an infrastructure for post-pandemic health surveillance, we require a method of inquiry that can get around the focus on the proximal future in order to take into account the received condition of infrastructures that will have achieved successful invisibility [99, 107].

For these reasons, we adopted a humanistic, rather than user-centered, approach to vulnerability. For the purposes of this paper, humanistic refers to an ontological framing that recognizes the end-user of a technology as first and foremost a *sui generis* human, unique in its form of subjectivity and challenged with the weighty responsibilities of self-awareness and ethical action [7]. User-centered, on the other hand, refers to an epistemological framing wherein humans are constructed as *users* through reductionist empirical observation. Such construction (e.g., through observation, data collection, generalization) provides the foundation for design implications grounded in the relationship between the present and proximal futures [27]. By adopting a humanistic approach, we attempt to see beyond the cycle of present-to-proximal-futures that broadly defines futuring and implicitly operationalizes people as observable users.

[3]While vulnerability to COVID-19 is mitigated by the uneven distribution of resources, access to care, and a broad suite of socioeconomic factors, a baseline biological vulnerability exists independent of the socioeconomic factors because the disease attacks basic human functions.

Our approach aligns with the theoretical underpinnings of infrastructural speculation [109]. Infrastructural speculation is defined as "an orientation towards speculation that aims to interrogate and ask questions about the broader lifeworld within which speculative artifacts sit, placing the lifeworld (rather than an individual artifact) at the center of a designer's concern" [109]. We expand upon the temporally-oriented analysis of futuring described by Kovubaez et al. [52] and embrace calls for non-linear and diverse futuring provided by Howell et al. [46]. We do so primarily because the temporal characteristics of infrastructures are not reducible to a human timescale [10]. The mismatch highlights a tension between the present-to-proximal-future orientation of design futuring [28, 46, 52] and the future conditions in which successfully invisible infrastructures will have already come into existence [81].

As a part of a would-be infrastructure – known as a "hopeful monster" in infrastructure studies [55] – pandemic-tracking apps constitute a site for a naturalistic form of infrastructural speculation [109] about the relationship between app-based public health surveillance and the implications of being *thrown* into conditions of infrastructure that has already, in one future or another, been realized as invisible.

2.2 Privacy and the Pandemic

Given that pandemic-tracking apps are data-driven, privacy considerations are an obvious aspect of the futures to which they allude. In combination with the daily effects of the pandemic, the ubiquity of data-hungry apps [84] is a prominent current facet of people's lifeworlds. Privacy-specific research about pandemic-tracking apps has become common since the onset of the COVID-19 pandemic (e.g., [40–42, 50, 65, 75, 104, 105]). Such work implicitly situates the study of pandemic-tracking apps in the greater context of "app culture" [84], wherein data practices constitute central points of contention. For example, Utz et al. [105] employed a contextual integrity framework to understand the factors that may contribute to people across three continents using pandemic-driven technologies.

Privacy and device-use norms differ across cultures and generations (e.g., [18, 53, 56, 64, 69]). As Sambasivan et al. [79] have shown, privacy concerns and policies play out differently for those who share mobile phones or whose phones are monitored by members of their family, as is common in India. Work in the MENA region has illustrated that the Western concept of privacy is inadequate for understanding privacy concerns in the MENA region because the latter are contextualized by the culture-specific concepts of "*hurma*, *awrah*, and the protection of them – *khososyah*" [1]. Such concepts are fundamentally driven by a concern for *honor* and do not easily map onto Western characterizations of privacy.

When privacy is grounded in the Western views regarding data access, research shows that privacy concerns related to pandemic-tracking apps are sometimes connected to the types of data that such apps collect [75, 105]. Privacy concerns further relate to people's perceptions of the third parties that may have access to the app data [84]. Notwithstanding the difficulties surrounding cross-cultural investigations of privacy [34], it is known that individuals rarely follow clear and universal guidelines for their privacy-related behavior. Instead, users appear to treat privacy as a trade-off with other factors and act according to context-specific privacy calculus [97], leading to calls to empower users through the provision of end-user privacy controls [43]. Yet, such controls are confounded by the cognitive limitations [2] and overburdening [44, 96] of users by the very privacy controls ostensibly deployed to help them. Further, app-based empowerment is conditional, with the relationships between "power over" and "power to" being culturally embedded [84]. There is no one-size-fits-all solution that is culturally sensitive. Mechanisms that aim to empower users to manage privacy inherit and enact the characterizations of privacy in the culture in which they are developed. The ubiquity of pandemic-tracking apps across the world presents an opportunity to

consider the relationship between different forms of vulnerability and culturally-situated "hopeful monsters" [55].

Complementary to privacy-oriented work, we approach the relationship between privacy and pandemic-tracking apps through the lens of affect. Affect is a fundamental aspect of *being* human. It thus provides a suitable lens to consider the experiences of vulnerability within infrastructures [83] and lifeworlds [109]. In fact, the pandemic and privacy are both often discussed using the language of affect. The pandemic is directly linked to the experience of negative affective states [77] such as fear and anxiety [19], depression [78], and anger [92]. Invasion of privacy is closely associated with negative affect. Such negative affect includes the experiences of intrusion [76], creepiness [94], loss of honor [1], digital resignation [29], and deceptive conditional empowerment [84]. Just as there is an affective element to the pandemic, there is an affective component to information privacy [100]. Both contribute to the common dread of the present period of the ongoing COVID-19 pandemic [35].

2.3 Pandemic-Tracking Apps

Many governments and corporations around the world have developed and deployed pandemic-tracking apps. A recent survey of pandemic-tracking apps revealed no fewer than 200 available for download [4], although that is likely a conservative estimate. Among such apps, we discuss those that are the most relevant to our participant sample: Aarogya Setu in India; E7mi in Tunisia; HaMagen, an app created by the Israeli Ministry of Health and used in Israel and Palestine; Wiqaytna in Morocco; Sehet Misr in Egypt; and the Apple-Google platform in the United States.

