Developer and End-User Perspectives on Addressing Human Aspects in Mobile eHealth Apps

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Abstract

Context: eHealth apps are mobile apps that help in self-management of critical illnesses, provide home-based disease management, and help with personalized care. Users of eHealth apps are naturally very diverse in terms of their *human aspects*, e.g., their age, gender, emotional reactions to the apps, cognitive style, physical and mental challenges. Unfortunately, many eHealth apps do not take these user differences sufficiently into account, making them ineffective or even unusable.

Objective: This paper reports a study from eHealth app stakeholders' – developers and end-users – perspectives on critical challenges and benefits of better incorporating *human aspects* into eHealth app development and usage. We also investigate how different *human aspects* are being addressed by developers, which ones are the most important for different user groups, and which ones are currently missing/poorly handled.

Method: A mixed-method approach that integrates qualitative and quantitative research was used for this study. We gathered and analyzed data from 240 online survey responses and 25 detailed interviews within the same study and validated the results.

Results: We report key issues encountered in eHealth app design, difficulty in addressing different *human aspects*, areas requiring further research and practical assistance, and recommend our findings to best address these challenges. We found addressing *human aspects* throughout the app development life-cycle is beneficial for more effective eHealth apps. Our findings also suggest the need for improved standards and guidelines, better developer-user collaborative culture, and better *human aspects* education to produce more effective eHealth apps.

Conclusion: This paper investigates current approaches used in the eHealth app domain that take into account the *human aspects* of app users. The paper guides eHealth app stakeholders, future researchers, academia and industry partners be aware of *human aspects* related challenges and improve produce apps.

Keywords: eHealth App, Human Aspect, User Study, Development, Improved Support.

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1. Introduction

More than six billion smartphones exist in today's world, increasing over forty percent in the last four years [1, 2]. Mobile app usage for day-to-day purposes has also been increasing by over seven percent on average per year in the last three years [3]. In 2020, smartphone users downloaded 218 billion mobile apps from app repositories, up from 204 and 205 billion downloads in the past two years, respectively [4]. The revenue earned by these mobile apps exceeds $580 billion in 2021, raising over $119 billion from 2019, and expected to reach $935 billion in 2023 [5]. Among the huge number of such apps, health-related mobile applications – that we term '**eHealth apps**' in this paper – 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 [6]. 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. Furthermore, demand from health professionals to push monitoring, education and care-plan implementation further motivates eHealth app usage and development. However, developing an effective eHealth app is challenging. The typical challenges of eHealth app development include consideration of hardware constraints, network, events, frameworks and ecosystems and social and personal aspects, as described in the framework of [7]. Like all mobile applications, eHealth apps need to adhere to general standards and regulations, e.g., meet various hardware constraints and deal with the coding framework, ecosystem, and network issues. However, they must meet additional regulations due to the sensitive nature of health data, their use for health management and advice, and they also face distinct 'social and personal' challenges that some apps might not have. For instance, flashlight or calculator apps face fewer 'social and personal' challenges as they have straightforward functions and do not typically involve sensitive data or health advice and monitoring. In this study we focus on the '*social and personal*' challenges - particularly the *human aspects* that have significant impacts on how these apps are developed and used.

We define '***human aspects***' as key differing characteristics of human users, including age, culture, gender, cognitive ability, emotions, language, educational attainment, socioeconomic status, personality and related attributes. Other 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 [8]. Incorporating *human aspects* into the eHealth app development process is more 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, differing user cultures and socioeconomic backgrounds, and so on. Our recent systematic literature review [3] identified that *human aspects* and their impact on app development and usage requires further attention.

Consider an example eHealth app '*SleepNea*' [9], which helps clinicians to continuously monitor a sleep apnea patient's breathing and oxygen from a remote location. In the app, data needs to be updated continuously to provide real-time information. This information can be updated every minute or batch uploaded after an interval. Dealing with the sensor data and handling network issues are technical domain concerns. However, the design and working procedure of the app must deeply appreciate and address the *human aspects* of users i.e., differing physical and mental challenges. For example, app usage, data exchange through sensors, and use of the extra device should not affect the day-to-day lives of the patients, their families and friends, as well as clinicians and community workers. It also must address the technological proficiency and acceptance by different users with different cultures, languages, and ages than the app developers.

The development of the '*SleepNea*' app should also factor in differing emotional – both positive and negative — reactions to the app, e.g., up-to-date feedback and suggestion is potentially positive but being continuously monitored potentially negative. The accessibility of the solutions needs to be considered for people with physical tremors, poor eyesight, being wheel-chair bound, or with cognitive decline. The usability of this app for groups of people should also address the varied needs, incorporating the use of sensors and modified smartphone interface, accommodating different ages, genders, cultures and languages of users, including appropriate use of text, colors and symbols. This is particularly important as one-quarter of the elderly in Australia are non-native English speakers and the majority who are women, but by far, the majority of software developers are 20-something-year-old English-speaking men, the same as in the United States and dominant English-speaking countries [10]. eHealth app user personality differences may be important, e.g., those who want flexible dialogue with doctors compared to those needing directive suggestions from the app itself. The failure of developers to incorporate such *human aspects* in their eHealth apps can result in an app that is unsuitable for whom it is designed for by introducing confusing, possibly unsettling and invasive, and even potentially dangerous technology [8].

We wanted to find out how different *human aspects* are being addressed by eHealth app developers, which ones are the most important for different user groups, and which ones are currently missing/poorly handled. To do this, we conducted two online surveys targeting mobile app developers and eHealth app end-users. We received 240 usable survey responses from app developers and end-users. Our participants reside in 18 different countries across 5 continents, aged 21-to-80, speak 15 different languages, have qualifications ranging from high school to Ph.D., worked in more than 32 distinct professions, and have experience ranging from 1 to 15 years in app development and usage. We then interviewed 12 app developers and 13 end-users from varying domains, specializations and experience levels to more deeply understand and report the current industry perspective and user demands for *human aspects* in eHealth apps. Our findings will facilitate more effective eHealth app development and create new opportunities for software engineering researchers, app stakeholders and industry academia partners. The main contributions of this paper include:

- We report how app developers perceive varying *human aspects* during eHealth app design and development in practice, and how their app users view these same issues. We present the results from 25 detailed interviews and two online surveys having 240 usable responses.
- We found that *human aspects* dominate practical and effective eHealth app usages. However, several factors affect appropriate identification and incorporation of *human aspects* in eHealth apps, e.g., less research and education, poor practice culture, restrictions from vendors, expert shortage, insufficient technical support for developers, and disengagement of users from the development process.
- We identified and described how different *human aspects* impact different eHealth app development life-cycle phases. We then provide a set of findings aimed to help app developers to better address these aspects. This will also facilitate deploying and monitoring more human-centric eHealth apps in future market.

The rest of this paper is structured as follows: Section 2 introduces the research questions for our study, Section 3 describes related work, and Section 4 outlines the research methodologies we used. Section 5 presents our analysis of results to answer our primary research questions. We present an overall discussion and implications of our findings in Section 6, threats to validity in Section 7, and a summary with key future directions in Section 8.

2. Research Questions (RQs)

We guided our study with the following two key research questions:

RQ1: What are developer and user perceptions and needs regarding *human aspects* in eHealth apps?
To answer this research question, we wanted to explore developers' views on designing human-centric eHealth apps, and users' opinions whether their *human aspects* are sufficiently addressed in their eHealth apps. We also wanted to investigate which *human aspects* in eHealth apps are the most important for different user groups. We explore this question from the following perspectives:

- **Rationale**: We evaluated recent human-centered mobile app design and development literature to identify the motivation for addressing *human aspects*, corresponding market demands, and root cause of success or failure in the eHealth app domain.

- **Challenges**: We investigate what challenges our survey and interview developer participants faced in practice in human-centric eHealth app design and development. We also investigate the roles of development companies, sponsors, vendors, developers, and users to successfully incorporate *human aspects* in eHealth apps.

- **Impact**: We look into the impact of *human aspects* in eHealth apps to better understand the end-users needs for different aspects. We reported why some *human aspects* seem to be ignored in the current apps and their consequences. We also include our recommendation to address these in future eHealth app design, development and deployment.

RQ2: How are *human aspects* currently addressed in eHealth apps?
Answering this research question provides a big picture view of current practices, challenges, and approaches being used to address *human aspects* in eHealth apps. We investigated how addressing *human aspects* fit into the app development lifecycle, what are the priority areas to improve, and identified key recommendations from the following two perspectives:

- **Development Life Cycle**: We investigated how different *human aspects* fit into the app development life-cycle phases, e.g., requirements collection, solution design, implementation and evaluation. We then identified development practices, tools and techniques that worked well for addressing different *human aspects*. We also tried to understand the main challenges eHealth app users face from a human-centric perspective, get their feedback on key deficiencies with their current apps, and triangulate with the above findings.

- **Proficiency and Effectiveness**: We investigated how proficiently developers resolve human-centric design problems and relative gaps to improve the produced eHealth apps. For example, how some of the existing *human aspects*, such as disability/accessibility related issues can be addressed in the current environment and future protocol(s) design. We reported how different approaches facilitate effectively combining important *human aspects* into the eHealth app development, its analysis, evaluation, and usage.

3. Related Work

We performed a systematic literature review to identify current trends, gaps and future challenges for mobile app development approaches in [3]. One key outstanding challenge is to create apps that better address diverse end-user *human aspects*. We then evaluated several authenticated and widely used existing guidelines for developing eHealth apps to see how *human aspects* are addressed. We analyzed a selection of eHealth apps using against these current standards and guidelines. We collected 4 major medical dictionaries and extracted around a hundred thousand keywords to identify the development patterns, including *human aspects* in eHealth apps to see how these are addressed in current apps [11].

3.1. Current Approaches for Human Centric Mobile eHealth App Development, Analysis, Evaluation, and Usages

Our fellow researchers have published various surveys and literature review studies covering different topics in the mobile app ecosystem, including human-centric software development protocols and methods [3]. However, to the best of our knowledge, only a few of them consider eHealth apps as primary points of concern. We present some primary studies on *human aspects* in the eHealth app domain and discuss our findings from these studies below[1]:

In 2015, Zapata et al. [12] systematically reviewed usability for mHealth apps. Later in 2018, they proposed a requirement catalogue for usability specifications to develop and evaluate mHealth apps [13]. An approach to identify usability requirements and limitations in mHealth app design that combines information systems research framework and design thinking is presented in [14]. Baysari et al. [15] reviewed human factors methods applied to eHealth app design, development, and evaluation for patient-centered care coordination. Schnall et al. [16] proposed a user centred model for designing consumer mHealth apps that can incorporate feedback into the development process. In [17], a user study was carried out to investigate integration of mHealth in primary care and enhance doctor-patient communication. In [18], the impact of mHealth tools and frameworks for low-socioeconomic, racial, and ethnic minority groups was investigated.

A Health app assessment guidance was prepared by the New Zealand Ministry of Health wings focusing on two key areas [19]: (i) guidance for clinicians and consumers that include key points to consider for selecting an appropriate health app and evaluate the effectiveness of the health app, and (ii) guidance for app developers that include key points to consider before deciding to develop a new health app. The W3C/WAI guidelines [20] define *Accessibility* and summarizes its applicability for mobile platforms. World Health Organization (WHO) guideline [21] recommends several health system improvements by evaluating current evidence, especially on emerging digital and mobile health interventions that are contributing. Mobile App Rating Scale (MARS) [22] measures the quality of mobile health apps in a simple and reliable way. It provides a checklist for high-quality eHealth app design and development. First, it evaluates apps through two sources -app targets, and -theoretical strategies. Then, it evaluates engagement, functionality, aesthetics, information and recommendation for app quality measurement. We analyzed a set of eHealth apps using MARS guidelines to identify the pros, cons, gaps and enhancement possibilities. These results are publicly accessible from [11]. Study [23] investigate improving usability for older adult users in mobile health app context.

[1] A part of the work presented here is published in [9]

Table 1: Literature review sum-ups: Studied areas, gaps and recommendation

Categories	Studied in eHealth apps	Gaps indicated	Recommendations
End-users issues	Diverse user characteristics [28] e.g., age, gender, personality and emotions [29, 30], language [31], technology proficiency [32] etc.	Lack of adaptive interfaces, not addressing user diversity [8, 33].	Need multiple ways to interact with, different phrasing, different workflow.
App workflow process	Taps, mode (landscape vs. portrait), platforms, OS versions, resolution, content responsiveness and data fill-up [16, 34].	Aesthetic and minimalist design, less user control, inconsistent and low standards for content [16, 35].	Need to develop and evaluate eHealth apps for diverse users using appropriate methodologies.
App component usage	Text contrast, alternate text vs. images, links, form, labels, timeouts, sitemap, table and navigation [16, 36].	Display variance, undermine users, no/low repair support and lack of assistive technologies [8, 37, 38].	Emphasized the input modalities and specific need of target audiences during design, development and deployment (app usages).
User concerns	Security, privacy, dependability, robustness and trustworthiness [39].	Information processing, synchronization, platform and independence [37, 39].	Identify potential failures point beforehand to perform equally well even when unexpected events occur through a secured mechanism.
Other improvement areas	Presentation, functionality, ease of use, and performance [8, 40]	Guidance, problem diagnosis (for usages), and assistance to use [34]	Include resource-aware mechanisms that incur negligible overhead, are assistive for service and interactive.

Several studies have looked into end user *human aspects* impacting software design, implementation, and evaluation. Fazzini et al.[24] characterize a range of *human aspects* found in the reviews of COVID-19 apps. Alamo et al.[25] investigate the impact of various ageing user characteristics on mobile apps used for smart city applications. Holzinger et al. [26] discuss a range of design considerations for mobile app design targeting elderly users in general. Mak et al.[27] study design considerations for mobile apps in the education domain, specifically targeting different *human aspects* of children. However, none of these studies investigate *human aspects* in eHealth apps by integrating both end-user and developer perspectives. We decided that a more detailed and rigorous investigation of this area is needed. This necessity arises from the observation that each of these perspectives – user and developer – offers unique but incomplete on its own insights into the challenges and considerations in the eHealth app domain. Focusing solely on diverse end-user only needs of eHealth apps could yield impractical design suggestions. An exclusive emphasis on only developer viewpoints on human aspects of eHealth apps might overlook essential user needs, especially for end users quite different to typical developers (elderly, young, low socio-economic status, low language literacy, diverse culture etc). Thus, our research adopts an integrated approach to investigate both user and developer perspectives, thereby aiming to contribute to the development of eHealth apps that are both technically feasible and incorporate diverse human-centric needs.

