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Applying a Social Determinants of Health Framework to Guide Digital Innovations that Reduce Disparities in Chronic Disease

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Abstract

Chronic diseases are among the top causes of global death, disability, and healthcare expenditure. Digital health interventions (e.g., patient support delivered via technologies such as smartphones, wearables, videoconferencing, social media, virtual reality) may prevent and mitigate chronic disease by facilitating accessible, personalized care. While these tools have promise to reach historically marginalized groups, who are disproportionately affected by chronic disease, evidence suggests digital health interventions could unintentionally exacerbate health inequities. This commentary outlines opportunities to harness recent advancements in technology and research design to drive equitable digital health intervention development and implementation. We apply "calls to action" from the World Health Organization (WHO) Commission on Social Determinants of Health (CSDH) conceptual framework to the development of new, and refinement of existing, digital health interventions that aim to prevent or treat chronic disease by targeting intermediary, social, and/or structural determinants of health. Three mirrored "calls to action" are thus proposed for digital health research: 1) Develop, implement, and evaluate multi-level, context-specific digital health interventions; 2) Engage in intersectoral partnerships to advance digital health equity and social equity more broadly; and 3) Include and empower historically marginalized groups to develop, implement, and access digital health interventions. Using these "action items", we review several technological and methodological innovations for designing, evaluating, and implementing digital health interventions that have greater potential to reduce health inequities. We also enumerate possible challenges to conducting this work, including

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leading interdisciplinary collaborations, diversifying the scientific workforce, building trustworthy community relationships, and evolving healthcare and digital infrastructures.

Background

Over 70% of all global deaths can be attributed to chronic diseases, with close to one third of adults reporting multiple chronic conditions (1, 2). These chronic diseases contribute to extraordinary health care costs, loss of productivity and poorer quality of life (3–5). Furthermore, there are clear disparities in chronic disease observed across race, ethnicity, gender, sexual orientation, age, disability status, socioeconomic status, and geographic location (hereafter referred to as "historically marginalized groups") (2, 6). There is thus a widely-recognized need to promote health equity and reduce health inequities in chronic disease prevention and treatment (7, 8). In this regard, digital health interventions (e.g., patient support delivered via technologies such as smartphones, wearables, videoconferencing, social media, virtual reality) are exciting tools with potential for increasing scalability and access to evidence-based support for health behavior change (9, 10). Unfortunately, evidence suggests that digital health interventions may be *less* effective for historically marginalized groups, and may unintentionally exacerbate inequities (11–13). This phenomenon is likely attributable to numerous inequities inherent in digital innovation (14); innovations developed based on the majority are often unsuccessfully translated to historically marginalized groups due to poor representation and inclusion in research throughout the "bench to bedside" pipeline, as well as inattention to important structural and social factors impacting these groups (15).

Experts have therefore highlighted the need for using action-oriented health equity frameworks to guide digital health intervention work (11). These frameworks act as scaffolds for helping researchers deeply understand the ecosystems perpetuating social disadvantage among the communities they wish to serve, thus resulting in digital health interventions that are more likely to promote health equity and less likely to maintain inequities. Previous commentaries have focused on developing novel *integrated* health equity, digital health, and behavioral science frameworks that provide high-level recommendations for future research (10, 16). For example, Alcaraz and colleagues proposed the ConNECT framework, which integrates principles from behavioral medicine and health equity fields to posit five broad guidelines for prevention/intervention research (from basic science to dissemination, inclusive of digital health) (10). This work has inherent value in breaking down siloes, however few existing commentaries focus on *how to apply* prevailing social determinants of health frameworks to galvanize equitable digital health intervention. This commentary seeks to add to prior literature by using an *already-established* social determinants of health framework with extant action-oriented principles (rather than developing another integrated model with new guidelines) as a basis for applying recent technological and methodological advances to develop, refine,

and implement new or existing digital health interventions that reduce health inequities. Additionally, we seek to illustrate how such a framework can, in turn, inform novel research directions for continuing to advance the technologies and methods discussed herein.

First, we describe how digital health innovation can be embedded within the World Health Organization (WHO) Commission on Social Determinants of Health (CSDH) conceptual framework, which illustrates the complexity of social, economic, and political mechanisms that drive health inequities. We selected the CSDH framework because it was developed with the intent to guide intervention and policies to reduce inequities. Second, we posit how the CSDH "calls to action" could be used to refine existing digital health interventions and drive future digital health research. Third, we enumerate challenges to conducting this work.