2.3.1 Pandemic-Tracking Apps in India. On May 1 of 2020, the Indian government made it mandatory to use Aarogya Setu, an application developed by India's National Informatics Centre (NIC) [25, 39]. Following controversies about privacy concerns, mandatory use of the app was curtailed in favor of "voluntary-mandatory" use on May 17, 2020 [25]. The voluntary-mandatory approach is seen as a means to sidestep several key privacy issues, including but not limited to: the use of location data rather than proximity, the ambiguous definition of "anonymized data," the collection of non-relevant information (e.g., profession); and the heightened surveillance by means of data sharing between government agencies and other actors [24]. The privacy-related debate surrounding Aarogya Setu is influenced by similar controversies in India emerging from the implementation of the universal identification card known as Aadhaar [5]. Despite the associated privacy risks, it has been argued that the population-level deployment of pandemic-tracking apps such as Aarogya Setu is a viable solution to managing the pandemic (e.g., [8]).

2.3.2 Pandemic-Tracking Apps in the MENA region. Pandemic-tracking apps in the MENA region have received relatively little scholarly attention within HCI. Tunisia's E7mi is briefly described in a few papers as a Bluetooth-based application (e.g., [50, 54]). Haggag et al. [40] describe E7mi as voluntary, closed source, anonymous, and separable from location data. Shahroz et al. [91], however, list E7mi as mandatory for Tunisian citizens. The Moroccan app, Wiqaytna, has received similarly passing research coverage, such as a timeline of its deployment [63] and an analysis of its user ratings [73]. Nachit et al. [63] have characterized Wiqaytna as an app entangled in the process of digital transformation. We did not find any research that considers users of the Sehet Misr app from Egypt.

HaMagen, the COVID-tracking app sponsored by the Israeli Ministry of Health, has received somewhat more research attention. Published work indicates that HaMagen uses location-specific data to inform users of potential exposure to the virus [17, 104]. Raman et al. [73] found that people held favorable perceptions about HaMagen's privacy policies. While HaMagen is the most frequently discussed among the pandemic-tracking apps deployed in the MENA region, much

of the discussion is in preliminary work [104] or in pre-prints that have not been peer-reviewed (e.g., [102]).

Notably, none of the above research efforts connected to pandemic-tracking apps in the MENA region cover the everyday situated lives of people who use (or choose not to use) such apps. Although systematic reviews of the available pandemic-tracking apps (e.g., [110]) are published and updated with some regularity, such reviews rarely consider and compare apps in the regions we covered in our study. A notable exception is the work of Sharma et al. [93] who found that people in the global south express fewer privacy-related concerns about pandemic-related apps than those in the global north.

2.3.3 Pandemic-Tracking Apps in the United States. The Apple-Google, Bluetooth-based contact tracing platform in the United States has been framed by a discussion of privacy from the beginning of its rollout in the second half of 2020.[4] A vast amount of work has considered the privacy implications related to pandemic-tracking apps in the United States (e.g., [26, 41, 42, 49, 58, 65, 75, 86]). In a sample of 2,000 people, Zhang et al. [111] found that decentralized data practices increase the acceptability of pandemic-tracking apps, noting that privacy concerns around pandemic-tracking apps are widespread. Similarly, Xing et al. [110] found that privacy concerns in the United States are much more unified even though opinions regarding governmental policies about COVID-19 are highly varied. More recently, Huang et al. [47] confirmed the centrality of privacy in the discourse about pandemic-tracking apps, identifying specific areas of concern such as the types of information the apps may collect and the parties with whom such data might be shared. Seberger and Patil [85] have noted fears regarding the influence of the economics of surveillance capitalism [112] on app-driven, post-pandemic healthcare.

3 METHOD

Our research is based on 23 semi-structured interviews conducted with participants from India, the MENA region, and the United States. We recruited eight participants from India; five from countries in the MENA region, covering Egypt, Morocco, Palestine, and Tunisia; and ten from the United States. Recruiting participants from these contexts allowed a broad analysis of people's views on pandemic-tracking apps. All study procedures were reviewed and approved by the Institutional Review Board (IRB) of Indiana University Bloomington.

3.1 Participants

We recruited participants from India and the MENA region through advertisements distributed via social media and the international office of Indiana University Bloomington. We sought participants from the United States by advertising through the `r/paidstudy`[5] and `r/paidstudies`[6] communities on Reddit. The study advertisement directed prospective participants to a brief online screening questionnaire used to determine their eligibility to participate (see Appendix A). We solicited participants from multiple global regions in order to facilitate the analysis of a speculative infrastructure across heterogeneous lifeworlds [109].

Table 1 provides an overview of the demographics of our sample. We sought to create as diverse a mix of ages, genders, and professions as feasible from among the eligible participants who completed the screening questionnaire. To that end, we used a deliberative process that leveraged our firsthand knowledge of the India, MENA, and United States contexts. We ceased conducting interviews upon reaching conceptual saturation. We attribute the higher proportion of participants from India and

[4] See, for example, https://www.google.com/covid19/exposurenotifications/
[5] https://www.reddit.com/r/paidstudy/
[6] https://www.reddit.com/r/PaidStudies/

Table 1. The demographics of the participants.

ID	Country	Gender	Age	Occupation	Locality
P01	United States	Female	40	Personal Assistant	Suburban
P02	United States	Female	66	Accountant	Urban
P03	United States	Female	43	Court Clerk	Suburban
P04	United States	Female	32	Analyst	Suburban
P05	United States	Male	36	Package Handler	Suburban
P06	United States	Male	27	Graphic Designer	Urban
P07	United States	Female	19	Student	Suburban
P08	United States	Male	37	Sales Executive	Urban
P09	United States	Female	41	Childcare Provider	Suburban
P10	United States	Female	31	Student	Suburban
P11	India	Male	21	Student	Urban
P12	India	Male	23	Financial Analyst	Rural
P13	India	Male	23	Student	Suburban
P14	India	Female	24	Software Engineer	Urban
P15	India	Male	20	Student (Intern)	Urban
P16	India	Male	25	Designer	Rural
P17	India	Female	42	Home Maker	Urban
P18	India	Male	27	Unemployed	Rural
P19	Tunisia	Male	20	Community Manager	Urban
P20	Egypt	Male	35	Landscape Engineer	Urban
P21	Morocco	Female	30	Architect	Urban
P22	Morocco	Female	29	Medical Researcher	Rural
P23	Palestine	Female	27	Unemployed	Urban

the United States to the pandemic-related complications of conducting online research in the MENA region [3].