Table 1 summarizes our literature review findings. We found that current approaches handle most *usability-related technical challenges* well, but there are inconsistencies in design techniques, and users feel they have little control [8, 9]. Researchers recommend that eHealth app development should follow usability-focused methodologies including task analysis, contextual analysis, multi-phase optimization, observational studies, and explore the association between the usage and behavioral outcomes [41]. Secondly, many current eHealth apps provide satisfactory accessible support for general users, mainly due to the guideline provided by vendors. However, *accessibility*

is often poor for vulnerable users, e.g. users with a medical condition or physical disabilities [42]. Thus the specific needs of target audiences during the design and development need further attention. Researchers have pointed out that the developers, manufacturers, and vendors assess app operation and security-related issues well for eHealth apps, *but performance evaluation for unanticipated events is partially ignored* [43]. The variety of health information or communication services at different levels in the *user community domain is often poorly handled*, especially the diversity of the eHealth app end-users e.g., age, gender variability, cognitive differences, socio-economic status, and cultural aspects are not well addressed [8, 42]. Researchers also pointed that resource-aware mechanisms that incur negligible overhead are needed for better user experiences [3, 9]. Overall, further investigation is required to incorporate these *human aspects* in eHealth apps [8].

4. Research Methodology

To answer our research questions (RQs) we designed two user studies, including two surveys and two sets of interviews. We obtained our Human Subject Ethics Committee approval for these studies (Project ID:25988 and Reference: 2021-25988-54639). Our user studies look at current user and developer engagement to support *human aspects* in eHealth app domain. We were particularly interested in getting user and developer insights for those developing apps for '*challenged*' end-users, e.g., those with physical or mental impairments; young or aging users; those with low socioeconomic status; those whose use of English language may be limited; and other vulnerable end-users. Our survey's primary focus was to gain a big picture view of current practices, challenges, and approaches being used to address the *human aspects* in this domain, impact of *human aspects* on eHealth app users and fundamental future needs. We were also interested in how users and developers take into account a range of *human aspects* in eHealth app, e.g., different end-user personalities, IT proficiency, emotional reactions to app-based solutions, cognitive approaches, age, gender, culture, level of engagement, human values, and so on.

- **Mobile app developers:** We surveyed mobile app developers experienced in different roles such as requirements/business analyst, front- and back-end developer, data analyst, database admin, quality assurance, control engineer, tester, team lead, project owners and managers.

- **eHealth app end-users:** We surveyed eHealth app end-users with different experience, e.g., medical practitioners, researchers, individuals with and without medical issues, business persons, architects, farmers, service holders, policymakers, and many more general eHealth app users with diverse demographic locations, cultures, ages and languages.

4.1. Research Approach: Qualitative and Quantitative Methods

We integrate qualitative and quantitative research methods, outlined in Figure 1. Initially, we defined the research scope of this study, designed our surveys and interviews, and obtained ethics approval. Secondly, we conducted two pilot studies among target populations. We then revised the study instruments as per the participants and experts suggestions and obtained ethics re-approval for our amendments. In the third stage, we conducted our online surveys and interviews, analyzed the collected quantitative and qualitative data within the same study, and validated the results. Our survey questionnaire and tentative interview guides are available in [44].

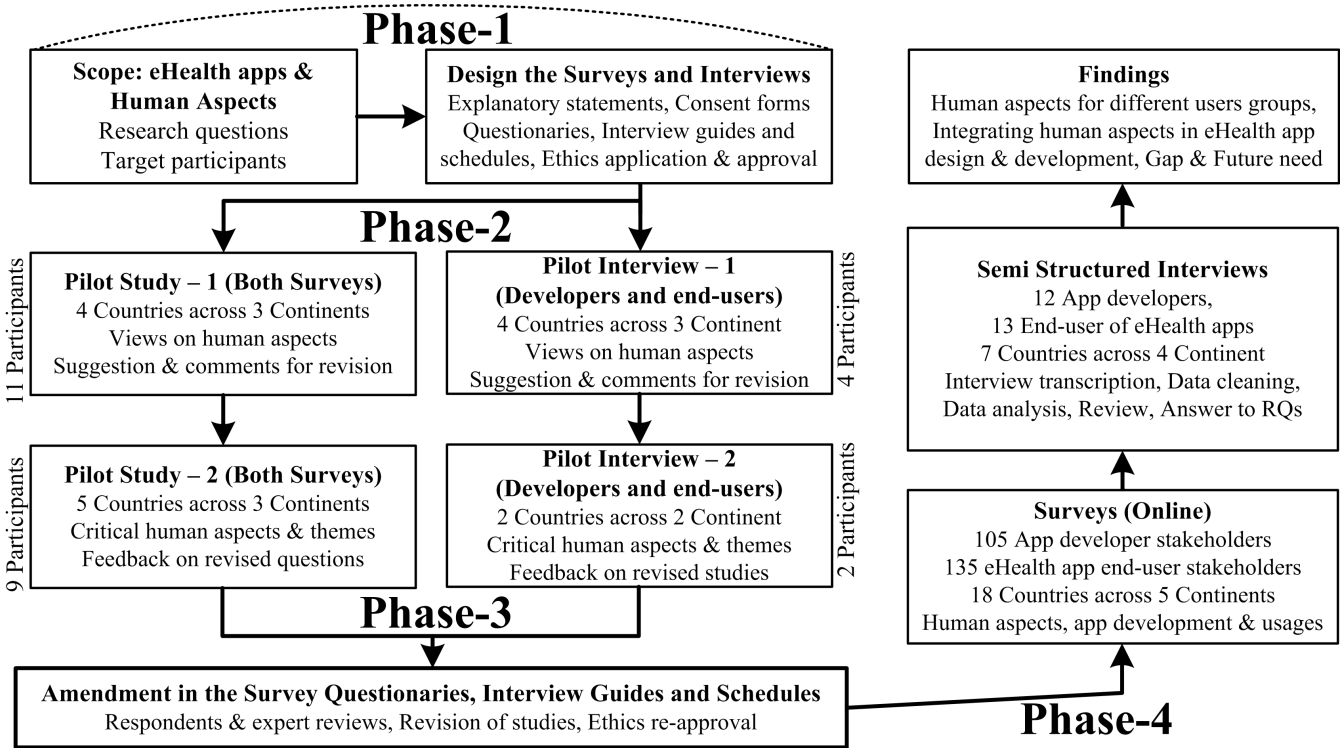


Figure 1: Diagram of the research methods used in this study

4.2. The Surveys

We designed two online surveys based on the guidelines provided by Kitchenham et al. [45]. The first survey focused on mobile app developers' issues in supporting *human aspects* in eHealth apps, including suggestions and recommendations for future improvements. The second survey aimed to find critical end-user matters in the current eHealth apps usages and associated future needs.

In both surveys, we collected respondents' demographic information to decide whether had we reached our target audience, how close the collected samples represent the target population, and differentiate between participants' sub-groups, but no identifying information was collected. We then assisted the respondents by defining what we mean by the eHealth app and *human aspects* (discussed earlier in Section 1) and collected their views on *human aspects* in eHealth apps using multiple choice and open answer questions. The multiple-choice question answers helped us to structure the findings, identify statistical significance and differences for different aspects. Participant answers to open-ended questions allow 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 the required actions.

4.2.1. Survey Participants

We distributed the app developer survey link among our own software development network, our contacts with large software developer networks, and professionals from renowned software development companies worldwide. We also requested them to disseminate our survey links to their contacts and colleagues. For the end-users, we sent our survey link to our contacts who have large networks in health, education, business and service domains. We also shared the survey links via our social media channels to reach diverse participants. During the recruitment and in the surveys, no identifying information was collected from the respondents.

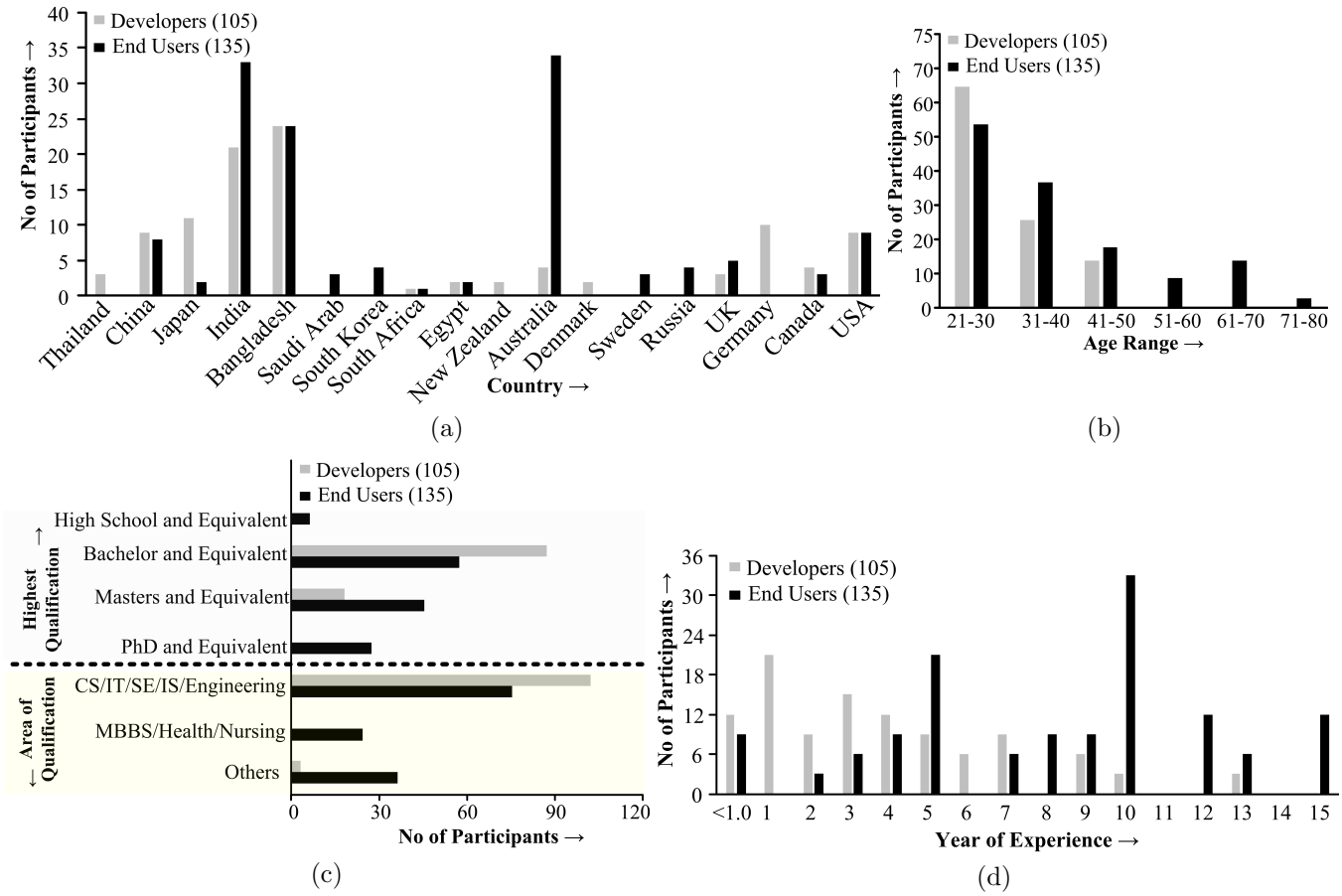


Figure 2: Distribution of our survey participants – (a) Locations (b) Age range (c) Academic qualification (d) Experience in app development and usages

We had over 400 online survey responses, but we excluded incomplete responses (bounce rate 23.25%), responses that had no direct or indirect eHealth app-related work/use experiences, as well as those with unusual response patterns (67 respondents). These participants skipped most of the survey questions and seldom included open text answers. Finally, we ended up with 240 valid responses for our analysis. The 240 respondents reside in 18 countries across five different continents. We check for possible duplicate responses (same demographics, very similar open answer text response) but found no obvious duplicate responses.

Figure 2 (a) shows the demographic location distribution of participants. Of the 240 respondents, 70% were male (90 developers, 78 end-users), 26.25% were female (9 developers, 54 end-users), and 3.75% were non-binary or preferred not to respond (6 developers, 3 end-users). Figure 2 (b) shows participants' age distribution. Most developers' age ranges are between 21-40 (87.67%, 92 participants), and the rest are aged 51 or below (13 participants). In contrast, end-users' age ranges are between 21-80, where 67.4% (91 participants) are between 21-40, 13.33% (18 participants) are between 41-50, and the remaining 26 participants (19.25%) were over 50 years old.

Figure 2(c) shows the academic qualification distribution of survey participants. We found all developers either have a bachelor's or master's degree in Computer Science (CS), Information Science (IS), Information Technology (IT), or Software Engineering (SE), except three who had Master's degrees in Mathematics. 24 end-users participants have degrees in medical fields such as MBBS, Nursing and Health Science; and 26.67% (36 participants) are from other areas such as Physics, Chemistry, Art, Finance and Agriculture. Most end-users have Bachelor's or Master's degrees (75.56%, 102 participants), one-fifth (27 participants) completed their Ph.D., and the rest

(6 participants) completed high school or equivalent education. Figure 2(d) shows the experiences of survey participants in developing or using mobile apps. The maximum development experience among app developers is 13 years. For end-users, it is up to 15 years in app usage. Most participants have experience between 4-10 years. We found twelve developers and nine end-users have limited experience (<1 year) in this domain.

4.3. The Interviews

We selectively interviewed two key participant groups to find out more details on *human aspects* that impact current eHealth app development and usage. The interviews were designed based on [46] guideline for qualitative research methods in empirical software engineering. In the interviews, we tried to better understand stakeholders challenges in addressing these *human aspects* from a human-centric perspective, get feedback on key deficiencies with the current apps they try and use, and triangulate with our survey findings. The idea was to enhance the broad picture obtained from the surveys to drill down to more specific information.

4.3.1. Interview Participants

We recruited app developer interviewees experienced in different domains, such as front-end development, back-end development, data processing, quality assurance, and project management, all of whom consented during answering of our survey to further interviews. For the end-user interviewees, we chose various types of end-users of eHealth apps, including policy makers, medical practitioners, admin personnel, business personnel, and general users from diverse age groups, cultural backgrounds, and socioeconomic statuses who agreed during the survey to be interviewed. We purposely recruited these participants to better understand their views and needs regarding *human aspects* in eHealth apps and to recognize how they are currently addressed.

