Analysis of Personal Data Visualisation Reviews on Mobile Health Apps

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***Abstract*—Mobile health apps give end-users tools to track and improve their health and well-being. The amount of data collected and managed by these apps grows massively over time, emphasising the need for user-friendly mobile data visualisations that make it easy for end-users to understand and make better decisions on their health and well-being. However, there are no clear guidelines or best practices for developing quality and user-friendly mobile data visualisations. App reviews offer an indirect anchor for researchers to examine how non-expert users perceive and interact with data visualisations and identify the key challenges and recommendations to develop mobile data visualisations. This paper introduces an analysis of app reviews on data visualisations reported on a data set of 217 mobile health apps on the Google Play Store. We identified 8,406 comments related to data visualisations. We then reviewed these comments and labelled them as neutral (919 comments), negative (1,557 comments) and positive (5,930 comments). We then manually clustered these comments into groups of concerning issues, including missing functionality, wrong charts, look and feel, etc. From analysing the user reviews, functional requirements turned out to be the most common problem across these app reviews, followed by the look and feel and then data problems. A complete set of data visualisations seem to be the most well-received capability of mobile health apps. We also introduce a set of mobile data visualisation guidelines based on these user reviews. We are currently working on an evaluation experiment to measure the impact of these guidelines on the quality of the produced mobile data visualisations.**

***Keywords*—smartphones; mHealth tracking apps; user experience; data visualisation assessment**

I. Introduction

The easy access to mobile devices made data visualisations widely adopted by non-experts for several personal needs. For example, tracking health data is one of the most common personal tracking aspects [1] in which end-users use the provided data visualisation as a communication tool [2], decision-making [3] and tracking tool [4]. Personal data visualisations rely on mobile devices as the primary platform for user interactions [5]. However, mobile data visualisations introduce new display size, resolution, computing power, storage, and interaction modality challenges. Consequently, the field of visualisation interface design needs improvement to achieve users' satisfaction and cope with the challenges of the unique environment [6].

Graphs, charts, and icons are the main components of health tracking apps that help users track their goals, habits, and achievements [5]. Commendable efforts have been conducted in data visualisation related to diabetes, but apparent gaps in designing and understanding visualised data in the personal tracking apps are still present [7]. The main two reasons for these gaps are the diversity of data visualisation audiences [8] and the lack of generic guidelines that suit non-expert users and mobile devices (smartphones). Furthermore, although research studies have been comprehensive and continuously evolving to provide better user experiences for mobile data visualisation, users still report issues and challenges with their data [6] [7]. Thus, there is a need to examine users' perspectives toward data visualisation in mobile apps and understand the usage context to achieve better data visualisation on mobile devices [5].

User surveys and app reviews are great tools to understand user needs and challenges. User surveys are useful to answer specific questions but usually are limited in terms of the number of participants and generic instead of reflecting on experience on a specific app. On the other hand, app reviews are beneficial for understanding the common challenges and gaps [14] across a range of apps, and a broad group of audience/users [10]. App reviews have also been used to source and inform app improvements and new features [11], [12], [13]. Thus, this paper focuses on app reviews to identify key challenges and problems that end-users face with regard to mobile data visualisations for mHealth apps as our specific application domain. The paper addresses the following research questions:

- RQ1: What are the common visualisation tasks and charts that have been adopted in mHealth apps?
- RQ2: What are the top data visualisation issues in health tracking apps?
- RQ3: What are critical user concerns on mobile data visualisations in mHealth apps?

The rest of the paper is organised as follows: Section 2 presents the related work and Section 3 presents the research method. Section 4 presents the results and analysis. Section 5 presents the analysis discussion related to the found gaps and introduces suggestions for better developing and designing data visualisation in the mobile health (m-health) apps and presents threats to validity. Finally, Section 6 concludes the paper with a summary of the paper's findings and discussions.

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II. Related Work

This section presents reviews on the importance and purposes of using app reviews. Then, it elaborates on the studies related to self-tracking and mobile health apps. In conclusion, examining users' reviews of m-health apps regarding data visualisation has not been studied yet.

A. User Reviews

Users feedback is currently applied to seek users' opinions, and satisfaction with a specific service or product [15]. For example, the industrial sector applied this communication method to evaluate the quality of products and services based on user experiences to improve their services. The same concept applied to app reviews in which users give either positive or negative comments [15].