3.2 Semi-Structured Interviews

We interviewed the participants via video conferencing using a semi-structured interview format with an interview guide prepared in advance (see Appendix B). The interview sessions lasted between 25 and 89 minutes (mean = 46 minutes). During the interviews, we maintained a natural conversation flow and probed for more in-depth insight as needed. We provided each participant with a gift certificate for US $10.00 as a token of appreciation for participating in the study.

We conducted the interviews with the participants in the United States during July and August of 2020, with those located in India in August and September of 2020, and with those in the MENA region between August and October of 2020. The sole exception is P23, who was interviewed in March 2021. When we conducted the interviews, the status of the pandemic in each region was roughly similar, with India and the United States each having recorded over one million cumulative COVID cases and the MENA region having reported roughly 700,000 cases at that point.

We interviewed the participants from the United States and India in English. One of the authors conducted interviews with the participants from the MENA region in Arabic, French, or English based on the language the participant preferred. We transcribed the interviews conducted in Arabic

and French in the original language and then translated the text into English to ensure uniformity in coding across all interviews.

3.3 Data Analysis

We analyzed the interview transcripts using reflexive thematic analysis [12–14], which aligns with our critical interpretivist position. The goal of thematic analysis is to "provide a coherent and compelling *interpretation* of the data, grounded in the data," which requires "close and critical" engagement [14, p. 848]. Thematic analysis is ideally suited for understanding "participants' lived experience, views and perspectives, and behavior and practices" [20, p. 297]. As such, knowledge production through thematic analysis aligns with the knowledge production mechanisms of infrastructural speculation [109].

For the work we present in the paper, researcher subjectivity is a resource, not a liability [36]. As Braun et al. [14, p. 848-849] have explained, researchers engaged in reflexive thematic analysis are "actively engaged in interpreting data through the lens of their own cultural membership and social positionings, their theoretical assumptions, their ideological commitments, as well as their scholarly knowledge." Our analysis was thus informed by our diverse cultural backgrounds (American, British, Indian, Nigerian, and Tunisian) and interdisciplinary expertise (social informatics, crisis informatics, and usable privacy). We explicitly assembled a set of diverse authors to avoid an inquiry siloed by culture and discipline.

First, we engaged in familiarization with the interview data via individual and collaborative reading of the interview transcripts, noting and memoing initial points of interest during the process. Given the interdisciplinary and culturally heterogeneous backgrounds of the authors, the familiarization process helped solidify an analytical common ground.

Through an iterative refinement of codes, we identified eight candidate themes. Upon checking these themes against the data, we consolidated them into a list of three higher-level themes: (i) "opinions about pandemic-tracking apps," which was used for excerpts containing thoughts of the participants about pandemic-tracking apps; (ii) "pandemic-related discomfort," which was applied to excerpts in which the participants discussed or expressed negative impacts of the pandemic; and (iii) "data concerns," which was used to mark excerpts in which the participants mentioned concerns about data practices of pandemic-tracking apps. Notably, the "discomfort" theme contained two sub-themes describing different temporal orientations of discomfort.

Upon verifying that the higher-level themes were reasonably exclusive, we employed them to develop a grounded interpretation of the data that allowed for speculation about the vulnerabilities latent within a potential public health surveillance infrastructure built upon pandemic-tracking apps.

3.4 Limitations

When considering our findings, several limitations of our sample must be taken into account. First, the participants were relatively young. Second, all participants from India and the United States were English speakers. Third, the participants were tech-savvy and had Internet access reliable enough to be able to participate in an online interview. Fourth, our sample is affected by the limitations of self-selection and self-report.

Additionally, the interpretivist paradigm we employed (i.e., reflexive thematic analysis) is not predicated on strict generalizability. While the conceptual foundations of our findings are sound, they do not necessarily lend themselves to cross-cultural generalizability. Further research is required to examine specific cross-cultural differences and similarities.

4 FINDINGS

The participants expressed generally favorable views on pandemic-tracking apps. Their views and expectations were contextualized by various forms of *persistent discomfort* brought about by the COVID-19 pandemic. Hopeful expectations rendered the participants acutely vulnerable to disappointment and invasive data practices. In this section, we present the various types of discomfort and their relationships to different kinds of vulnerability that emerged from our study.

4.1 People's Perceptions of Pandemic-Tracking Apps

The overwhelming majority of participants expressed positive attitudes about pandemic-tracking apps as a means of pandemic mitigation:

> "*I feel that this contact-tracing app is definitely a good idea, but the participation of the people is very important too. So fifty percent is technology, but fifty percent is the people, the audience.*" – P14, India, Female, 24, Software Engineer, Urban

However, as described above by P14, the participants did not necessarily believe that pandemic-tracking apps are a standalone technological panacea. Rather, to be successful, such apps must be accepted and used by members of the population, echoing the outcomes of prior work in which personal traits were seen to be related to the attitudes toward such apps [86]. The observation further contextualizes pandemic-tracking apps in the discourse of infrastructure, wherein infrastructures of daily life are learned by membership [83, 99]. The generally positive attitudes toward pandemic-tracking apps we observed are similar to the findings presented in other work [85, 105, 106].

