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Better Supporting Human Aspects in Mobile eHealth Apps: Development and Validation of Enhanced Guidelines

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eHealth apps are mobile apps that help in self-management of critical illnesses, provide home-based disease management, and assist with personalized care through education, sensing, and interaction. Users of eHealth apps are naturally very diverse in terms of their human aspects, e.g., their emotional reactions to the apps, varying language proficiency, socioeconomic status, educational level, cognitive style, physical and mental challenges, gender, age, personality, etc. Unfortunately, many eHealth apps do not take these user differences sufficiently into account, making them ineffective or even unusable. This paper presents our enhanced and actionable guidelines developed to better support human aspects in mobile eHealth apps. Some of these guidelines are specific, such as collecting minimal personal data or requirements, while others are more generic, applicable specifically to eHealth apps. We discuss how key human aspects, such as usability, accessibility, reliability, and validity, as well as diverse user issues can be addressed in practice with real-life eHealth app examples. We then collected feedback from expert mobile app developers, software engineers, and other relevant eHealth app stakeholders to assess the usefulness and applicability of the proposed guidelines and to identify areas where further refinement and development are needed.

CCS Concepts: • **Software and its engineering** → **Software usability**; **Software design engineering**; • **Social and professional topics** → **User characteristics**; • **Human-centered computing** → **User centered design**.

Additional Key Words and Phrases: eHealth App, Human Aspects, Improved Support, Guidelines, Recommendations.

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1 INTRODUCTION

In today's world, over 68% of the global population uses smartphones [1]. The number of smartphones, over 6.5 billion, exceeds the number of individual users due to multiple device ownership. Additionally, the number of smartphone users has increased by more than 40% over the past four years [2]. Mobile app usage for daily activities has been increasing at an average rate of 7.71% per year since 2021 [3]. In 2022, smartphone users downloaded 255 billion mobile apps, up from 230 billion and 218 billion downloads in the two preceding years, respectively [4, 5]. Revenue from these apps exceeded $580 billion in 2021, an increase of over $119 billion from 2019, and is expected to reach $935 billion in 2023 [6]. Among these apps, health-related mobile applications – we term hereafter as '**eHealth apps**' – have become extremely popular. The revenue earned by these eHealth apps is expected to exceed $102.35 billion in 2023, around 11% of all payments received by the mobile apps in that year [7]. These eHealth apps help people take greater control over their health and aim to support them in managing chronic disease and living more healthier lives. Additionally, demand from health professionals to push monitoring, education and care-plan implementation further motivate eHealth app usage and development.

Developing a modern eHealth app is not a trivial exercise [8]. Key steps in app development include requirements gathering, platform selection, target user identification, constraint mapping, and problem modeling. During design, app developers draw approximate **U**ser **I**nterface (UI) sketches. They may also use a prototyping tool to create the model aspects of the visual design and the navigation flow. The architecture of the app is designed based on needed functionality and user interface mockups. Finally, the app is coded and the clients download it (mainly from app repositories), use and provide feedback on the app [9]. However, many apps still fail to address the diverse *human aspects* of many of their end users, i.e., impact of end user age, gender, physical and mental challenges, socio-economic status, language and education, personality and emotions, and/or other human differences that may impact eHealth app usage [10].

In this paper, we focus on how to better take into account diverse human aspects that significantly impact how eHealth apps are used. We define '**human aspects**' as differing key characteristics of human users, including age, culture, gender, cognitive ability, emotions, language, educational attainment, socioeconomic status, personality and related attributes. The related attributes influence how end-users interact with eHealth apps and the role these apps play in their daily lives. They include elements like technological proficiency, diversity of app end users, health literacy, personal beliefs and values, and even the influence of friends and family – all of which can affect the design and usage of eHealth apps [11, 12]. Incorporating these diverse human aspects into the eHealth app development process is challenging, e.g., addressing varying needs of differently aged end-users, users having a wide range of differing physical and mental challenges, users with diverse languages and language proficiency, users from differing cultures and socioeconomic backgrounds, and so on. Our recent systematic literature review [3] and user studies [10, 13] also identified that *human aspects* and their impact on mobile app development and usage requires further attention.

Consider an example representative eHealth app '*TeleDoc*', which allows patients to consult remotely with healthcare professionals, manage prescriptions, medical certificates and referrals. The design and work process of *TeleDoc* should address a wide range of human aspects of its users, including varying levels of technological literacy, medical knowledge, and emotional states. The apps' front-end (app interface) and back-end (data exchange mechanisms) should not affect the day-to-day lives of the patients, their families and friends, as well as clinicians and community workers. *TeleDoc* work process (usages) should also appropriately align with the expectations of patients, healthcare providers' expertise, and even the technological proficiency of family members assisting patients in consultations. The app should also be designed to be attractive to a diverse user base that varies in terms of age, language, culture, and gender. This is crucial, especially since the majority of app/software developers are young, English-speaking men from countries like Australia and the United States, whereas over one-fourth of app users are non-native English speakers, with a significant portion being women and elderly [14].

The *TeleDoc* app also needs to address different emotional responses and personality types among its users. For example, it should be intuitive for those who prefer a flexible dialogue with doctors, as well as for those who like a more structured, step-by-step consultation. Reliability aspects, e.g., encryption and authentication for data protection and robust back-end infrastructure for uninterrupted consultation, should not negatively impact the app's performance and interface. The accessibility of the app needs to be considered for people with physical tremors, poor eyesight, those who are wheelchair-bound or cognitive decline. The usability of this app for various groups should also address their varied needs, incorporating modified interface to accommodate different ages, genders, cultures, and languages of the users through intuitive use of text, colors, and symbols. The failure of developers to incorporate such human aspects in their eHealth apps can result in apps that are unsuitable for the audience for which they are designed, introducing confusing, possibly unsettling and invasive, and even potentially dangerous technology.

Recently [10, 13], we systematically identified the range and nature of human aspects that need to be addressed in the eHealth app domain. For example, we identified the most important human aspects that are essential for different eHealth app end-user groups, collected stakeholders' perceptions and needs regarding these aspects, distinguished which ones are missing/poorly handled, specified how app developers are addressing different aspects in practice, and determined how we can proficiently incorporate important human aspects to improve the produced eHealth apps, e.g., how some of the existing human aspects such as usability or accessibility-related aspects can be addressed in the current environment or future protocol(s) design. Findings from these research works revealed that we need an improved approach for better supporting human aspects in the eHealth app domain.

In this paper, we propose an improved approach for better supporting human aspects in the eHealth apps domain for their diverse user groups in the form of improved actionable guidelines, best practice examples, and evaluation methods. To do this, we explored gaps in the current guidelines/standards and integrated our findings from the previous research works [3, 10, 13] to develop these new and enhanced sets of guidelines. These measures collectively enhance the applicability of the proposed guidelines in practice. We also collected feedback from 35 experienced eHealth app developers, software engineers, and other relevant stakeholders to evaluate and verify the proposed guidelines' strengths, limitations, practicality, and feasibility in real-world scenarios to produce more effective eHealth apps. Finally, we discussed potential challenges and recommended future actions to produce more human-centric eHealth apps. The key contributions of this research include:

- ❖ We propose an integrated approach to better emphasize human aspects in eHealth apps to make them more effective by developing improved actionable guidelines, best practice examples, and evaluation techniques. These promote user-centered design, usability, accessibility, reliability and validity, diverse user issue in the eHealth app development process.
- ❖ We explore real-life eHealth app examples to demonstrate how some key human aspects can be addressed in practice and what app developers need to do to produce more human-centric eHealth apps, i.e., offer them comprehensive guidance to create more human-centric eHealth apps.
- ❖ We have collected feedback from expert mobile app developers, software engineers, and other relevant eHealth app stakeholders to assess the usefulness and applicability of the

proposed guidelines in practice. We collected and analyzed data from 35 survey responses to validate our proposed guidelines. This included identifying areas where further refinement and development of our proposed eHealth app development guidelines may be necessary.

❖ We identify potential challenges in this domain and recommend corresponding actions for the future. We find that personalized and customizable eHealth apps can better address diverse user needs and offer a better user experience, while standardized protocols and evaluation metrics can ensure better effectiveness and reliability.

The rest of this paper is structured as follows: Section 2 describes the related work, Section 3 outlines the research methodologies we used, and presents our proposed guidelines. An overall discussion, validation results, threats to validity, and conclusion with key future directions are presented in Section 5, Section 6 and Section 7, respectively.

2 RELATED WORK

Approaches to integrate human aspects into mobile eHealth apps have been reported in the literature, although not explicitly labeled under '*human aspects*'. Most of these studies have focused on addressing only one aspect, e.g., usability, accessibility, or reliability. In this section, we present the related work required to understand our proposed guidelines for better supporting human aspects in eHealth apps.

2.1 Accessibility in eHealth Apps

Accessibility in eHealth apps is defined as the degree to which the apps can be used equally by people with and without disabilities [15]. This includes users' ability to effectively access app contents and features irrespective of their conditions, such as physical tremors, poor eyesight, being wheelchair-bound, cognitive decline, context-specific impairments, or users with no medical issues [16, 17]. It also aims to improve user engagement with eHealth apps by incorporating the following key components:

❖ **Perceivable:** The capability of eHealth apps to effectively present content and information to end-users, irrespective of their conditions or abilities. For example, the perceivable characteristic allows individuals with vision impairments to use screen readers to access and benefit from the app features and content, while users who are deaf or have hearing impairments can rely on video captions to obtain the necessary information.

❖ **Operable:** The capability of eHealth apps to enable end-users to interact with and operate the app effectively, regardless of their physical or cognitive abilities. For instance, operable characteristic ensures appropriate input and output mechanisms other than graphical interfaces for users with hand deformities to interact and operate apps with ease.

❖ **Understandable:** The capability of eHealth apps to enable end-users to clearly understand apps functions, feature set and user interface operations. For example, the understandable characteristic ensures that users from various educational backgrounds have the ability to interpret the app's data and information accurately without any barriers to comprehension.

❖ **Robust:** The capability of eHealth apps to guarantee that end-users can accurately and reliably interpret information through assistive technologies. This encompasses ensuring app content is accurate and error-free, preventing any potential risks to end-users, and providing appropriate support to end-users when needed.

Accessibility has been well studied in eHealth app literature. In 2021, Radclief et al.[18] developed a systematic protocol to evaluate eHealth app accessibility for people with disabilities, highlighting the need for improvement in future apps. The evaluation protocol was designed to assess existing eHealth apps and contribute to a curation website to assist consumers in finding better accessible eHealth apps and inform developers about opportunities for improvement. Zhou et al.[19] investigated accessibility issues for people with a fine motor impairment or lack of dexterity in eHealth apps. They aimed to improve app accessibility by adding customizable features. The work of [20] provided an architecture for an accessible eHealth app, while [21] investigated accessibility in the input system for end-users. A comprehensive review of research works that focus on improving eHealth app accessibility for vulnerable end-users can be found in [22].

A systematic review study by Paiva et al. [23] explored accessibility in the software development process. Recently, Bi et al. [24] investigated the key challenges and benefits of incorporating accessibility into software development and design from the practitioners' perspective. The authors discovered a significant gap in understanding accessibility issues between practitioners with and without relevant work experience. These gaps influence how accessibility aspects are addressed during software design and development. Additionally, the authors provide some recommendations to help practitioners become more aware of accessibility challenges and potential advantages.

The accessibility guidelines from the World Wide Web Consortium (W3C) [25] and the World Health Organization (WHO) [26] have become the standard for accessibility and are often adopted by governments and organizations worldwide. Both WHO's Accessibility of Health Facilities guidelines and the W3C's Web Content Accessibility Guidelines (WCAG) can be applied to the eHealth app domain, with at least the minimum recommended compliance level. WCAG 2.0, released over a decade ago, includes twelve significant guidelines for digital accessibility. In 2018, WCAG 2.1 was introduced, adding seventeen additional criteria related to mobile app accessibility, including examples for each issue. Some other works explicitly investigate methods for evaluating accessibility in eHealth apps [18, 27], and discussed de facto standards to consider in eHealth apps [28].

2.2 Usability in eHealth Apps

Usability in eHealth apps is defined as the simplicity of app usage under specified conditions [29]. We found that eHealth app usability is an essential measurement criterion to fulfill the app usage objectives satisfactorily and effectively, offering users more choices with four key components:

- ❖ **Understandability:** The capability of eHealth apps to enable end-users to determine whether the apps are appropriate for their needs, comprehend their intended purposes, and understand how to use them effectively.
- ❖ **Learnability:** The capability of eHealth apps to enable end-users to acquire knowledge of basic app functions effortlessly, i.e., how easy it is for the end-users to perform fundamental tasks when using the app for the first time.
- ❖ **Memorability, error protection and recovery:** The capability of eHealth apps to enable end-users to operate and control the app proficiently. For example, how adeptly do users use the app after they learn its usage? how many errors do users make during their daily app usage, how severe are these, and how easily can users resolve them? how easily can users regain app use proficiency after a period of inactivity?
- ❖ **Usefulness and satisfaction:** The capability of eHealth apps to fulfill the desire, need, or expectation of their end-users, i.e., how eHealth apps assist end-users with their health-related issues and how satisfied they are with the app. This also involves attracting app users in daily usage, e.g., how pleasant it is to use the apps.

Usability for eHealth apps has also been well explored in the literature. In 2017, a three-phase human-centered design framework was presented to enhance the usability, human factors, and user experience between eHealth apps and connected systems [30]. The authors explored a set of use case documents to demonstrate how usability could be assessed and how expert reviews can improve overall usability prototypes. Recently, Farao et al. [31] identified usability requirements in the eHealth app domain using an Information Systems Research (ISR) framework and design thinking approach. The authors employed the combined framework to redesign an eHealth app for tuberculin skin test reading. They then collaborated with end-users and found many usability-related challenges and limitations in existing apps, especially for image capture and a lack of clarity in the app instruction set. Both of these approaches [30, 31] enable contextually aware and low-cost eHealth app development, and facilitate proper consumer engagement in development process.

In 2019, the Xcertia guidelines were introduced to specifically address usability concerns in eHealth app domain [28]. Since then, it become a leading resource in the eHealth app usability ecosystem. The guidelines consist of ten distinct sections addressing key usability issues for eHealth apps, as summarized below:

i. **Visual design:** Suggests actions for creating user-friendly interfaces.
ii. **Readability:** Advises how to ensure clarity and conciseness of app content
iii. **App navigation:** Proposes smooth and logical navigation best practices
iv. **Onboarding:** Outlines strategies for registration and initial interaction
v. **App feedback:** Highlights ways to provide relevant actionable feedback
vi. **Notifications:** Guides on designing appropriate notification strategies
vii. **Alerts and alarms:** Explains recommendations for alerts and alarms
viii. **Historical data:** Covers approaches to access and analyze data in apps
ix. **Ongoing app evaluation:** Recommends practices for regular assessment of app performance and effectiveness, along with necessary improvements
x. **Help resources and troubleshooting:** Indicates how to integrate support materials and recommends troubleshooting advice.