In 2008, Gebauer et al. [16] investigated the required factors of 4 mobile devices from users' point of view. These devices included a cell phone, 2 PDAs, and an ultra-light laptop. The data was collected from www.cnet.com, an online website that allows users to write their technology-related comments. The authors followed automated and non-automated processes to evaluate 144 comments as a sample size. After evaluating the results of each process, the authors decided that these two methods had their advantages and disadvantage. However, they concluded their study that both processes are the basis for continued analysis of highly dynamic technological development and proved that user reviews aid in delivering user requirements.

In 2014, Khalid. H [18] studied the impact of app reviews on user preferences when selecting apps from the app store. In addition, he investigated how to use app reviews to source new features and issues that need to be addressed by the development teams to achieve user satisfaction and solve problems reported in the comments. The author investigated the apple store's user reviews by reviewing 6390 comments across the most popular 20 apps. He collected the 1 and 2 stars comments using a web crawler and applied an iterative process to classify the comments. Finally, he classified the issues into 3 groups, developer issues, strategic issues, and content issues. He concluded his study that low rating comments negatively impact the quality of the apps, which affects the app's popularity and revenue.

In 2018, Caldeira et al. [17] published a review of 32 mood tracking apps and deeply analysed 1,000 reviews. One of their primary findings was that data visualisation needed to be varied to match multiple people's preferences. As patient share their mental state with health providers, the authors claimed that the used data visualisation might be suitable for patients or the general population but not for the health providers. Thus, possible audiences of health data visualisation need to be considered through developing m-health apps.

B. Self-tracking and mobile health apps

The widespread of mobile devices has helped increase the number of end-users interested in tracking their data. These include tracking sports activities, nutrition, health conditions, memories tracking [21], mood tracking [22] and other tracking activities. As a result, significant efforts have been made mainly in 2 areas. The first is related to user interaction with their data. The latter is related to developing and evaluating apps that help users track health data.

We found that heroic efforts have been made to understand quantified selfers and their interaction with tracking apps [23]. In this study, users have been requested to record videos and answer 3 questions: "what you did", "how you did it", and "what you learned" [23]. After analysing 52 videos, the authors reported that health condition was the main tracked data. However, they also stated that the presented data was too much, making users give up tracking and analysing their data. By answering the question "how you did it?" participants reported a spreadsheet as the primary tool to analyse their data and commercial hardware for data collection. However, users wanted to have their tool. They also complained about the complexity of reading their charts due to a lack of scientific knowledge. Thus, developing simple m-health apps is needed to serve this group of people to understand their data.

In 2018, Lee et al. [24] published a workshop proposal to investigate mobile devices' opportunities as data visualisation platform. They named multiple apps that have been developed for self-tracking. Examples of these apps are sleep tight which visualises sleep patterns by showing sleep duration and quality. Another application is ConCap which shows diabetes patients their data over a timeline. Finally, OmniTrack included a dashboard of charts presenting different data types that the app collected. However, the authors claimed the lack of methods to evaluate data visualisation on mobile apps.

These apps take us to a new mobile health app (m-health) terminology. We found that research efforts have been made in this area, focusing on providing a specific framework to develop a well-defined contextual m-health app [25], and another study focused on m-health designing based on customers' experiences [26]. In addition, further investigations in the health area are related to providing a security framework for m-health apps in terms of data analysis and visualisation [26].

There is a noticeable development in mobile data visualisation apps. Nevertheless, a set of best practices to develop and evaluate these mobile data visualisations has not been studied yet [24], specifically in developing guidelines that include targeted audiences, data visualisation components (charts, data and tasks), and smartphone capabilities.

III. Research Method

This section presents our process of extracting data visualisation related reviews from the Google Play Store and assigning these reviews to different clusters of issues related to data visualisations. Figure 1 shows these processes highlighting the sub-tasks in each step.