Our 25 interviewees reside in 7 countries across four different continents. Figure 3 (a) shows interview participant's demographics location distributions. Of the 25 respondents, 72% were male (10 developers, 8 end-users) and 28% were female (2 developers, 5 end-users). Figure 3 (b) shows the distribution of the age ranges of the interviewees. The developers' age ranges are between 21-40, and the end-users age ranges are between 21-70, where 61.54% are between 21-40 and 5 participants were over 41 years old.

Figure 3(c) shows the interviewees' academic qualifications. We found most developers (83.83%) have a bachelor's degree in CS/IT/SE, except two who had their Masters degree in CS. Many end-users had IT and related training (61.54%). 23.08% of users have their degree in medical fields such as MBBS, Nursing and Health Science; and the rest are from other areas. Among the interviewees, 4 participants have completed their Ph.D., 2 completed their High School, and rest have bachelor or masters equivalent degrees.

Figure 3(d) shows the experiences of interviewees in developing and using mobile apps for two participant groups. The maximum experience of app developers in developing a mobile app is 7 years, whereas, for end-users, eHealth app usage experience is 10 years. Most developers had between 3-5 years (66.67%) and end-users had between 5-10 years (69.23%) of experience. We found two developers and two end-user had less than 2 years but more than 1 year experiences.

4.3.2. Interview Process

The first author conducted a series of interviews with the 32 participants, 16 from each group. However, we excluded seven responses from reporting in our results analysis, as it turned out that these participants had very limited or no eHealth app-related work/use experiences. The interviews were semi-structured, all the questions were open-ended and each interview was completed in around 50-60 minutes. Interviews consisted of the following four parts:

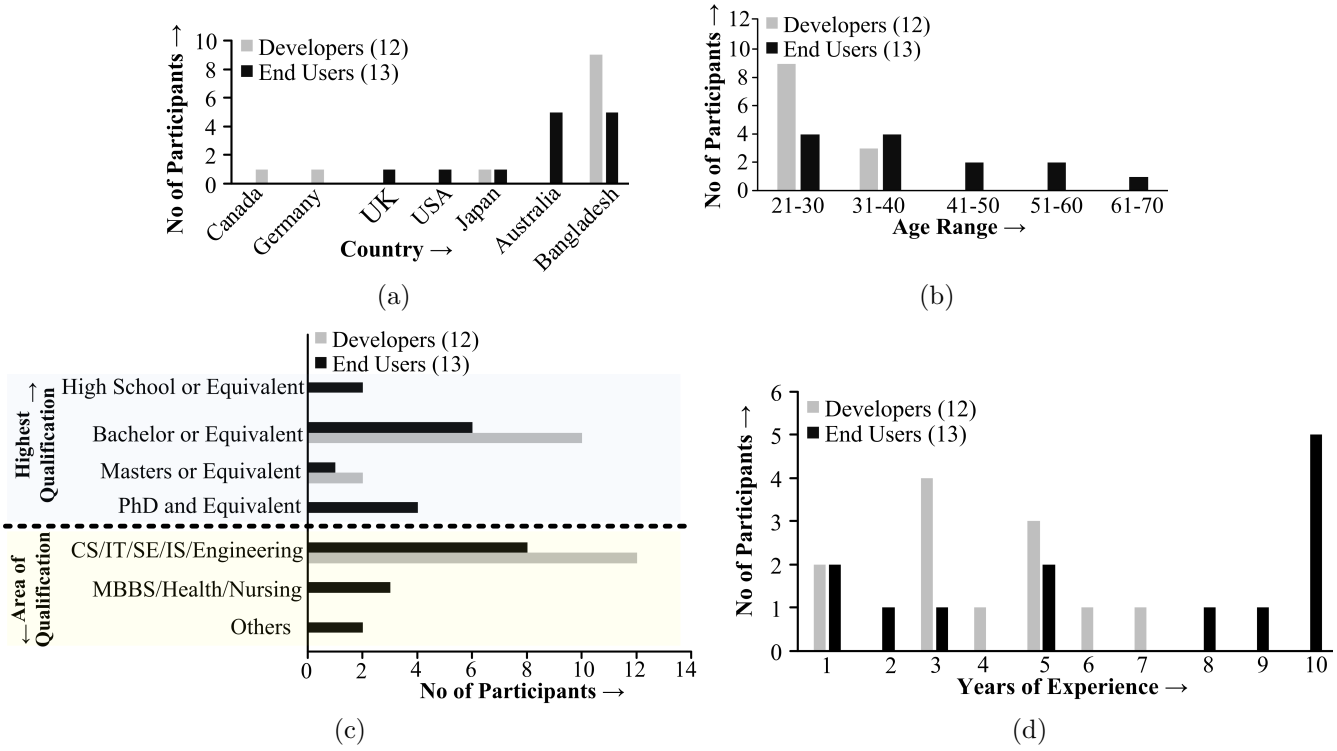


Figure 3: Distribution of the interviewees – (a) Locations (b) Age range, (c) Academic qualification (d) Experience in app development (for developers) and app usages (for end-users)

- We asked some demographic questions including experience in eHealth app development and usage. Then, we asked the app developers to pick a mobile app development project they have worked on and discuss the human-centric challenges related to the project. Similarly, we asked the end-users to pick a mobile app they had used/know well and to discuss the observed and missing human-centric characteristics, including their impact.

- Secondly, we tried to identify when app developers found key *human aspects* mentioned in part 1, specifically which aspects were found during which phase of app development and who highlighted them. We asked when end-users noticed *human aspects* related issues in a different part of the app, e.g., UI, design, working process, recommendation/outcome.

- We then asked for their opinions as to what they perceive as 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 it. In contrast, we asked the end-users how their friends and family talk about*human aspects* in eHealth apps, do they use additional hardware, IoT devices or plugins to help address *human aspects* in eHealth app usages.

- We ended the interview asking all participants for their suggestions and comments about the interview, eHealth apps in general, and *human aspects* impacting eHealth apps in particular.

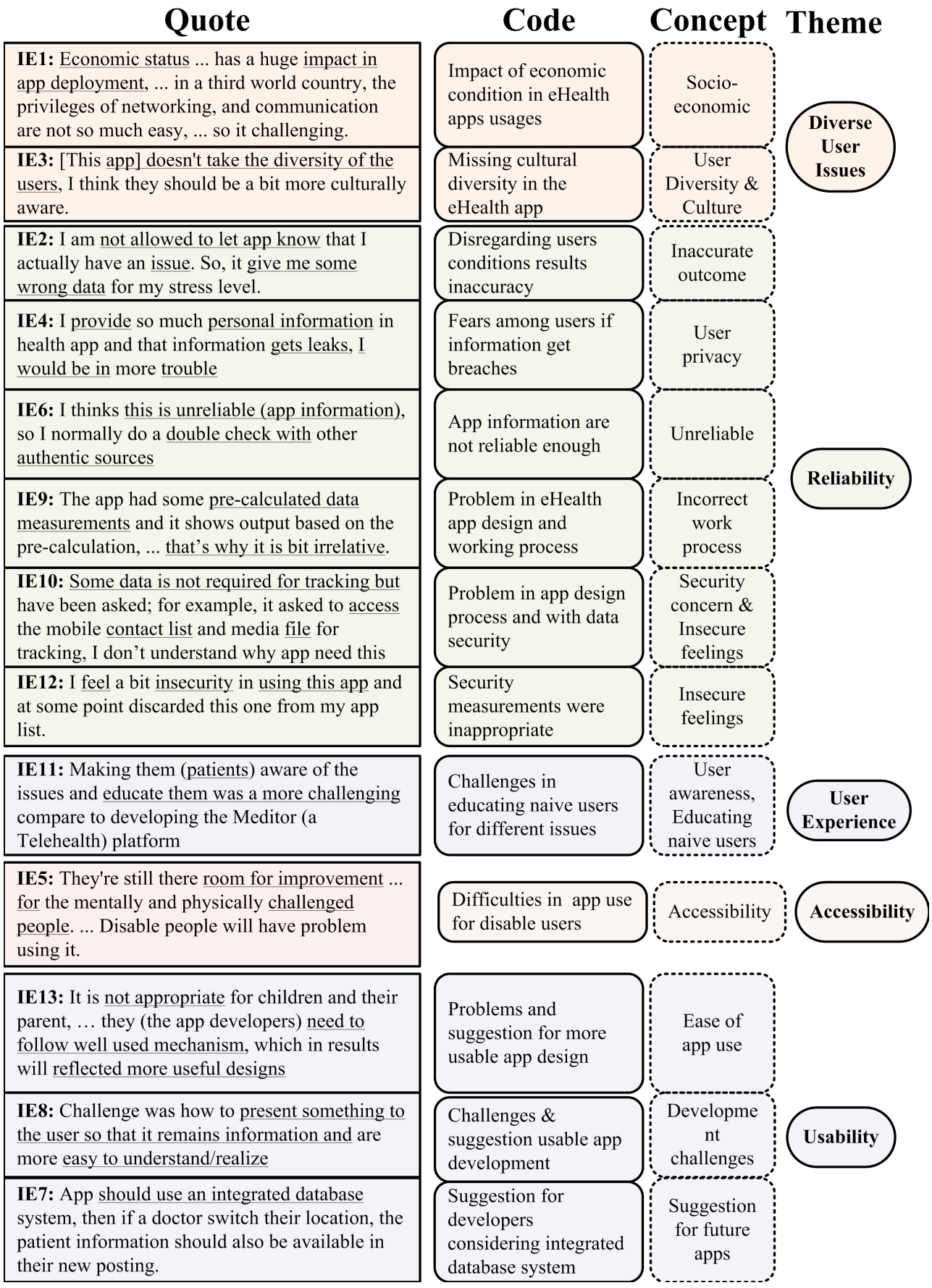


Figure 4: The steps followed for our study qualitative data analysis

4.3.3. Interview Data Analysis

We transcribed interview recordings using a secure commercial transcription service (Otter.ai). The first author cleaned the transcripts and coded the contents of the interviews using qualitative data analysis software (NVivo). Despite these measures, a few errors may remain in the transcripts, which highlight the potential benefits of human transcription compared to automated ones.

We combined thematic analysis with open coding to identify themes as underlying codes emerged. We categorized the textual interview data into codes that generate concepts and categories by comparing open-ended answers. For example, when we asked for views on *human aspects* in an eHealth app, end user interviewees discussed a few challenges they experienced, difficulties with the system, and *human aspects* they wanted to accommodate.

Figure 4 illustrates how we analysed and merged some quotes to form our codes, then code into concepts (sub-themes), and concepts into categories (higher level themes) for the questions. For example, the quote from IE2 *"I am not allowed to let app know that I actually have an issue. So, it give me some wrong data for my stress level."* was coded into 'disregarding user conditions results inaccuracy' which matches the concepts (sub-theme) 'Inaccurate outcome', which was then linked to the higher-level theme 'Reliability'. Similarly, quotes from IE4, IE6, IE9, IE10, and IE12 were also linked to the theme 'Reliability'. Due to the ethical constraints of this study, we are unable to share the raw transcripts of our interviews to protect the privacy and confidentiality of our participants. However, we made our codebook publicly available in [44] to provide some insight into our coding process.

In between transcription and analysis, we invited two research fellows 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 industries, specializing in digital health and software engineering. The first author analyzed the codes and sorted the generated code into potential themes. All authors then discussed expert researchers' suggestions with the revised analysis to agree on the differences. We considered the code list as stable when the concepts and themes reached saturation and no new code appears. To reduce bias, all the authors reviewed and settled on the final set of themes after three alterations. The themes were chosen after the analysis finished. We also dropped sentences during the coding process unrelated to mobile app development, app usages and *human aspects*.

5. Study Results

This section initially presents the pilot study results in Section 5.1. Then, our findings to answer the RQ1 and RQ2 based on the survey and interview data analysis are presented in Section 5.2 and Section 5.3, respectively. We present relevant statistics from the survey responses to highlight statistical significance and differences about the impact of *human aspects* in eHealth apps. We also present detailed analysis results of the open-ended survey questions and interviews. We highlight future needs in this domain and present a set of recommendations for research and practice.

5.1. Pilot Study Results

In August 2020, we conducted a first pilot run of our developer and end-user surveys among five developers and six end-users, respectively. Similar to our actual surveys (discussed in Section 4.2), we initially collected respondents' demographic information and their views on *human aspects* in eHealth apps. We informed the respondents that these were pilot studies and expected their suggestions, comments and corrections for future adjustments. We received feedback about the questionnaire formation and clarification on different concepts. Four out of five developers suggested that questions asking for '*consideration for human aspects in the eHealth app developments*'

Table 2: Summarized results of the pilot surveys

Criterion		Pilot Study-1		Pilot Study-2	
		Developers	**End-Users**	**Developers**	**End-Users**
Ethnographic Information	Countries	Australia (20%), Bangladesh (60%), Canada (20%)	Australia (16.67%), Bangladesh (50%), Japan (33.33%)	Australia (25%), Bangladesh (50%), Canada (25%)	Australia (40%), Bangladesh (20%), Italy (20%), UK (20%)
	Age groups	21-30 (20%), 31-40 (80%)	21-30 (66.67%), 31-40 (33.33%)	21-30 (50%), 31-40 (25%), 51-60 (25%)	21-30 (40%), 31-40 (40%), 61-70 (20%)
	Gender	Male (60%), Female (40%)	Male (66.67%), Female (16.67%), N/A (16.67%)	Male (75%), Female (25%)	Male (40%), Female (40%), Non-binary (20%)
	Qualification	BSc (100%)	MBBS (33.33%), BSc (33.33%), MS (33.33%)	Diploma (25%), BSc (75%)	Secondary (20%), MBBS (20%), BA (20%), PhD (40%)
	Experience	4+ years on average (development)	6+ years on average (usages)	6+ years on average (development)	7+ years on average (usages)
***Human Aspects* & eHealth**	*Human aspects* demands	Absolutely Essential: 70%, Important: 30%	Absolutely Essential: 73.33%, Important: 10%, N/A: 16.67%	Absolutely Essential: 78.57%, Important: 21.42%	Absolutely Essential: 57.14%, Important: 14.28%, N/A: 14.28%
	Issues pointed via open ended questions, comments and suggestion	*Accessibility* and *Usability* are most important *human aspects*, young users are more adaptive to app usages than the older adult, app should comply current practice and account user feedback.	Data privacy and security are of significant concerns, precise and reliable health information should be advised during app usages, app presentation largely motivate users.	Emphasize *Accessibility*, tutorials smoothen app usages for understanding app features or functionalities, improved prototyping schemes are needed for future health apps.	Should be authorized or check with hospital/clinic before suggesting health advice, especially in critical conditions, alerts/notification help users, need more automated services.

and '*critical human aspects for practical usages of the eHealth apps*' can be merged to a single question to collect both detailed and boarder responses. Similarly, three end-users suggested to merge '*Impact of human aspects in eHealth apps*' and '*effective app usage and recommendation*' questions. Seven out of eleven respondents suggested including definitions for eHealth app and *human aspects*.