The Xcertia guidelines were then examined by Roy et al. [32] to further assists eHealth app stakeholders in developing safe and intuitive apps. Recently, Huang et al. [33] conducted a systematic review of mobile app usability. They explored the relationships among usability principles, attributes, and design features to inform mobile app usability design. Furthermore, they emphasized a set of standard usability design features common in mobile apps and pinpointed specific usability features essential for certain app categories. An excellent systematic review for existing usability definitions (reliance on the ISO 9241-11 definitions), attributes and measures to recognize all associated aspects in mobile app context is presented in [34]. Some official and de facto standards and guidelines are also available for different usability elements [35, 36], including respective evaluation methods [27, 37, 38].

2.3 Reliability and Validity in eHealth Apps

Reliability in eHealth apps refers to the app's ability to perform intended tasks accurately and consistently while remaining trustworthy [39]. ***Validity*** in eHealth apps refers to the accuracy of the app outcomes, including data collection, measurement, recommendations, and results [40]. We found that reliability and validity characteristics significantly build confidence among end-users and developers of eHealth apps. For users, it ensures that the app provides reliable and accurate information, while developers can ensure that the developed app serves its intended purpose. We also found that reliability and validity aspects in eHealth apps have been significantly influenced by the usability and accessibility guidelines and evaluation methods.

In 2018, Nouri et al. [41] conducted a systematic literature review on tools and methods for evaluating the eHealth apps' reliability and validity aspects. They identified thirty-eight primary assessment criteria and consolidated them into seven higher-level classes – Design, Information/-Content, Usage, Functionality, Ethical issues, Security and Privacy, and User-perceived value. The authors pointed out that in-app heterogeneity features can negatively impact eHealth apps' reliability and validity. They then suggested a set of recommendations to improve the distinctness among features for better apps. A similar review was conducted in [42] for clinically accessible apps to help clinicians quantify clinical measurement and test app reliability and validity.

Recently, Nurgaliva et al. [43] conducted a comprehensive scoping review for the evaluation frameworks and techniques available until 2020 that assess security, privacy, and overall reliability for eHealth apps. The study examined existing evaluation methods and encompassed research-based guidelines, recommendations, and best practices to better support security and privacy, facilitating more reliable and trustworthy eHealth app development. Aufa et al. [44] developed a set of trustworthiness checklists to evaluate five reliability related sub-aspects in eHealth apps – informational content, organizational attributes, societal influence, technology-related features, and user control factors. They then modified some of its contents based on eHealth app stakeholders' ratings and report the results in [45].

The European Commission has developed guidelines and criteria lists to enhance eHealth apps' usage, development, recommendation, and evaluation by assessing their safety, quality, reliability, and validity [39]. The Mobile App Rating Scale (MARS) [46] has become the most widely adopted tool for systematically evaluating the quality of eHealth apps, including their reliability and validity. Additionally, different reliability and validity elements are addressed by various standards and guidelines [35, 36, 39], accompanied by their respective evaluation methods [47, 48].

2.4 Diverse User Issues in eHealth Apps

We define ***Diverse User Issues*** in eHealth apps as the app's ability to be effectively used by a wide range of users and accommodate their needs, e.g., those with varying language proficiency, socioeconomic status, educational level, cognitive style, physical and mental challenges, gender, age, personality, and many more [10, 11]. This also includes catering to various user requirements appropriately integrating different technologies, methods, and practices. We found that diverse user issues in eHealth apps are not well-categorized as discussed earlier. As a result, there exists limited guidelines, standards, and frameworks addressing diverse user issues in eHealth apps within the literature. Nevertheless, some works have explored the challenges related to user age, gender, vulnerability, cultural sensitivity, language, and socioeconomic status in the eHealth app domain [10–13].

An early human-centered eHealth app design approach for elderly users is discussed in [49]. The authors developed a mobile app prototype and evaluated its effectiveness, efficiency, and user satisfaction. Their findings indicated that pre-assigned paths (for task completion) and guided activities (for app usage) were more effective for end-users than self-planning/learning. Some other works examined elderly user issues and provided similar recommendations [50]. Majeed-Ariss et al. [51] examined young user issues in eHealth apps. The authors identified a need for more evidence-based apps and insufficient data to assess eHealth apps' effectiveness conclusively. They also provided recommendations for evaluating eHealth apps to manage adolescents' chronic and physical conditions, including their impact on young users. A summarized set of guidelines for age-appropriate app design were presented in [52].

Recently, Llorens-Vernet et al. [53] systematically reviewed eHealth app standards and recommended guideline development strategies for addressing end-user gender, culture, and working conditions. Grene et al. [54] emphasized the importance of designing eHealth apps with linguistic diversity and discussed the relative requirements. A best practice recommendation for language-related issues in eHealth apps is discussed in [55]. Wang et al. [56] demonstrated how sex and gender impact all aspects of health apps and discussed current best practices to address them. Some other guidelines [26, 57] and review [58] discussed how to better address the dynamics of gender equality in eHealth app design, development, and deployment.

Several other studies have reviewed vulnerable user issues in eHealth apps and proposed preliminary guidelines to address them [22, 59]. Nadal et al. [60] investigated challenges related to technology acceptance in the eHealth domain and proposed a Technology Acceptance Lifecycle method to establish a common terminology and measurement framework. The guidelines for developing geographically sensitive eHealth apps are presented in [61]. Sharma et al.[62] developed a framework for evaluating issues in eHealth apps for low-income users. The framework facilitates the development of culturally, educationally, and socioeconomically appropriate eHealth apps connecting clinicians and patient advisory groups.

3 RESEARCH APPROACH

The research project progressed in three stages, as depicted in Figure 1: (i) Related work, literature review, and app analysis; (ii) Identifying key human aspects and collecting stakeholder perceptions; and (iii) Developing and validating guidelines to better support human aspects in eHealth apps. The first two stages of this research have already been published; in this paper, we mainly report the third part of this project. However, we briefly discuss the research approach for all stages to help readers better understand the proposed guidelines development process.

3.1 Related Work, Literature Review and App Analysis

Initially, we performed an extensive **S**ystematic **L**iterature **R**eview (SLR) on mobile apps and tools. Our review was not limited solely to eHealth apps; instead, we investigated the development of all mobile apps. This inclusive approach enabled us to understand a broad range of methodologies and strategies, and then use them to identify relevant issues and develop solutions, locating and synthesizing relevant academic literature in eHealth app domain. Our SLR search protocol identified a total of 1,042 peer-reviewed academic research papers from four major software engineering databases. These papers were subsequently filtered, and 55 high quality relevant studies were selected for analysis, synthesis, and reporting. We investigated what methodologies have been used to date to support app development, how these techniques have been employed, and identified key benefits, gaps, and future research potential. These findings have been published in [3].

We then investigated a reverse engineering-based approach to analyze a total of 24,652 Android apps, including eHealth apps to identify the underlying issues, called REACT. We adopted a general approach that encompassed not only eHealth apps but also all types of mobile apps for better methodological inclusivity and broader understanding. We did this by curating the well known CHABADA dataset [63] (not obtainable from the authors) and utilizing new topic modeling approaches. We also evaluated our approach on our newly curated dataset and discuss how our reconstructed testing datasets and tools can be enhanced for different research purposes i.e., identify human aspect patterns in eHealth apps. We made our REACT dataset and tools publicly available in [64] which provide all necessary information for replication and reuse. For example, `Dataset_1.xlsx` contains all data extracted from each app. `Dataset_2.xlsx` includes preprocessed and clean data, while analysis results are in `Dataset_4.xlsx` and `MALLET Result.xlsx`. The `eHealth Apps Analysis Results.xlsx` file lists all the eHealth apps that were exclusively reviewed. A curated subset of key eHealth apps linked to the guidelines it adheres to and areas where it could benefit from further improvements is shown in Appendix A. Interested readers can refer to our replication package in [64] and [65] for more detail.

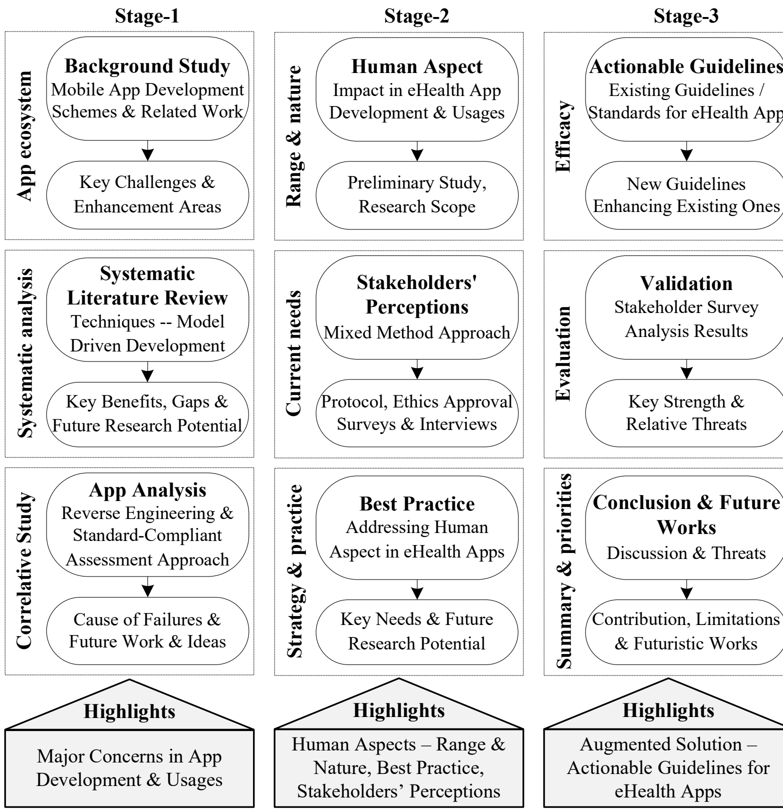


Fig. 1. Diagram of our enhanced eHealth app guidelines research approach

3.2 Identifying Key Human Aspects and Stakeholder Perceptions for eHealth Apps

Our literature review, app analysis, and related works (discussed in Section 3.1) indicate that creating eHealth apps that better address end-user human aspects is an outstanding challenge. Thus, we investigated eHealth app stakeholders (developers and end-users) perspectives on critical challenges and benefits of incorporating human aspects into eHealth app development and usage. We obtained our Human Subject Ethics Committee approval for these studies (Project ID: 25988 and Reference: 2021-25988-54639). In these studies, we explored how different human aspects are being addressed in practice, identified the most important human aspects for different user groups, and determined which ones are currently absent or poorly handled in eHealth apps through two sets of surveys and interviews. We gathered and analyzed data from 240 online survey responses and 25 detailed interviews within the same study, validating the results. Preliminary results of the user study were presented at a CORE A conference [13], and the full version of the research study has recently been published in a journal as a research article [10]. Below, we briefly present the methods and results of this study to help readers better understand the proposed guidelines development.

3.2.1 Surveys. We designed two distinct online surveys based on the guidelines provided by Kitchenham et al [66]. The first survey focused on mobile app developers' issues in supporting human aspects in eHealth apps, including suggestions and recommendations for future improvements, while the second survey aimed to identify critical end-user issues in the current eHealth app usage and associated future needs. We distributed the survey links via our social media channels, within our own network, and through our contacts who have large networks in app development, health, education, business, and service domains. We collected participants' views on human aspects in eHealth apps using multiple-choice and open-ended questions. The multiple-choice responses helped us structure the findings, identify statistical significance, and highlight differences between different aspects. Participant answers to open-ended questions allowed us to delve deeper into their perceptions of human aspects in eHealth apps, corresponding challenges in identifying and addressing different aspects, sorting outstanding issues, and retrieving required actions.

3.2.2 Interviews. The first author conducted a series of interviews with participants from each group (developers and end-users) who had consented during the surveys. Although interviewees were selected from survey participants, there was no overlap in the roles covered between survey responses and interviews. The interviews were designed based on Seaman's guidelines for qualitative research methods in empirical software engineering [67]. We recruited app developers experienced in different domains, such as front-end development, back-end development, data processing, quality assurance (QA), project management, and so on, who consented to be interviewed during the survey. For the end-user interviews, we selected different types of end-users of the eHealth apps such as policy makers, medical practitioners, admin personnel, business personnel, general users from different age groups, cultural diversity, socioeconomic status, and so on, who consented to be interviewed during the survey. The interviews were semi-structured, all the questions were open-ended and each interview was completed in around 50-60 minutes. Interviews had the following four parts:

- We initially asked demographic questions about their experience in eHealth app development and usage. We then asked the app developers to select a mobile app development project they had worked on and to discuss the human-centric challenges they encountered during the project. Similarly, we asked the end-users to choose a mobile app they had used or were familiar with and to discuss the human-centric characteristics they observed or found lacking, including the impact of these characteristics.
- Secondly, we tried to identify when app developers encountered key human aspects, which aspects were specifically found during which phase of app development and who highlighted them. We asked end-users when they noticed human aspects related issues in a different part of the app, e.g., UI, design, working process, and recommendation/outcome.
- We then tried to find out the key limitations in current app development approaches for recognizing or handling some human aspects, and whether they use any particular design approach, tools, coding, APIs or test cases to fix them. In contrast, we asked the end-users how their friends and family discussed about human aspects in eHealth apps, and whether they use additional hardware, devices or plugins to help address human aspects in eHealth apps.
- We ended the interview by asking all participants for their suggestions and comments about the interview, eHealth apps in general, and human aspects impacting eHealth apps.

The first author transcribed interview recordings and coded the contents using qualitative data analysis software (NVivo). We combined thematic analysis with open coding to identify themes as underlying codes emerged. We categorized the textual interview data into codes that generated concepts and categories by comparing open-ended answers, i.e., quotes to code, then codes into concepts (sub-themes), and concepts into categories (higher level themes).

During transcription and analysis, we invited two senior researchers to verify the initial analysis for a set of transcripts (3 end-user and 3 developer interviews) and provide suggestions for improvement. The research fellows have over two decades of experience in academia and industry, specializing in digital health and software engineering. The first author then analyzed the codes and sorted them into potential themes for all transcripts. All authors discussed the expert researchers' suggestions along with the revised analysis to resolve differences. The code list was considered stable when the concepts and themes reached saturation, and no new codes appeared. To reduce bias, all authors reviewed and agreed on the final set of themes after three iterations. Themes were chosen after the analysis was completed. Sentences unrelated to app development, app usage, and human aspects were dropped during the coding process.