Step1:Query Google App Store for mHealth Apps: The first step was to identify the relevant apps to consider in this study. We decided to focus on apps on Google Play Store, given that there are available APIs that we can use to get

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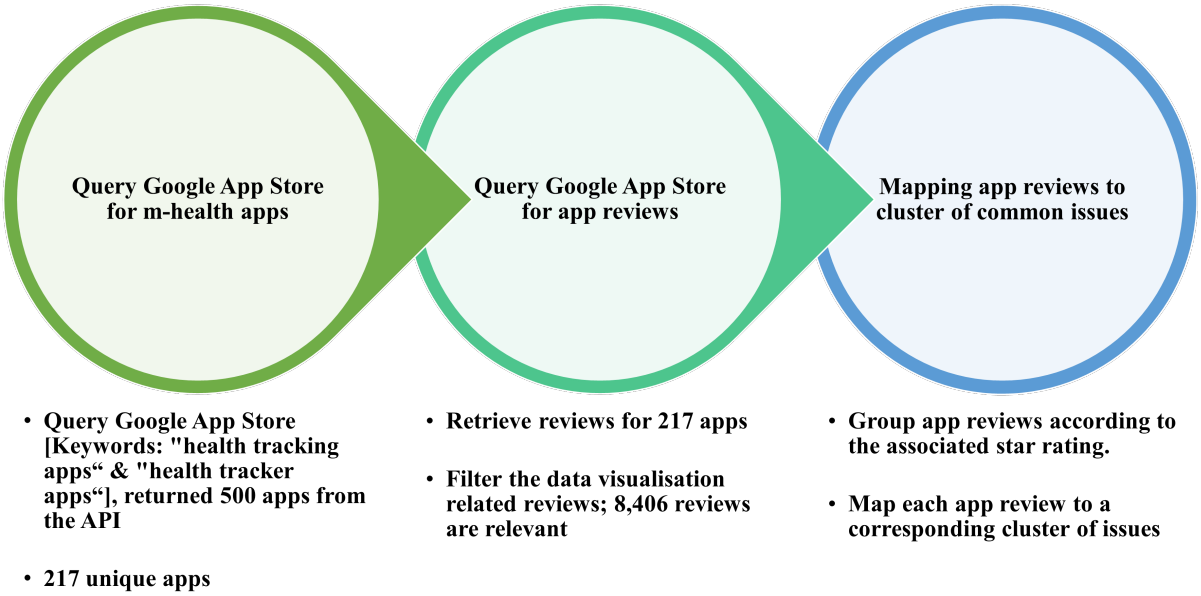

Figure 1. Apps and comments collecting, filtering and mapping process.

details about the apps on the store. These APIs expect to pass in a list of keywords (here, we used “health tracking app” and “health tracker apps”). Additionally, these APIs are limited to only the top 250 apps per query. Although this sounds to be a limited number of apps compared to the number of mHealth apps on the Google App Store (hundreds of thousands), we used these apps to represent the issues even on the top apps under this category. Ideally, with the highest number of downloads and higher potential for user feedback. We ran the query twice and got 500 apps with some duplicates that we removed and ended up with 217 unique mobile health applications (mHealth) apps. The list of apps included step tracker, food tracker, sleep tracker, fertility tracker, water drinking tracker, sport and activity, mood tracker, pet training, body measurement and weight loss tracker, pill reminder, chronic diseases, blood pressure and heart rate tracker, baby feeding tracker Stress and Anxiety. The query results are in the following format:

App metadata: app ID, URL, icon, version, score

Step2: Query Google App Store for App Reviews: The second step was to identify and filter the returned comments. We had 2,750,000 app reviews for the 217 apps. After removing duplicate and undefined rows, the remaining rows have decreased to 10,601. First, we manually analysed 200 comments as sample (Tables II, III, IV and V example comments) to identify the data visualisation related terms (graph, chart, visual). Then, we filtered the reviews associated with these visualisation terms (graph, chart, visual) and ended with 8,406 rows (reviews) related to data visualisation in the following format:

App review: rating, review, reviewer, user image, date, score, reply text, reply date

Step3: Mapping App Reviews to Cluster of Common Issues: The third step was mapping the reviews to a cluster of common issues. We first separated reviews based on their star ratings (minimising and organising the investigation process). Then, two of the team manually reviewed the app review and assigned two labels to each review: 1) sentiment label (positive, negative and neutral) regardless of the review star rating; and 2) common issue cluster/type. The number of clusters (issues) grow organically as we go through the reviews - i.e. every time we find a new type of concern, we created a new cluster and revised the previous labels to make sure there is no wrong labels or overlaps. The final list of reviews, sentiment and cluster is available (here).

IV. Results and Analysis

This section presents the results and key findings of our study mapped to the research questions in Section I (Introduction).