In late-September 2020, we performed a second pilot run among a different set of four developers and five end-users to collect their views on revised surveys. We found the surveys were much more stable and did not receive any comments about survey questions reformation. However, we received suggestions from six of the respondents to define concepts of reliability, accessibility, usability, diverse user issues, and user experience, similar to the eHealth app and human aspect definitions. Two developers and one end-user suggested including N/A options for the direct questions. Interestingly, one end-user suggested collecting other forms of communication for those willing to be interviewed but do not have/access email.

Table 2 summarizes collected responses from our pilot surveys. In the pilot runs, respondents over six different countries stated that *human aspects* in eHealth apps are essential, but need further attention. The respondents were satisfied with current apps' resourcefulness but were less satisfied with adaptive service, user interface and security. We conducted six pilot interviews among three mobile app developers and three end-users. Overall, participants were satisfied with interview structures and schedules. They mentioned that most questions were open-ended and the topic

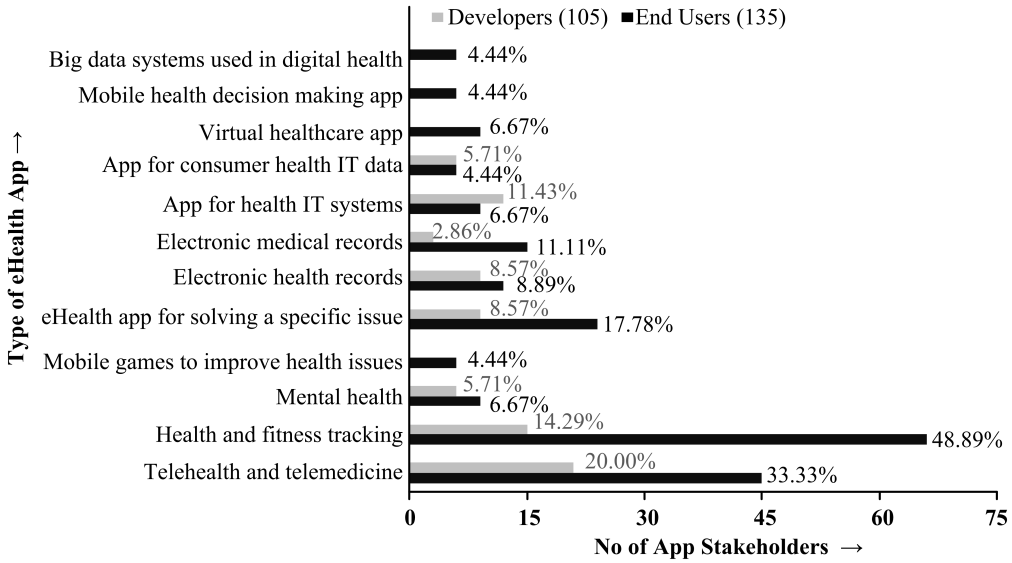


Figure 5: Types of eHealth app that users have used and development projects that developers have worked on

seems easy to follow once someone completed the survey, but requires prior expertise in these domains. Interviewees also said that the interview sub-topics were sequentially aligned, which helped them to provide comparative examples. The end-user interviewees were primarily concerned about diverse user issues and discussed several related sub-problems. In contrast, developers interviewees mentioned that the UI/UX-related issues were more complicated to incorporate in current eHealth apps.

We revised our instruments as per pilot participant suggestions and obtained ethics approval for these changes. We launched our surveys publicly in February 2021, following re-approval for our amended instruments, and continued data collection until May 2021. Please note that the collected responses from the pilot studies have already been published in [9] and are excluded from the presented results in the rest of this section.

5.2. RQ1: What Are Developer and User Perceptions and Needs Regarding Human Aspects in eHealth Apps?

Types of e-Health apps: We found that 81.90% of our participants have familiarity with eHealth app through development projects (developers) and daily usage (end-users). We found our end-users used 12 types of eHealth apps, whereas our developers said they had worked on 8 kinds of eHealth app development projects. The distribution is shown in Figure 5. The end-user survey participants mentioned that an eHealth app helps them to manage their health care system more efficiently, whereas developers mentioned that eHealth apps have more business value, but designing and developing an effective app is more challenging than many other types of apps.

Key human aspects in e-Health apps: We asked the survey participants which *human aspects* need to be supported in eHealth apps and what aspects they think are mostly affected, including assessed/experienced issues – for developers in their development projects and –for end-users in the apps they used. The distribution of the key impacted areas is shown in Figure 6. We found most respondents were concerned about the reliability, user experiences and diverse user issues of their eHealth apps. Furthermore, participants grouped 'app availability', 'automatic user identification' and 'support decision making' under other *human aspects* for eHealth apps.

We received 171 comments from the surveys and 352 statements from the interviewees related to *human aspects* impacting eHealth apps. We merged these statements to 7 high-level groupings,

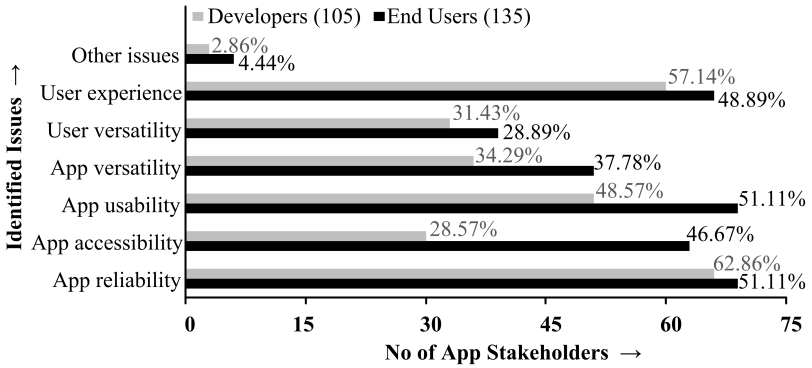


Figure 6: Distribution of key *human aspects* pointed by the survey participants

as shown in Figure 6 and 12 sub-classes that are discussed later in this section. We visualize interviewees' statement patterns in Figure 7 using two hierarchy charts. The sizes of nested rectangles in this chart represent the amount of coding, corresponding attribute values with reference. For example, we sorted 39 statements from 11 end-user interviewees[2] about *User Experiences* in eHealth apps, among which 23 are directly coded and 16 are aggregated from sub-themes *Comfort* and *Correctness*. Thus, *Comfort* and *Correctness* are grouped within the *User Experience*.

5.2.1. Diverse user issues

Diverse User Issues in eHealth apps we define in this work as the app's ability to effectively meet the needs of a wide range of users e.g., those with varying language proficiency, socioeconomic status, educational level, cognitive style, physical and mental challenges, gender, age, personality, and many more [8, 9, 47]. This also includes catering to various user requirements by appropriately integrating different technologies, methods, and practices [15]. Thus, a fundamental need from eHealth apps is to appropriately address the diversity of their user base. We received more than 100 statements from interviewees and 159 survey comments about this aspect and merged it into '*diverse user issues*' class having 12 sub-classes, as shown in Figure 7. We extracted survey respondents' experiences with these 12 issues, shown in Figure 8. Key *human aspects* include users' *age*, *accessibility needs*, *physical and mental challenges*, *technological comforts*, and *language proficiency* were highly reported. The other issue (sub-class) includes *emotional reaction of the users*, *limited education*, *social values*, and *support in working conditions*.

i. User age: We found two-thirds of survey respondents considered issues related to elderly users need to be more appropriately addressed in future eHealth apps. In addition, 24 developers pointed that they have had to explicitly (always) address the needs of younger users during an app development project. 21 end-users agree with this (always). We found 13 direct and 58 aggregated statements about age-related issues in eHealth apps from the interviewees, where 28 comments directly pointed to elderly user issues and 17 comments directly pointed to issues related to the young users. Developer interviewees described the differences in different age groups, corresponding interests and how they managed such challenges in their project.

In contrast, end-user interviewees mentioned the problems they faced which need to be resolved for effective app usage. For example:

'*For the children and older users, if the app use some sort of related icons than actual text for*

[2]We use IE, ID, SE, and SD throughout the paper to refer end-user interviewees, developer interviewees, end-user survey respondents, and developers survey respondents, respectively.

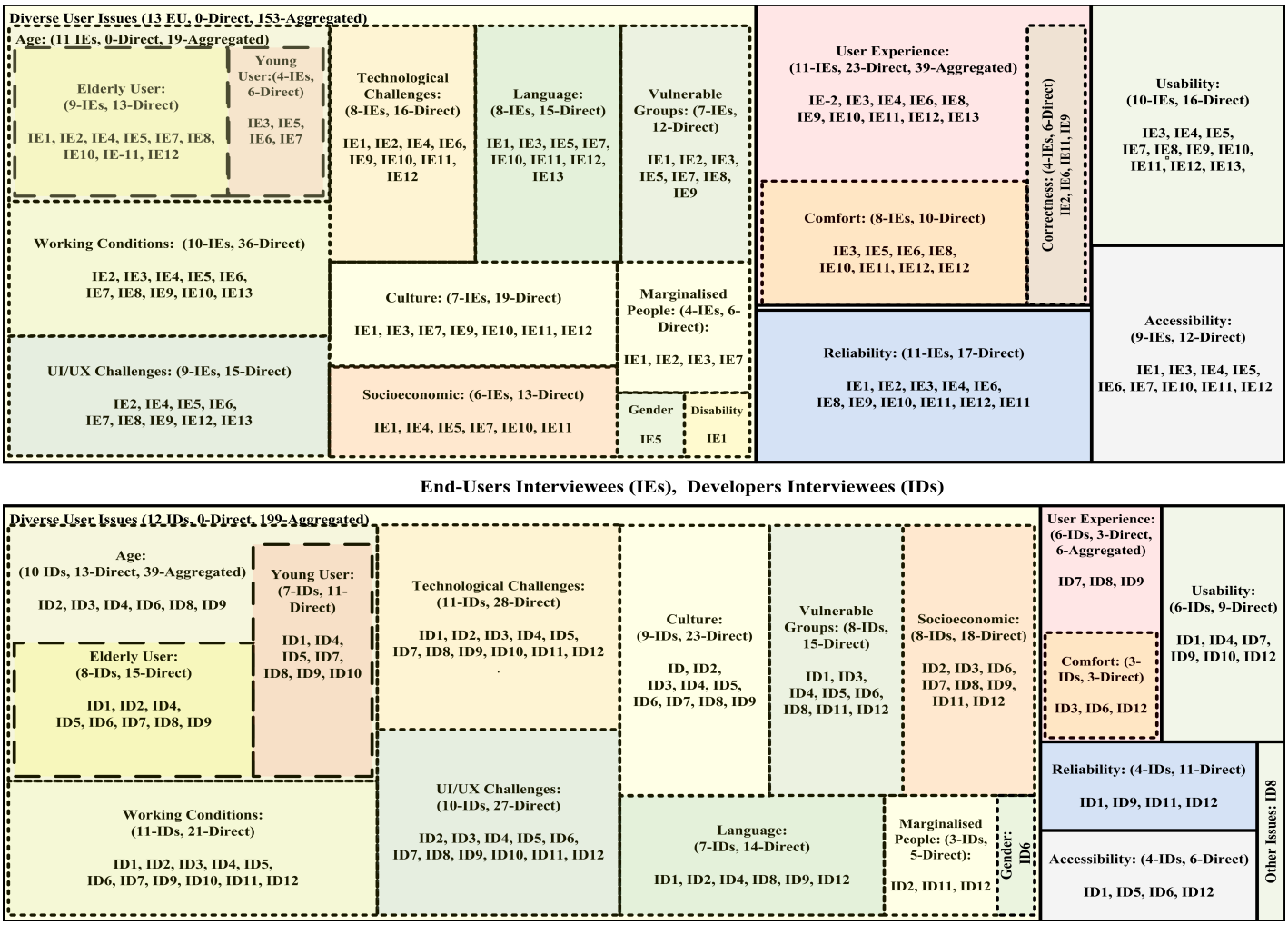


Figure 7: Hierarchy charts representing interviewees' statements for answering RQ1

different symptoms, ... then it would be much easy for them.' [IE7 - Medical Practitioner (Doctor)]

'*Problems our app had is for a little bit aged user, because it is not like a news portal or game or something they [users] are mostly familiar with.*' [ID4 - Software Architect]

'*For children it was quite difficult to explain the app work process... we needed to rethink how we can effectively explain our app to children so that they feel interest on basic sanitation process ... we use some comic characters, as we think children will love cartoon characters. But during test[ing] it conflict with other [elder] client interest.*' [ID7 - Software Engineer & UX Specialist]

> Developers often provide identical app design and workflow for all age users, which negatively impacts eHealth app usage, because users come from a wide range of ages and do not share the same interests and understandings.

ii. Language: More than half of the survey participants reported language-proficiency and language mismatch between developers and end-users is a primary concern with current eHealth apps. We found that 42.85% of developers have experienced this problem in their eHealth app projects, whereas 35.55% of end-users marked that they were in discomfort due to the language-related issues. We found 29 direct statements from the 15 interviewees about this issue. Developer interviewees