3.2.3 User Study Results. Our participants specified which human aspects need support in eHealth apps and which are most affected, including assessed and experienced issues. We categorized survey and interview findings about human aspects impacting eHealth apps into four high-level aspects: Accessibility, Usability, Reliability and Validity, and Diverse User Issues. Our developers pointed out that accessibility issues were easy to identify but challenging to cover, while diverse user issues were hard to comprehend during the first phase of app development (requirements), and reliability issues were harder to manage. Our end-users indicated that the app interface and performance mainly impact accessibility and user experience, while usability and diverse user issues were least affected by app business logic and data sources. We also found that incorporating human aspects into eHealth app development stages is essential but time-consuming. The importance of guidelines, checklists, or standards for incorporating human aspects into eHealth apps was highly emphasized. Further discussion on these results is beyond the scope of this paper; interested readers can refer to our open-source publication [10].

3.3 Developing and validating guidelines to better support human aspects in eHealth apps

From the previous two research tasks, we found that we need an improved approach for better supporting human aspects in eHealth apps. Thus, the final task of this research project focused on developing improved ways to support human aspects in eHealth apps. To do this, we developed a set of enhanced guidelines to better support human aspects in eHealth app development, aiming to improve their effectiveness, acceptance and take-up, which we report in this paper. Our proposed guidelines emerged from the analysis of key findings from previous research tasks and aimed to address identified gaps in key human aspects such as accessibility, usability, reliability, and diverse user issues. Some of these guidelines are specific, e.g., collecting minimal personal health-related data for specific diseases. Others are more generic, e.g., considering age, gender, socioeconomic diversity, culture, technological acceptance challenges, health literacy, and more. We framed the guidelines based on the analysis of key findings of previous research works, e.g., evaluations of existing methods and state-of-the-art techniques, current standards, guidelines, checklists, and industry practices.

In the previous section (Section 2), we provided an overview of related works, including state-of-the-art guidelines, frameworks, and evaluation methods that consider human aspects in the eHealth app domain. In Section 4, we present our proposed set of new and enhanced actionable guidelines, best practices, and evaluation methods for better supporting human aspects in eHealth apps. Following that, we present collected feedback from app developers, software engineers, and other relevant eHealth app stakeholders to evaluate and verify the proposed guidelines' strengths, limitations, practicality, and feasibility in real-world scenarios in Section 5. We also discuss potential challenges and recommend future actions to produce more human-centric eHealth apps throughout the following sections.

Table 1. Comparison of Existing and Enhanced Guidelines

Aspect	Existing Guidelines	Proposed Enhanced Guidelines
Usability	General usability principles focusing on basic interface design.	Detailed usability metrics, including specific recommendations for different user demographics and contextual usage scenarios.
Accessibility	Basic accessibility features such as screen reader compatibility.	Comprehensive accessibility measures including support for cognitive disabilities, customizable interface options, and context-aware accessibility adaptations.
Reliability	Focus on basic functional reliability and uptime.	Advanced reliability strategies incorporating user feedback mechanisms and dynamic performance tuning.
Validity	General guidelines on data accuracy and consistency.	Enhanced validity protocols with detailed validation processes for user-generated data and cross-referencing with medical standards.
Diverse User Issues	Limited considerations for diverse user needs.	Extensive guidelines addressing diverse user issues including cultural sensitivity, age-related adjustments, and socio-economic status considerations.

4 GUIDELINES FOR BETTER SUPPORTING HUMAN ASPECTS

This section presents our proposed set of enhanced and actionable guidelines to better support human aspects in eHealth app development. Table 1 illustrates the enhancements of the proposed guidelines compared to the existing ones. The table also highlights the specific improvements and additions made to address various human aspects more effectively in the proposed guidelines. Our guidelines are aligned with the four high-level human aspects categories introduced in Section 2 — Accessibility, Usability, Reliability and Validity, and Diverse User Issues. We have labelled the guidelines to enable referencing, for example, when creating design check-lists, evaluation check-lists or defect reports. Top-level labels are A (Accessibility), U (Usability), R (Reliability and Validity), and D (Diverse User Issues). Next level guidelines within these are labelled 1, 2, 3, ... and so on. Finally, specific guidelines are labelled a, b, c etc. For example, Accessibility functionality guidelines around anticipation of behaviour is guideline A.2.b.

4.1 Guidelines for Better Supporting (A)ccessibility in eHealth Apps

Careful consideration of accessibility in eHealth apps is particularly critical. Many app users may have physical or mental challenges due to their health conditions and/or age, which can exacerbate accessibility issues. For example, in the TeleDoc app, users with visual or motor impairments need help inputting data, and integrating an accessible virtual keyboard with large keys and a high-contrast interface greatly helps such users. Similarly, users with cognitive impairments benefit from step-by-step voice-guided instructions and clear operational guidelines in the TeleDoc app. Recognizing these challenges, we developed a set of accessibility guidelines to address them. These guidelines are divided into content and functionality dimensions, based on the key accessibility components in eHealth apps discussed in Section 2.1. The accessibility content guidelines address issues related to content format, standards, hardware compatibility, user preferences, and validation. The accessibility functionality guidelines cover aspects such as communication, predictability, compatibility with assistive technologies, user assistance, reversibility, motion control, programmatic actions, testing, and feedback.

4.1.1 ***A.1. Accessible Input/Output.*** eHealth apps should facilitate accessible content and provide diverse input-output mechanisms for all users, regardless of any physical or cognitive limitations they may or may not have [21, 22, 28]. We found that addressing accessibility issues related to content and input-output in eHealth apps involves providing alternative input-output options, adjusting presentation styles, color schemes, and fonts, properly labeling components, and ensuring adaptability, hardware compatibility, and user-specific customizations. Due to the diverse and accessibility challenged nature of many eHealth app users, multiple input/output mechanisms are particularly important.

- ❖ **A.1.a. eHealth app components should maintain consistency** to allow end-users to better understand the app's operation and reduce cognitive load during app use [22]. To ensure consistency in app components, best practice standards and templates and prototypes [25] should be followed. This is especially important for input/output, information presentation, and the shape, size, and visual location of actionable elements. These consistencies ensure that users use the app more confidently and effectively, aiding them in making informed health decisions. Decision-making with health-related data means that component consistency is critically important for effective app usage, particularly to prevent misunderstandings, incorrect interpretations, or errors during app use.
- ❖ **A.1.b. Default settings should accommodate standards** and common patterns, such as auto-updates running in parallel with other content; the touch targets size should be at least 44dp×44dp; actionable elements should support different input modes; apps should facilitate one-handed use; and auto-complete should be provided where possible for standard inputs [68, 69]. Limiting auto-interaction should only be done when essential or to ensure app security. For instance, in the TeleDoc app, unexpected auto-updates might cause users to miss crucial alerts during consultations, while the lack of support for different input modes can hinder user interaction, leading to data inconsistencies and incorrect outcomes. Following standards and common patterns in default settings significantly mitigates these risks [53].
- ❖ **A.1.c. Hardware should not impact eHealth app operation**, and the app should automatically adjust data usage, processing power, and displays to accommodate various sensors, screen sizes, and hardware configurations [68, 69]. Due to the diverse eHealth app users and usage contexts, many eHealth apps need to run on very diverse devices with greatly varying sized and capable phones, tablets, wearables and even smart home devices. When hardware doesn't hinder the app's functionality, the eHealth app remains appropriately accessible, optimized, and adaptable for all users.
- ❖ **A.1.d. Developers should prioritize supporting adaptable app features** such as simpler layouts, scalable fonts, alternate color schemes etc., that ensure eHealth app content is visible and legible on all devices. Alternative input-output modes – such as text alternatives, voice commands, touch gestures, sign language, captions, and audio descriptions – should be compatible with assistive technologie and adaptable to users with diverse physical and cognitive abilities [11, 22]. This is particularly important for users who have their devices mounted in a fixed orientation, such as on a wheelchair arm, or those with limited motor skills who struggle to rotate their devices but still want to access app, i.e., content format should not affect app users.
- ❖ **A.1.e. Users should have the flexibility** to choose and adjust their input-output preferences during app installation and switch between options as needed while the app is in use. This adaptability is crucial, as users' needs and preferences may change over time, or different circumstances may require alternative configurations [28]. As noted above, users of many ehealth apps are highly diverse, use highly diverse devices, and many eHealth apps are used in very diverse usage contexts.
- ❖ **A.1.f. Users should be able to track and validate their inputs** through responsive design and actions. For instance, voice commands may produce inexact results, so users should be able to validate and correct them [25]. Users should also be able to adjust time limits without unexpected changes in-app content or context and suppress or postpone interruptions if

necessary. For many health-related data inputs and confirmations, accurate input is critical and can even significantly impact user health and safety.

❖ **A.1.g. Users should have the option to customize** presentation styles, foreground, and background colors, and contrast ratios to suit their needs. Enabling text resizing up to 200 percent without horizontal scrolling or content bypassing is recommended [25, 28]. For instance, consider a visually challenged user of our example TeleDoc app with age-related impairments. Allowing this user to customize contrast ratios, foreground, and background colors can significantly improve the app's operability and understandability [59] (both are key components of accessibility as discussed in Section 2.1). Such customization ensures proper interaction and guarantees accurate interpretation of the TeleDoc app's content [70], addressing the robustness component of eHealth app accessibility.

4.1.2 ***A.2. Functionality and assistance.*** eHealth apps should integrate accessibility features throughout the key app functionalities [13, 25]. We found that addressing accessibility issues related to app functionality involves providing clear operation instructions, compatibility with technologies, effective feedback loops, ensuring efficiency, accuracy, compatibility, and maintaining a visually appealing appearance.

❖ **A.2.a. Developers should provide clear and concise operational instructions** within eHealth apps that are understandable to all users. This includes using clear and straightforward language [54], enabling accessibility features such as text-to-speech or closed captioning [17], and explaining complex instructions [21]. This primarily helps users with cognitive disabilities, low literacy, and non-native speakers and ensures that apps are effective and adequately usable by all. For instance, in the TeleDoc app, consider a user with low literacy or a non-native speaker. Providing clear and straightforward operational instructions, along with text-to-speech and closed captioning features, significantly enhances the app's usability for this user. Similarly, complex gesture controls that require multiple fingers or taps for navigation present significant challenges for users with dexterity impairments and limited motor disabilities [59]. Then, ensuring clear guidance on enabling accessibility features from the outset of the app development process supports better accessibility [19].

❖ **A.2.b. End-users should be able to anticipate the behavior of eHealth app elements**, ensuring that they function predictably. This guideline mainly encompasses navigation options [70] such as those hidden behind menu icons, coded with links, or embedded within list structures, which should be easily identifiable and actionable by users of varying experience levels and abilities. This is particularly important in eHealth apps implementing care plans, including exercise and medication instructions.

❖ **A.2.c. Assistive technologies should not change an eHealth app's operational context without user input.** Developers need to avoid duplicate attributes in control elements for clear recognition by assistive tools, ensuring the app performs consistently across various devices. For instance, alternative keyboards utilizing head pointers, single switches, sip/puff, or other specialized input devices should maintain the same functionality, regardless of the device used. Evaluation with these devices and ideally with experienced end users of these devices is ideal.

❖ **A.2.d. eHealth apps should offer adequate assistance during data input** to ensure ease of use for all users. This includes suggesting appropriate auto-corrections when input errors are detected [25], verifying critical inputs to minimize errors [25], and providing context-sensitive help [71]. Accuracy in health-related data input is particularly critical in the eHealth app domain, not only for effectiveness but also for user safety [10].

- ❖ **A.2.e. eHealth apps should enable users to reverse actions and offer reduced motion control options** during task completion and overall app usage. This includes options to cancel accidental triggers through undo, abort, or backspace [72]. This feature benefits not only individuals with disabilities, such as cerebral palsy, who may experience involuntary movements or blind users relying on screen readers who want to disable motion control, but also general users without any medical conditions. Additionally, it helps minimize distractions and discomfort caused by animated or moving content [22].
- ❖ **A.2.f. eHealth app developers should ensure all UI components have programmatically accessible states, properties, and values** that users can use and interact with ease [17, 68]. For example, an image with a text description should include an 'ALT' tag describing the content [25], enabling screen readers to offer audio descriptions for users who cannot see the image [22]. Then, Notifications for changes should always be available within the app [26].
- ❖ **A.2.g. eHealth apps should undergo rigorous, diverse user accessibility testing and provide user feedback**. This includes offering feedback through visual or auditory cues and availing feedback loops [28]. App developers should also collaborate with diverse users and conduct standard accessibility testing to better ensure suitable accessibility support during app usage [18, 27, 73].

4.2 Guidelines for Better Supporting (U)sability in eHealth Apps

Usability in eHealth apps is equally important as accessibility. Given that the audience can include individuals with diverse health conditions or those from various age/culture/socioeconomic groups, the app's design and work flow should be intuitive and user-friendly. For example, in our TeleDoc app, providing clear and simple operational instructions ensures that users with varying levels of literacy can navigate the app effectively. Therefore, we have devised a set of usability guidelines to address issues commonly encountered in eHealth apps. These guidelines are structured into three primary dimensions: app design, navigation, and user support, each reflecting the key usability components in eHealth apps as discussed earlier in Section 2.2. The app design guidelines address considerations related to layout, color schemes, screen elements, text formatting, paragraph structures, and information organization. The navigation guidelines emphasize maintaining a consistent app state and simplicity, providing best practices for effective user interaction. Lastly, the user support guidelines address issues related to user requirements, the inclusion of help sections, clear communication channels, and timely notifications.

4.2.1 ***U.1. eHealth App design.*** eHealth apps should adhere to best practice design standards and reference guidelines, e.g., as those provided by Android [35] or iOS [36]. Our findings indicate that addressing usability issues in eHealth app designs also requires attention to – layout, color, graphics (screen elements), text, fonts, information, and functionalities – to ensure meaningful presentation and appropriate functionalities [13, 28]. Due to diverse device usage by end users of many eHealth apps, usability can easily be adversely impacted.

- ❖ **U.1.a. eHealth apps should offer adaptable landscape and portrait orientations** to ensure consistent usability across diverse devices, users, and environments. This involves displaying information equally well in both landscape and portrait modes [28] and allowing users to easily adjust screens that extend beyond scroll lines [32].
- ❖ **U.1.b. eHealth apps should utilize contrasting colors for backgrounds, contents, icons, and labels** to help users distinguish different app elements efficiently. Developers should consider cultural acceptability for color choice and accommodate users with visual impairments or color blindness [74]. The recommended contrast ratio for body text is 4.5:1,

and 3:1 for larger text such as headings [25, 28]. For some eHealth apps, the ability of users to accurately understand charts, tables and other complex information is critical for effective app usage.