Embedding Digital Health Innovation within a Social Determinants of Health Framework

The CSDH conceptual framework for alleviating inequities in health and well-being is shown in Figure 1 (17). Building upon previous social determinants of health frameworks (18–20), the CSDH framework highlights levels of causal impact on health inequities by distinguishing between social, economic, and political context as key drivers of social hierarchy and, in turn, daily living conditions (21). This framework shows Socioeconomic and Political Context (e.g., Policy, Societal Values) as key structural determinants but also demonstrates how other Structural and Social Determinants of Equity in Society (e.g., gender, racism, income) shape Intermediary Determinants of Health, and ultimately perpetuate health inequities. The Intermediary level includes material (e.g., physical environment), psychosocial (e.g., stressors) and behavioral and biological factors (e.g., nutrition, genetics).

Many digital interventions to prevent and treat chronic disease target intermediary level determinants, namely the biological, psychological, and/or behavioral factors that influence health (22, 23). Research has shown that health-related behaviors (e.g., cigarette smoking, physical activity, diet), as well as biological processes (e.g., gene variants, inflammatory reactions, cortisol production) and psychological factors (e.g., positive and negative affect, depression, optimism), are related to socioeconomic position and health outcomes (24–29). However, biological, psychological, and behavioral factors often do not completely explain the association between social context and health, indicating that continuing to target only intermediary determinants of health will be insufficient for promoting health equity (17, 26, 27, 30, 31).

Acknowledging the importance of considering social context and varied socioeconomic positions in future efforts to advance health equity, the CSDH framework posits three "calls to action": (1) the importance of context-specific strategies and tackling structural as well as intermediary determinants; (2) intersectoral action; and (3) social participation and empowerment (17). Below, we propose three mirrored "calls to action" in the field of digital health that align with the action items from the CSDH framework and discuss how technological and methodological innovation can both support, and be driven by, these efforts.

"Calls to Action" to Develop and Implement Equitable Digital Health Interventions

Our CSDH-consistent "calls for action" apply to the development of new, and refinement of existing, digital health interventions that aim to prevent or treat chronic disease by targeting intermediary, social, and/or structural determinants of health. These calls to action (not in order of priority) are: 1) Develop, implement, and evaluate multi-level, context-specific digital health interventions, 2) Engage in intersectoral partnerships to advance digital health equity and social equity more broadly; and 3) Include and empower historically marginalized groups to develop, implement, and access digital health interventions. In the context of each call, we discuss how recent technological and methodological advancements can result in more equitable digital health interventions. Table 1 provides examples, along with priority areas for researchers who intend to harness these approaches for reducing health inequities. Table 2 (and Table S1, Supplemental Digital Content) contains practical recommendations and training resources for those who would like to incorporate the below-described technologies and/or methods into their work.

First call to action: Develop, implement, and evaluate multi-level, context-specific digital health interventions

"Context" is defined within the CSDH framework as 'all social and political mechanisms that generate, configure, and maintain social hierarchies'(17). A common criticism of many digital health interventions is that they primarily focus on intermediary determinants, and often overlook relevant 'social contexts' (i.e., structural and social determinants of health) (32, 33). We discuss how novel research methods, advanced analytics, and assessment approaches could support the development, implementation, and evaluation of digital health interventions targeting determinants of health at multiple levels.

Apply optimization methods to incorporate social and structural determinants of health.—The optimization framework was derived from engineering principles and involves three phases: preparation (e.g., finalizing conceptual model, piloting), optimization (e.g., developing an optimal intervention), and evaluation (e.g., confirming effectiveness/ efficacy of the optimized intervention) (34). We focus on the research methods used in the *optimization* phase (hereafter referred to as optimization methods). These approaches aim to "engineer an intervention" by identifying the ideal intervention component(s) and/or the best timing or sequencing of intervention delivery that leads to optimal treatment outcomes (35). Optimization primarily occurs by considering practical constraints (e.g., time, cost, scalability) and individual needs (e.g., based on individual characteristics and/or response to interventions). Optimization methods can therefore be used to tailor digital health interventions to individual and contextual needs prior to conducting efficacy or pragmatic trials (36, 37).

Optimization methods encompass three main approaches (examples provided in Table 1). The Multiphase Optimization Strategy (MOST) framework allows for simultaneous testing of multiple components at once to identify the most effective combination of interventions, while optimizing relevant practical elements (e.g., cost-effectiveness) (34,

36, 38). Sequential Multiple Assignment Randomized Trials (SMARTs) can optimize stepped-care approaches, which increases efficiency and cost-effectiveness of digital health implementation (36). Micro-Randomized Trials (MRTs) can empirically evaluate how to tailor in-the-moment digital health interventions to someone's immediate internal state and relevant social determinants of health (37).

Optimization methods are commonly being applied to ensure that our best available interventions targeting intermediary determinants also address social and structural contexts (e.g., tailoring an evidence-based behavioral intervention to a particular culture or treatment setting). To ensure cost-effective interventions that can be widely disseminated, these designs should focus on optimal interventions that are more feasible for implementation within extant structures, like healthcare or education systems. Furthermore, these powerful research designs could lead to interventions that directly target social and structural determinants of health. For example, a study could seek to optimize operations in structures that promote health equity (e.g., early education, community prevention programs) and the empirical data on cost savings and improved health outcomes could catalyze widespread programmatic change.