Participants expressed opinions that pandemic-tracking apps are sufficiently powerful to force behavioral change upon their users:

> "*I think [pandemic-tracking apps] would scare people into being better. [...] 'Maybe I should be more careful. Maybe I should put on a mask on maybe I should do this.'*" – P10, United States, Female, 31, Graduate Student, Suburban

The expectation that pandemic-tracking apps might "scare" their users into "being better" speaks to the power-oriented work on vulnerability [61] as well as the relationship between "power over" and "power to" in privacy studies [84]. It forms an implicit point of friction between the recognition that pandemic-tracking apps are useful only when they are widely used and the idea that such apps wield enough power to coerce users to change behavior. It is possible to interpret the power of pandemic-tracking apps to exert influence (e.g., "scare") as a factor relevant to the necessity of people's adoption of pandemic-tracking apps described above by P14.

Even the small number of participants who did not hold outright positive views of pandemic-tracking apps acknowledged the apparent necessity of such apps:

> "*I guess that this [pandemic-tracking apps] is a necessary evil at this point, but I'm not sure what we're going to lose by it in the long run. What are we losing in terms of using this? What's happening that is negative*?" – P01, United States, Female, 40, Personal Assistant, Suburban

The above remark highlights a trade-off signified through the characterization of pandemic-tracking apps as "a necessary evil." Something (i.e., public health) is gained through the deployment and adoption of pandemic-tracking apps. At the same time, P01 expected that, in return for such a gain, something will be lost too. The generally positive perceptions of pandemic-tracking apps were often qualified by trepidation about such future losses:

> "*It's gonna be a strange new world, and people will have to adapt to it.*" – P06, United States, Male, 27, Graphic Designer, Urban

In the comment above, P06 made a clear reference to the impact of the pandemic on his lifeworld. The generality of "a strange new world," as signified by the indefinite article, speaks to the uncertainty of futures. Such futures appear as potentials to be found in the remix of benefits, hopes, wariness, loss, and trepidation. As we describe in the following subsections, trepidation – the recognition of a potential "strange new world" and the fear that something may be lost through engaging with a "necessary evil" – is broadly contextualized by an experiential spectrum ranging from discomfort to the harm central to conceptualizations of vulnerability (e.g., [59, 80]). Such a spectrum covers a vast range of experiences, including those that are not directly related to apps, but which *contextualize* the use of such apps. In the following sub-sections, we shift focus toward participant discussions of such broader contexts.

4.2 Real Vulnerabilities That Contextualize Perceptions of Pandemic-Tracking Apps

Generally, participants in our study expressed their vulnerability to the pandemic through discussion of discomfort:

> "*[COVID-19] affects me very much because it is very uncomfortable for us to live like this.*" – P17, India, Female, 42, Homemaker, Urban

> "*Honestly, the situation is very annoying. We're at home all the time and it's frustrating. I was never used to living like this.*" – P23, Palestine, Female, 27, Unemployed, Urban

Since vulnerability is regularly defined as susceptibility toward harm (e.g., [80]), the relationship between harm and discomfort merits conceptual investigation. Discomfort may be approached as an initial manifestation of vulnerability because it is possible for routinized, persistent discomfort to amount to notable harm. We classify such persistent discomfort as *real* because of its temporality. That is, it *is and has been* experienced by those who participated in our study. In having been experienced, such discomfort describes and informs the expectations of everyday life in a person's lifeworld. We might get purchase on this accumulative process by considering the temporal orientation of pandemic-related discomfort.

4.2.1 Discomfort Situated Between the Past and the Present. Discomforting impacts described by the participants ran the gamut from interruptions of cherished routines to fundamental problems of sustenance and living arrangements. While these negative effects of the pandemic are of varying seriousness, they can be aligned with a temporal perspective on the relationship between the past and the present that leads to the formation of expectations.

Complications of daily life were framed by marked disappointment and wistfulness. The pervasiveness of these attitudes among the participants in our study speaks to discomfort that approaches the threshold of harm. For example, P23 (above) and P02 (below) discussed the frustrations of life during the pandemic in comparison to the pre-pandemic days:

> "*I used to help my son transport his children to school and back because he's divorced. Now I can't do that. Hopefully, the schools will start back up. Then, I will be able to see my grandkids again more often.*" – P02, United States, Female, 66, Accountant, Urban

Vulnerability to COVID-19 manifested in a reduction in the ability of P02 to exert agency over the daily routines of her life. The expectations of everyday life based on a past routine were violated by the circumstances of the present. The discomfort of P02 is particularly notable given that prior work on vulnerability has cautioned that categorizing older adults as "vulnerable" *per se* might not be appropriate [66]. P02 was clearly an "anchor" of her family's life [66]. When this nuance is recognized, not all who may be assumed to be vulnerable are accurately described as such, nor does such description necessarily do service to those to whom it is applied. Therefore, it is necessary to explore vulnerability itself with heightened sensitivity.

While the regret of the missed opportunities of daily life – "hanging out with friends" (P10); being "at home all the time" (P23); "help[ing] my son" (P02) – comes through, the effects of the pandemic extend quite a bit further. For some participants, the discomfort of life during the pandemic was not principally that of monotony. Rather, it encompassed more fundamental types of discomfort related to basic needs:

> "*In the villages, it changed people's lives for the worse since they are not going to the [bigger] town more often because there is a complete lockdown here. So it changed people's lifestyle because it changes how one is going to eat; it changes what one is going to eat because there are limited supplies.*" – P12, India, Male, 23, Financial Analyst, Rural

Admittedly, to frame such discomfort in terms of the expectations born of past routines and their interruption in the present downplays the severity of diminished access to food. It is emphatically not our intent to reduce such a potentially catastrophic situation to mere "discomfort" and "violations of expectations." Rather, we posit that such faceted classification [74, 98] speaks to the myriad ways in which vulnerability should be theorized as we design our way out of the pandemic and into the future. Such theoretical flexibility is useful for identifying anticipatory vulnerability (i.e., vulnerability oriented predominantly in the relationship between the present and the future).