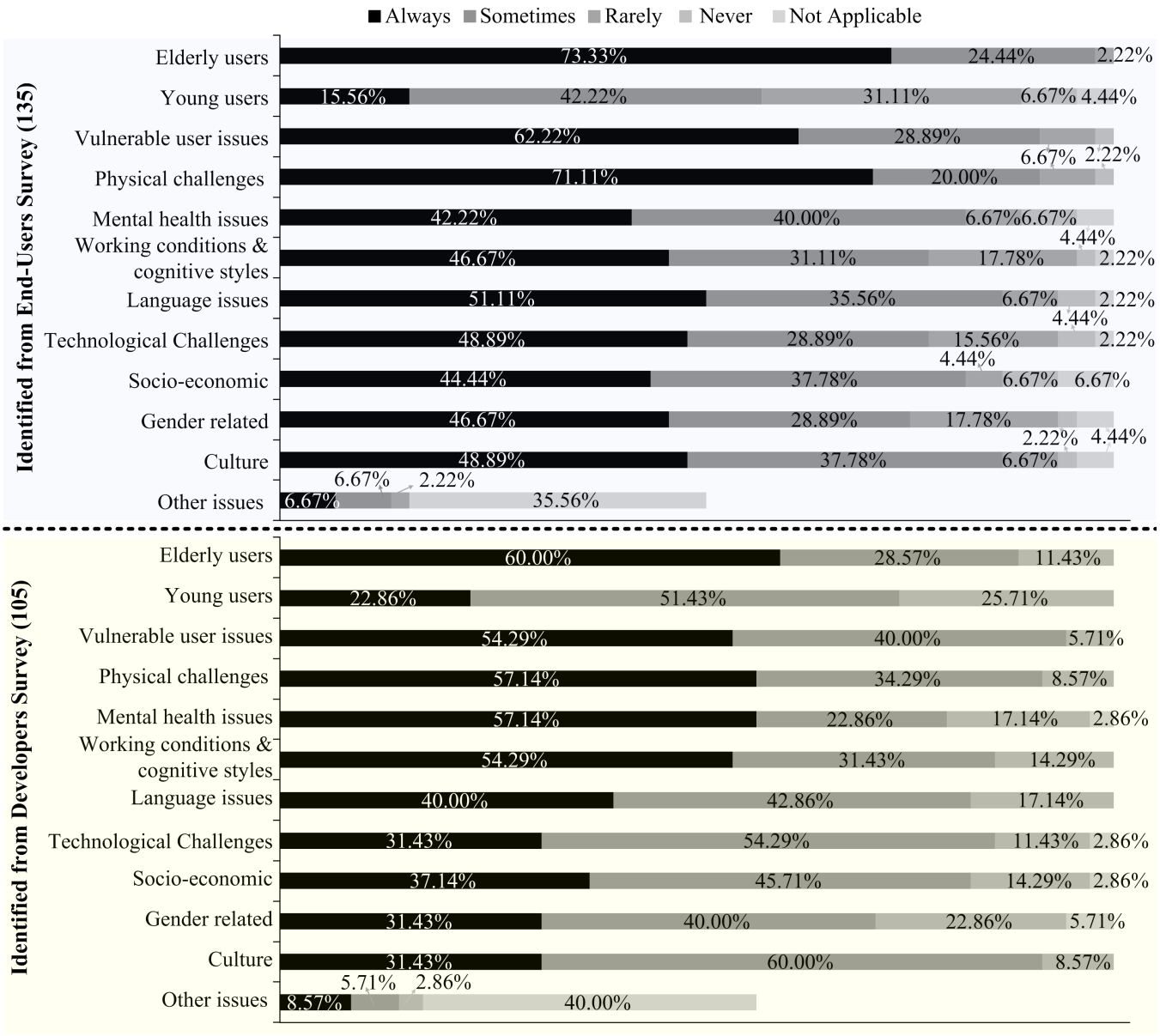


Figure 8: Sub-classes of diverse user issues in the eHealth app that survey respondents have pointed

mentioned that generally they provide multilingual support in the app through third-party APIs, which are not always up to the mark. Most end-users said that automatic language translation sometimes creates confusion about the meaning, and three mentioned that language structure in eHealth apps was sometimes too complex to understand:

'*Government realized earlier last year that cultural minorities don't get the messages, and they tried to translate information in multiple languages. Sometimes I get messages about COVID in Russian [in app]. I don't know who translates them, we just don't speak Russian this way. ... they [developers] use Translator software or some auto approach to do this, but I can tell you, some of the messages are even more confusing than if they were in English.*' [IE3 - Academician (Professor)]

'*Problem we found over using the apps are related to language structure ... when consulting patient, sometime they unable to let us [doctor] know what was actual problem they observed. This not due to English, but due to technical language used in the apps'.* [IE7 - Medical Practitioner (Doctor)]

Most end-users suggested that eHealth apps' information should be presented straightforwardly, avoiding complex structure and technical terms. App developers generally use automated translation services to provide multilingual support, but this does not always correctly translate a complete sentence meaningfully and can confuse users.

iii. Culture: Over 200 survey respondents reported that cultural issues may significantly impact eHealth app usage. We found 42 statements from the 16 interviewees on cultural matters in eHealth apps. Our developer interviewees mentioned that they try to coordinate with cultural issues incorporating changes in design techniques. However, we found that the impact of culture in the eHealth app still has had less attention than others. Our end-user interviewees mentioned that culturally aware eHealth app would be much more effective. They also said that if the development team contains diverse developers from different demographics and positions, they will adjust to some issues inherently. Nine developer interviewees strongly agree that diverse stakeholder involvement in app development will help developing more culturally aware eHealth apps:

'*If you want to develop a culturally aware tool, you have to work with communities. ... eHealth apps offered by the companies say from Eastern Europe or Middle East or those from English speaking countries, they all kind of have stereotypical view of the users. Every user that they assume have the same language command, the same interface preferences. ... It's kind of limiting the choices that people have. ... this is due to not having enough diversity in the development team. ... If the team involve people from different cultural backgrounds, age, gender, then they would bring those diversities into the apps just naturally.*' [IE3 - Academician (Professor)]

'*In Germany, how the app based solution impact people, it will be not be same in Australia... [we found] acceptance level of our app depends on the locality need and [followed] culture... We gather cultural information that differs and then design the app accordingly.*' [ID8 - Software Engineer]

'*We use slightly different user interface for that app [ride sharing app] based on different country where it is in use, ... in Malaysia, it is more like of green colour as Malaysian people like it, whereas in Singapore, it is more like aesthetic and flashy.*' [ID9 - Senior Software Engineer]

Many eHealth app users have different cultural expectations. Our participants pointed out three levels of anticipation, i.e., individual, family, and communities, to adopt for developing culturally aware human-centric eHealth apps. Developers primarily handle cultural and locality needs through different designs in app interface elements and workflows.

iv. Socio-economic: We asked respondents about the issues in eHealth apps associated with the social standing of the users. 82.85% of our developers and 78.57% of our survey respondents reported that issues related to education, living situation, income and occupation of users impact eHealth apps. We found 13 statements from 6 end-users and 18 statements from 8 developers about this issues. Our interviewees mentioned that people from low socioeconomic groups need more services from eHealth apps, but they are not convinced to use these apps. Suitable advertisements and governments initiative can help to improve this situation. One developer pointed that ignoring financial circumstances of the users in app design resulted in customer loss and a lot of harm to the organization's reputation:

'*Privileges of communication are not so easy for people who live remote areas [in third world countries]... and user living situation always a challenging issue for this [effective app usages].* ' [IE1 - Medical Practitioner (Doctor)]

'*Most of our people are still unaware about apps can help them with health issues. ... I think their living situation don't allow them to do so,... if we able to convinced them, they will use the [eHealth] app, ... like in Covid time, they did.*' [IE5 - Service Holders (HR)]

'*These people [lower socio-economic group] needs low cost health services. Here eHealth app can be a good solutions.*' [ID2 - Team Lead & Requirements Analyst]

'*One of our largest demographic users were from Indonesia, most ... cannot afford a good mobile phone that support all the things of our app. In lower configuration devices ... our application ... got out of memory and app closes automatically. ... we did not actually put attention about the size of the app initially. So, a lot of crash report comes in... that has a huge negative impact...*' [ID9 - Senior Software Engineer]

Generally, low socioeconomic groups less aware of the importance of eHealth apps and have insufficient access to newer handsets, high bandwidth networks and related resources. Ignoring the socio-economic situation of users in eHealth app development process can cause failure.

v. Technological acceptance challenges: We asked our participants to tell us the primary technological challenges in eHealth apps they experienced and exemplify the primary reason for these concerns. In the surveys, 77.78% end-users and 85.82% developers reported that eHealth app technological challenges are significantly different from other app types and are crucial for its effectiveness. We found 44 direct statements about technical challenges in eHealth apps from 19 interviewees. Developer interviewees mentioned that organizational factors such as team size, budget and deadline are the main obstacles for handling technological difficulties. Three developers specifically pointed out that the hardware configuration introduced a couple of unanticipated technical problems. 61.53% of end-users pointed that issues for those uncomfortable with technologies are still not adequately addressed. However, our developers felt most of these problems could be managed by redesigning interfaces, including intelligent system and simplifying data collection processes:

'*I found tracking [in the eHealth app] is difficult, I would say features are not modifiable and meaningless, I can't work with it at all... [then] depending on the screen size, some features are visible and some are not... for example, when I used lower configuration mobile, I found there/four features don't shows up, I mean they exists, but I can't access.*'[IE10 - Service Holder (Retail)]

'*We aims to give user an experience that they're touching the interface, but they don't have to, ... It was technologically challenging to provide this type of service 24/7... [also] app vendors poses a lot of restriction what we can use and what we can't, which add more challenges to address some of the related issues.* ' [ID1 - Programmer & UI Designer]

Key development factors that impact managing technological challenges in eHealth apps are team size, budget and deadline. Appropriate technology acceptance by end-users is critical to eHealth app adoption and usage in practice.

vi. Vulnerable user groups, marginalised people and gender identity: In our surveys, more than half of the developers and end-user respondents reported that issues related to vulnerable user groups and marginalized people were disregarded in existing eHealth apps (57%), but gender-related issues are currently well addressed (73.75%). We found 28 direct statements from the interviewees about this ignorance. Generally, developers ignore the issues related to vulnerable user groups and marginalized people due to the lower number of such users. Moreover, they face technological challenges in many projects to support their challenges. Our end-user interviewees highlighted that vulnerable user issues were ignored in many cases. Two end-users pointed that they prefer not to use eHealth apps, as they are vulnerable users and that their issues were not considered in the apps. They also observed that such app usages create additional problems in their daily lives compared to not using it. Interviewed developers mentioned that app store vendors play the most crucial roles incorporating such vulnerable user issues in eHealth apps:

'*When it comes to people affected by certain conditions, ... mental health and things like that, you don't really want to make people more stressed than they already are in, so there should be a balance, how much information as opposed to just necessary ones.*' [IE3 - Academician (Professor)]

'*I have a health issue that is called the Hypothyroidism. I take hormone supplementation medicine named Thyroxine for this. So, for that medicine, my heart rate actually remains high, even if I actually taking rest, my heart rate remains higher, ... Now the problem is, there's no provision for me to let the app know that I have Hypothyroidism, and hence it read that I'm always in stress. I would say, since, I am not allowed to let app know that I actually have an issue, hence, it is actually giving me some wrong output for my stress level. While working in a single day, I get like 30-40 alerts that I'm in stress, even if I'm actually sitting back relaxing.* ' [IE2 - Chemical Engineer]

'*Our app aims to track user so that they don't attempt suicide... we crack user input, voice call and analyzed these data ... -how is the voice tone of the user or how the frequency and -how much is the difference between conversations and input... Combining these data we prepare an analysis result and send to the carers and authorities... Doing this real time analysis correctly, and action accordingly was too challenging.*' [ID8 - Software Engineer]

'*Recently I find the Apple app store attached many regulation for app to get published in its cloud if your target audience are vulnerable users. ... Even a simple app with no sensitive information need to pass through many quality assurance and auto system checks. Only then you'll get your app published. ... I think this is the most effective way to solve such issues.* ' [ID4 - Software Architect]

Generally, many issues related to vulnerable user groups seem to be ignored in current eHealth apps due to the low number of such users, associated cost to address these issues, and relative technological challenges.

vii. Cognitive style and working conditions: In surveys, 85.82% of developer respondents reported that the users' cognitive style strongly influences app interface design. In our interviews, we found 57 statements related to cognitive style and relative interaction. 42 survey respondents also commented on these issues. Three Developer interviewees mentioned that UI design often concerns user definitions and cognitive style. Many pointed at efforts to minimize cognitive load in app usage, and one said they had to rethink app design patterns when contracted by an end-user about his cognitive limitations. For example [ID8] said '*Everyone's thinking, planning and*

remembering capabilities is not same. ... It is very very challenging to ensure appropriate design for those user who have such limitations.'

We also found that end-users' working conditions impacted practical app usage. Many users face challenges related to their working conditions (77.78%). One developer interviewee mentioned that they always sort app design considering users' working conditions as first-class citizens. Three interviewees pointed to following a more dynamic app work process that automatically changes based on input, location, date, and time to address working condition-related issues. Two pointed out that artificial intelligence-based approaches perform well to take over such matters. An end-user said that the eHealth app he used is trendy with over millions of downloads, but he feels that the app is unsuitable for him during workouts. Two developers pointed out that the rapid app development approaches help provide new app versions quickly but don't help in giving effective solutions for a user whose working conditions are not ideal e.g., fire and rescue service employees:

'*Consider a situation, where a truck driver is the user of our app and he is driving in a cold winter season. The driver using some gloves in his hand. Here we found general app button size was too small to work with. ... Now if the weather is normal, then larger button size may not be accepted by the same driver. So, knowing about it [user condition and weather] and executing dynamic actions were challenging. ... these are same for a doctor/nurse users who wears PPEs, gloves and masks, and try to use some eHealth app feature.*' [ID5 - Software Architect]

In practice, developers face difficulties in addressing the diverse working conditions and users' cognitive differences-related issues. Several participants pointed out that successful adaptation to users' cognitive styles and working conditions differentiate helpful and ineffective eHealth apps.

5.2.2. Usability:

Usability in eHealth apps we define in this work as the appropriateness of an app interface for usage by diverse end users under specified conditions [48]. We found that eHealth app usability is an essential measurement criterion to fulfill the app usage objectives satisfactorily and effectively, aiming to provide a greater variety of choices for the users with Understandability, Learnability, Memorability, Usefulness, and Satisfaction [34]. Different end users may have quite different usability experiences with the same interface, due to their human aspect differences. Our survey and interview participants also understand eHealth app usability as simplicity of app usages. They pointed out that usability as an essential measurement criterion to fulfill the app use objectives satisfactorily (for users) and effectively (for developers) availing more choices. We found 29 statements from the 16 interviewees about the usability-related issue. Our survey respondents found that at least one usability-related context in eHealth apps needs further works i.e., not well addressed in current apps (88.89%). Most participants suggested avoiding unnecessary navigation and resolving landscape-orientation issues more efficiently. Some pointed cases where they felt uncomfortable due to the unresponsiveness of the app gestures. Then, 28.88% of users had a poor experience due to unclear app content. One said that color contrast ratio is not suitable for him, and he was not allowed to change/adjust it to make the app unusable. One service holder end-user interviewee mentioned that too much variation in the UI creates confusion. Most developers strongly agree that enhanced usability evaluation techniques (e.g., integrated card sorting) may be beneficial to improve user experience issues. They also claimed that most existing usability evaluation guidelines are outdated.