Incorporate advanced analytics to inform context- and person-specific digital health interventions, and enhance digital infrastructure.—Personalized medicine typically uses advanced analytic approaches (e.g., machine learning, network analysis) to glean salient drivers of health behavior change, and can thus be used to create digital health interventions that are tailored to these factors. For example, "big" datasets from hundreds of thousands of individuals can be used to develop algorithms for detecting a disease state, predicting behavior, and/or selecting an optimal treatment (39). There are also "small" data paradigms, or N-of-1 methods, in which algorithms can be built for each individual based on their own data (rather than using data from a examples of how these methods can improve digital health interventions for historically marginalized groups.

One clear path for advanced analytics to reduce health inequities is by providing support that is tailored to social or material circumstances (41–43). Ideally, this support is more accessible than standard care because it facilitates automated, personalized intervention sent directly to the individual. However, this form of personalized medicine often requires that participants possess certain technologies (e.g., recent smartphone models, wireless internet, wearable devices), as well as levels of digital literacy, that are less prevalent in some historically marginalized groups (44). Creating tools that provide precision care regardless of device quality (e.g., intervention delivery via text message, e-mail, or mail) and improving digital literacy are therefore important areas for future work. Advanced analytics could also be applied to improve the quality of healthcare, education, or other community resources. For example, machine learning could be integrated within digitized record systems to better understand and anticipate the needs of a community or an individual (e.g., improve clinical care via automated clinical decision support, identify families in need of services via housing records). While promising, this work is time- and resource-intensive, including requiring expertise to maintain novel digital infrastructures. Additionally, there is an urgent need to understand and address algorithm bias to ensure positive impact among historically marginalized groups (see Parikh et al for details (45)).

Combine digital assessment tools to achieve context-specific evaluation of digital and non-digital interventions.—Digital tools (e.g., wearable devices, smartphones, remote sensing) support detailed data collection on health outcomes, as well as relevant intermediary, social, and structural determinants of health, over long periods of time. They can provide insight into the various structural and social contexts that shape an individual's health (and vice versa) before, during, and after digital and non-digital interventions. Measuring a *single* outcome of interest via two types of digital tools (i.e., using both smartphone-based subjective reports of stress and heart rate variability) is commonly referred to as multimodal assessment. Multimodal assessment is especially important among historically marginalized groups because some digital tools (developed and validated on the majority) can be less accurate and reliable when translated to the minority (e.g., FitBits may produce less accurate estimates of heart rate, oxygen saturation, and energy expenditure for people with darker skin tones (46, 47)). Multimodal assessment should be employed to validate new technologies and measurement approaches among historically marginalized groups (see Table 1 for an example), which ultimately improves the quality of outcomes assessment for (non)digital interventions.

Digitally measuring *multiple* outcomes of interest (e.g., a health outcome and its contextual correlates) could also be employed in a study or program evaluation. For example, a study could pair a measure of heart rate variability with location-based data to contextualize the experiences of stress among individuals living in blighted neighborhoods. Results from such assessment protocols can improve our understanding of *how* our (non)digital interventions are working within historically marginalized groups and therefore inform the refinement of these interventions to be more impactful. Moreover, the data could be combined to improve the measurement quality of digital tools for those in historically marginalized groups. For example, global position systems (GPS) have been integrated with accelerometry to ascertain physical activity type and setting (vs. standard step counts or physical activity minutes) (48).

Use implementation science to inform the dissemination of digital health interventions through explicit attention to structural contexts.—After initial development, digital health interventions that are designed to prioritize health equity must be thoughtfully integrated into the ecosystems in which individuals receive care. Digital health intervention uptake is catalyzed by provider referral, and engagement is often enhanced by clinician support and coaching (49, 50); however, many barriers exist to getting these interventions into the hands of users who may benefit (51). Implementation science can maximize reach and impact of digital health interventions by using established, equity-focused frameworks to answer questions about how best to engage with stakeholders and adapt interventions (and their implementation) to align with a given healthcare context. For example, the Health Equity Implementation Framework conceptualizes implementation determinants at the level of the organization/healthcare delivery system, recipients, and the technology itself, with explicit attention devoted to healthcare inequities manifested during implementation (e.g., details of the clinical encounter and understanding societal-level influences on implementation outcomes) (52, 53). Guided by such models, researchers can

employ a variety of established implementation strategies to promote sustainable, real-world delivery of novel digital health interventions (54).

Second call to action: Engage in intersectoral partnerships to advance digital health equity and social equity more broadly

Intersectoral partnerships across key players in the healthcare ecosystem and outside of health sector (e.g., education, governmental agencies, housing authorities, civil rights organizations, policymakers) is required to achieve and sustain digital health equity (17). We outline two overarching areas in which intersectoral collaboration can facilitate equitable digital health intervention: 1) reducing structural barriers to digital access and supporting digital infrastructure, and 2) developing novel intervention approaches.