- ❖ **U.1.c. eHealth app elements should clearly indicate their actionability through distinct designs**. The ideal dimensions for actionable elements are 7-to-10 millimeters in both length and width [28], with appropriate spacing to prevent accidental taps or clicks [32]. Many studies have shown over-complexity of app interfaces is a major challenge in eHealth apps. App developers should also ensure that every element on the screen serves a purpose, provide selectable options for data input whenever possible, and minimize extraneous text, graphics, and animations from the front screen [10, 11].
- ❖ **U.1.d. eHealth apps should use clear language (well-known terminologies), appropriate text format, font size, and line spacing** for better supporting readability. App users should easily distinguish between headers and paragraph text [37]. Adhering to platform standards such as 17-point text for iOS, 14-scale text for Android paragraphs, and 1.2 times of font's height line spacing is recommended [35, 36]. Easy user access to definitions of complex health terms, explanations of visual data presentation, and ability to ask for assistance are highly recommended [10].
- ❖ **U.1.e. eHealth app developers should facilitate information grouping** (clustering) in app information and content presentations. This involves emphasizing essential app elements [12], presenting information above the scrolling line [32], and avoiding long paragraphs to ensure that key information and app functions remain visible on the screen during usage [28, 74]. For instance, in the TeleDoc app, consolidating information such as upcoming appointments, recent consultations, and prescription refills onto a single screen allows users to quickly access relevant details without excessive scrolling. This streamlined presentation significantly enhances both the app's usability and overall user experience. Leveraging the health condition the app targets to structure presentation of information may assist developers to improve usability.

4.2.2 ***U.2. eHealth App navigation.*** eHealth app developers should prioritize intuitive and seamless navigation to enable users to complete their desired tasks effectively. Our findings suggest that addressing usability issues in eHealth app navigation entails addressing issues for destination paths and states [28], actions required for task completion [38], and adhering to established standards and best practices [74]. When implementing a care plan for a health condition in an eHealth app, characteristics of the health condition and associated care plan steps may be leveraged to assist in more intuitive app navigation design.

- ❖ **U.2.a. eHealth apps should enable users to determine their current location within the app and provide straightforward navigational paths to reach desired destinations**. This involves providing clear indications of the user's position within the app and implementing best practice principles, such as temporal locality, which facilitates faster access to recently accessed screens, and spatial locality, enabling direct access to screens closely related to the current screen [33, 34]. Leveraging characteristics of the health condition and associated care plan steps may assist in more intuitive app navigation design.
- ❖ **U.2.b. eHealth app developers should streamline navigation and minimize user interactions** within eHealth apps for more effective task completion. This includes reducing the number of taps, swipes, or screens required for tasks and offering reversible actions to return to previous pages [72]. Furthermore, the app should present user-friendly options for registration, common types of health data entry, recovery, re-entry, and storage, with each

option clearly communicating its purpose [28]. Common terminology and appearance of health-related inputs and outputs across eHealth apps will assist users of the apps.
For example, in the TeleDoc app, a feature that allows users to book an appointment or schedule a consultation with a one-click reschedule button and pre-filled patient information significantly enhances usability and efficiency. This is particularly beneficial for users with limited technological proficiency or physical impairments, ensuring a seamless and accessible experience.

- ❖ **U.2.c. eHealth apps should incorporate familiar menu designs**. This includes placing menus on the top or left side of the screen or using a hamburger icon [28, 37]. Additionally, enabling end-users to bypass detailed instructions, non-essential information, and unnecessary personal data entry enhances app usability, particularly for users with cognitive disabilities, low literacy, and limited technological proficiency [50, 74]. Furthermore, offering returning users the option to skip registration, onboarding, and walkthrough tutorials improves overall app usability [28, 32].

4.2.3 ***U.3. User support***. eHealth apps should ensure comprehensive technical support and help features to prevent user dissatisfaction and improve overall app usability. We found that addressing user support-related issues involves providing a well-structured help section, offering feedback during app usage, supplying walkthrough materials, assisting with feature customization, and delivering notifications for critical events such as abnormal health conditions or user-specified reminders and alarms [10, 33].

- ❖ **U.3.a. eHealth apps should feature a comprehensive and concise help section** to assist end-users. This includes offering informative links for complex issues [37], pop-ups with suggestions [32], health condition taxonomies [11, 12], health condition definitions [29], step-by-step guidance for addressing technical problems, error messages and app usage [10], and incorporating visual aids, e.g., charts, graphics, or videos to complement text-based descriptions and explanations of app functions [68–70]. Assistance-related communications should be presented clearly and concisely using language understandable to all users, irrespective of their background, expertise, or medical condition [55, 62]. For example, in the TeleDoc app, providing a comprehensive help section with pop-ups for suggestions, step-by-step guides for troubleshooting, and instructional videos ensures that users, regardless of their technical proficiency or medical background, can easily understand and utilize the app's features, significantly enhancing their app usage experience.
- ❖ **U.3.b. eHealth apps should provide notifications for critical events or changes** within the app to keep users informed about them. This includes alerts for low storage or battery, necessary data deletion, registration requirements, feedback reception, or errors [28]. Notifications should adhere to best practices, such as displaying near input fields or in top or side panes of the app, while non-urgent notifications should not obstruct or disrupt app operation [25]. Then, app update notifications or new feature announcements are essential in eHealth apps but can be deferred or ignored without affecting critical app functions [75]. Furthermore, users should be able to customize notifications for various events based on their preferred settings [38]. As many eHealth apps may be used in diverse contexts, pro-active warnings may better assist users e.g. charge before leaving home / time of day vs at set battery level.
- ❖ **U.3.c. Reminders and alarms in eHealth apps should be designed to capture users' attention** effectively. This involves utilizing redundant signals and requiring users to acknowledge them before continuing with other tasks within the app [28]. Implementing such a design strategy ensures that users are consistently aware of important events such

as medicine intake or doctor appointments. Linking reminders and alarms to health care plan steps and step information may assist users to better adhere to care plans, especially important for the eHealth app domain.

- ❖ **U.3.d. Informing users of minimum system requirements is crucial** for eHealth app effectiveness. Users should know the necessary prerequisites during installation or setup, such as password requirements, data entry, storage space, and operating system updates [28]. Testing connectivity to diverse devices e.g. wearables, sensors needed for a number of eHealth apps is essential as this is a very common usability problem for users [76].

4.3 Guidelines for Better Supporting Reliability and Validity in eHealth Apps

Ensuring reliability and validity in eHealth apps is crucial, as they significantly influence users' trust based on the app's consistent performance and the authenticity of its information. For instance, in our TeleDoc app, clear communication about data handling practices and transparent privacy policies build user trust. This gives users confidence that their data is appropriately used and protected, leading to greater uptake and usage of the app. To address these issues, we have developed a set of reliability and validity guidelines categorized into app information, disclosure, development, and maintenance. Each segment reflects the core reliability and validity components discussed earlier in Section 2.3. Within the app information segment, the guidelines emphasize content clarity, compliance with established standards, user consent, and thorough verification processes. The development segment explores clear communication, timely updates, user safety assurances, rigorous data privacy protocols, strict policy adherence, and efficient feedback channels.

4.3.1 ***R.1. App information and policies.*** eHealth apps should guarantee reliable and valid information to establish trust and credibility in user communities. We found that addressing the reliability and validity of information in eHealth apps involves verifying the accuracy and consistency of data [39], maintaining transparency in sources [44, 45], updating content regularly [40], and ensuring adherence to policies and guidelines for user safety and privacy [42, 48]. In the eHealth domain, adherence to these is especially critical due to the education, monitoring and/or treatment applications of the apps.

- ❖ **R.1.a. Developers should ensure transparent and truthful eHealth app descriptions**. This includes providing accurate information about the app's capabilities [48], avoiding misleading claims [77], and explicitly pointing out any relevant disclosures [39]. This approach helps users make informed decisions, builds trust within the user community, and ensures the app is used effectively and as intended. For many users, maintaining trust of the app is essential to ensure appropriate take-up and usage [11].
- ❖ **R.1.b. eHealth app developers should document all health-related content with references** to support better credibility of information, users' trust, and overall effectiveness. This includes citing recognizable, authentic, and credible sources [28], especially health-related ones, aligning content with current practices [25, 42], and providing documentation for content formulation when sources are not identifiable [39]. This primarily helps users verify the app's information's trustworthiness and ensures that the app adheres to required regulations [10, 77]. For example, in the TeleDoc app, documenting all health-related content with references to credible sources ensures that users can trust the information provided. This practice enhances the app's credibility, builds user trust, and ultimately boosts their confidence and reliability in using the app for health-related decisions.
- ❖ **R.1.c. eHelath app users should be able to clearly distinguish between app information and any advertising** via clear and distinct designs and presentations within app, i.e.,

incorporate transparent advertising practices. This includes placing advertisements unambiguously [39], complying with regulatory requirements and copyright policies and disclosing any advertising within the app [78]. This primarily helps users avoid confusion between educational content and promotional material. Then, misleading users with false claims or overemphasizing the benefits of advertised products can create distrust and hinder the app's overall effectiveness [10, 13].

4.3.2 ***R.2. App development and maintenance.*** eHealth app developers should prioritize continuous maintenance to ensure consistency and accuracy of outcomes, particularly in data collection, measurement, recommendations, and results. We found that addressing such issues entails updating security patches, enhancing app functionality, and resolving bugs to avert data breaches [28, 47].

- ❖ **R.2.a. eHealth app developers should emphasize regular content updates and communicate key changes** in the app to the users. For example, in the TeleDoc app, providing regular content updates and clear communication about key changes ensures that users are always informed about the latest clinical recommendations and guidelines. Additionally, by validating and explaining deviations from the original guidelines, the TeleDoc app helps users understand the relevance of updates, building trust in the app's information. This approach significantly enhances user confidence and reliability in using the app for health-related decisions. Addressing content update needs involves adhering to protocols [78], informing users of significant changes resulting from updated clinical or medical guidelines [42], validating and explaining any deviations from the original source [48], and providing credible sources to support recommendations [39].
- ❖ **R.2.b. eHealth apps should appropriately integrate with other healthcare information systems**, such as electronic health records, without compromising data security or user privacy. App developers should ensure proper interoperability [79], employing standardized protocols [28] and formats for data exchange and other essential communication processes [78]. Increasingly health apps interact with wearables, smart home sensors or similar technologies, and a common problem reported by users are connectivity issues [76].
- ❖ **R.2.c. eHealth app developers should prioritize the following of safety guidelines** throughout the development process. Addressing safety concerns involves considering users' conditions and offering relevant information to help them make informed decisions [39]. This also involves providing clear instructions on app usage and outlining potential risks and side effects, and providing contact details (of developers or customer service) in case users encounter issues while using the app [28].
- ❖ **R.2.d. eHealth apps should collect minimal personal data** required for app functionality and proper operating. For example, a medication tracking app may only needs to collect the name of the medication, dosage, and frequency, sometime user age, not the user's address, phone number, or other personal information. Addressing related privacy concerns involves limiting the app to share the user data with third parties [43, 78], fostering trust, and empowering them to decide which data should be stored, deleted, or processed i.e., end-users should have complete control over their own information [12, 44]. eHealth apps should not store data for longer than it is needed and should not pass it to third parties without explicit user consent.
- ❖ **R.2.e. eHealth app developers should emphasize user privacy in app design and development**, consequently, their usage. This involves adopting practices such as anonymizing and encrypting app-generated data, protecting users' personal information from unauthorized access or theft by ensuring non-identifiability, even in potential security breaches [39, 80]. Clear

and consistent and usable privacy policies should be provided using language understandable to end users.

- ❖ **R.2.f. eHealth apps should always maintain transparent terms of service policy statements**, using easily understandable language free from technical jargon and legal terms. Displaying policy statements during the app onboarding process and conveying information about data handling practices is strongly recommended [28, 78, 80]. It should be very clear to users what they are consenting to when using the app.

4.4 Guidelines for Better Supporting (D)iverse User Issues in eHealth Apps

The diversity of eHealth app users necessitates an emphasis on catering to their diverse needs. Our proposed guidelines for Diverse User Issues (defined in Section 2.4) encompass human aspects in eHealth apps addressing issues related to – age, gender, culture, language, cognitive style, working conditions, socioeconomic diversity, technological acceptance challenges, vulnerable users, marginalized people, and health literacy. For example, in our TeleDoc app, incorporating age-appropriate designs, multilingual support, and culturally sensitive health advice ensures that users of different ages, languages, and cultural backgrounds can effectively use the app, enhancing their overall experience. We do not explicitly mention the term 'user experience' in the guidelines, but it is encompassed throughout, particularly when discussing presentation, functionality, performance, and interactive behavior issues.

4.4.1 ***D.1. User age.*** eHealth apps should cater to users of varying ages and recognize that elderly users may have distinct needs and preferences compared to younger users and app developers. Our findings suggest that addressing age-related concerns in eHealth apps involves better interface design, feature set customization, component adherence, and availing personalized experiences [81]. Any apps to be used by children require appropriate privacy and safety considerations, as well as consent of guardian and use of appropriate language and concepts.

- ❖ **D.1.a. eHealth apps should prioritize user-friendly interfaces tailored to user age**, e.g., larger font sizes and simplified navigation for elderly users [70], audio prompts and reminders for individuals with visual or cognitive impairments [82], and age-appropriate designs for younger users [51].
- ❖ **D.1.b. eHealth apps should ensure age appropriate user engagement**. This involves integrating social media platforms and interactive component such as chatbots [28]. We found that connecting users with peers facing similar health concerns or interests enhances their experience and encourages app usage [10, 13]. App developers can follow the standard and best practice examples to achieve this [25, 35, 36]. Incorporating social media features, such as sharing achievements, joining support groups, or connecting with healthcare professionals, can make eHealth apps more effective.
- ❖ **D.1.c. eHealth apps should collect user age ranges during onboarding** and customize app components to address age-specific needs, which enhance overall user satisfaction and app effectiveness. For example, in the TeleDoc app, collecting user age during onboarding allows the app to provide tailored advice and features. Younger users receive interactive health education tools, while elderly users get medication reminders and easier access to medical consultations. Additionally, this ensures that users under the age of consent require a guardian's permission for treatments and data provision. This process includes proper age data collection, its intended use, and implementing protective measures [78]. Regular automatic updates of user age information can enable relevant, age-specific recommendations and actions, particularly when utilizing machine learning algorithms [3, 10].