'*In children development monitoring app, some content were unclear and the navigation is not good. ... many new parents find it difficult to understand how it actually works, ... some of them fill disengaged.*' [IE13- Medical Practitioner (Nurse)]

'*Our product analysis team find that we don't think much about the simplicity stuff, which was the primary reason for the app failure. ... one challenge for us to determine how we can pass all information effectively to the users but in a simplistic manner.*' [ID9 - Senior Software Engineer]

Need for good usability is well understood for eHealth apps. However, outdated usability-focused methodologies and evaluation guidelines created obstacles for appropriately collecting related requirements and incorporating current standards for eHealth apps.

5.2.3. User experience:

We distinguish between user experience and usability in eHealth apps. In this paper, we consider user experience as the comprehensive experience that users have while interacting with the eHealth app. This includes various factors such as presentation, functionality, performance, interactive behavior, and assistive capabilities of the app or service [9, 35]. Over half of our survey respondents (52.5%) marked user experience as a crucial factor for practical eHealth apps usages. We then found 34 statements from the interviewees about this issue in eHelath apps. Then, 61.53% of end-user interviewees stated negative sentiment about the comfortless eHealth app, while 41.66% of developer interviews mentioned that their design decision makes users uncomfortable. 14 interviewees (4 developers and 10 end-users) pointed out that the end-user is the most essential factor associated with any eHealth app, and to make the app beneficial, their experiences should be improved than what it is now:

'*I found this [presentation from app] impact my mental health. ... So I think app admin should have put something to filter out this kind of display results.*' [IE6 - Service Holder (Transport)]

'*Rice is most common food for us in lunch and dinner, sometime as in breakfast as well. But, when we give such input, the app can't relate it with its parameters. ... I think it has some pre-calculated measurements and it shows output based on parameters it had.*' [IE9 - Service Holder(Government)]

'*Our clients were really uncomfortable with some of the app features. ... what we did wrong is, we misunderstand user expectations and their familiarities [behavioural pattern] ... we were asking too much effort during app usages, which we shouldn't.*' [ID7 - Software Engineer & UX Specialist]

User experiences broadly impact and differentiate between the success and failure of an eHealth app. Three-quarters of our end-user respondents had poor experiences with either in-app functionalities, the effort required to use the app properly, app assertiveness, or in-app designs. Developers tried to address this issue in eHealth apps, allowing users to follow unique behavior patterns, which is not trivial.

5.2.4. Accessibility:

Accessibility in eHealth apps is defined as the degree to which the apps can be used equally by people with and without various disabilities [49]. 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 issue. It also aims to improve user engagement with eHealth apps through Perceivability, Operability, Understandability and Robustness [50]. We found 46.67% of end-users and 28.57% of developers survey respondents suggested prioritizing accessibility issues in eHealth apps over other issues. More than half of the end-users pointed out that accessibility is essential, not only for vulnerable users who cannot use apps due to disabilities, but also for healthy and fit users. Developer respondents pointed out that accessibility needs evolve during app development phases. We identified 57 statements about distinct accessibility issues in the eHealth apps from end-user and developer participants. Our interviewees draw attention to more accessible eHealth apps for users with special needs to increase app usability. Two interviewees mentioned that current mobile apps are less accessible for the people who do not associate themselves with technologies. One interviewee said that more accessible app components (features) could be developed with the help of additional hardware and third-party APIs. Interestingly, one developer mentioned that they introduced Machine Learning-based features to implement an accessibility requirement in the app. Several interviewees stated that accessibility could be integrated into current approaches as a competitive functionality that evolve during the app life cycles. Our end-user interviewees also reported that the apps originated from relatively small companies and under-developed countries were less accessible. The developer interviewees specified time and budget constraints as main obstacles to address this issue in eHealth apps:

'*In ⋆[3] app, there is a problem, let's say a train station is underwater and bus replacement is going on. Now, if you put your destination during start of your journey, it does not show this, just shows an exclamation mark. Then if you click on the mark, you realize something is going on, ... This is problematic for the people who are not that much associate themselves with technologies. ... similar kind of problem I faced with my health apps too.*' [IE4 - Teacher & Engineer]

Accessibility needs to be incorporated into all eHealth apps as a priority, but some needs could not be adequately addressed and this impacts app usability. Accessibility evaluation in the app workflow process needs to be re-examined. Limitations of resources, organizational factors, developer experience and lack of supporting methods and tools are the primary barriers for this problem.

5.2.5. Reliability and Validity:

Reliability in eHealth apps refers to the app's ability to perform intended tasks accurately and consistently while remaining trustworthy [51]. Validity in eHealth apps refers to the accuracy of the app outcomes, including data collection, measurement, recommendations, and results [52]. Most of our user study participants also understand reliability and validity in eHealth apps to be 'correct operation without failure all of the time', i.e., equal performance in unanticipated events, maintain user data privacy and operate securely. In our surveys, 62.86% of developer and 51.11% of end-user

[3]We use the ⋆ symbol throughout the paper to hide app/tool names mentioned by our participants due to ethical concerns.

respondents considered reliability as a central improvement area in future eHealth apps. We found 29 separate statements from 16 interviewees (11 end-users and 5 developers) that illustrate reliability-related difficulties in the eHealth apps. One developer mentioned that they needed to adjust some functional features of an app after it was launched because that was operating incorrectly. One male end-user interviewee pointed out that the faulty recommendation from the eHealth app caused several mental and health problems in his daily life. Two developers and one end-user referred to some uneven performance in the apps for the special unforeseen events. Then, 56% of interviewees were concerned about the security related issues in eHealth apps and suggested that an eHealth app should be dependable, robust, and trustworthy all the time.

'*This ⋆ [eHealth] app is not much reliable in the sense that the wrong decision it provides bypassing all my current situation, previous data.* ' [IE2 - Chemical Engineer]

'*I found, patients generally hesitate to give input in the apps, but fells more comfortable to give us verbally... they thinks if these information get breaches [from app sources], it can hamper their social life.*' [IE13- Medical Practitioner (Nurse)]

'*If it requires some input, you may be concerned about the privacy of your data. I came across ⋆ app. As I started registering, it was asking questions which were too personal, and I actually abandoned the registration process in the middle, because I found that they [app management companies] were selling these information to pharmaceutical companies. ... transparency of how data is collected and used is very important.* [IE3 - Academician (Professor)]'

Previous experience helps app developers to address reliability issues in their eHealth apps. Large-scale companies handle unforeseen problems after release through observational investigations, but others can not afford related costs.

5.3. RQ2: How Are Human Aspects Currently Addressed in eHealth Apps?

To answer RQ2, we explore key approaches reported in our surveys and interviews to address *human aspects* in eHealth apps. We asked developer participants to tell us (i) which particular aspects were discovered during which phase of app development; (ii) who highlighted them; (iii) which ones they find harder to address; (iv) which one takes longer to address; and (v) how do their software teams talk about these aspects? We aggregated developer responses for these questions and visualized the results in Figure 9. This shows key eHealth app issues impacted by *human aspects* and developers' judgments about the difficulty of addressing these aspects (easy, moderate, or hard) in each development phase. We found developers spent most of their time on requirements elicitation (71.42% respondents) and implementation (88.57% respondents), whereas testing takes the least of their time (68.57% respondents). The respondents' percentages were calculated by averaging the ratings we obtained for the 'moderate' and 'hard' categories across the five listed *human aspects* shown in the figure. Most developer participants mentioned that accessibility-related issues in eHealth apps are easy to identify but are most challenging to cover. In contrast, diverse user issues is difficult to comprehend during the requirement, and reliability-related issues are harder to manage.

We asked end-users to tell us (i) which part of their eHealth apps they think should address which key *human aspects*; (ii) do they think app developers sufficiently incorporate *human aspects* in the different eHealth app components appropriately; (iii) do they use additional hardware/IoT device/-plugins to address any specific issue, and if yes, what difference does it make to their eHealth app

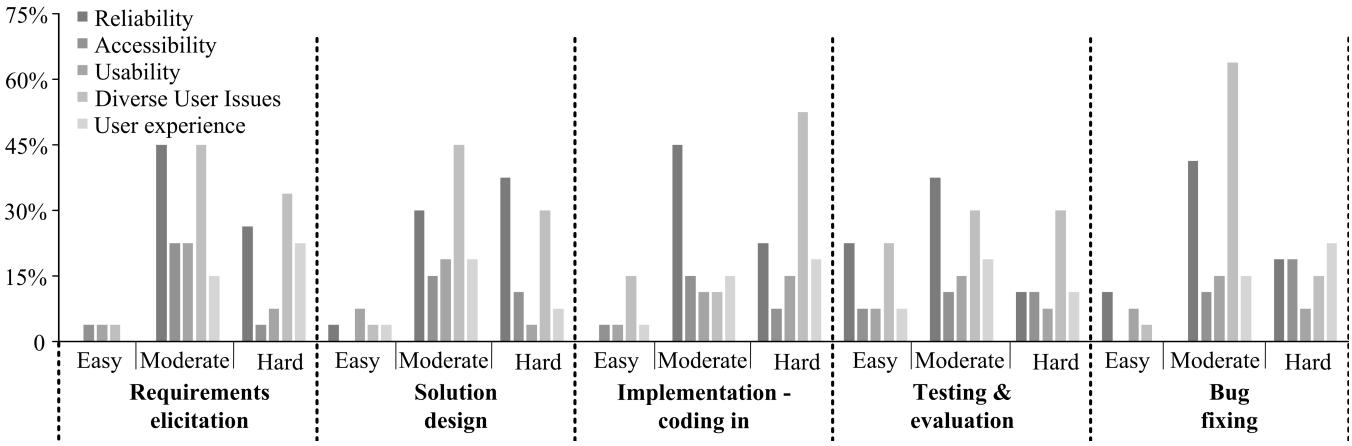


Figure 9: Distribution of the developer responses for perceiving and addressing *human aspects* in different eHealth app development lifecycle phases

usages; and (iv) how do their friends and family talk about different *human aspects* in eHealth apps? We also requested them to give us reasons for their responses, if possible. Figure 10 summarizes the key areas reported by the end-users. They reported that user interface and app performance mainly impact eHealth apps' accessibility and user experience. In contrast, usability and diverse user issues were least affected by the app business logic and data sources.

5.3.1. Requirement elicitation, analysis, documentation and management for human aspects in eHealth apps

Nearly every developer participant (97.14%) told us that they do not have sufficient requirements engineering solutions for addressing *human aspects* in eHealth apps, which significantly impacts developing effective apps. They said that *human aspects* are difficult to elicit and model, following existing requirements engineering processes. The main challenges reported included the extensive effort, time and cost required for human aspect-related issue collection; lack of sufficient knowledge about how to incorporate *human aspects* during requirements analysis; ethical concerns in gathering and documenting sensitive human aspect-related requirements; and difficulties in requirements management including modelling human aspect-related issues. The majority of our developer participants (62.58%) found requirements for reliability, user experience and diverse user issues were much more complex to understand.

Four interviewees pointed out that they revised initial development requirements due to hardware limitations identified after the app was launched. One senior software engineer said that identifying platform-based requirements is critical for eHealth apps. We also found that developers have started to use machine learning and artificial intelligence based tools to aid them in eliciting human-centric requirements. Many said that a compact checklist for identifying human centric requirements in the eHealth app domain would be very helpful. Our developer participants also pointed out that requirements reuse and involving users worked well for them in issue prototyping.

Collecting and analyzing human-centric requirements for eHealth apps is not trivial. Limited existing supporting approaches is a primary obstacle, where issue checklist, prototypes, comparative study and requirements reuse concepts help app developers.

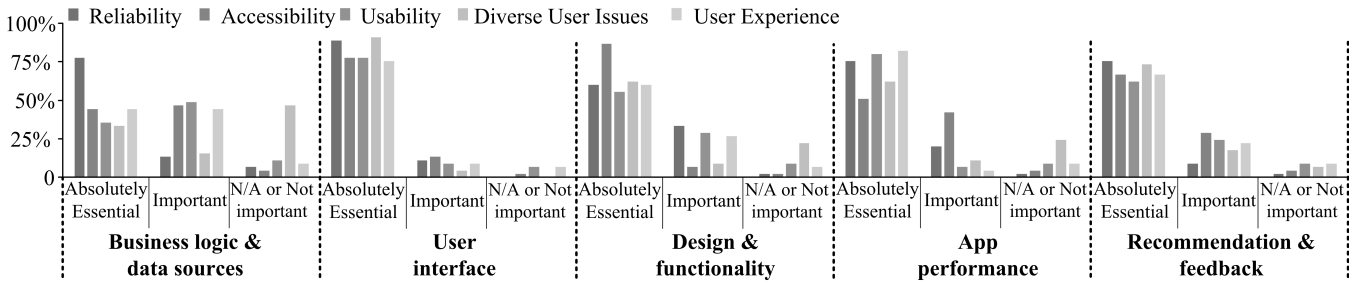


Figure 10: Distribution of end-user responses for necessity of addressing *human aspects* in eHealth app components

5.3.2. App design and implementation

Our developer participants ranked incorporating *human aspects* in the design/implementation phase of the eHealth app as moderately straightforward, compared to in the evaluation and requirements stages. They commented on approaches to structural app design, modeling, adopted standards, platform-dependent strategy, and particular design challenges in the eHealth app domain. We found that demand for more powerful hardware such as smartphone memory, processor, graphics and IoT devices increases (70.21% responses) when app designs need to integrate *human aspects*. However, it is challenging for manufacturers to manage it due to product cost and market values, specifically for the consumers from low socio-economic groups to keep upgrading handsets or even access top-end handsets. This also impacts the eHealth app design structure, such as the app to database query process and response time as mentioned by two participants.

Secondly, we found developers generally design and code independent modules without much concern for the internal implementation of other modules for integrating and addressing *human aspects* in eHealth apps. This module-based strategy for the app development process helps developers ease app design. However, various human aspect-relaetd quality attribute parameters are very hard to achieve in such cases, especially when component modeling is carried out using visual tools. We were also told that R & D is crucial for designing human-centric eHealth apps, which helps improve developer skills as well.