A. RQ (1) What are the common visualisation tasks and charts that have been adopted in these mHealth apps?

We analysed the screenshots included in the app description looking for data visualisation screens. 93% of the returned apps included data visualisations. We identified 12 common visualisation charts across these apps including: Waterfall, stock,

table, timeline, scatter, map, line chart, calendar, area chart, bar chart, pie chart, maps and Iconography. The maximum number of charts found in each app was 5.

Figure 2 summarises the percentage of each chart in the total number of data visualisations we found in 203 apps that included data visualisations. Based on the data collected, five charts are the most commonly used in the top best apps: line chart, area chart, pie chart, calendar, and bar chart.

Iconography was the most used visualisation type (found in 141 apps) as it was used in indicating statues using numbers or texts with related symbols and colours. Line and bar charts are the second most common visualisation type (83 apps). Calendar as a visualisation type has been found in 32 apps. It is mainly used to track mood, period, pregnancy, and medication reminders. The map was used in 21 apps as data visualisation to help users track their walking, running, and cycling activities. It shows the number of steps and starting and endpoint information. Another visualisation type found is colours. They indicate high and low moods for monthly or yearly tracking and create patterns and trends. Stock, waterfall, and scatter plot visualisation types were the least (1 app).

Fourteen mHealth tracking apps in our dataset (7% of the 217 apps) did not include any charts. It was interesting to find out that these apps were all rated either 1 or 2 stars. Additionally, user reviews reflected these highlighting that charts are essential to track their progress and goals. Four apps had the maximum number of charts (5) (Anxiety Tracker - Stress and Anxiety Log, Blood Pressure Diary, Heart Rate Monitor, morePro), three are rated with more than four stars, and one app is rated with 2.5, which turned to have other issues. Therefore, this shows that including data visualisations can lead to positive impact on app adoption and rating.

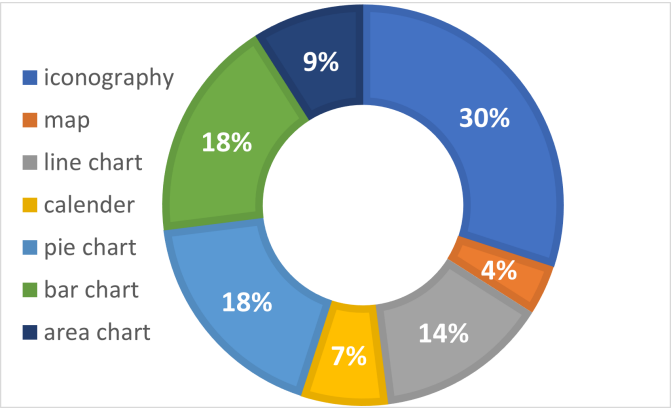

Figure 2. The most adopted charts in 203 apps.

In terms of visualisation tasks, we used Saket et al. [19] list of 10 essential data visualisation tasks including finding Anomalies, finding clusters, finding correlations, derived values, characterise distributions, filter, order, range, min-max, and retrieve value. In the apps in our dataset, developers focused primarily on one primary task: tracking progress. The purpose of this task varied based on the tracked activity. For example, in weight loss apps, the main functions were to track progress and achieve goals, and in mood tracking, the primary process was to track mood and find a monthly mood pattern. A comparison task was adopted in 2 apps (Fasting app and K health — Telehealth app). All apps provided read-only interactions with the data visualisations. However, app users have requested to consider adding other data visualisation tasks of these essential ten tasks:

- "..,but is terrible for comparing your results to previous results, everyone wants to see how they progress on all the fields."
- "you can't view plots from X date to Y date"
- "There is no continuity in calculation between months (maybe other timespans as well when you zoom out or in). If I weigh x at the end of a month, x-2 on the first measurement of the next month and x-2.1 on the next measurement, 2kg will be unaccounted for in the monthly totals shown above the graph. That's just useless."

B. RQ (2) What are the Top Data Visualisation Issues?

We manually reviewed the comments reported by app users to extract the common data visualisation issues. We grouped issues based on the following categories: functional requirement - related to user needs, data – related to data used to create the visualisations, look and feel – related to usability and types of charts, interactivity and device compatibility - related to screen and platform related issues. For each category we considered three attributes: completeness, correctness, and consistency. After reviewing the app reviews, we ended up having 18 issues, as shown in Table 1. Missing functional requirements were the most frequent negative reviews. For example, 50 % of the functional requirements issues are related to missing some needed graphs such as weekly or monthly charts, progress charts and charts to track aspects such as blood pressure, heart pulse, and baby feeding. Other complaints were about the functionality and display of the chart. Additionally, there are four main issues related to data visualisation design (look and feel):