4.2.2 Discomfort Situated Between the Present and the Future. For some of the participants, the desired return to pre-pandemic routines was not strictly about going back to the way things were before the pandemic. That is, some discomfort born of COVID-19 is future-oriented since it is based on the experiences in the present that not only violate expectations in the present, but also shape expectations about how the present is likely to influence the future. In the case of P07, such discomfort was connected to the stunted ability to continue along her planned life trajectory:

> "*[. . .] Because of the quarantine, I had to leave [university] campus and come back home. As a result, I'm in constant contact with my family in a way that's almost reminiscent of when I was in high school. [. . .] I have realized how much I love interaction with people my own age. I really miss them.*" – P07, United States, Female, 19, Student, Suburban

The above remark of P07 alludes to a regression of sorts. The pandemic interrupted the trajectory of her social development, necessitating that she revert to a mode of living "almost reminiscent" of a previous life stage. In this case, we see vulnerability in the form of prolonged discomfort manifest in the breach of expectations not only about the present, but also about how the present relates to the future.

The various quotes above highlight that vulnerability necessarily has a temporal facet. As such, vulnerability does not exist solely as a complete and known set of phenomena limited to specific populations (i.e., "vulnerable populations" [59, 80]). Rather, vulnerability may manifest in novel ways across time in relation to complex sociotechnical circumstances. The manifestation of vulnerability across time is particularly relevant given uncertainty about the future expressed by the participants. The framing of pandemic-related changes with the language of "a strange new world" (P06) indicates the scale at which we are obligated to consider vulnerability. For instance, for P07, the strange new world is one predicated on the interruption to her pre-pandemic life trajectory.

Given the digitally-mediated context of contemporary daily life, it is not reasonable to separate the pandemic from the technology, such as pandemic-tracking apps, that is deployed to combat it. The findings we have presented up to this point deal with discomfort and the relationship between persistent discomfort and the appearance of vulnerability in a general sense. In the following subsection, we turn our attention to participant discussions that focus specifically on concerns related to digital data. Notably, these concerns emerge relative to the expected data practices of pandemic-tracking apps and the privacy issues they raise.

4.3 Discomfort Related to the Data Practices of Pandemic-Tracking Apps

In the subsections above, we discussed the persistent discomfort participants experienced during the pandemic. At the same time, the participants routinely expressed long-term concerns regarding pandemic-tracking apps and the expected data practices of these apps.

App-based strategies to contain the pandemic position data as a mediator between people and their own bodies. In the context of app culture, *data* implies the participation of unknown third parties [94]. Such positioning creates potential vulnerability which can be framed as a fear of stigmatization. We broadly define stigmatization as an unwanted social outcome resulting from information disclosure. P23 discussed the difficult relationship between app-based pandemic mitigation and stigmatization:

> "*In the beginning of the pandemic, they were posting sick people's names. [...] An app should be on a high level of privacy for every user because many people get bullied as a result of catching the virus. Anyone who people knew had the virus was being treated like an outcast or like the person had a disease that was way more dangerous than COVID-19. So anyone who uses this app should be respected, and names or any personal information about sick people shouldn't be shared. At the same time, the app should be able to follow the patient and the people who were in contact with the person and communicate with them without mentioning who was the person that they contacted and was sick.*" – P23, Palestine, Female, 27, Unemployed, Urban

The above quote highlights the profound influence over privacy wielded by app developers. While P23 supported pandemic-tracking apps that function anonymously (i.e., allowing for contact tracing without disclosing identity), such support was tempered by the implicit recognition that pandemic-tracking apps are, in and of themselves, a source of potential discomfort. Maintaining the privacy of one's bodily state becomes all the more difficult as technological interlocutors are added:

> "*I feel vulnerable when my data is being collected by someone else.*" – P11, India, Male, 21, Student, Urban

People tend to lump app developers into a single category characterized by exploitative data practices:

> "*These big organizations really don't handle your data the way you would want it to be handled or the way they say that it will be handled.*" – P12, India, Male, 23, Financial Analyst, Rural

As the above remarks of P23, P11, and P12 imply, the mere presence of an additional party – an app, organization, or individual – in the network of parties that know about one's infection status can be problematic. In the case of pandemic-tracking apps developed and deployed by powerful institutions (e.g., governments and technology companies), further privacy-related problems likely stem from the increased uncertainty created by the power imbalances between such institutions and users [60, 84]:

> "*In this era of connectivity you don't know how your information can be used and how it can affect you in the long run.*" – P18, India, Male, 27, Unemployed, Suburban

The uncertainty associated with the digital realm adds to the persistent discomfort of the pandemic by creating an expanding set of vectors through which the persistent discomfort may eventually manifest as categorical vulnerability. Given the relationship between knowledge and power (i.e., knowledge *is* power), the absence of knowledge about "how your information can be used" implies a power imbalance. Power imbalances signify vulnerability [61].

Concerns about future data use are similarly compounded by the enacted resignation (see [29, 88]) to privacy violation as represented by the general disregard for the stated terms and conditions:

> "*We go through a lot of terms and conditions when we sign up for things. There are tons and tons and tons of pages of information. We don't read them. We have given up. [...] So the companies are doing whatever they want with it essentially.*" – P03, United States, Female, 43, Court Clerk, Suburban

Even though, as P3 put it, "we have given up," some participants identified that a loss occurs through such resignation. Wariness of something being lost through the ubiquity of apps and data collection colors people's long-term concerns about pandemic-tracking apps:

> "*Privacy is lost or something's lost. But the reality is, every time we sign on to WiFi, we're tracked; every time we drive our cars, Google tracks us. The reality is that we're being tracked anyway. So what is the difference to me? I don't know.*" – P01, United States, Female, 40, Personal Assistant, Suburban

Persistent discomfort over the intangible *losses* (P01) of app culture translate to future-oriented vulnerability. While recent work has situated the loss of privacy as a voluntary trade-off between individual privacy and public health [85], we identify the framework of the trade-off itself as a vector of vulnerability. Such vulnerability may be characterized through the lens of hyperbolic scaling [86] in which people assume that the privacy-concerning characteristics of a specific app are generalizable to other apps they use. Notably, extrapolating from the remarks of P23 and P11, wariness toward privacy-related data practices appears unrelated to app functionality. HaMagen (Israel/Palestine), for example, employs a decentralized framework while Aarogya Setu (India) does not [73]. If wariness about pandemic-tracking apps was driven primarily by app functionality, one would expect to see a difference between those in Palestine and those in India. Instead, the expressions of wariness of the participants in our study are in line with the recent observation that people's expectations of invasive data practices being the norm influence their willingness to accept the invasive data practices [88].