Efforts to reduce structural barriers and support digital infrastructure are particularly critical for ensuring equitable access to digital innovations.—Such efforts can include policy-level change (e.g., broadband access), but also systems- or program-level change (e.g., digital literacy education). Suggestions include (but are not limited to): identifying and serving areas of highest need for broadband expansion; reimbursing expenses for, or providing affordable, digital devices to those without access; establishing incentives and cost offsets for use of digital health applications ('apps'); improving digital literacy and access to technical support (for both staff and patients); addressing issues of data security and privacy; digitization of record systems, and providing intervention content in different languages. Intersectoral efforts can focus on supporting the necessary infrastructure to ensure widespread implementation of novel digital health interventions. For example, private-sector companies (e.g., electronic health record providers) could offer more transparent and accessible options for interoperability between existing healthcare platforms and newly-developed digital health tools to ensure implementation of these tools into usual care (55). While these suggestions can narrow the future digital divide, the importance of considering the current status of the digital divide when designing and studying digital health interventions is discussed in the 'Potential Challenges and Considerations' section.

Intersectoral partnerships can be harnessed to inform the development of novel intervention approaches.—Exciting partnerships between researchers, healthcare decision-makers, policymakers, and community members can result in utilizing the above-mentioned technologies and methods (e.g., advanced analytics, combining digital assessments) to inform data-based intervention at the community or policy levels (56, 57). Intersectoral collaboration can also be used to design digital health interventions that directly support practical implementation of equity-focused health policy—regardless of the policy's initial digital emphasis. See Table 1 for examples of these types of intersectoral actions.

In Table 2, we list practical recommendations for building strong and lasting partnerships needed to advance digital health equity in the main areas described above. However, a notable barrier to intersectoral work is that partners may have competing motivations and priorities. Two plausible solutions are to clearly outline the increasingly recognized benefits of intersectoral and multi-sector collaboration and, subsequently, foster partnerships around

shared goals and collective impact (58, 59). There are several published frameworks that serve to guide individuals from different sectors to develop shared agendas to address a specific health need or social problem, including but not limited to the collective impact framework (60) and the Health in All Policies (HiAP) framework (61–63). For detailed recommendations on intersectoral collaboration, see Chircop et al. (59) and Bryson et al. (64).

Third call to action: Include and empower historically marginalized groups to develop, implement, and access digital health interventions.

The goal of social participation and empowerment is to re-distribute power that allows a community to influence decision-making geared towards improving their own health and quality of life (17). Working in *close ongoing partnerships* with historically marginalized communities is consistent with *human rights* and justice-oriented *right to health* perspectives, which can improve perceptions and relationships in communities (7). These community partnerships can lead to more accessible, relevant, engaging, and sustainable digital health interventions. We discuss two methods for engaging and empowering communities through development and implementation of digital health interventions: community based participatory research and social media.

Use a community engaged participatory research approach to empower communities and make digital health interventions more acceptable.—

Community engaged research can be defined as "the process of working collaboratively with groups of people affiliated by geographic proximity, special interests, or similar situations with respect to issues affecting their well-being" (65). By working "with" communities instead of "on" communities, research questions and interventions will be more appropriate and meaningful for target populations. Meaningfully engaging with the community can ensure that digital innovation "meets people where they are at" by being mindful of levels of empowerment and access to flexible resources (66). Community engaged research can range from consultations with community partners to using a community based participatory research (CBPR) approach (67, 68). While the approach may vary across projects, it is critical that the shared community engaged principles (e.g., trust, bidirectional influence, equitable financing, shared governance) guide research to ensure meaningful community engagement and health equity outcomes (69).

A recent narrative review posed six best practices that should guide future community engaged research to develop digital health interventions targeted for historically marginalized communities (11). We elaborate on three ways in which recent and future innovations can emulate these best practices (examples provided in Table 1). First, researchers should begin efforts with a deep understanding of the structural factors and social determinants of health and action-oriented frameworks for advancing health equity (11). CBPR methods can be uniquely leveraged, especially within the context of the CSDH framework, to support a nuanced understanding of the determinants of health at multiple levels and at all stages of the research process. Second, community participation should occur throughout intervention development, implementation, evaluation, and dissemination (11). While authors cited integration of CBPR with traditional technology-based design

methods (e.g., human-computer interaction, participatory design), we will further posit that research would benefit from formally integrating CBPR methods within the context of newer optimization frameworks described above (e.g., 70). Such innovation would support interdisciplinary collaborations and rigorous programs of research that have direct benefit to historically marginalized groups. Third, community-based research can tap into existing social and community networks while supporting marginalized communities. *Partnerships forged by community engaged research* can empower community and bolster cross-sector collaboration to design and implement interventions that leverage community assets, leadership, expertise, cultural norms, and systems infrastructure while achieving desired health outcomes (71). By quantifying the ways in which partnerships between communities and researchers impact individuals *beyond the resulting digital health intervention*, studies could elucidate methods by which we can continue to empower historically marginalized communities.