- Chart scaling issues (40%)
- Graph styling (font size, chart ranges, and colours do not indicate meaningful information, including grid lines in the charts and axis titles)
- Interactivity (scrolling, zooming, landscape, choose graphs options)
- The chart type is not appropriate (bar chart, pie chart and bar chart)

Data is another primary aspect that users criticised. Data related issues included issues related to insufficient and incorrect data presented in the graph. In contrast, there are more general positive reviews than negative reviews that are related to users' satisfaction, which includes "love this graph" and "like this chart" without specifying any unique feature of the chart or graph (single and app visualisation). The other aspect that users rarely mention is device capabilities and adaptability including: 1) being able to rotate the device to see the graph

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TABLE I
SUMMARY OF APP REVIEWS' ISSUES

Issues	Count	Percentage
1: Missing graphs and functionalities	948	34 %
2: Displaying the wrong charts	22	0.7%
3: Charts are mixed up	60	2%
4: Missing the chart type	224	8%
5: Chart scaling, layout and font size	404	14%
6: Zooming problem and graphs lines are mixed	128	4%
7: Missing graph information	202	7%
8: Not accurate info charts units	98	3%
9:Not showing information correctly	32	11%
10: Missing the ability of phone rotating	10	0.3%
11: Scale is not suiting screen size	4	0.1%
12: Different OS & different functionalities	36	1.2%
13: Two colour menus confusing	154	5.5%
14: Visualisation is meaningless	74	2.6%
15: Low quality of graphs charts	94	3.3%
16: Missing Tooltips	20	0.7%
17: Screen size problems	36	1.2%
18:No consistency in showing graphs	4	0.1%

in landscape mode and visualisation consistency between the two operating systems, android and IOS; and 2) Chart fitting with screen size.

C. RQ (3) What are critical user concerns on mobile data visualisations in mHealth apps?

In this research question, we reviewed the comments of the five best and worst apps to key issues that could affect app rating, as shown in Figure 3.

Figure 3 (left side) showed the top 5 apps: These are non-free apps rated with more than 4.5 stars and had the highest number of positive reviews related to data visualisation compared with negative reviews. **Functional requirement:** These 5 best apps were the highest-rated apps in terms of data visualisation among 217 apps. However, there were still some missing graphs that could be added according to the collected comments (C) in table 2, such as weight blood pressure(C1 - Table 2), A1C (a simple blood test that measures your average blood sugar levels over the past three months) (C2 - Table 2) [20], blood sugar results (C3 - Table 2). In contrast, users were satisfied with the other functions provided in the app related to data visualisation, such as charting entries (C4 - Table 2) and (C5 - Table 2). **Data:** Users commented that they felt happy as they could understand their progress through the charts: (C6 - Table 2), (C7 - Table 2) and (C8 - Table 2). **Look and feel styling and interactivity:** are the most important aspects that users' mentioned in their positive reviews, such as (C9 - Table 2) comment. However, some users were not satisfied with the colour selection (C10 - Table 2) **platform and device:** There were no comments mentioned related to this dimension in any of these apps.

Figure 3 (right side) shows the top 5 worst apps in terms of the total number of negative reviews. As displayed, 2 apps were in the best 5 apps due to the number of positive reviews, and appeared in this graph as 5 of the worst apps (Blood Glucose and Baby tracker). Withings health mate is the worst app used to track various aspects such as weight, activities and sport, sleep analysis and blood pressure. However, it is a free app that has been downloaded by nearly 100,000 times. The 1- and 2-stars rating reviews were about look and feel, presented data, and adaptability to devices' screens. In terms of look and feel, users complained that the trend line is missed in the charts, so they cannot do any comparison tasks. User comments related to this aspect are shown in Table 3. The issues related to the adaptability of devices are about the screen size, touch interaction and rotating devices to get landscape mode (Table 4).

In terms of the lowest negative reviews, carb manager is a non-free app downloaded by more than 103,000 users. The biggest issue that users complained about was missing functional requirements. Examples of these issues were blank charts, and missing graphs are shown in Table 5.

V. DISCUSSION

This section discusses the findings and implications of developing and designing data visualisation for mHelath tracking apps.