5 DISCUSSION

Our findings highlight the relationship between persistent discomfort and vulnerability. Situated within people's pandemic lifeworlds, we point out the vulnerabilities that resonate through the pandemic, from the real to the anticipatory and beyond. In this section, we explore the temporality of vulnerability as it emerged from the interviews. We then provide a definition and explanation of *speculative vulnerability*, highlighting its theoretical relevance to the process of design futuring and long-term societal impact.

5.1 Exploring Vulnerability

Our findings help identify a productive temporal analytical framework for the study of vulnerability in HCI. Although vulnerable populations are of common interest (e.g., [6, 31, 59, 60, 80]), little work has provided systematic conceptual analysis of vulnerability itself. Concern for known vulnerable populations makes it easy to focus on the immediate problems at the expense of understanding and preventing problems that might arise in speculative futures. This is particularly true when the future is routinely understood as proximal.

5.1.1 Temporal Orientations of Vulnerability. Grounded in a consideration of the differences between *persistent discomfort* (see Section 4) and *social vulnerability* (see Section 2), we identified two forms of persistent discomfort related to the experience of daily life during the COVID-19 pandemic. The persistence of such discomfort obligates us to understand where discomfort ends and vulnerability begins. Further, it is necessary to understand how the persistent discomfort associated with invasive data practices in app culture may amount to vulnerability that technology enables and perpetuates through a consistent concern for linear, progress-based proximal futures [46].

Since vulnerability is defined as the susceptibility to harm [80] and discomfort is understood intuitively as a symptom of harm, persistent discomfort appears to share conceptual space with vulnerability. By acknowledging the shared conceptual space of persistent discomfort and vulnerability, we can infer that vulnerability is not a stable and fully known set of conditions. Rather, it is subject to change as the conditions of daily life change.

From the highest vantage point, vulnerability is *emergent* relative to historical, sociotechnical, cultural, economic, and individual factors. Being invulnerable yesterday, or in yesterday's tomorrows [9], does not guarantee invulnerability in the future. Given the calls for researchers to account for the implications of their work and its role in mitigating or perpetuating the experience of harm [45, 101], it is necessary to dig deeper into the relationship between *persistent discomfort* and *vulnerability* in order to ensure that the technologies pushed out into the world [7] do not inadvertently create vulnerability.

We engage in foundational conceptual work by exploring the assumption that the persistence of discomfort is one means by which vulnerability emerges from within a sociotechnical system. In considering the persistence of discomfort as a harbinger of normalized vulnerability, we focused on two temporal facets. The first facet is present, or *real*, vulnerability wherein expectations about daily life rooted in *the way things have been* are violated (see [83]). Such *real* vulnerability is expressed in participant discussions of the discomfort of solitude (P17, P23), the inability to maintain the traditional family role (P02), and the interruption in the access to sustenance (P12). We identified near-future, or *anticipatory*, vulnerability as a second facet wherein violations of what is expected in daily life in the present derail future plans. The discomfort of a stunted life transition described by P07 is an instance of anticipatory vulnerability.

At a higher level, real and anticipatory vulnerabilities are not necessarily mutually exclusive. Their differentiation is illustrative rather than categorical. The non-exclusivity of these initial categories of vulnerability is apparent in the emotional content of several participant quotes presented in Section 4. The low-level anguish and anxiety of "a strange new world" (P06) and the sense of loss that comes with data-hungry apps (P01) arise from a particular reality that characterizes anticipatory vulnerability. In such instances, one feels discomfort by the expectation itself, experiencing anticipatory vulnerability as a reality that results in negative "affective conditions" [103].

Yet, logically, the temporal boundary between real and anticipatory vulnerabilities is porous. Anticipation is an experience that is *real* in the present. Thus, real and anticipatory vulnerabilities are both tied to the phenomenological present.[7] Their relation to the present necessitates consideration of proximal futures and their place in the linear processes of design futuring (cf. [28, 46, 52]). Echoing the concerns of P01, such consideration may be captured via the following question: "In focusing on the relationship between the present and the proximal future, what is lost?"

5.1.2 Speculative Vulnerability. Real and anticipatory vulnerabilities are grounded in experience, requiring a realized infrastructure of daily life to situate them. Yet, infrastructures of daily life are built only *partly* through explicit design. The un-designed experience of daily infrastructures (i.e., their received invisibility [83, 99, 107]) necessitates a consideration of the wicked problems of infrastructures [15]. In order to identify the sets of vulnerabilities that novel infrastructures *will have given rise to* in the future, we need to work around the entrenched relationship between the present and the proximal futures.

The combination of persistent discomfort in daily life during the COVID-19 pandemic and the worries about the data practices of pandemic-tracking apps points to a third temporal facet of

[7] Situating the vernacular use of "lifeworld" [109] in its longer tradition of Husserl's [48] phenomenology in which "lifeworld" refers to the temporal and experiential *horizon* of an individual subjectivity [33, 70], we see that real and anticipatory vulnerability are fundamentally grounded in the long present (i.e., *le grand maintenant* [37]).

vulnerability. This is a complex facet manifest in considerations of infrastructures that people imagine to have been realized in the future. Such considerations are predicated on the success and received condition (i.e., invisibility) of "hopeful monsters" [55], represented in this case by pandemic-tracking apps. We refer to this facet as *speculative vulnerability*, defined as the heightened exposure to harm facilitated through extrinsic, technologically-mediated changes in the received condition of one's infrastructurally mediated lifeworld. Speculative vulnerability resides in futures in which presently emergent or speculative infrastructures *will have* achieved invisibility. Such vulnerability constitutes a propensity toward persistent discomfort, normalized through the received nature of infrastructures.