4.4.2 ***D.2. Gender identity.*** eHealth apps should carefully consider gender-based user preferences and needs, presenting features and information tailored to various genders while upholding an inclusive atmosphere. This involves personalizing the user experience, supplying pertinent health resources, nurturing support and recognizing diverse gender identities within user communities [56, 58].

- ❖ **D.2.a. eHealth apps should enable users to self-identify their gender**. For example, in the TeleDoc app, allowing users to self-identify their gender helps provide more personalized health recommendations and services. This approach not only addresses the threat of developers' unconscious biases and gender-based presumptions but also ensures that the app provides appropriate advice for certain health conditions and remains inclusive to the diverse needs of its user base. [57].
- ❖ **D.2.b. eHealth app developers should consider that not all users are identified as male or female** and should accommodate users of diverse gender identities by refraining from gendered language that could exclude non-binary or transgender individuals. This involves utilizing gender-neutral terms like 'they' or 'the user' in the documentation and information presentations instead of gender-specific pronouns like 'he' or 'she' [56].
- ❖ **D.2.c. Developers should test and evaluate eHealth apps** to uncover instances where language, imagery, or features inadvertently exclude or misrepresent specific gender identities before app release. This allow app developers to rectify the issues and create a genuinely inclusive and pertinent eHealth app for users of all genders [57, 58].

4.4.3 ***D.3. Language and communication.*** eHealth apps should cater to users with various language and communication needs, which entails providing multilingual support, ensuring linguistic appropriateness in medical language usage, language complexity, and offering clear explanations for different terms [54, 55].

- ❖ **D.3.a. eHealth apps should address language concerns** appropriately, including multilingual assistance and linguistic diversity. This involves enabling users to choose their preferred language during onboarding, allowing them to conveniently switch between languages at any time while using the app [54, 83].
- ❖ **D.3.b. eHealth apps should utilize simple language structures** and minimize technical jargon or medical terminology to convey health information clearly and effortlessly [55]. For instance, while reminding users about their vaccine schedule, the TeleDoc app should use simple language such as 'It's time for your vaccine shot' instead of 'You need to book a consultation to update your immunoprophylaxis'. This approach ensures users understand the importance and timing of their vaccines without being confused by complex terms [54]
- ❖ **D.3.c. eHealth apps should clarify any medical or technical terms**, enabling diverse users to understand better the information presented. For instance, in our running vaccinations example, the TeleDoc app might clarify the importance of a vaccine by explaining its protective role against certain diseases and outlining its potential risks and benefits. This approach ensures that users are fully informed about why the vaccine is necessary, how it helps prevent illness, and what to expect in terms of possible side effects [54].

4.4.4 ***D.4. Cultural diversity.*** eHealth app developers should prioritize addressing users' cultural diversity in app design and development processes. This involves addressing distinct user communities' social values, beliefs, and norms [10, 84].

- ❖ **D.4.a. eHealth apps should avoid cultural stereotypes or assumptions** that might offend or alienate app users based on their cultural heritage. A development team having varied cultural backgrounds can better address cultural perspectives in the developed apps [13, 85].

At the least, evaluation of eHealth apps with diverse users and user personas should be undertaken prior to release or update release.

- ❖ **D.4.b. eHealth app developers should consider addressing the cultural sensitivity, including diverse concepts of health** of app users during app design and development. This involves assessing user cultural context, adapting relevant information and resources, and incorporating features that accommodate cultural beliefs and healthcare practices [84]. For instance, the TeleDoc app could provide culturally appropriate healthcare advice by offering tips for managing health during cultural events like Ramadan or Diwali. The app might include reminders to adjust medication schedules around fasting hours in Ramadan or provide dietary advice that aligns with users' religious practices. Additionally, the app should offer health recommendations that consider dietary restrictions and guidance tailored to users cultural and religious practices.
- ❖ **D.4.c. Testing and evaluating eHealth apps with participants from diverse cultural origins is recommended** to identify unintentional biases or assumptions and enable developers to address these issues [27].

4.4.5 ***D.5. Cognitive style and working conditions.*** eHealth apps should consider the diverse cognitive styles and working conditions of end-users. This involves catering various learning preferences incorporating adjustable settings[86], and ensuring seamless integration with different work settings of user that fosters app efficiency, accuracy, and satisfaction [39].

- ❖ **D.5.a. eHealth app developers should prioritize strategies to reduce users' cognitive load during app interactions**, especially when completing tasks or following up on recommendations and outcomes. For instance, when designing a mental health care app like 'Wysa [87]', developers should consider users who might face challenges managing anxiety or depression. These intuitive work processes, interfaces, instructions, and simplified navigation aid users in focusing on their health issues without feeling overwhelmed of app usage [70, 86].
- ❖ **D.5.b. eHealth apps should incorporate adaptable solutions for dynamic work process** implementing needs of their diverse user base. For example, our running mental health management example app, could offer visual cues to guide users through breathing exercises to alleviate anxiety when identifying related symptom [17, 88].
- ❖ **D.5.c. eHealth apps should address the varying working conditions of app users**. This involves providing app features and content tailored to user contexts, ensuring users can access context-specific information based on their work environments [71]. For instance, our running mental health example app could offer clinical guidelines when used by doctors while providing resources for addressing mental health issues in emergency response situations when used by firefighters [10, 37]. This is similar for our TeleDoc app as well. The app could offer different interfaces and resources when used by patients at home versus healthcare professionals in a clinical setting, ensuring each user group receives relevant information and support tailored to their needs.
- ❖ **D.5.d. Determining user working conditions dynamically can be challenging**, but the modern sensor and AI-based technology may facilitate easy automation [10, 12]. For example, the mental health app could utilize microphone sensors to monitor the ambient noise levels of their users and act accordingly. Similarly, the TeleDoc app could utilize GPS sensors to detect if a user is at home or traveling and adjust appointment reminders, a nutrition app could analyze the time of day for meal plan recommendations, or a sleep tracking app could employ accelerometer sensors to identify non-standard work hours.

4.4.6 D.6. Socioeconomic diversity.

eHealth apps should consider the socioeconomic issues of end-users. This entails adapting to their financial and educational circumstances [11, 62], collaborating with community organizations during app design and development [10], and leveraging user data for targeted services in diverse socioeconomic contexts [61].

- ❖ **D.6.a. eHealth app developers should address concerns related to users' educational levels, living situations, incomes**, and other socioeconomic factors. For instance, apps targeting common health issues like fever, headache, and nausea should provide easy-to-understand information [55] and recommend affordable remedies for users with limited healthcare access [61]. Similarly, the TeleDoc app could include a feature to recommend cost-effective healthcare options and generic medications for users with limited income, ensuring that they receive necessary care without financial strain.
- ❖ **D.6.b. Determining users' socioeconomic conditions is challenging**, and providing app service accordingly is not trivial. However, analyzing factors such as device configuration, geo-location data, and mobile carrier data can assist developers in understanding user socioeconomic conditions [10, 11], allowing them to tailor app services to suit different user groups based on these findings.

  D.6.c. Developers should collaborate with community-based organizations during app design to gather valuable insights into user needs and preferences. As trusted information sources, these organizations can also enhance awareness of eHealth app services and benefits [39, 42], reaching a wide range of user groups, including those who might be hesitant to try eHealth app services, particularly users in underdeveloped and rural areas who depend heavily on their community leaders [54].

4.4.7 D.7. Technological acceptance challenges.

eHealth apps should address technological acceptance challenges to ensure seamless operation and user satisfaction. This involves tackling issues related to devices, operating systems, platforms, updates, and incorporating intelligent systems.

- ❖ **D.7.a. eHealth apps should function equally well across various devices, operating systems**, and hardware and software versions. For instance, our example TeleDoc app should perform equally well on smartphones and tablets with different screen sizes, adapting the interface and functionality for different platforms such as iOS and Android. Otherwise, users may experience compatibility issues, leading to reduced user satisfaction, limited adoption, and potentially causing adverse outcomes due to a suboptimal user experience [60, 89].
- ❖ **D.7.b. eHealth apps should incorporate interactive forms or automated tools** to guide users through data collection processes, addressing technological acceptance challenges and enhancing user experience [10, 60].
- ❖ **D.7.c. App developers should conduct compatibility and performance optimization testing** to ensure that developed eHealth apps are tailored to users' needs and expectations while addressing technological acceptance challenges, or it will decrease trust in the user base, lower adoption rates, and potentially compromise patient care [10, 12, 24].
- ❖ **D.7.d. eHealth apps should be routinely updated** to adapt to current technologies, related challenges and integrate features following a formal release and update process [78], ensuring that updates resolve identified technical issues and bugs without negatively impacting app usage [60].
- ❖ **D.7.e. Addressing technological acceptance challenges in eHealth apps can be costly**. Agile methodologies, which involve breaking down projects into smaller sprint phases, use of feedback loops and compatibility testing, significantly help developers to solve relative technical issues as they arise, and manage project budget and deadlines [26, 28].

4.4.8 *D.8. Vulnerable users, marginalised people and health literacy.*

eHealth apps should address the unique challenges faced by vulnerable and marginalized user groups, ensuring that features and design elements cater to their needs and overcome physical, cognitive, and emotional barriers [22].

- ❖ **D.8.a. eHealth apps should address health literacy challenges** for vulnerable and marginalized user groups, as discussed earlier. This includes using plain language for users with limited health literacy [54], incorporating culturally appropriate visual aids [84], and providing contextually relevant health information [90] tailored to the specific needs of these user groups.
- ❖ **D.8.b. eHealth app developers should actively collect feedback from vulnerable and marginalized users** during app development to identify areas where the eHealth app may not adequately meet their needs. For instance, an app designed for maternal health care such as 'Healofy -Pregnancy & Parenting [91]', may need to account for community practices and beliefs of racial and ethnic minorities, which can only be identified by gathering input from these user groups. Similarly, the TeleDoc app could include tailoring features for non-native speakers, improving connectivity for rural users with light versions of the app, and offering culturally sensitive telemedicine services. This also helps enhance culturally sensitive in the apps [28], such as including traditional practices for indigenous communities during pregnancy, or providing baby birth information on healthcare access procedures for immigrants and refugees [13, 86].

5 EVALUATION OF THE PROPOSED GUIDELINES

We conducted an online survey among expert app developers, software engineers, and other relevant eHealth app stakeholders to evaluate the effectiveness of the proposed guidelines in producing more human-centric and effective eHealth apps. The study was approved by Monash University Human Research Ethics Committee (Project ID: 36592).

In the survey, we assisted the respondents with definitions of the eHealth app and human aspect. We also shared our guidelines with the participants via publicly accessible links. Initially, we collected demographic information from our respondents, but no identifying information was collected. This helped us to decide whether we had reached our target audience and how closely the collected samples represented the target population. Following this, We collected participants' views and assessment on the proposed guidelines using multiple-choice and open answer questions. We explicitly asked the participants to assess the applicability of the proposed guidelines in practice, provide feedback on the guidelines' strengths and limitations, and suggest future improvements. The responses to the multiple-choice questions helped us in organizing the evaluation results (findings and ratings), determining statistical significance, and assessing various segments of the guidelines. Meanwhile, participant responses to open-ended questions enabled us to gain a deeper understanding of their assessment of the proposed guidelines, addressing outstanding issues, and identifying necessary actions for future implementation. We have a clear understanding of the diverse needs and challenges faced by different user types from our previous works [12, 92], which we have integrated into our guidelines assessment.

Table 2 presents a relative ranking and measurement criteria for each guideline to facilitate more effective eHealth app development. The guidelines are categorized into three levels: Critical, Important, and Helpful. This ranking assists developers in prioritizing efforts and in systematically assessing app implementation in practice. Guidelines ranked as Critical are essential for the functioning, safety, and usability of all eHealth apps. Such guidelines directly impact user experience, accessibility, and data integrity. For example, in the TeleDoc app, clear operational instructions

Table 2. Ranking and Summarized Subjects for the Proposed Guidelines

Item	Subject	Rank	Item	Subject	Rank
A.1.a	Component consistency standard	Critical	A.1.b	Customizable default settings	Important
A.1.c	Optimal hardware configurations	Critical	A.1.d	Adaptable features and assistive tech.	Important
A.1.e	Input-output preferences	Critical	A.1.f	Input validation and tracking	Critical
A.1.g	Presentation styles and accessibility	Important	A.2.a	Operational instructions	Critical
A.2.b	App behavior predictability	Important	A.2.c	Performance consistency	Critical
A.2.d	Data input assistance	Critical	A.2.e	Reverse actions and motion control	Helpful
A.2.f	Programmatically accessible component	Critical	A.2.g	Accessibility testing and user feedback	Critical
U.1.a	Adaptable orientations	Important	U.1.b	Color contrast for app elements	Critical
U.1.c	Design for app elements actionability	Critical	U.1.d	Language and text format	Critical
U.1.e	Information grouping	Important	U.2.a	Location and navigational paths	Critical
U.2.b	Streamlined navigation	Important	U.2.c	Menu designs standard	Important
U.3.a	Comprehensive help section	Critical	U.3.b	Notifications for events	Critical
U.3.c	Reminders and alarms	Important	U.3.d	System requirements information	Helpful
R.1.a	App descriptions	Critical	R.1.b	Documentation and reference	Important
R.1.c	Information and advertisement	Helpful	R.2.a	Content updates and communication	Critical
R.2.b	Integration with existing systems	Critical	R.2.c	Prioritize safety guidelines	Critical
R.2.d	Personal data collection	Important	R.2.e	User privacy issues	Critical
R.2.f	Terms of service policy	Helpful	D.1.a	Age-tailored interface design	Critical
D.1.b	User engagement	Important	D.1.c	Age-tailored customization	Helpful
D.2.a	Gender identification	Critical	D.2.b	Gender-neutral documentation	Helpful
D.2.c	Gender inclusive evaluation	Important	D.3.a	Multilingual assistance	Critical
D.3.b	Language structure	Important	D.3.c	Clarification of terms	Critical
D.4.a	Cultural stereotypes avoidance	Critical	D.4.b	Cultural sensitivity context	Critical
D.4.c	Testing with participants	Important	D.5.a	Strategies for cognitive load	Critical
D.5.b	Adaptable and dynamic solutions	Important	D.5.c	Users working conditions	Critical
D.5.d	Sensors and AI usages	Important	D.6.a	Socioeconomic factors in app design	Critical
D.6.b	Data analysis to know user conditions	Important	D.6.c	Community collaboration	Critical
D.7.a	Equal functionality	Critical	D.7.b	Interactive form or automated tool use	Important
D.7.c	Test compatibility and performance	Critical	D.7.d	Routine app update	Important
D.7.e	Technological acceptance challenges	Critical	D.8.a	Health literacy challenges	Critical
D.8.b	Feedback collection	Critical			

(A.2.a) were implemented during the early stages of development to ensure accessibility for users with varied levels of technological proficiency. Similarly, transparent and accurate app descriptions (R.1.a) were prioritized to enhance trust and support informed decision-making. In contrast, Important guidelines are necessary for proper operation and overall effectiveness, but are more context-dependent and developers may chose to implement them progressively. For instance, in TeleDoc, flexible features (D.5.b: adaptable and dynamic solutions) were introduced at later stages of development to accommodate diverse needs. The Helpful guidelines are valuable but have a lower impact on functionality and user experience. They can be implemented as resources become available. For example, in TeleDoc, optional features such as motion control (A.2.e) or gender-neutral documentation (D.2.b) were added later to enhance user convenience and engagement. In practice, an app development team should begin by addressing Critical guidelines to establish a robust and reliable foundation. They would then incorporate Important guidelines, focusing on refining features to better serve a diverse user base. Finally, they could adopt Helpful guidelines.