Use social media as a digital health intervention tool to facilitate social participation.—Participation in social media is a meaningful predictor of social capital and participatory behaviors (both online and offline) (72, 73). Developing digital health interventions that harness social media can engage communities and thereby reduce health inequities. Meta-analytic reviews have revealed that social media interventions for health behavior change were effective for populations demonstrating health inequities, however there was a substantial amount of variability in outcomes (74–76). Given pervasive feelings of mistrust and skepticism of social media that are prevalent among historically marginalized communities, social media interventions for historically marginalized groups could benefit from integrating CBPR methods, as described above (75, 77). Working *with* communities can lead to social media interventions that are more appealing and safer to the target population. Addressing privacy concerns and the spreading of misinformation is critical to the success of social media interventions, and researchers should remain flexible to considering alternative intervention modalities as appropriate (78).

Another novel research direction could be to develop interventions that specifically target *productive engagement* with social media more broadly. Effectively engaging with social media has the potential to promote awareness surrounding health inequities and facilitates access to health information. Moreover, raised awareness and increased political discourse on topics related to health and healthcare have the potential to influence policy (79, 80). Interventions to promote engagement with social media platforms could therefore reduce health inequities by empowering individuals to effect change, both directly and indirectly.

Potential Challenges and Considerations

Guided by three "calls to action" from the CSDH framework, we have enumerated several innovations that have the potential to drive the future of equitable digital health interventions for all. However, this work is not without challenges, and we therefore close by discussing logistical and practical barriers to actualizing our proposed research and policy goals.

Interdisciplinary collaboration & training

A significant challenge to the development of equitable digital health interventions is the effort and time required to successfully engage in interdisciplinary collaborations. Bringing researchers from different disciplines together ensures that teams have well-rounded expertise in content areas (e.g., chronic diseases, marginalized populations), but also various empirical methodologies (e.g., qualitative research, mixed methods designs, quantitative research) that could be leveraged in combination to enrich this work. Interdisciplinary teams of researchers with formal training and expertise in health equity and social determinants of health are *thus critical*. Extrapolating from CDSH's calls to action, in the context of developing and disseminating equitable digital health interventions, the role of researchers involves growing the evidence base on the underlying causal processes of health inequities and developing or enhancing interventions to effectively alleviate them (81).

In addition to bringing teams from different research disciplines together, these projects must bring in experts from multiple levels—individual (e.g., members of the target population, family members, caregivers), structural (e.g., case workers, providers, healthcare administrators), *and* policy (e.g., political advocates) (82). Creation of these teams must be carefully considered from the outset, with time allotted to identify experts and forge appropriate partnerships. Moreover, project leaders would benefit from expertise in team organization and communication across disciplines and educational backgrounds (83). Team members would benefit from mutual cross-disciplinary and cross-sector training (59).

Lack of diversity and inclusion on our research teams

Diversity and inclusion in the scientific workforce drives innovation, and is critical for teams seeking to tackle health inequities (84). Along with continued efforts to recruit and retain individuals from diverse backgrounds in higher education, technological innovation can be harnessed to support teams in prioritizing diversity. For example, researchers have made electronic health record databases accessible to scientists across the world who can pose novel research questions and develop new methodologies to test them (85, 86).

Another way to promote diversity and inclusion is to create opportunities for individuals from representative communities to join research teams or conduct research independently. In this regard, there is a rapidly growing field of 'citizen science' through which nonscientists engage in scientific research (for detail, see (87)). While applying principles of citizen science and community engaged research can improve digital health equity, several barriers exist, including higher levels of mistrust toward the healthcare system, mistrust of research due to historical events, differences in priorities between community members and other partners, and the lack of time and resources to fully engage with community members (88). Distrust can be heightened with regards to digital health technologies, where human rights issues, such as privacy and confidentiality, are particularly salient (89). There is thus a need to increase research infrastructure in the community, prioritize genuine community engagement in academic research institutions, and continue to evaluate effective ways to engage in partnerships.

Persistent structural, socio-economic, and political challenges

The ever-evolving socio-economic and political contexts that historically marginalized groups face can impact the progress and relevance of digital health interventions (90). Digital health tools for historically marginalized groups must be considerate of, and operate alongside, ongoing structural changes that will disproportionately affect different populations. One such factor is the digital divide. While we make several suggestions for narrowing the digital divide in the long-term, this barrier will unfortunately persist over foreseeable future. Researchers should conduct an in-depth analysis, in partnership with all relevant partners, of how the digital divide impacts the digital infrastructure, digital inclusivity, institutional solutions, and digital proficiency of their target population prior to developing digital health interventions (91, 92). Such information should also be used in planning a study or program evaluation, e.g., reducing participant burden, developing appropriate study timelines, capitalizing on existing institutional/community resources, budgeting study staff and resources. Taking steps to account for the digital divide bolsters more inclusive research and ensures adequate evaluations of efficacy among historically marginalized groups. However, structural and policy-level changes are essential for ensuring that historically marginalized groups can benefit from digital health innovations outside of the context of research studies (90).