We found that mhealth tracking apps covered different health aspects related to users' interests, such as sports activities, diet activities, and health conditions monitoring. However, the analysis revealed a lack of support for the data visualisation component in these apps. By analysing the app reviews, we found that users complained about issues related to data visualisation components such as functional requirement, data presented, chart styling, and suitability of the chart functions with the smartphones.

Users raised multiple concerns about missing charts. For example, some apps did not include charts like "map my fitness", "WhatsUp mental health app" and "pregnancy and baby tracker". Further issue related to missing charts, was about charting the correlated data in one app, such as heart monitoring and blood pressure. For example, "A chart shows the heart beating, but no chart shows blood pressure". Therefore, there is a lack of complete and correct functional requirements.

Furthermore, users wrote negative reviews about the chart's interactivity and styling. Approximately 90% of the 217 apps provided read-only charts. In the app comments, users complained about the difficulty of doing some tasks such as: comparing between two variables, enlarging font size, setting the preferred colour theme, getting details of the presented data, and rotating the device to landscape mode to get a detailed chart. This, in turn, leads to a sense of the incomplete look and feels and interactivity.

The presented data was another issue that users repeated in their reviews. Insufficient and uncomprehending data were the two main reported issues. Thus, many users highlighted the difficulty of making conclusions from the presented data as the presented data is not detailed and included miss leading labels. Device compatibility was a minor issue reported in user reviews. However, all the issues reported occurred due

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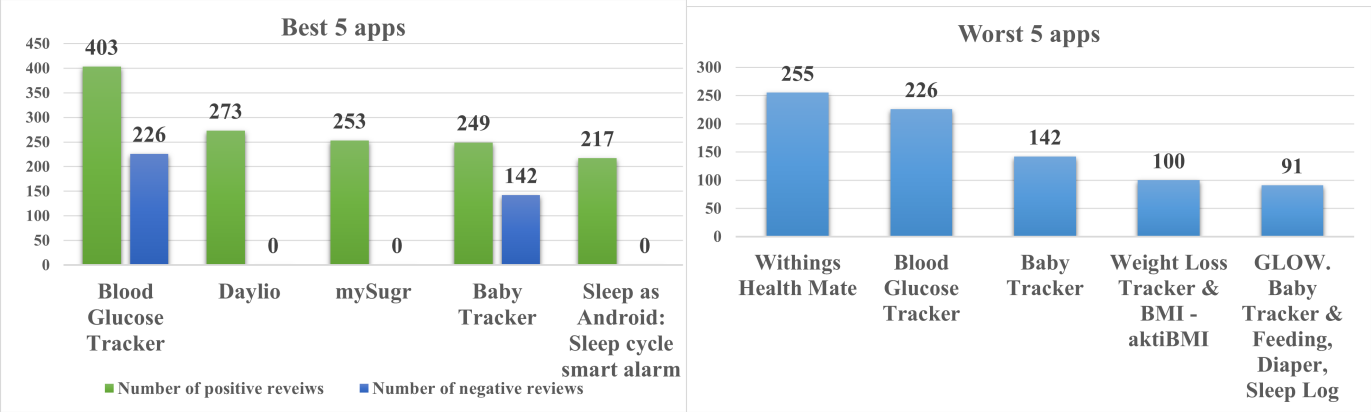

Figure 3. Best and worst 5 mHealth apps according to data visualisation reviews.

TABLE II
EXAMPLES OF POSITIVE AND NEGATIVE USERS' REVIEWS

C1: A lot of info you can put on here. It would be nice to see multiple graphs for weight blood pressure as well. Even an option to send info as an attachment to emails for our doctors– negative
C2: As a glucose tracking log it is easy to use and the chart is handy.Would like a similar chart for A1C results. If it linked to my meter, it would be awesome –negative
C3: An excellent app. Wish it graphically displayed blood pressure the way it does blood sugar but it's still the best blood sugar app I've found –negative
C4: Charts and graphs your blood sugar and tracks–positive
C5: Does just what I needed it to Gives you the average and plots a graph so it shows your entries easily. Thanks – positive
C6: love it brilliant at visually showing me how I've been and can predict my moods even bought the full app – positive
C7: Being newly diabetic this app has been extremely helpful in keeping things logged. It's also given me some comfort as I am able to see the effort I put in as clear to read results through their graphs and whatnot. I would recommend this app to anyone.–positive
C8: Has helped me visualise and control my blood glucose levels –positive
C9: The easy-to-read graphs show when I am in the red or in the green and ultimately show my blood sugar trending down. –positive
C10: For the feeding graph the colours blend too much and hard to see the difference Another colour scheme would be favorable.–negative

TABLE III
NEGATIVE REVIEWS RELATED TO LOOK AND FEEL

C11: Used to be great, but in the newest version the trend lines have all gone, and individual points are no longer plotted on the graphs, making it largely useless.
C12:..., Further issue is related to the graph size.
C13: Very hard to see weight trends and you have to zoom weigh in on a finicky scale to see daily weights plotted.
C14: unfortunately now the scale used for the weight graph is so huge that your weight line looks completely flat.