Table 3 presents a systematic mapping of the identified use cases to their corresponding guidelines. Each use case – such as voice-guided instructions, text-to-speech features, and simplified interfaces – aligns with specific guidelines it addresses. This mapping assists app developers in understanding the practical application of these guidelines and demonstrates how the use cases exemplify them in real-world scenarios.

Table 3. Systematic mapping of use cases to the guidelines

Use Cases	**Accessibility (A.x)**	**Usability (U.x)**	**Reliability/ Validity (R.x)**	**Diverse user issues (D.x)**
TeleDoc: Accessible virtual keyboard (visual/motor)	A.1.d, A.1.g, A.2.f	U.1.c, U.3.a	R.2.b	D.7.e, D.8.a
TeleDoc: Voice-guided instructions (cognitive)	A.2.a, A.2.d	U.1.d, U.3.a	R.2.b	D.5.a, D.8.a
TeleDoc: Text to speech & close captioning (low literacy/non-native)	A.2.a	U.3.a	R.1.c	D.3.b, D.8.a
TeleDoc: Clear/simple instructions (varying literacy)	A.2.a, A.2.b	U.3.a	R.1.a	D.3.b, D.8.a
TeleDoc: Prevent unexpected auto-updates	A.1.b, A.1.c	U.3.b	R.2.a	D.7.d
TeleDoc: Custom contrast/colors/fonts (visual)	A.1.g	U.1.b, U.1.d	-	D.8.a
Users (cerebral palsy/ blind): Reversible actions	A.2.e	U.2.b	-	D.1.a, D.8.a
TeleDoc: One-click reschedule appointments	-	U.2.b	-	D.1.b, D.5.b
TeleDoc: Comprehensive help section	A.1.d	U.3.a	R.1.b	D.1.b, D.6.a
TeleDoc: Transparent data handling	A.1.f	-	R.1.a, R.1.b	-
TeleDoc: Document content with references	-	U.1.d	R.1.b	D.4.b
TeleDoc: Regular updates/guideline deviations	A.1.a	U.2.a	R.2.a	D.1.b
TeleDoc: Age-appropriate, multilingual, culturally sensitive & age for tailored features	A.1.d	U.3.a	R.2.a	D.1.a, D.1.c, D.3.a, D.4.b
TeleDoc: Different interfaces (patients vs professionals)	A.1.b	U.1.a, U.1.d	R.2.b	D.1.a, D.5.c
TeleDoc: Non-native/rural/marginalized support	-	-	R.1.c	D.3.a, D.8.b
eHealth: Integrate social media/chatbots (engagement)	-	U.2.a, U.3.b	R.2.d, R.2.e	D.1.b
Wysa: Simplified interface (anxiety/depression)	A.1.e, A.2.d	U.3.a	R.2.b	D.5.a
Mental health app: Information for doctors vs firefighters	A.1.b	U.1.a, U.3.c	-	D.5.c, D.6.b
Mental health app: Microphone sensors (ambient noise)	A.1.a, A.1.d	U.3.d	R.2.b	D.5.d, D.7.a
eHealth app: Interactive forms (tech acceptance), Affordable remedies (low-income), Community collaborations,	A.1.e, A.2.D	U.1.c	-	D.2.c, D.6.a , D.6.c, D.7.b
Healofy: Simple language & visuals	A.1.d, A.2.d	U.3.a	R.1.a,	D.5.a, D.8.a
Maternal health app: Feedback, minority communities, traditional practices	A.2.g	-	R.2.f	D.2.c, D.4.c, D.8.b, D.7.c

5.1 Pilot Study Analysis Results

After obtaining ethics approval, we conducted a pilot study among the target population to identify any issues with the survey design and assess the clarity of the questions and response options. Our pilot study participants were generally satisfied with the survey, two typos in writing were pointed out, and no suggestions were received to reform the questionnaire or response options.

Table 4 summarizes the pilot study evaluation results. The five pilot study participants had significant experiences in industries, with three having more than five but less than ten years of experience and two having ten-plus years of experience. They worked in various eHealth app sub-domains, as summarized in the table's seventh row.

In the pilot study, respondents from four countries expressed satisfaction with the proposed guidelines for managing human aspects at different stages of eHealth app development. Of the five developers, 80% indicated they were happy to use the guidelines with high confidence, while the remaining 20% said they would use them confidently. Additionally, all participants agreed that the guidelines were helpful in addressing human aspects in eHealth apps.

Two participants suggested adding regulatory checklists for AI and API usage in eHealth apps in the next version of the guidelines. Another participant recommended regularly updating the guidelines to stay aligned with current best practices. Two emphasized the importance of providing training and support through tutorials, open-source materials, and videos. We excluded these pilot study responses from the results presented in the remainder of this section.

Table 4. Summarized results of the pilot surveys for guideline evaluations

Criterion		Results
Ethnographic Information	**Countries**	Australia (20%), Bangladesh (40%), Singapore (20%), USA (20%)
	Age groups	31-40 (60%), 41-50 (40%)
	Gender	Male (40%), Female (60%)
	Qualification	Bachelor (60%), Masters or Above (40%)
	Current role	Programmer and UIs' developers (40%), Software architect (20%), Business consultant (20%), Project manager (20%)
	eHealth domain experience	5-10 years (60%), 10+ years (40%) in industries **Domains:** Telehealth and telemedicine, Consumer health IT data, Health and Fitness tracking, Virtual healthcare, Electronic Medical Records, Health app for social activities, Mobile health decision making, Health IT systems
Views on the Guidelines	**Assist Developers**	Strongly Agree (96.67%), Agree (3.33%) **Observations:** Easy to follow, need to be compact a bit more.
	Key aspects management at app development phases	Extremely helpful (84%), Very helpful (12%), Helpful (4%) **Observations:** Guidelines have – explore key human aspects in a structured way, strong focus on usability and UX, aligned best practices, provide a foundation to produce effective and engaging eHealth apps.
	Confident on using our proposed guidelines	Highly confident (80%), Confident (20%) **Observations:** Guidelines are – well-structured, can significantly improve the quality of produce eHealth apps to meet the diverse user needs.
	Overall Feedback	The proposed guidelines represent a comprehensive and advanced approach for addressing key issues in human-centric eHealth app development, surpassing existing guidelines with their completeness and integration of best practices.

5.2 Survey Participants

We distributed the survey links to our industry contacts and professionals from renowned software development companies worldwide. We also requested that they disseminate our survey links to their contacts and colleagues. Additionally, we publicized our survey links via our professional social media channels. We received over 60 online survey responses. However, we excluded incomplete responses and those without direct or indirect app development experience. Finally, we had 35 valid responses for our analysis. Like most software engineering studies, we used Convenience Sampling, though did some Purposive and Snowball Sampling to increase the reach of our survey and its representativeness [93]. Although our sample size may seem limited, this study is exploratory and aims to identify primary trends and patterns. Similar sample sizes are commonly employed in software engineering research [93, 94]. The range of professional backgrounds, range of diverse eHealth app development experience, and years of experience of our respondents enhance the credibility of their feedback on our proposed guidelines. While the findings may not be statistically generalizable, they provide a solid foundation for future investigations. The survey questions are available in a publicly accessible GitHub repository [65].

Figure 2(A) shows the distribution of age ranges of our survey participants. 80% of the developers were aged between 21 to 40, while the rest were over 41. Our participants reside in 13 different countries across five continents, and of these, 65.71% were male, and 34.28% were female. Figure 2(B) shows the distribution of organizational size for the participating developers' companies. Out of the 35 participants, 11 (31.43%) work for organizations with more than a thousand employees, 3 (8.57%) work for organizations with a size of 500-1000 employees, 8 (22.86%) work for organizations with a size of 51-200 employees, and the remaining participants work in relatively small scale companies. These distributions show that the proposed guidelines are well evaluated with the diverse eHealth stakeholders. A more detailed discussion is presented in Section 6.2.

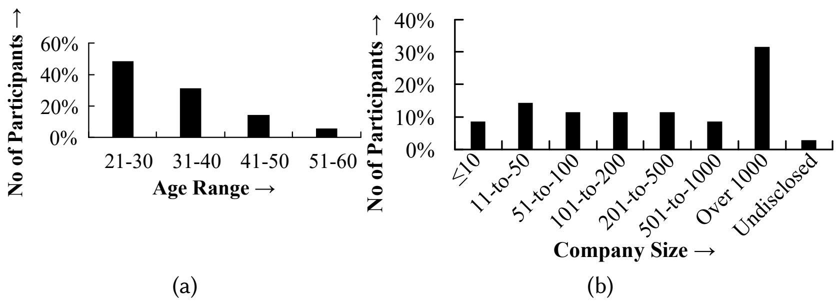


Fig. 2. Distribution of survey participants based on (A) Age range and (B) Their current organization size

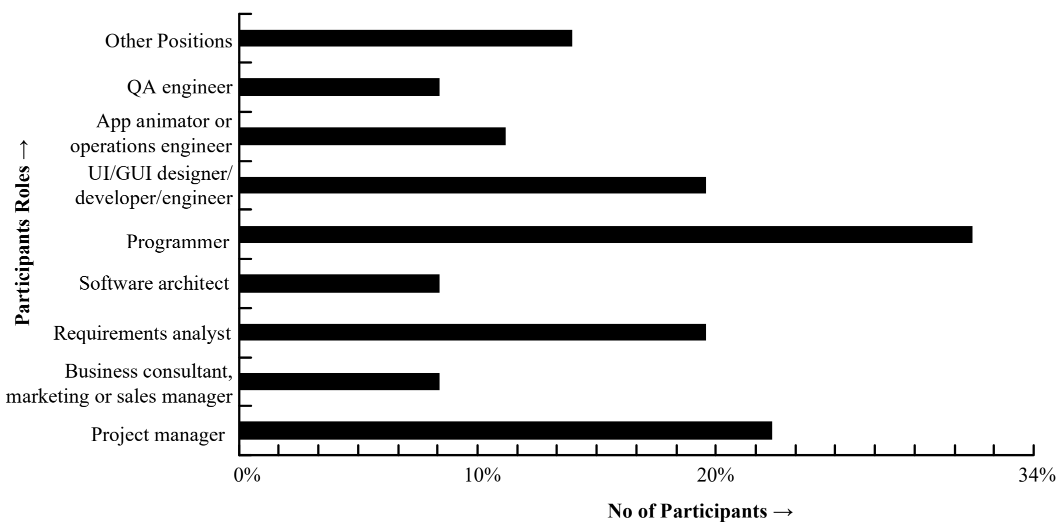


Fig. 3. Distribution of survey participants based on their current roles within their organizations.

Figure 3 shows the current job roles held by the survey participants. The most common roles were project manager (22.85%), programmer (31.43%), requirements analyst (20%), and UI/GUI developer (20%). In contrast, business consultant (8.57%), software architect (8.57%), app animator (11.43%), and QA engineer (8.57%) were the least frequently reported roles.

We then found that all our survey participants either had a bachelor's or master's degree in Computer Science, Computer Engineering, Information Science, Information Technology, or Software Engineering, except for two who had their masters in Embedded System Development and Management Information System, and one who held a Diploma in Computing and IT.

Figure 4 shows the distribution of app types that our survey participants have worked on. We found that 45.71% of participants have worked on more than one eHealth app development project in their careers. The maximum experience reported was 15 years in app development, with 37.14% of participants having over 5 years of industry experience, 25.71% having 2-to-5 years of working experience, and the rest having ≤2 years of experience.

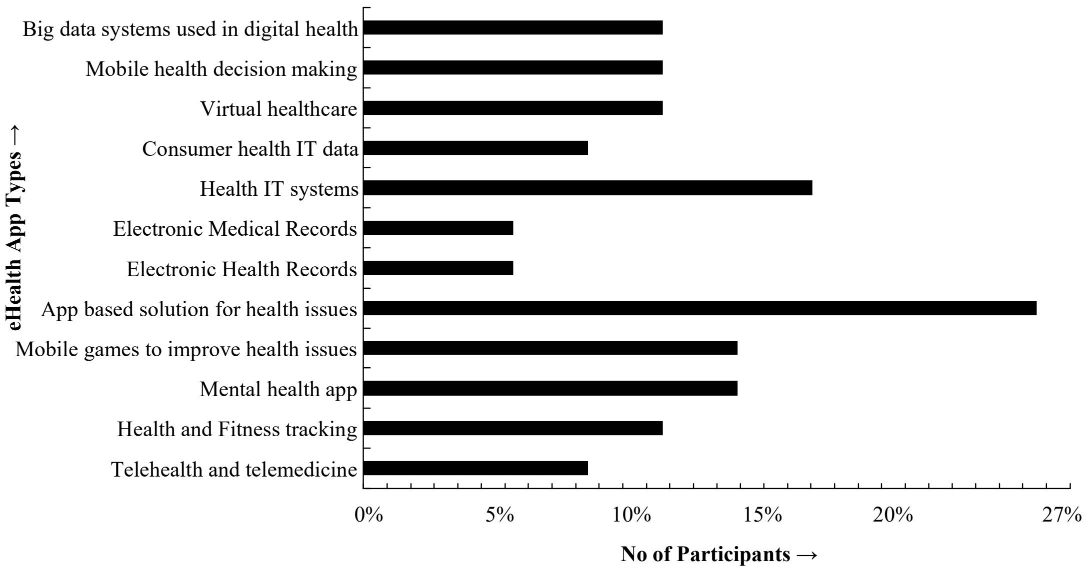


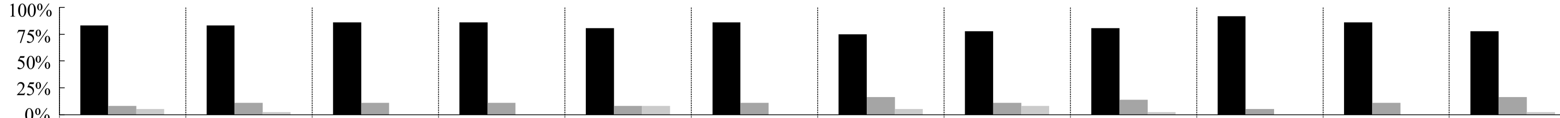
Fig. 4. Distribution of survey participants based on the eHealth app types they have recently worked on.