There must also be more dedicated public and private funding opportunities that prioritize the necessary work to develop more equitable digital health interventions. These efforts may be geared towards prioritizing: multidisciplinary trials in which at least one of the leads is not an MD/PhD, studies that validate tools or tailor existing treatments for new populations, digital health approaches that tackle social/political determinants of health at multiple levels, simplifying or streamlining tools for populations with low digital health literacy and access, and develop institutional infrastructures necessary to support this work (e.g., community advisory boards).

Lastly, digital interventions, methods, and tools may not fit certain social issues, health conditions, and/or historically marginalized groups. Researchers should remain aware of the overall impacts of technology on societal inequities (93). The decision to use a digital approach should be empirically, conceptually, and theoretically informed. There will be many instances in which non-digital interventions are more appropriate for targeting a particular chronic illness, social issue, and/or historically marginalized group. Importantly, many principles discussed herein, such as the importance of optimization designs, combining digital assessment tools, implementation designs, intersectoral action, and community-based participatory research can also be applied to non-digital interventions to prevent/treat chronic disease in historically marginalized groups.

Conclusions

Digital health interventions demonstrate *both* potential benefit and harm for addressing health inequities. For digital health interventions to truly revolutionize healthcare for all, efforts must be made to directly address the research and practice gaps that perpetuate this dialectic. The goal of this paper was to illustrate how an established social determinants of health framework can be applied to generate innovative research directions in the equitable

development, evaluation, and implementation of novel digital health interventions. In doing so, we illustrated that digital health innovation for addressing health inequities can take many different forms. Innovation can be the technology itself but also the methods to develop, validate, deploy, sustain, and/or integrate technology into the everyday lives of marginalized communities.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Source of Funding:

Abbreviations

WHO	World Health Organization
CSDH	Commission on Social Determinants of Health
MOST	Multiphase Optimization Strategy
SMART	Sequential Multiple Assignment Randomized Trials
MRT	Micro-Randomized Trial
GPS	Global Positioning Systems
HiAP	Health in All Policies
CBPR	Community based participatory research
API	Application Programming Interface

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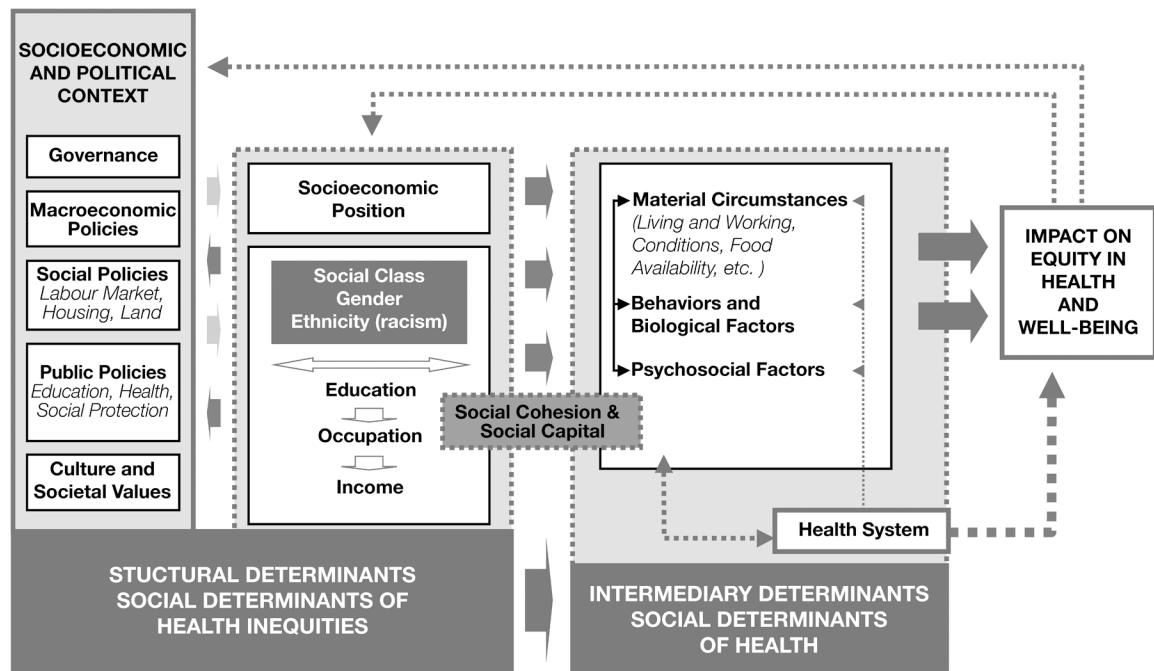
Figure 1.
World Health Organization (WHO) Commission on Social Determinants of Health (CSDH) Conceptual Framework to guide action aimed towards reducing inequities in health and quality of life (17). Reproduced with permission from: Solar O, Irwin A. A conceptual framework for action on the social determinants of health. Social Determinants of Health Discussion Paper 2 (Policy and Practice), p. 48, Copyright 2010 (21).