TABLE IV
NEGATIVE REVIEWS RELATED TO DEVICES ADAPTABILITY

C15: Weight graph scale is difficult to read on a smart phone and their website
C16: charts not responding to the touch not able to expand charts
C17: Biggest frustration is there's no landscape mode Not useful looking at graphs in portrait.

TABLE V
NEGATIVE REVIEWS RELATED TO FUNCTIONAL REQUIREMENT

C18: I've used this app for a while and I've liked it but lately the app keeps crashing. It's not saving my weights. Tells me that there's "no chart available".
C19: Carb tracking function works ok, but the weight chart is blank. Also, there is no way to incorporate exercise into this program, other than logging steps.
C20: When I try to see the graph of my weight loss (by turning the phone sideways) it doesn't show.

to the device functionality limitation and not addressing the features and limitations of the smartphones. Therefore, it is required to reframe building m-health apps by focusing on data visualisation components.

This paper introduces 3 recommendations for research opportunities related to data visualisation in m-health apps. Recommendations 1 and 2 are linked to each other. First, the development and design process of m-health data visualisation should be parallel process. All aspects identified in the discussion need to be considered when developing and designing charts for m-health apps. A further recommendation is related to the app review system, in which the authors highlighted the need to include the data visualisation aspect of the reviewing system.

Developing data visualisation: It is argued that data visualisation development needs special consideration due to the unknown multi-users. For example, it needs to adopt a complete set of functional requirements and data related to users' control and understanding of the graphs. That is, users should control their entries and be able to chart their progress easily. Further reviews associated with the functional needs are related to the device compatibility. For example, the touch, tap

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and rotating interaction are facilities provided by smartphone manufacturers that enable users to navigate and control their app screen easily.

Designing data visualisation: Data visualisation design has been discussed widely in the academic and industrial sectors. However, still, there are some limitations related to smartphone design. These limitations are chart size, scale, colour adoption, font size, data and interactivity.

Including data visualisation in the app review: Since app review does not include chart evaluation in the app feedback, it was not easy to find a protocol to classify the apps based on data visualisation reviews. So, it is recommended to add data visualisation feedback in the app review as it is a central part of health tracking.

From threats to validity perspective, we have identified the following limitations and threats:

- The apps considered in this paper were collected using an existing Google Play Store search API where it could only provide 250 apps through passing keywords and it returns a random list of apps whose titles match the search keywords. Thus, it is acknowledged that the considered apps in this paper are only samples of mHealth apps, and it does not reflect all of the available apps in the store.
- Some comments have been excluded as they were written in another language rather than English.
- The research team randomly evaluated a sample of these comments and solved the border cases.
- The research team used screenshots to extract the charts and tasks. However, analysing apps' screenshots and descriptions might not be accurate.

Finally, this paper targeted Android health apps that limited Android users' results. iOS platform is acknowledged. So, an extension to this paper have been planned to involve both mobile device operating systems' comments.

VI. Conclusion and future work

This paper presented a manual analysis and categorisation of app reviews of data visualisations in 217 health tracking apps. We identified 8,406 comments app reviews related to data visualisations. Overall, the number of the positive reviews was more than the number of negative reviews. However, the negative comments raised concerns regarding the m-health data visualisation aspect. The concerns included missing visualisations, missing visualisation tasks, look and feel and missing or incorrect data. Functional requirements and data aspects were the top concerns reported by mHealth app users. M-health app developers and data visualisation designers need to consider these concerns. Especially the target audiences, as mHealth apps are provided for all individuals who have smartphone access. In the future, the authors plan to dig deeper into user reviews across different mHealth apps, e.g., food vs physical activity and chronic conditions. It would help in identifying the differences between issues across different health domains. We also plan to work on designing mHealth data visualisation guidelines.

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