5.3 Effectiveness of Our Proposed Guidelines

We evaluated the effectiveness of our proposed guidelines using the following four criteria derived from the survey findings:

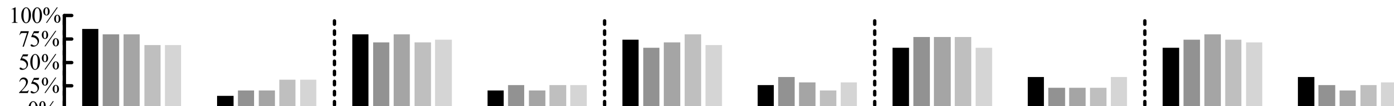
i. **Addressing key end-user issues** to measure how well the guidelines identify and address the primary concerns and challenges faced by the diverse end-users of eHealth apps, ensuring that their needs are met appropriately.
ii. **Managing human aspects at different phases of eHealth app development** to evaluate the extent to which the proposed guidelines emphasize understanding and catering to different human aspects throughout various stages of app development.
iii. **Confidence in using the proposed guidelines in comparison to existing standalone ones, and alignment with current best practices for ease of use** to ensure that the guidelines comply with standards and regulations, and that they promote the development of eHealth apps that are user-centric, intuitive, and effective.
iv. **Evaluating the strengths, limitations, and suggestions for enhancement** to understand what the guidelines excel at, identify areas of potential improvement, and suggestion for further refinement and evolution.

5.3.1 ***Addressing key end-user issues.*** We asked survey participants to indicate whether the guidelines would helped them address key end-user issues in their eHealth apps. The response options provided were: Strongly Agree, Agree, Undecided, Disagree, and Strongly Disagree. Additionally, we requested them to list and indicate any issues that need to be added, edited, or removed from the proposed guidelines, along with the key reasons for such suggestions. Figure 5(A) summarizes participants' ratings on how well the guidelines help address key end-user issues. In this figure, we aggregated the received responses into three categories to provide a clearer summary of participant sentiment and enhance visual clarity by merging 'Strongly Agree' and 'Agree' into one category, 'Undecided', and 'Disagree' and 'Strongly Disagree' into another category.



	Elderly users issues	Very young users issues	Users with accessibility issues	Users with physical challenges	Users with mental health issues	Users with cognitive challenges	Users with limited language proficiency	Users uncomfortable with technology	Users socio-economic status	Users gender identity	Users cultural diversity	Other issues with vulnerable users
Strongly Agree/ Agree	85.71%	85.71%	88.57%	88.57%	82.86%	88.57%	77.14%	80.00%	82.86%	94.29%	88.57%	80.00%
Undecided	8.57%	11.43%	11.43%	11.43%	8.57%	11.43%	17.14%	11.43%	14.29%	5.71%	11.43%	17.14%
Disagree/ Strongly Disagree	5.71%	2.86%	0.00%	0.00%	8.57%	0.00%	5.71%	8.57%	2.86%	0.00%	0.00%	2.86%

(a)



	Usability		Accessibility		Reliability and Validity		Diverse User Issues		Other Human Aspects	
	Extremely Helpful / Helpful	Neutral/ No-choice	Extremely Helpful / Helpful	Neutral/ No-choice	Extremely Helpful / Helpful	Neutral/ No-choice	Extremely Helpful / Helpful	Neutral/ No-choice	Extremely Helpful / Helpful	Neutral/ No-choice
Requirements elicitation	85.71%	14.29%	80.00%	20.00%	74.29%	25.71%	65.71%	34.29%	65.71%	34.29%
Solution design	80.00%	20.00%	71.43%	25.71%	65.71%	34.29%	77.14%	22.86%	74.29%	25.71%
Implementation - coding in	80.00%	20.00%	80.00%	20.00%	71.43%	28.57%	77.14%	22.86%	80.00%	20.00%
Testing and evaluation	68.57%	31.43%	71.43%	25.71%	80.00%	20.00%	77.14%	22.86%	74.29%	25.71%
Maintenance, bug fixing & others	68.57%	31.43%	74.29%	25.71%	68.57%	28.57%	65.71%	34.29%	71.43%	28.57%

(b)

Fig. 5. Distribution of participants' rating on the effectiveness of the proposed guidelines for – (A) Addressing key end-user issues (B) Managing key human aspects at different phases of eHealth app development

Our survey results indicate that most developer participants found our proposed guidelines helpful for addressing key end-user issues in eHealth apps. On average, 85.24% agreed or strongly agreed that the guidelines were helpful, while only 3.10% disagreed or strongly disagreed, and 11.67% remained undecided. The guidelines were found to effectively address concerns for various user groups, such as the elderly, very young users, users with accessibility or cognitive challenges, mental health issues, and users with limited language proficiency or discomfort with technology. As shown in the figure, The highest agreement rate was observed for addressing users' gender identity (94.29%), with cultural diversity and socio-economic status also receiving strong support (82.86% and 88.57%, respectively). Most participants (80%) found the guidelines helpful for addressing other vulnerable users or aspects, with a small percentage (2.86%) disagreeing. Some example comments we received include:

'*The guideline[s] discuss the needs for eHealth apps users to [cater to their] diverse human aspects and [associated] issues, ... such as age, gender, culture, language, cognitive patterns, physical and mental challenges, and others. ... The guidelines also [encapsulate how to well address] these varied user issues ... in eHealth apps.*' [Requirements Analyst and Project Manager]

'*I [particularly] like the guidelines on diverse user issues ... and how they were initiated with hypothetical scenarios, ... the discussion of technical guidelines to address them (diver user issues) are well [articulated and] comprehensive.*' [Programmer and QA Engineer]

'*The emphasis on eHealth apps to support the varied needs [of users] have been well-integrated in the proposed guidelines. ... The guidelines also provide actionable insights ... [which] I found very helpful.*' [Software Engineer & UX Specialist]

Our developer participants then shared their experiences and several suggestions for addressing key end-user issues in the eHealth apps using the proposed guidelines. For instance, a senior developer recommended to include an executive summary of key end-user issues at the beginning of the guidelines, and pointed that this would make developers more conscious of critical issues when designing apps and help them quickly understand main concepts. Most participants praised the inclusion of real-life eHealth app examples in the guidelines. One developer commented that these examples would benefit newcomers to the field and serve as case studies. Another participant emphasized that the guidelines enable developers to create more inclusive and human-centric eHealth apps that cater to a wide range of user needs. Overall, the guidelines were widely acknowledged as effective in addressing diverse end-user needs.

5.3.2 ***Managing key human aspects at different phases of eHealth app development***. We asked our developer participants to assess the effectiveness of our proposed guidelines in managing key human aspects during various eHealth app development stages, i.e., requirements elicitation; solution design; implementation - coding in; testing and evaluation; and maintenance, bug fixing and others. They used a numeric scale from 1 to 5, where 1 stands for 'extremely helpful', 2 for 'very helpful', 3 for 'somewhat helpful', 4 for 'not very helpful', and 5 for 'not at all helpful'. Figure 5(B) displays participants' ratings of the guidelines' effectiveness in managing key human aspects during various eHealth app development phases. On average, the guidelines received ratings of extremely helpful or helpful for all aspects (73.94%), with usability and accessibility receiving the highest ratings (71.43% to 80.00% as extremely helpful/helpful). However, 25.43% of participants were neutral or did not respond for at least one human aspect. We observed the following patterns in the ratings across various stages of eHealth app development for different human aspects:

- ❖ For usability aspects, requirements elicitation, solution design, and implementation received high ratings (extremely helpful/helpful) of 85.71%, 80.00%, and 80.00%, respectively. However, during both the testing and evaluation phase, as well as the maintenance, bug fixing &

others phase, the ‘helpful’ ratings decreased to 68.57%, while a notable 31.43% of participants provided either neutral feedback or chose not to respond.

❖ For accessibility aspects, requirements elicitation and implementation both secured high ratings (being extremely helpful/helpful) of 80.00%. During the solution design and testing phases, the ’extremely helpful/helpful’ ratings dropped to 71.43%, while in the maintenance, bug fixing & others phase, the ratings slightly improved to 74.29%. However, a significant 25.71% of participants either offered neutral feedback or opted not to respond.

❖ For managing reliability and validity aspects in eHealth apps, the testing and evaluation phase recorded the highest ratings, with 80.00% of participants rating the guidelines as either extremely helpful or helpful. In other phases of eHealth app development, the ratings for being extremely helpful or helpful varied as follows: solution design was rated at 65.71% as extremely helpful/helpful, with 34.29% being neutral or non-responses; implementation - coding in was rated at 71.43% as extremely helpful/helpful, with 25.71% being neutral or non-responses; and maintenance was rated at 68.57% as extremely helpful/helpful, complemented by 28.57% neutral or non-responses.

❖ For addressing diverse user issues, the solution design, implementation, and testing phases secured high ratings (extremely helpful/helpful) of 77.14%. Then, the requirements elicitation and maintenance phases were rated as extremely helpful or helpful by 65.71% of the participants. Notably, 22.86% of participants either provided neutral feedback or chose not to respond for the solution design, implementation, and testing phases, while this percentage increased to 34.29% for the requirements elicitation and maintenance phases.

These findings suggest that the proposed guidelines effectively assist in managing essential human aspects throughout the eHealth app development process. The guidelines are especially useful during the early and foundational stages of app development. However, inherent complexities in testing, evaluating, and maintaining eHealth apps in real-world settings present challenges in the later developmental and operational stages. Our survey participants also provided feedback in conjunction with their ratings, highlighting aspects of the guidelines that should be added, edited, or removed, and explaining their reasons for these suggestions. For instance, one developer felt that the guidelines could delve deeper into accessibility testing and related issues. Another QA engineer emphasized the importance of gathering feedback, especially for eHealth apps aimed at minority user groups in specific regions should be more enhanced. A project manager found socioeconomic diversity part as the key to addresses the diverse needs and challenges faced by the eHealth app users. Some other valuable feedback we received includes:

‘*The proposed guidelines ... [have the potential to guide] developers in dealing with essential human aspects throughout app development life cycle. ... I like the specific design, navigation, and assistance recommendation. ... I [also appreciate] the recommendation [of] including feedback loops and regular real world user testing case, ... this is really helpful ... in early detection and address[ing] human centric issues [during] app development.*’ [Senior Software Engineering)]

‘*The proposed guidelines ... meets the requirements for addressing [essential] human aspects [in different app development stages]. ... These guidelines will be useful for producing more effective eHealth apps.*’ [User Interface Designer]

‘*The guidelines propose a much-needed human-centric design approach for eHealth apps. ... It’s great to see such valuable input coming from the [academia]...*’ [Senior App Developer]

‘*This guideline is [helpful in addressing] human-centric issues we face daily in developing apps and [related] duties.*’ [Programmer]

Fig. 6. Distribution of survey participants' ratings for the proposed guidelines on (A) Making it easy to use in line with current best practices. (B) Their preference (confidence) of using them over existing standalone guidelines

5.3.3 ***Confidence in using the proposed guidelines and aligning with best practices***. In our survey, we asked participants to evaluate the ease of use of our proposed guidelines in line with current mobile app development and software engineering best practices for addressing key human aspects in eHealth apps. They used a numeric scale from 1 to 5 for the evaluation, where 1 represented 'very easy', 2 represented 'easy', 3 'represented neutral' (i.e., neither easy nor difficult), 4 represented 'difficult', and 5 represented 'very difficult'. The participants' ratings of their preference are summarized in Figure 6 (A). These results shows that three-fourths of the participants (74.29%) found the proposed guidelines either extremely easy or easy to use in line with current (best) practices. About 22.86% had a neutral response, and one developer found them challenging due to her usual way of working and her unfamiliarity with the concepts.

The survey participants also rated their confidence in using the guidelines over existing standalone guidelines for addressing human aspects in eHealth apps using a scale: 'highly confident', 'moderately confident', and 'slightly confident', and 'not confident at all'. The participants' ratings of their confidence is shown in Figure 6 (B). These results show that most participants (91.43%) expressed confidence in using the proposed guidelines over existing ones, while a small percentage (8.57%) was doubtful. This doubt is mainly due to the adjustment they need to make from their routine practices and the need to adopt new methods, as identified from their comments.

We also found that participants consistently praised the proposed guidelines for their comprehensiveness and clarity. For example, one senior developer commented that the guidelines are among the best resources for new app developers to address human aspects with ease and confidence. Another project manager mentioned that the guidelines would improve the development workflow and make developers more comfortable addressing human aspects in eHealth apps. A consultant expressed appreciation for the valuable guidelines emerging from academia and confirmed they will soon be applicable in the industry on a large scale. One developer participant particularly appreciated how the proposed guidelines segmented various aspects to stay in line with best practices. Another developer emphasized that by centering on key human aspects only, the guidelines remain concise and user-friendly for them. Additional feedback we received are as follows:

'*Your guidelines ... ensure that the eHealth apps are not only functional but also resonate with the target audience, ... facilitating engagement and fostering long-term adoption [in industry].*' [Software Architect)]

'*The need for eHealth apps to consider the diverse human aspects of their users is nicely accommodated. ... The real-world scenarios [included the guidelines] provide ... a solid foundation for developers to create contextually relevant, [effective] and empathetic [eHealth app] solutions, ... [also help] enhancing the overall user experience..*' [App Animator]

'*The included recommendations ... provide a comprehensive overview of best practices and industry standards, ... [The guidelines also] detail the necessary precautions to protect sensitive user data and maintain compliance with relevant regulations. This can help build trust between users, developers, and developed eHealth apps, ... [that helps] individuals feel confident using these digital tools to manage their health and well-being..*' [Project Manager]

5.3.4 ***Highlighted additional strengths, limitations, and suggestions.*** Our survey participants provided several comments highlighting additional strengths and limitations of the proposed guidelines. The majority acknowledged the guidelines' strong focus on prioritizing user-centered design, accessibility, and inclusivity for a variety of eHealth app development. The guidelines' emphasis on quality assurance while ensuring functionality, as well as their use of easy and understandable language were also mentioned. Some explicitly highlighted the guidelines' commitment to ensuring secure eHealth apps and the adoption of the universal design principle. App developers and UI designers specifically praised the categorization of diverse user issues in the proposed guidelines and their corresponding addressability concepts. Some related feedback we received is as follows:

'*The user focused approach is the key [in your work]*' [Requirement Analyst]
'*The primary advantages ... are that you prioritize user-centered design, ... [which also] promote more user satisfaction [with the developed apps and their] acceptance*' [QA Engineer]
'*Your guidelines [are] well [resonate with] universal design principal ... [for example,] I like how you recommend using W3C or GDPR regulations.*' [App Developer]
'*The guidelines helps to build apps that are more inclusive, ... practically possible and ... [commercially] feasible.*' [Business Consultant]
'*The guidelines recommendations help [to] build trust [among] users, developers and [developed eHealth] apps.*' [Project Manager]
'*The language is easy to understand ... this is quite helpful [for industry audience].*' [App Developer and Programmer]

Our survey participants also highlighted a few potential limitations and recommended suggestions. These comments mainly involved addressing technology changes over time and the generalizability of the guidelines to domains other than eHealth apps. One participant commented on enhancing sensor-related issue adjustments in the testing process; three suggested creating a toolset, and two requested customizing the guidelines for specific populations and usage locations. We received a request to make the guidelines open-source. Other feedback and suggestions included adding a summary at the beginning of the guidelines and providing more specific case studies or examples related to the reliability aspects, similar to diverse user issues. Some related feedback we received is as follows:

'*[To follow] this guideline might require advanced technology or specialized development environment.* [Project Manager]
'*Different cultures may have different perspectives on health and wellness, ... [which could affect] how the guidelines are interpreted and applied.*' [Requirement Analyst]
' *User's data collection and privacy concerns could be discussed more elaborately.* [App Developer]
'*One suggestion [is] to ... include more specific case studies or examples of successful implementation of the guidelines in existing app domain. ... This help demonstrat[ing] the practical application of the guidelines and make them more relatable to other [non-eHealth] app developers and designers.* [Senior Software Engineer]
'*[please consider] converting this one into a tool or tool-set, ... automatic checking would be much more helpful* [Operations Engineer]

6 THREATS TO VALIDITY

Several threats exist to the proposed guidelines' development and their evaluation approaches. Below we identify, categorize, and summarize how we attempted to mitigate these threats.