Two developers mentioned that it is problematic for them to implement a proper authentication mechanism in the eHealth app while maintaining user data privacy. Three participants indicated that working with focus groups including domain experts, stakeholders and diverse users from different demographics helped them address more human-centric app features and functionalities, especially usability, accessibility and diverse user issues. Two developers explicitly mentioned the use of AI and machine learning-based algorithms to improve human-centric designs of their eHealth apps. One said specific domain-based design helps in implementation, but not always. A software engineer faced challenges implementing a good plan that operates correctly in all versions and all platforms. One said that good guidelines for incorporating *human aspects* in the eHealth app designs is missing, especially having all the key issues in one place.

'*Ensuring same reliability, accessibility and other [user] issues for different platforms [Android/iOS/Windows] is challenging, ... deciding which design is more intuitive and useful, and then implementing the same design for different platforms is not trivial.*' [SD110: Senior Software Engineer]

'*A well scalable design before implementation is recommended, specific to the device type wouldn't work. However, writing reusable code for different devices keeping the same performance efficiency makes it hardest to meet.*' [SD19: Mobile app Developer]

'*User become confused with pause or resume state in [our app] download feature. ... We don't*

know this when coding as white box, we just followed the requirements. ... domain experts play a vital role here ... and suggest[ed] what to do for these missing requirements and how to avoid simiar problem in future.' [ID6 - Programmer & UI Designer]

> Developers re-use and formulate code modules to ease incorporating *human aspects* in eHealth apps, where communication among teams and domain expert involvement worked well. Obstructions for designing and generating such apps are hardware costs, platform variance, quality maintenance and the absence of good guidelines/standards.

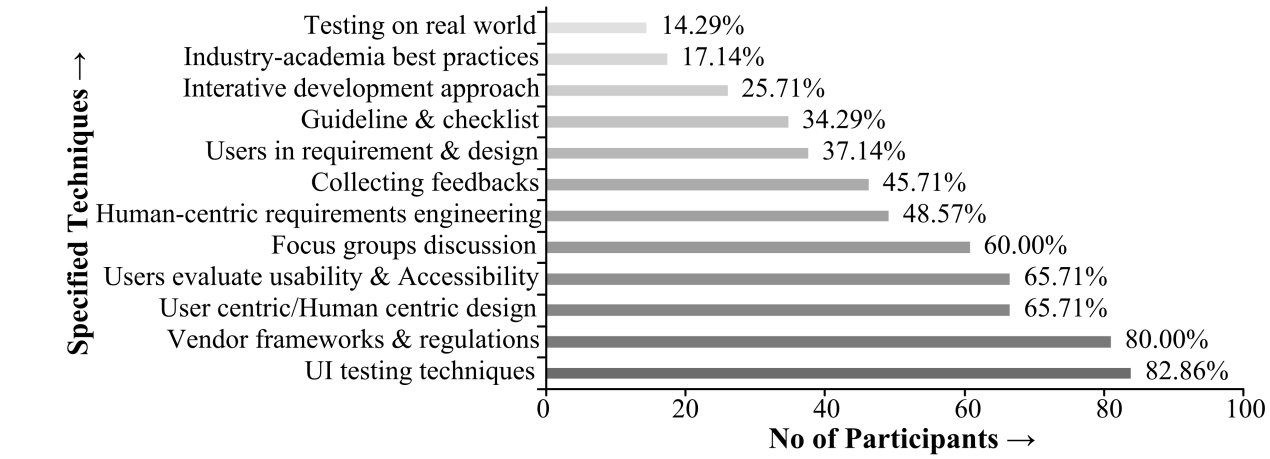
5.3.3. Testing and evaluation of human aspects in eHealth apps

The two right most columns of Figure 9 summarize developers' ratings for difficulties in testing, evaluating and maintaining *human aspects* in eHealth apps. More than half of the developers marked reliability and diverse user issues as complex and moderately difficult to test and maintain. 7.61% of participants rated accessibility, usability and user experience as easy, compared to 41.90% of respondents (on average) who rated these issues hard and difficult to evaluate. We grouped participants perceptions for these difficulty ratings into the following:

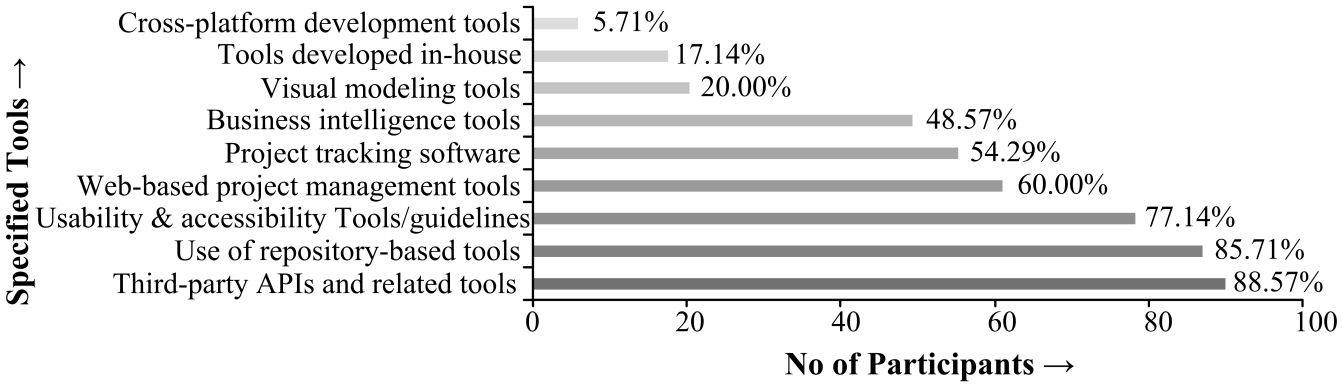
- **It is not easy to find developers from diverse backgrounds experienced in eHealth app testing and maintenance**. For example, most of the app testing personnel reported in our study were aged 25-40. Thus sometimes inherent understanding for the elderly user issues and corresponding actions do not appear during app evaluation, which is also valid for other *human aspects*.
- **Recruiting vulnerable personnel for app evaluation maintaining ethical concerns is hard** e.g., children, patients or users with mental health issues. However developers recognise that they are major groups of users for some eHealth apps.
- **It is difficult to appropriately determine some end-user conditions and living situations**, such as user socio-economic status, their mobile device configuration, access to the internet etc. Hence, some of the related issues remain unaddressed in deployed eHealth apps.
- **Existing test suites can not find many human-centric faults in current eHealth apps**. However, it is challenging to write new test suites for different platforms (iOS, Android, and Windows) that investigate if apps address different end-user *human aspects* appropriately or not.
- **The list of requirements that need to be tested and evaluated for *human aspects* in eHealth apps is long**. Hence, it is challenging to maintain deadlines and budgets as some of these issues also require extensive testing and evaluation.
- **Existing tools, checklists, and standards do not incorporate appropriately with new technologies** that are being adopted for the eHealth apps, such as sensors, increasing manual testing and evaluation that are time-consuming.

Some example comments we received include:

'*Automated tools saves a lot of time [in testing and evaluation]... for UI we create a user flow using* $\star^3$ *tool, ... it tests our app in a lot of different periods and provides us reports for hundreds of different devices. ... but there is a problem, they are not updated, so, some can't handle new [applied] technologies.*' [ID9 - Senior Software Engineer]



(a)



(b)

Figure 11: Reported – (a) Technique (b) Tools for addressing different *human aspects* in eHealth apps

'*Testing and QA team members are quite different than the real users ... So sometime they don't find the issues related to real users. ... recruiting actual users to test and evaluate the app is difficult, ... [to] collect their feedback is even more difficult.*' [ID6 - Programmer & UI Designer]

Appropriate testing and evaluation of *human aspects* in eHealth apps are essential. However, it is challenging due to the lack of resources, such as the complex recruitment process of participants, varying conditions of the users, outdated tools and techniques, development constraints, and long list of requirements that need to be evaluated.

5.3.4. Tools and techniques used to combine human aspects

Figure 11 (a) and (b) summarize techniques and tools that our developer participants used for addressing *human aspects* in their eHealth app development, respectively. The first figure shows that most developers utilize UI testing techniques (82.86%) and follow vendors' guidelines (80%) for addressing *human aspects* in eHealth apps. While specifying Vendors, nearly every participant who responded to this question pointed to Google for Android apps and Apple for iOS apps. We found that app testing (15%) in the real world before launching and employing industry-academia best practices (17%) were the least examined techniques. Moreover, 60% of the participants reported that they scheduled focus group discussions during the planning stage that were extremely helpful

to combine *human aspects* for improved app designs. Several respondents mentioned that usability evaluation techniques, human-centric design, and user feedback were beneficial for addressing *human aspects* in eHealth apps. From Figure 11 (b), we see that 17.14% participants stated they do not have any specific tool support to incorporate *human aspects* and have to address them independently. Some developers (20%) use visual app modeling tools to model issues discussed earlier in Section 5.3.1, and most of them use third-party APIs and project management tools. Interested readers can view the full list of tools and techniques mentioned, along with their references, in our online data repository that accompanies this paper, as cited in [44].

5.3.5. Data, business logic and presentation

Figure 10 summarizes end-user rating for identifying *human aspects* in eHealth apps from different app component layers. The first block of this figure shows that 63.11% of end-user survey participants (on average) identified *human aspects* in eHealth apps from app sources i.e., data and business logic. More than a hundred end-users considered reliability issues largely dependent on the data source and back-end data processing. Sixty end-users think that business logic has several impacts on accessibility and user experience-related issues in eHealth apps. Interestingly, 46.67% of end-users feel that data has less impact for eHealth app adaptability. The end-user participants pointed that app developers must carefully define what data is required for the app, what needs to be shown, and how it should be presented.

'*An app must be reliable or people will give up on it. ... In the case of apps supporting medical or psychological issues, it could be detrimental to find the support unavailable or unreliable when it is counted on. So, data source and techniques that handle the information exchange among app elements should be chooses cautiously.*' [SE106: Service holder]

In addition, we found that 84% of our end-user survey participants (on average) ranked eHealth app UIs as more troublesome than other app types. Ten out of thirteen of our interviewees mentioned the absence of effective interface that follows natural flow of the platform. For example, [ID5] said, '*it is difficult to navigate through the app since it is more like a windows type, but my device is based on iOS*'. We also noted a trend in adopting clumsy UIs in current eHealth apps that impact its daily usages. In contrast, only 3.11% of participants rated eHealth app UIs have little effect on its practical use. Five interviewees suggested reducing technical terms as much as possible from the front screen. One said that the rest of the app does not matter to its user when UI is inappropriate. Several participants pointed that inconsistent UIs and overwhelming creativities in UIs make app less usable. One said he left an eHealth app because that does not allow him to try it without signing in. Most end-users pointed out that app developers can offer more pleasant and highly accessible eHealth apps through better interfaces, which helps in ease of app use and widespread app adoption.

'*While it is desirable for apps to be accessible and usable to the widest possible audience, there are some accommodations that a target audience might require in app interface, for example navigation and visual hierarchy may work for most users, but a group of audience may also need voice command or modified tap functions, ... user always prefer simple interface.*' [SE54: Marketing manager]

Interface depicts eHealth apps impeccability for its users. In best practice, effective interfaces are designed by placing users in control, reducing cognitive effort for comfortable interaction and using platform oriented consistent designs.

5.3.6. Functionalities, performance and outcome

Over 75% of our end-user participants ranked app functionalities (73.33%), performances (79.55%), and outcomes (78.22%) as heavily impacting eHealth app usability, user experience and diverse user issues. Our interviewees pointed out that well-defined functionalities make it easy to use eHealth apps, enable them to achieve set goals befittingly and in human-centric way. We classified the following attributes are needed for better performance in eHealth apps analyzing participants perceptions:

- Increased flexibility in app use.
- Fast start-up and screen loading
- Optimal memory use and battery consumption.
- Easy and quick navigation with multiple options.
- Correct integration with hardware and third-party services.

Most of our end-user participants (84.44%) said that their eHealth app performance degrades when they enable human-centric features, for example, [ID5] mentioned '*enabling voice command for accessibility reduces app speed*'. Seven app developers also mentioned that quality performance is difficult to guarantee while incorporating some *human aspects* in app design. Two developers pointed out that modifying eHealth app functionalities is more complex than other app domains because many general users want different ways to interact with the eHealth app than physically/mentally challenged users. One said that adequate app assessment helped developers amend better app functionalities and develop more human-centric eHealth apps that are easier to access, more reliable and better to use. However, assessment and rectification add additional costs in the development process. Two stakeholders mentioned that they use effort estimation techniques in context with development cost calculator tools to identify potential business values of an eHealth app. This then helped them understand more about their investment and potential risk. We found such analysis and validation were not mentioned by those in new start-up and small-scale companies.

'*The more content included, the more likely it will drive value for app users, but this should not affect the performance, ... users must not feel lost using the app, or they will give up and find other sources that give a better experience... Quality performance is challenging to maintain in a app [while] offering equal access for all, no discrimination due to race, gender, ethnicity, sexual orientation.*' [SE18: Service holders]

We then found that less text and good graphics combinations in app recommendations make the app more usable. Three participants exemplified how inaccurate suggestions from the eHealth apps added additional stress in their daily lives. Several users (69.23%) agree that the accuracy and recommendation from eHealth apps were their primary concern. For example, [SE54] commented that '*Failing to provide desired and accurate outcomes will result in reducing human interest in the eHealth app. This eventually resulted in fewer quality apps being developed and useless apps being deployed in the market. Unfortunately, two-third of apps I tried failed to provide exact outcomes.*'

Performance and accuracy are the most important evaluation parameters in eHealth apps. Developing human-centric functionalities without compromising app performance increases development and hardware costs.