Table 1.

Examples and Suggested Research Priorities for Technologies and Methods that Can Support Equitable Digital Health Interventions

Proposed Call to Action based on WHO CSDH	Supporting Technologies & Methods	Example(s)* *denotes hypothetical example	Research Priorities
Develop, implement, and evaluate multi-level, context-specific digital health interventions	Optimization methods (Multiphase Optimization Strategy [MOST], Sequential Multiple Assignment Randomized Trials [SMART], Micro-randomized Trial [MRT])	Factorial experiment (MOST) to optimize engagement in HIV care among Black & Hispanic people living with HIV by evaluating 5 culturally-based treatment additions to usual care (e.g., support group, peer mentors, patient navigation) (94) SMART evaluates how, when, and in what combinations to use EHR-based interventions, text messaging, and phone counseling to increase reach and feasibility of a smoking cessation treatment in low-income Community Health Centers (95) An MRT targeting physical activity considers a user's geospatial location and concerns about neighborhood safety to suggest appropriate exercise options*	1) Leverage optimization designs to intervene *directly* on social or structural determinants of health; 2) Integrate optimization designs with community-engaged research methods; 3) Address questions related to burden (what is the ideal dose of assessments/interventions) and cost-effectiveness
	Advanced analytics (e.g., machine learning, network analysis)	Study evaluating different ways to train machine learning models to improve prediction of cancer prognosis among African Americans in a large cohort dataset (96) An N-of-1 study explores how stress interventions can impact diet and physical activity among ethnically minoritized mothers over 6 months (97)*	1) Solutions to prevent/address algorithm bias; 2) Understand social/structural impacts on algorithm performance and perceptions of precision medicine; 3) Use N-of-1 study designs to bolster research while improving patient care and outcomes.
	Combining digital assessment tools	Using transdermal alcohol concentration readings to validate ecological momentary assessment ratings of alcohol use among adults experiencing homelessness (98) Pairing heart rate variability with geolocation of neighborhood safety, food sources, & walkability contextualizes stress among individuals in blighted neighborhoods *	1) Continue to validate tools and methods across multiple settings & individuals from historically marginalized communities; 2) Develop best practices on how to triangulate data from multiple assessments
	Implementation science	Series of five implementation studies of digital health tools in low-resource settings–gathered formative qualitative input from end users in groups experiencing structural healthcare barriers & designed to address specific community barriers to care (99) Use the Double Diamond model (iterative user-centered design with ongoing evaluation) to develop a digital COVID-19 vaccination promotion platform to address disparities in information access & improve uptake (100)	1) Utilize established conceptual frameworks to guide engaging with stakeholders; 2) Adapt existing interventions to align with a given healthcare context (e.g., community health centers, primary care, daily life app use)
Engage in intersectoral partnerships to advance digital health equity and social equity more broadly	Innovative partnerships to improve access & address digital divide	An electronic health record provider offers an application programming interface (API) to securely read in data from a smartwatch app that passively monitors activity, heart rate, & sleep.* A healthcare provider partners with educators and researchers to develop a digital health literacy program.*	1) Generate evidence on the process of successful intersectoral collaboration; 2) Develop common digital platforms to promote shared space across sectors; 3) Improve interoperability and clarify centralization of technology in healthcare; 4) Conduct studies that allow technologies to meet regulation and accreditation standards
Engage in intersectoral partnerships to advance digital health equity and social equity more broadly	Combining digital assessments & Advanced analytics	A researcher partners with a local community health center to collect data on substance use patterns, location, and stress using a wearable devices & uses the findings to argue for a state-run safe injection site.*	1) Provide mechanisms to support funding for integrating digital innovations, particularly among financially struggling organizations; 2) Use 'information officers' within organizations to improve trust and enhance willingness; 3) Conduct feasibility studies to quantify the potential labor new innovations requires of staff