Real and anticipatory vulnerabilities are born of the persistent discomfort at the nexus of the pandemic and a digitally mediated lifeworld, resonating through known forms of infrastructures. When one transplants such vulnerabilities into possible infrastructural configurations wherein persistent discomfort about data practices colonizes the maintenance of public health [85], they are no longer simply real or anticipatory – they transcend the edges of the subjective horizon (i.e., the phenomenological lifeworld [48]). In the context of the COVID-19 pandemic, such speculative vulnerability is manifest in the form of a perpetual discomfort related to invasive data practices and the normalization of affective discomfort in app use [88] (P01, P03, P11, P12, P13).

The wicked problems [15] and hyper-functionalities [83] of future infrastructures are not easily ascertained through a direct observation of the present. Rather, they require *humanistic* inference of the form facilitated by infrastructural speculation [109]. Instead of a specific concern for known individuals or sub-populations that presently face harm, speculative vulnerability is oriented toward a broad concern for future generations who will be born into the infrastructures we envision today as having been realized in the future. Although we cannot possibly be aware of the full sociotechnical effects of such infrastructures, we can attempt to shape them through a design focus on proximal futures and implications for design.

We might additionally think of speculative vulnerability as a form of ontological vulnerability where *being known* through and by means of infrastructures yields discomforting or harmful effects regarding identity (see [11, 83]). The problem of being known emerges from concerns about parties that have access to the data collected through pandemic-tracking apps (P11, P12, P23). Speculative vulnerability accounts for the "strangeness" (P06) of the post-pandemic world more completely than real or anticipatory vulnerabilities. The latter two forms of vulnerability are already grounded in present discomfort. In contrast, speculative vulnerability severs ties with the present and emerges as an object of study in the temporality of infrastructure that is not reducible to that of human temporality [10]. We contend that speculative vulnerability exists in a future wherein today's "hopeful monsters" [55] *will have* become invisible. Such future aligns with the mode of speculation found in infrastructural speculation [109] and effectively separates itself from the cycle of present-to-proximal-future [46]. By taking the inaccessibility of the future as a given, speculative vulnerability constitutes a lens through which one can engage in critical and infrastructural futuring not wholly tethered to the empirical observation of the present in which the human is often reduced to a mere user.

The continuum between persistent discomfort and real or anticipatory vulnerability is grounded in the situated present of daily life (i.e., a combination of the vernacular lifeworld [109] and the phenomenological lifeworld [48]). In contrast, speculative vulnerability is a hypothetical and conditional facet of vulnerability that exists in distant futures wherein presently emergent infrastructures will have become invisible. As such, speculative vulnerability is inherent to the process by which the "hopeful monster" [55] becomes infrastructure (i.e., the process by which a widely deployed and adopted technology recedes into the invisibility of infrastructure [99, 107] and saddles future generations of humans with normalized persistent discomfort, which is as difficult to infer today

as "digital resignation" [29] would have been 50 years ago). Speculative vulnerability offers a conceptual framework through which we can identify future conditions of normalized vulnerability that may characterize daily life when the digital transformation – inherently tied to the trajectory of the COVID-19 pandemic [63] – is functionally complete.

6 IMPLICATIONS

The implications of our work are directed toward two audiences: those who are interested in the role of technology in mitigating vulnerability and those who wish to ensure that potential public health surveillance infrastructures rooted in technology will be designed, deployed, and used in ethical and sensitive ways.

6.1 Implications for Vulnerability-Related Research and Design

Technologists are obligated to protect against the real and known harms that face vulnerable populations (cf. [62]) and prevent the manifestation of what we have termed speculative vulnerability [45, 101]. Doing so requires acknowledging and accounting for the differences between *humanistic* and *user-centered* approaches. Such acknowledgment and accounting is possible through a temporal reorientation beyond the lens of present-to-proximal-future.

Through a naturalistic application, infrastructural speculation [109] is ideally suited to help researchers see beyond the present and proximal futures (cf. [28, 46, 52]). It is increasingly necessary to see beyond such a cycle to include humanistic considerations [7, 83] as a part of the user experience. A focus on speculative vulnerability enables designers to consider the effects of their designs on the *human*, rather than on the reductionist *user* born of concern for the immediate impact of design choices.

The relationship between the present and the proximal future is reflected in the means by which implications for design motivate work in HCI [27], seeking solutions to real vulnerability in the present. Such a perspective is indeed necessary (e.g., [6, 31, 59, 60, 80]), but it is not sufficient in and of itself to account for the involvement of HCI in pushing the computer out into the world [7]. Focusing on the relationship between the present and proximal futures may blind researchers to inherent long-term vulnerability, thus perpetuating the reduction of the *human* to the *user*. Such a reduction from the human to the empirically operationalized user constitutes a realized form of speculative vulnerability: people have not always been *users*. Yet, owing largely to the success of HCI, people are routinely categorized and therefore understood (i.e., interpellated [23, p.75-82]) as such.

If we are serious about leveraging apps to mitigate the pandemic, we are obligated to ensure that such mitigation does not itself result in the realization of vulnerability should those apps become infrastructural. By solving one problem we should not contribute to the entrenchment of another. Our scope needs to be broader, going beyond the present of the *user* to the future possibilities of the *human*.

6.2 Implications for the Oversight of Public Health Infrastructures

We recommend that developers and champions of pandemic-tracking technology (e.g., governments, corporations, universities) leverage people's generally positive expectations regarding pandemic-tracking apps by setting appropriate public policy and precedents for the ethical deployment of such technology. Relevant approaches may involve: (i) transparency regarding current and future third parties who may access the data collected through pandemic-tracking apps; (ii) disclosure of known or aspirational alternate uses for pandemic-tracking infrastructure (e.g., public health surveillance); and (iii) communication of the medical and ethical justifications for data practices in a format understandable by the general public.