Table 3: Identified challenges for incorporating *human aspects* in eHealth apps and priority areas to improve

Categories	**Group Codes - Sub-themes**	**Impacts**	**Discussion**
App development process	Hard to collect appropriate requirements Impact of uncertain project scope and planning Indecisive feedback and faulty defect reporting Insufficient development frameworks, supporting tools, modeling techniques and testing suits Response: Survey-84, Interview-9, Statement-97	Snowball effect App relevancy, deployment and effectiveness	It's difficult to fix project scope up-front, audiences should be specified more precisely. More technical resources and non-technical support are required for developing effective apps.
Guidelines and checklists	Outdated/incomplete guidelines Non-comprehensive checklists Difficult to integrating with new standards Guidelines/Standards don't exist for addressing some *human aspects* Response: Survey-72, Interview-7, Statement-86	App quality Ease of app use Development cost	Formulate and refactor app development guidelines that are effective and well-designed; Updated guidelines/checklists should also correctly integrate with new technologies.
Organization and involved people	Minimal knowledge about *human aspects* in eHealth apps Insufficient collaborations among stakeholders Organizations and teams are understaffed Weak workplace culture, management, sponsor for addressing diverse end user *human aspects* Response: Survey-67, Interview-11, Statement-79	Developers motivation and performance App effectiveness and users satisfaction	Development companies need to improve developer training, enable collaborative culture with diverse end-users, employ self-organizing teamwork, and include more skilled developers in the development team.
Literacy, research and practice	Lack of education for IT students and app developers about diverse end-user *human aspects* Insufficient research and practical assistance from researchers and domain experts Inappropriate technical training for developers Response: Survey-59, Interview-10, Statement-72	Developmental needs App feasibility usability and management	More research and better *human aspects* education will help developers to develop more reliable, accessible, available, scalable, and secure eHealth apps.

6. Discussion

In this section we interpret the overall results of this study and discuss key implications of our findings for current approaches for handling *human aspects* in eHealth apps. Table 3 summarises the most important concerns raised by our participants grouped by influencing factors.

6.1. App Development Process

Our results suggest that *human aspects* can be incorporated into different eHealth app development life cycle stages, but achieving reasonable human-centric solutions takes a lot of effort and time. We grouped participants concerns into four major sub-themes which are shown in the second row of Table 3. Firstly, we found unclear project plans significantly impact app development steps in many current development projects (with a snowball effect). Here, decisions regarding the target audiences are crucial for a clear understanding of user groups, their particular needs, and related issues. Several participants pointed out that a project turns into a failure for some user groups when the scope and target audience remains insufficiently well-defined. Three consequences were pointed out: (i) the business team could not determine where and how to market the developed apps; (ii) most *human aspects* remain unaddressed; (iii) users stop using the app as it fails to address their own critical *human aspects*. One example is that some *human aspects* in eHealth apps related to children are quite different from issues related to older adults, in terms of interest, place of usage, data and reliability (discussed in Section 5.2.1). Our participants recommended grouping

end-users into smaller segments concerning their gender, age, culture, socioeconomic status, technological proficiency, etc. This would help app developers analyze and address issues related to the smaller groups appropriately and also requires less effort.

We then found human-centric requirements identification methods for the eHealth app need to be refined for improved app design and development. Participants suggested ensuring improved requirements capture and human aspect modeling support to better identify and better track user needs throughout the development process. They pointed out the limitation of resources, especially current design frameworks and tool support for productively addressing end-user *human aspects* in current eHealth apps. For example, it was suggested that an AI-based tool could support analysis of requirements and code for key *human aspects* and notifying them about the missing issues considering different usage scenarios. Several participants recommended testing eHealth apps with a set of actual end-users and in situ (live) before the app is deployed in the market. It helps app developers to minimize the number of excluded issues (unconsidered samples), adjust app features (accurate description), and interpret market scenarios. We found that if the app developers receive suitable suggestions to improve app performance, missing or poorly incorporated *human aspects*, they can produce more effective eHealth apps.

6.2. Standards and Guidelines

We found 86 separate statements from our participants regarding the importance of guidelines, checklists, or standards for aiding developers in identifying, addressing, and analyzing *human aspects* in eHealth apps. We thematically analyzed these statements into four sub-themes which are shown in the third row of Table 3. Many of our participants were aware of some existing standards, checklists and guidelines for designing, measuring and analyzing individual human aspect, for example, guidelines for - accessibility, quality measurements and health system improvement recommendations (discussed in Section 3.1). However, they mentioned that most of these existing guidelines failed to accommodate new techniques and methods, e.g., combining supporting AI/ML features for accessibility issues in eHealth apps. Secondly, some policies are not applicable for eHealth apps such as some discussed in W3C/WAI. Some guidelines ignore several crucial factors related to *human aspects* in eHealth apps, for example, absence of partial reliability and predictive validity for diverse user issues in health app quality assessment guidelines (discussed in Section 3.1). Thirdly, some health app assessment guidelines [19] do not consider many diverse *human aspects* of users as points of concern. Instead, they only suggest points to consider for selecting (effectiveness) and developing (business values) of an eHealth app. Overall, our participants mentioned that no guidelines/standards exist for all identified *human aspects*, especially for eHealth apps. We found that this lack impacts app quality, ease of app use and increase app development time and budget.

6.3. The Organization and Involved People

Our participants said that there are several limitations related to app development organizations, management, sponsors, development teams, and related people. Primarily, they pointed out that the structural issues of app development companies impacted developers and relative staff motivation, which affects app development process to identify and incorporate *human aspects* in current eHealth apps. A lack of knowledge about *human aspects* among app designers, project managers, and developers drive developing less useful eHealth apps for their users. Our participants said that including experienced developers in the development team will help improve such scenarios. Thirdly, app development software companies outsource development projects or at least a part of the project due to understaffed in-house teams. We found that outsourced developers' abilities to identify and address *human aspects* in eHealth apps are claimed to be much lower than in-house developers.

The in-house team then faces difficulties managing such outsourced apps after being launched in the market. More than half of our developer participants found a lack of staff in the organization as a challenge or major challenge in developing and managing more human-centric eHealth apps. In some cases, talent shortages cause understaffed teams, but misdirected long-term vision from organization management amplifies this problem.

We found that better communication is required among participating eHealth apps entities during its entire development life-cycle. However, maintaining such contact is expensive, and hence most small-scale organizations ignore this. The communication problem also hampers unifying and grouping opinions about *human aspects* from different stakeholders. Therefore, many eHealth app projects could not reach agreements with the proper judgment for requirement, development, and design. We recommend prioritizing known concrete human-centric requirements for eHealth apps and defining how to address these requirements based on current best practices. Moreover, trade-offs between design decisions for incorporating *human aspects* in eHealth apps can easily be managed with proper communication among participating entities, i.e., not every human-centric requirement might be met initially, still it would be easy to figure out the most crucial ones. Finally, most requirements analysts and developers avoid detailed documentation strategies. Only four participants agree that they document their development processes. Our results found three types of documentation, i.e., team documentation, reference documentation, and project documentation, greatly help in future app development (e.g., similar project), app maintenance (e.g., app update), and team developments (e.g., knowledge transfer to newly recruited developers).

6.4. Software Engineering Education, Research and Development

Our results suggest that current IT education, teaching, research and development strategies are not well aligned to integrate *human aspects* into existing eHealth app development and related software engineering projects. The majority of developers interviewed and 59 survey participants indicated – none of their higher education course material focuses on the *human aspects* of modern software, mobile apps, or hardware devices. Ten developers said that they learned about different *human aspects* for mobile apps from industry experiences and nothing related from their universities or educational institutes. We also found that design and implementation approaches that help address these aspects were less prioritized in most higher educational institutes.

Furthermore, including *human aspects* experienced industry professionals in teaching and training may help to eliminate some of these challenges and lead three key benefits: (i) Development of appropriate curriculum for the IT student, app developer and software engineer informed by real-world needs; (ii) Prepare more skilled students ready for industry and hence software companies will save training cost investments; and (iii) Freshly graduated students will have prior experiences to identify potential human-centric challenges and can prepare solutions to meet these challenges.

These findings indicate that higher educational institutes need to further emphasize *human aspects* in their software engineering, programming, and project management units, including student engagement on human-centric design, documenting relative challenges, step-wise solutions preparation that fits within app development life cycle, testing apps with diverse users, and evaluating efficiency considering its effectiveness and app market standards. This will help fulfill increasing industry demands (shortage) for mobile app developers with knowledge of human-aspect for mobile apps, especially eHealth apps.

Finally, we recommend increasing research and practical assistance from researchers and domain experts. For example, we did not find any comprehensive method that evaluates *human aspects* in eHealth apps and its development process due to their high versatility (ad hoc implementation). A more comprehensive evaluation method and tools for eHealth app domain, like improved devel-

opment guidelines that address diverse user issues, would help developers validate their developed work and identify pitfalls more easily. Practical assistance from domain experts embodied in these tools and guidelines could support better addressing diverse human-centric needs. This would help development team to increase understanding of their customer human-centric issues, objectives, and challenges they face and can assist how end-users can best use developed eHealth apps.

7. Threats to validity

The results and recommendations for this study were prepared to help the eHealth app stakeholders identify the gaps, limitations, opportunities, and essential future needs for more effective apps development and usages. To this end, we ignored those focusing on other types of apps unrelated to eHealth and other issues not related to human-aspect for eHealth apps. We also ignored making recommendations in mobile app development that exclude eHealth app and human-centric problems. Below we identify, categorize and summarize how we tried to mitigate standard user study threats in our study.

A primary limitation of our study is that we use user and developer opinions about support *human aspects* in the eHealth app domain. Therefore, how we measure our claims about answers to our research questions is challenging. First, we articulate and design our studies following a well-established method for user studies in software engineering (discussed earlier in Section 4.2 and Section 4.3). We also obtained full human subject ethics approval for this research. Secondly, we conducted two pilot runs of both developer and end-user surveys. These pilot studies helped us to identify the point of failures for our research project, including where we failed to follow the research methods appropriately and whether our approaches were too complicated for the target populations (explained in Section 5.1). We conducted a couple of pilot interviews to understand whether we gathered enough detail to answer our research questions appropriately. We then revised the study accordingly with the help of experts and obtain ethics re-approval. We also pointed out positive and negative impacts of *human aspects* in eHealth apps observed through several findings in Section 5.2 and Section 5.3.

The further threat is whether we capture enough details to answer our research questions from participants. We assisted our participants to understand our research objectives and constructs through detailed and precise explanatory statements, definitions and examples. Even then, we may not collect all relevant concerns for eHealth apps or participants may mis-understand our questions. For example, interviewees may only explain crucial issues they experienced in past projects or past app usages.

A third threat to this study is the representativeness of the respondents. We had participants from 18 countries over 5 different continents, their age range are 21 to 80, academic qualification are high school to Ph.D., they have 1 to 15 experiences in app usages and developments. We tried to select interviewees who had good experience in mobile app development or usages, and surveyed a large number of eHealth app stakeholders. For example, all our interviewees are from distinct organizations, the developers have worked in 12 types of varying eHealth app development projects, 64.44% of end-users have used more than three eHealth apps. Still, our findings may not be general enough and will not represent all eHealth app developers' and users' concepts. For example, most of our app developers were below 50 years old.

There is a possible threat from duplicate responses as we ran anonymous surveys. We checked for essentially duplicate answers (demographics, open text answers) but could not identify any. Nevertheless, there is the possibility the same person answered the survey twice, though we think it highly unlikely.

A further key threat for this research is whether the analyzed data answers the research questions appropriately or not. For example, some respondents may have misinterpreted our questions and our analyzed data may not incorporate key concern points related to *human aspects* within eHealth apps. To help reduce this threat, we provided 'not applicable/other/no clue' option in our surveys and allowed most questions to be optional. We found that less than 5% of participants chose these options altogether. For the interviewees, we did our best to use well-known terminologies, provide brief explanations for each question and asked interviewees to clarify their comments with examples when relevant.

We conducted all interviews online due to the COVID-19 travel restrictions. Some interviewees may have found the online discussion less ideal than the face-to-face interview, especially their engagement may be low, and some might be uncomfortable. Our pilot interviews helped us identify the process of enhancing interviewees' engagements in the online discussion and minimizing such related threats. It is also possible that our findings from respondents' perceptions and explanations were incorrect. To mitigate this interpreting and finding threats (data analysis) we discussed among authors until consensus was reached for each findings.

We may have biased findings addressing by only expert needs. For example, our results may not be comprehensive as the people involved have extensive experience in human aspect of software engineering and eHealth app domains. We tried to counter this by (i) providing detailed documentation on the survey and interview data collection and analysis, (ii) including participants from the various professions, expertise and localities, (iii) providing an option for the participants to articulate their own opinions after each question, (iv) asking participants suggestions, comments and examples, including topics that may not be highlighted (v) choosing widely used and well-understood topics and question from research papers, textbooks and online resources.

We have merged similar *human aspects* into five major groups to make our findings compact but left the observation that does not directly belong to *human aspects* or eHealth apps. We found most of the leftover comments provided a supplementary explanation to our five major groups. For each aspect, we then present corresponding sub-aspect, for example, 12 sub-aspects have been discussed under the diverse user issue group.

8. Conclusions and Future Work

We examined current approaches used in developing mobile eHealth apps that consider *human aspects* of app users. We aimed to determine which *human aspects* are essential to include when designing eHealth apps, how different aspects fit into the app development life cycle phases, how developers perceive *human aspects* in their app development projects, and how they can incorporate *human aspects* in order to increase eHealth app effectiveness. We also examined different ways people use eHealth apps in terms of *human aspects* and reported detailed insights into the usage of these eHealth apps for "challenged" users, such as those with disabilities, aging users, people from low socio-economic backgrounds, those with limited language proficiency, and other vulnerable end-users. Additionally, we reported how human factors like personality type, technology competency, emotional reactions, cognitive approaches, culture, ethnicity, level of engagement, and others that may influence eHealth app usage.

Overall, seven key groups of obstacles were identified for designing and implementing human-centric eHealth apps: (i) Lack of education, knowledge, guidelines/standard, and tool support for app developers; (ii) Lack of management support, e.g., time, budget, deadline, include experience developers in team and restriction from vendors; (iii) Lack of work by manufacturers and government initiatives to educate and influence the user community; (iv) Limited support for human-centric

requirements collection, for example, recruiting users and domain experts to work with app developers throughout the entire app development life cycle in addressing *human aspects*; (v) Hardware costs, platform dependencies, managing conflicting issues, and quality maintenance for code re-use and formulation; (vi) Collaboration problems among different app stakeholders; and (vii) Lack of research and practical assistance from researchers and experts in this domain. We then recommended several ways of better addressing these challenges.

In our future work, we plan to design new and improved ways to support *human aspects* in eHealth apps in the form of improved actionable guidelines, workflows, best practice examples, evaluation techniques, and supporting tools. We also want to work with app development companies to carry out observational studies to confirm or refute this study findings, and to evaluate our proposed improvements. We want their feedback on key deficiencies with the current app they develop or use and triangulate with the findings above. Finally, we want to better understand how other *human aspects* impact app developers and end-users themselves and how we might better address these issues in future eHealth apps.

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