6.1 Construct Threats to Validity

The primary construct threat in developing the proposed guidelines is the potential incompleteness (quantification) of key human aspects. Additionally, some aspects may have been prioritized over others in the guidelines, resulting in the incorrect measurement of the studied constructs (the guidelines). To mitigate these two threats, we have focused on essential human aspects only for eHealth apps through a literature review, collected stakeholders' perceptions, and consulted with experts in the eHealth app domain before the guidelines' development as discussed in Section 3.

Furthermore, the validation of the proposed guidelines largely depends on the opinions of app developers, software engineers, and other related stakeholders. To mitigate this threat, we followed a well-established methodology for user studies (referred to Section 5), obtained full ethics approval, and conducted a pilot study (discussed in Section 5.1). Additionally, we provided detailed explanatory statements, definitions, and examples to assist participants in understanding the constructs so that they could capture all critical factors. Another construct threat arises from the structuring of survey questions to evaluate the overall satisfaction with macro-categories of guidelines. This could potentially confound the responses as several guidelines are evaluated under a single question. To mitigate this, we included other options and open-ended questions, allowing respondents to elaborate on specific guidelines and provide detailed feedback on particular aspects they found satisfactory or unsatisfactory. Even then, there is still a possibility that participants may not have identified all relevant concerns regarding the developed guidelines. For instance, respondents may indicate agreement with 'Usability' as a whole but fail to address specific issues such as 'learnability' or 'error protection and recovery'. While open-ended questions provided opportunities to capture such details, they did not guarantee complete coverage of all sub-guidelines. To further mitigate this risk, we provided as much detailed coverage as possible for each human aspect and explained them with real-life eHealth app examples in the guidelines and survey questionnaires. We categorized the proposed guidelines into sections, subsections, points, and enhancing existing works. This helped our participants to identify and provide any missed or important aspects/issues. We also encouraged our participants to provide suggestions and feedback that could enhance the comprehensiveness of the developed guidelines.

6.2 External Threats to Validity

The primary external threat to the proposed guidelines is that they may need to be more generalized. In the developed guidelines, we considered only the target population of eHealth apps and the contexts of human aspects. We mitigated relative barriers by engaging with diverse stakeholders in the eHealth app domain, such as end-users, medical practitioners, app developers, software engineers, and other related personnel during the guidelines' development stages as discussed in Section 3. Even then, our respondents may not represent a fully complete pool, which makes it difficult to evaluate the guidelines from all viewpoints, especially during the guideline evaluation phase. For example, health perspectives from Euro-centric versus South Asian contexts might require different wordings, workflows, and approaches in the proposed guidelines. This is a common challenge (ensuring comprehensive feedback from all possible viewpoints) for all empirical software engineering research. We have tried to engage a diverse range of participants to mitigate this issue as much as possible. This is the only version of the guidelines, and we plan to regularly update them to reflect changes in the eHealth apps and human aspects landscape.

An additional external threat to this study is the representativeness of the respondents during the evaluation of the guidelines. We had participants from 13 countries across five continents, with ages ranging from 21 to 60, academic qualifications from Diploma to Ph.D., and 1 to 15 years of experience in the app industry. Most of our participants worked in large and renowned companies worldwide. For example, 31.43% of our participants worked in an organization with over 1000 developers/software engineers. They also worked on 12 types of varying eHealth app development projects. Even then, our findings may not be general enough to capture all concepts and concerns. For example, most of our app developers were below 60 years old and might need support in understanding some guidelines presented in the Age section (under diverse user issues). We have an explicit understanding of such problems and the action required to reduce relative risk from our previous studies and works [10, 11, 13]. To further mitigate this threat, we asked participants to explicitly point out the issues with our guidelines, human aspects, and eHealth apps, including strengths, limitations, and suggestions they might have. To enhance cultural representation in future investigations, the following two key measures can be adopted: (i) Expanding survey dissemination efforts to reach culturally diverse regions and underrepresented communities through targeted collaborations with local organizations, universities, and industry professionals. (ii) Conducting both cross-regional and region-specific studies to capture cultural nuances and perspectives more comprehensively.

6.3 Internal Threats to Validity

The primary internal threat to this study is whether we have appropriately evaluated the proposed guidelines. We provided brief explanations for each question and asked participants to clarify their comments with examples when relevant. We included 'not applicable/other/no clue' options in our surveys and made most questions optional to help reduce this risk further. Even then, our findings may also be subject to interpretation and bias. To mitigate this, we discussed our interpretations among experts until a consensus was reached for each finding. Finally, we may have biased findings addressing only expert needs. To counter this, we included participants from various roles and localities and provided participants an option to articulate their opinions after each question in the survey. We also asked participants for suggestions, comments, and examples, including topics that may not have been highlighted.

7 FUTURE WORK

Although our proposed guidelines are based on extensive research and feedback from experts in the eHealth fields, the rapidly evolving eHealth app landscape and varying relative contexts may require further refinement and adaptation over time. While, overall results suggest that the proposd guidelines provide a valuable resource for developers, researchers, and other eHealth app stakeholders to emphasize human aspects, several potential areas of future work have emerged, which we outline and categorize below:

(i) Expanding guidelines for broader app categories: While our primary focus has been on eHealth apps, the universality of human aspects suggests that the proposed guidelines can potentially be adapted for other app categories, such as financial apps, educational apps, and mobile games. For example, understanding human aspects within financial apps can lead to the development of tools that better cater to users' financial behaviors, risk tolerances, and educational needs. This ensures that apps are not only secure but also user-friendly and effective in promoting financial literacy. In the context of educational apps, incorporating human aspects can enhance personalized learning experiences, adapt to different learning styles, and ensure the content remains engaging and interactive for users of varying age groups and educational backgrounds. Similarly, for mobile games, a deeper understanding of human aspects can significantly improve user engagement, tailor game mechanics to diverse user personas, and optimize the gaming experience to be both enjoyable and cognitively enriching. These future enhancement requires contextualizing and adapting the proposed guidelines to meet the unique challenges and requirements of the defined app category that is significantly different from eHealth apps but is still related.

(ii) Engaging with app development companies: The most significant outstanding future work of this project is engaging with app development companies to conduct observational studies for a set of current eHealth apps they develop with and without the proposed guidelines. This engagement will provide valuable insights into the practical implications of the proposed recommendations and their impact on various eHealth app development aspects. The learning will help to develop new app development processes and make existing techniques more efficient to address the related issues, identify outstanding human aspects, better understand how different human aspects impact the app stakeholders themselves, and how we might better address these aspects in the future eHealth apps. Additionally, such partnerships will facilitate the development of more comprehensive performance indicators to better measure the developed apps' effectiveness, user-friendliness, privacy, security, dependability, and overall quality. This will ultimately contribute to producing eHealth apps that better address diverse user needs and human aspects while maintaining user trust, rigorous standards, and quality compliance benchmarks.

(iii) Updating our proposed guidelines from use in practice: Key future work entails updating the proposed guidelines based on insights gained from industry collaborations and observational studies. In this regard, the primary actions include developing a set of tools derived from the guidelines to streamline their real-world implementation. This will further assist app developers with practical resources for incorporating human aspects in eHealth app projects. Simultaneously, the guidelines should be continually reviewed and updated in response to the evolving eHealth app landscape, ensuring their relevance, effectiveness, and adaptability to the changing user needs and stakeholder preferences.

(iv) Establishing a collaborative platform for co-design: Many eHealth apps seem to lack sufficient end user input into their design. A key future work is thus in establishing a collaborative platform for co-design and evaluation of eHealth apps that unite researchers, app developers, healthcare professionals, users, and related stakeholders. This collaboration will facilitate more comprehensive understanding of user trends, needs, preferences, and concerns. This will also lead to produce eHealth apps that better incorporate their stakeholder requirements, support seamless user-developers knowledge exchange, and easy sharing of best practices, eventually contribute to the advancement of human-centric eHealth app research and development.

8 SUMMARY

Appropriately incorporating human aspects in eHealth app design can lead to more effective apps and better user experience. Our proposed guidelines for integrating human aspects into eHealth apps encourages app developers and stakeholders to address these factors according to best practices and to optimize the app's overall quality. Our proposed guidelines emphasize user-centered design, usability, accessibility, reliability, validity, and diverse user issues in the eHealth app development process. The guidelines also include real-life eHealth app example scenarios to demonstrate how some key human aspects can be better addressed in practice. We presented analysis results from 35 survey responses to perform an initial validation of our proposed guidelines. The results show that our proposed guidelines are well-formulated to offer more human-centric and effective eHealth apps for their diverse user groups.

APPENDIX A: LIST OF KEY REPRESENTATIVE EHEALTH APPS

Table 5. Subset of key eHealth apps exclusively reviewed and their relevance to the proposed guidelines

App Name	eHealth Sub-domain	Description	Relevance to Guidelines (Adheres and Needs Improvement)
TeleDoc	Telemedicine and Remote Consultation	Offers remote consultations with clear instructions and varied input methods.	Adheres: A.1.a, A.2.a Needs: D.3.b
Wysa	Mental Health	Provides a chatbot that supports anxiety relief, depression, and stress management.	Adheres: D.5.a, U.1.c Needs: A.1.d
Healofy	Maternal Health, Parenting	Provides a platform for pregnancy, parenting, and women's health.	Adheres: D.4.a, R.1.a Needs: R.2.d
CDC Vaccine Sch.	Vaccination Management	Provides recommended immunization timelines for children, adolescents, and adults.	Adheres: A.1.g, R.2.c Needs: D.8.a
Health2Sync	Diabetes Management	Helps manage diabetes with tools for tracking blood sugar and health data.	Adheres: D.3.a, U.3.a Needs: D.4.b
MyFitnessPal	Diet & Exercise Tracking	Tracks calories, nutrition, and exercise to support health goals.	Adheres: U.2.b, A.2.d Needs: A.1.e
Headspace	Meditation & Mindfulness	Offers guided meditation and mindfulness sessions for stress, sleep, and focus.	Adheres: U.1.d, D.5.b Needs: D.3.c
Strava	Fitness & Social Networks	Tracks workouts with social features for sharing and competition.	Adheres: D.1.b, U.1.a Needs: R.2.e
Medisafe	Medication Management	Provides reminders for taking pills and tracking medication adherence.	Adheres: U.3.b, A.2.f Needs: A.1.f
Fitbit	Activity & Health Tracking	Integrates wearables to track activity, heart rate, sleep, and workouts.	Adheres: D.7.a, U.1.e Needs: D.2.a
Calm	Sleep/Meditation	Offers guided sessions, music, and stories for stress reduction.	Adheres: A.1.b, R.2.a Needs: A.2.g
Glow	Reproductive Health	Provides insights for tracking fertility, ovulation, periods, and pregnancy.	Adheres: D.2.b, D.6.a Needs: D.2.c
Kardia	Cardiac Health	Works with devices to monitor heart health, record ECGs, and detect heart conditions.	Adheres: R.1.b, R.2.c Needs: D.8.b
Noom	Weight Loss	Combines psychology-based coaching with food and exercise tracking to promote healthier habits.	Adheres: U.2.a, D.6.c Needs: A.2.c
Sleep Cycle	Sleep Tracking	Tracks sleep patterns and wakes users during their lightest sleep phase.	Adheres: D.5.d, U.3.d Needs: R.2.f
Pregnancy+	Pregnancy Tracking	Tracks pregnancy progress with updates, baby development insights, and personalized tools for expecting parents.	Adheres: D.1.a, D.7.b Needs: D.3.b
Couch to 5K	Fitness	Trains beginners to run 5K through guided workouts.	Adheres: A.2.e, D.5.c Needs: U.1.b
Endomondo	Fitness	Social & Tracks workouts with social features for motivation.	Adheres: D.4.a, U.3.c Needs: D.7.c
WebMD	Health Information	Provides medical information, symptom checkers, and tools for managing health conditions.	Adheres: R.1.c, D.3.c Needs: R.2.d
Habitica	Health Management	Gamifies task management, turning habits and to-do lists into a role-playing game.	Adheres: U.1.a, D.3.a Needs: D.7.e
MySugr	Diabetes (Gamified)	Tracks blood sugar, carbs, and insulin to simplify diabetes care.	Adheres: A.1.c, D.1.c Needs: A.2.b
Nudge	Health Data Integration	Combines lifestyle tracking and coaching to improve wellness habits.	Adheres: R.2.b, D.6.b Needs: D.5.a
Aaptiv	Workouts	Provides audio-guided workouts for various exercises.	Adheres: A.2.d, D.7.a Needs: U.2.c
Freeletics	Fitness	Offers AI-powered personalized workout plans and bodyweight exercises.	Adheres: U.1.d, D.5.b Needs: D.4.b

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