Proposed Call to Action based on WHO CSDH	Supporting Technologies & Methods	Example(s)* *denotes hypothetical example	Research Priorities
	Community-engaged research methodologies (e.g., CBPR)	Food distribution stakeholders, digital health developers, community organizations, and community members partner to develop an 'app' that supports individuals in accessing food assistance resources in their local community, providing feedback on how they are using food assistance, and identifying areas of greater need for food assistance.*	1) Use CBPR to fully appreciate macro-, meso-, and micro-barriers to uptake of digital innovations; 2) Adopt CBPR practices and priorities to garner trust and understanding between stakeholders
Include and empower historically marginalized groups to develop, implement, and access digital health interventions	Community-engaged research methodologies (e.g., CBPR)	Work with community members from historically marginalized communities to communicate research results utilizing digital health platforms (101) The Family Listening Program used digital stories from community members to translate and disseminate research findings into the broader community (102)	1) Combine CBPR with mixed methods approaches to understand determinants of health at multiple levels prior to developing digital health interventions; 2) Formally integrate CBPR methods into optimization frameworks; 3) Leverage existing partnerships to empower community stakeholders and bolster cross-sector collaboration
	Social media	Exposure to a Facebook page with sexually transmitted infection prevention messages improves condom use over 2 months (103) A trial finds that a Facebook smoking cessation intervention tailored to sexual and gender minority smokers reduces smoking over 3 months (104)	1) Conduct subgroup analyses to understand how social context impacts efficacy & engagement w/social media interventions; 2) Develop social media interventions via CBPR; 3) Develop digital literacy interventions that target productive engagement with social media.

Table 2.

Practical Recommendations and Training Resources for Working with Technologies and Methods to Equitable Digital Health Interventions

Supporting Technologies & Methods	Practical Recommendations (What to know when getting started)	Training Resources (How to learn more about technologies/methods)
Optimization methods	1) Designs require expertise to plan & execute randomization; 2) Pilot studies are necessary to determine intervention components & optimization parameters; 3) Aiming to maximize cost-effectiveness is critical for equity work	• Optimization of Behavioral, Biobehavioral, and Biomedical Interventions book (available for free download through many universities) • Free online course in MOST and links to recommended reading for example studies
Advanced analytics	1) Use publicly-available datasets or secondary analysis of your own data to test initial models and feasibility, but collecting your own sample may be desired; 2) Run descriptives prior to model development so you know *who* the models are learning from; 3) Model development is an iterative and collaborative process	• Introduction to Statistical Learning YouTube series & free textbook (beginner level), and deeper-dive, theoretical textbook • Mobile Sensor Data-to-Knowledge mHealth Training Institute
Combining digital assessments	1) Be sure that the tool has been validated in your population; 2) If funding is a concern – consider doing this work on a subset of participants or structuring data collection so you can re-use devices; 3) Consider how privacy concerns may differ across populations	• Mobile Health: Sensors, Analytic Methods, and Applications & Digital Phenotyping and Mobile Sensing: New Developments in Psychoinformatics textbooks
Implementation science	1) Address multiple steps along a patient's journey to receiving a digital health tool; implementation strategies can be deployed at all levels of a system (clinic, doctor, payer, health network); 2) Allow room for flexibility to adapt existing interventions to meet needs of diverse populations	• Open access training resources for the National Cancer Institute's Training Institute for Dissemination and Implementation Research in Cancer • UCSF Implementation Science Mini-Course • U.S. Veterans Affairs Implementation Research Group network (webinars & network groups open to the public & civilian researchers)
Innovative partnerships to target access & address digital divide	1) Use structured frameworks to guide collaborative decision-making; 2) Address power dynamics via hypothetical scenarios, continuous assessment, and accountability benchmarks; 3) Mutual training across sectors contributes to success; 4) Clearly differentiating between goals of intervention or policy implementation and policy design will be helpful.	• Urban Institute Guidebook on Changing Power Dynamics among intersectoral partners • Public Health Institute Report on Adapting to Local Context & Confronting Power Dynamics • Toolkit for Creating and Maintaining Coalitions and Partnerships from University of Kansas Community Tool Box • Designing and Implementing Cross-Sector Collaborations: Needed and Challenging article
Community-engaged research methodologies	1) Focus on building on strengths and assets of a community *vs.* taking a deficit-focused approach; 2) Allow for additional time and funds - although the process may take more time and money, the results will be more relevant and sustainable	• University of Kansas Community Tool Box • CBPR Report from UC Berkley and PolicyLink: • CBPR Downloadable Toolkit
Social media	1) Directly address mistrust and privacy concerns specific to the target population during consent and in the context of the intervention itself; 2) Social media	• Participatory health through social media textbook

Supporting Technologies & Methods	Practical Recommendations (What to know when getting started)	Training Resources (How to learn more about technologies/methods)
	technologies evolve rapidly – be mindful of potential for updating technology in future implementation & sustainment efforts; 3) Consider needs for combating misinformation & promoting safe Internet practices	• CDC National Prevention Information Network Social Media Support for Public Health Professionals • Adapting Behavioral Interventions for Social Media Delivery article • Using social media for health research: Methodological and ethical considerations for recruitment and intervention delivery article

Note: URLs to all listed resources provided can be found in the Supplemental Digital Content, Table S1