While technological solutions to the COVID-19 pandemic may be harbingers of vulnerability, such solutions also have the potential to serve as beacons for the ethical and transparent development of technology that does not rely on the economics of surveillance capitalism [112]. Thoughtfully crafted public policy related to public health matters could help ensure that app developers move beyond treating data as primarily a resource for financial gain. The wide reach of the COVID-19 pandemic is partly what makes it a global crisis. At the same time, the global reach makes the pandemic an opportunity to normalize more ethical technology design and deployment.

7 CONCLUSION

We found that hopeful and positive perceptions of pandemic-tracking apps are typically tempered by the persistent discomfort of daily life during the pandemic and a wariness of invasive data practices of mobile apps in general. While persistent discomfort and data-related concerns are connected to separate temporal facets of vulnerability, they are ultimately grounded in the observable present. Our findings reveal that speculative vulnerability is an additional temporal facet of vulnerability that can serve as a useful lens for seeing beyond the present and the near-term future. The lens of speculative vulnerability enables an interrogation of future states of received infrastructure and accounts for the situated humanity of the people whose daily lives are shaped by the envisioned technological solutions. A focus on speculative vulnerability can thus facilitate more critical reflection on long-term societal impact of technological solutions that affect the lives of future generations.

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A SCREENING QUESTIONNAIRE

- **What is your year of birth?**
  [Dropdown of years]
- **What is your gender?**
  - Male
  - Female
  - Non-binary
  - Prefer to self-describe: [Text field]
  - Do not wish to answer
- **What is your country of citizenship?** [Text field]
- **In which country do you currently reside?** [Text field]
- **How would you characterize the locality where you live?**
  - Urban
  - Suburban
  - Rural
  - Other. Please specify: [Text field]
- **What is the highest level of education you have completed?**
  - Less than high school
  - High school diploma
  - Vocational training
  - Some college (no degree)
  - College graduate (B.S., B.A., or other 4-year degree)
  - Master's degree
  - Doctoral degree
  - Professional degree after college (e.g., law or medical school)
  - Other. Please specify: [Text field]
  - Prefer not to say
- **What is your current employment status?** (*Select all that apply.*)
  - Employed full-time
  - Employed part-time
  - Unemployed looking for work
  - Unemployed not looking for work
  - Homemaker
  - Student
  - Retired
  - Disabled
  - Other. Please specify: [Text field]
  - Prefer not to say
- [If the participant selected current employment status as "Employed full-time" or "Employed part-time":] **What is your profession?** [Text field]
- [If the participant selected current employment status as "Student":] **What is your field of study?** [Text field]
- **If you qualify for the study, would you agree to be interviewed online (e.g., via Zoom)**?
  - Yes
  - No

- **If you qualify for the study, which email address should we use to contact you for scheduling a study session?** [Text field]

B SEMI-STRUCTURED INTERVIEW PROTOCOL

The study used the following semi-structured interview protocol. We used the protocol flexibly to ensure natural conversation flow and seek additional information as needed.

B.1 Introduction

Thank you for participating in this study.

The purpose of the study is to understand your opinions of health technologies in the context of the COVID-19 Pandemic. This study is being conducted by researchers at Indiana University Bloomington.

This study consists of an interview lasting between 45-70 minutes during which we will ask you a series of questions. There are no right or wrong answers. We are interested in your honest responses to our questions.

So that we can pay full attention to your answers, we would like to record the interview session to transcribe the audio later. The recording will be destroyed after the audio is transcribed. Any information you provide during the course of the interview will be anonymized in the transcripts.

- Do we have your permission to record the interview? [If "yes," commence recording.]

- Would you like to continue participating in this study? [If "yes," proceed. If "no," end.]

Before we start, do you have any questions?

B.2 Rapport Building

Please tell us a bit about yourself:

- What was the last piece of music you listened to that you chose?
- What is the last movie you saw that you liked?
- What do you do for work?

B.3 Current Situation

Please tell us about your household:

- Who lives in your household?
- What do they do?
- What are their typical routines?
- Please tell us about your work. [Reference the response to the above question about occupation.]
- [If work context changed because of the pandemic (e.g., office to home)]: How do you feel about the current work arrangement?
- Please tell us about your own and your community's response to COVID-19:
  - What is your understanding of these measures?
  - How would you describe your response to these measures?
  - How has COVID-19 affected you, your family, and your friends?

B.4 Perceptions of COVID-19

- Have you personally taken any action in response to COVID-19?
- [If yes:] What actions have you taken? Whom would those actions benefit?

B.5 Perceptions of the Role of Health Technology for Responding to the COVID-19 Pandemic

- Please tell us what you know about how technology is being used during the COVID-19 pandemic.
- Do you or would you use any of the technologies you mentioned? Why or why not?
- How would you describe the perfect health technology to study or mitigate the COVID-19 pandemic?
- Have you seen any health technologies become more prominent as a result of the COVID19 pandemic? If yes, which technologies have you observed? How do you feel about these technologies?
- What is your opinion on contact-tracing applications as a tool to study and mitigate the COVID-19 pandemic?
- How would you feel about contact-tracing applications implemented by [ask sequentially]: a university; a non-profit organization; an industry start-up; your government; the United Nations?
- What data would you *want* contact-tracing apps to collect?
- What data would you *expect* contact-tracing apps to collect?
- Which data should contact-tracing apps NOT collect?
- Where would you like contact-tracing apps to store the data?
- Whom would you want to have access to the data collected through contact-tracing apps?
- Do you believe contact-tracing apps would handle your data the way you want? Why or why not? If responses mention 'trust' or 'privacy,' could you elaborate on your thoughts regarding trust or privacy?
- What, if any, influence has the COVID-19 pandemic had on how you use apps and technology?
- What are your thoughts on balancing your individual needs and freedom with the public health needs of others in the community who want to avoid getting infected?

B.6 Conclusion

- Is there anything that you think we missed asking you?
- Is there anything you would like to add?

Thank you for your participation in the study. If you think of anything else afterward, please feel free to reach out to us.

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