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DESIGN PRINCIPLES FOR APP-BASED HEALTHCARE INTERVENTIONS: A MIXED METHOD APPROACH

Loknath Sai Ambati

DAKOTA STATE UNIVERSITY

DESIGN PRINCIPLES FOR APP-BASED HEALTHCARE INTERVENTIONS: A MIXED METHOD APPROACH

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By
Loknath Sai Ambati

Dissertation Committee:

Omar El-Gayar, Ph.D. (Chair)
Ronghua Shan, Ph.D.
Nevine Nawar, MD, Ph.D.
Renae Spohn, Ph.D.

DISSERTATION APPROVAL FORM

We certify that we have read this dissertation and that, in our opinion, it is satisfactory in scope and quality as a dissertation for the degree of Ph.D. in Information Systems.

Student Name: Loknath Sai Ambati

Dissertation Title: Design Principles for App-based Healthcare Interventions: A Mixed Method Approach

Dissertation chair:____________________ Date: April 18, 2023

Committee member: Ronghua Shan Date: 4/18/2023

Committee member: Nevine Nawar Date: 4/18/2023

Committee member: Renae Spohn Date: 4/20/2023

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ABSTRACT

Despite the ubiquity of mobile health applications (apps), the practical use and success of the apps have been questionable. Design Principles (DP) can affect chronic health app user satisfaction and have been studied for ensuring favorable app usage. However, there is no consensual definition of DP within the preceding literature, which has a technical rather than an end-user-centric focus and lacks a rigorous theoretical basis. Moreover, different levels of DPs' application can lead to differential user satisfaction as influenced by the user-contextual environment, warranting a quantitative assessment.

Accordingly, the overarching question to be addressed is which DP for the self-management of chronic conditions contributes to better user satisfaction outcomes. The research focuses on Multiple Sclerosis (MS) as a representative condition. This research uses a mixed-methods, with a qualitative approach for DP identification and a quantitative approach for the studying the DP-Satisfaction relationship. The DP identification is achieved through - 1) An in-depth review of foundational theory for greater validity, 2) A Systematic Literature Review (SLR), for DP themes grounded in theory, and 3) Manually coded user reviews for MS apps. The theoretical underpinnings of the empirical approach are established through a composite theoretical lens, based on technologically, behaviorally, and cognitively oriented frameworks.

The DP extracted from theory, SLR, and manual coding methods are found to be largely consistent with each other, namely *'Communication with Clinicians', 'Compatibility, 'Education', 'Notifications', 'Tracking', 'Social Support', 'Ease of Use', 'Technical Support', 'Usefulness', 'Privacy and Security', and Quality*. An ordinal logistic regression analysis is conducted to understand the relationship between DP and User Satisfaction outcomes based on the manually coded DP scores of the user reviews. All DP have a significant impact on User Satisfaction. From a theoretical perspective, the research improves our understanding of key design principles for the self-management of chronic conditions such as MS and the impact of such principles on user satisfaction. From a practical perspective, the findings provide guidance to the user requirement elicitation process, potentially leading to the development of more successful, sustainable, and responsive healthcare interventions.

Keywords: Design Principles, User Satisfaction, SLR, Multiple Sclerosis

DECLARATION

I hereby certify that this dissertation constitutes my own product, that where the language of others is set forth, quotation marks so indicate, and that appropriate credit is given where I have used the language, ideas, expressions or writings of another.

I declare that the dissertation describes original work that has not previously been presented for the award of any other degree of any institution.

Signed,

Loknath Sai Ambati

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CHAPTER 1

INTRODUCTION

Digital interventions have become popular as means for self-management of chronic disease conditions (Elamin et al., 2018). There has been a huge expansion of mobile health with over 100,000 mobile apps that can be accessed at the major mobile app stores. Mobile health evolved to an extent where it facilitates high-quality decision-making in relation to user or patient health (Koskie, 2020). Despite the pervasiveness of mobile health apps, the practical use and success of the apps have been curtailed owing to a lack of user satisfaction (Serrano et al., 2016; T. Wang et al., 2022). The concept of Design Principles (DP) for apps in general and healthcare apps, in particular, has been studied for ensuring favorable app usage for several years.

While app design and requirements elicitation are two different aspects of app development, they are interconnected, and both contribute to the success of an app (Durst et al., 2017; Seraj & Wong, 2012). In practice, a good mobile app design is based in part on a careful consideration of user requirements (Kamaruddin et al., 2011). Requirements analysis studied or followed over a span of time, use cases and applications to help improve and redefine the DP (Ashritha et al., 2017; Kamaruddin et al., 2011). However, DP are more stable and prominent than requirements and subsume the latter. Suitable DP can help guide the user requirement elicitation and development and lead to the development of more successful, sustainable, and responsive healthcare interventions (Awale & Murano, 2020; H. N. C. Fu et al., 2020; Huang & Benyoucef, 2022; Kirwan et al., 2012; Lucero et al., 2022).

Previous approaches to the study and elicitation of health app DP have a technical rather than an end-user-centric focus. Traditional design approaches focused on the technical and technological, i.e., software and hardware design and resources aspects of the design features and ignored the social, human, and organizational dynamics, leading to inconsistency between the investment and adoption of chronic health interventions (Durst et al., 2017; Er & Kay, 2005). A rigorous theoretical basis for identifying and translating the practical guidelines into DP for improved chronic health app interventions is lacking (H. D. Nguyen & Poo, 2016a). Frameworks like User Centered Design (UCD) and Activity Theory (Good &

Omisade, 2019), the Human-computer interactions (HCI) framework (Camargo-Henríquez & Silva, 2022), and socio-technical systems (STS) approach (Wickramasinghe et al., 2020) have been primarily proposed to address the app design, and analysis aspects. The applications of these approaches are incoherent, with a focus on divergent developer, procedural, and analytical perspectives, which are inconsistent with DP identification and articulation. Suitable and coherent theoretical basis for DP appropriate to the design of chronic health apps should also be identified and established. Research suggests that different levels of design factors or principles can lead to variable user satisfaction outcomes (Frie et al., 2017; Oh & Kim, 2022; T. Wang et al., 2022), which signify the need for a quantitative study of the relationship between DP and user satisfaction.

The overarching purpose of this research is to identify a comprehensive set of design principles involved in self-management chronic-health app design associated with greater user satisfaction. These design principles are theory-based and user-centered. Given the exponential growth in the chronic mobile health app space, the design factors are likely to vary by the type of disease and app design motivations. Multiple Sclerosis (MS) is one such example. MS is a chronic neurological condition (Marziniak et al., 2018) affecting more than one million people in the United States and 2.3 million people globally (Koskie, 2020). There are many apps related to this condition. MS, a chronic disease, has distinguishing features that include trouble walking, impaired vision, fatigue, cognitive problems, and mood disturbances (Giunti et al., 2018; Rudick et al., 1992a). Recent research has also identified improved self-management as the overarching motive in the field of MS mobile app usage, leading to better user satisfaction outcomes (Anderson & Emmerton, 2016; Elamin et al., 2018; Sai Ambati et al., 2021; Salimzadeh et al., 2019).

In the context of the self-management of chronic conditions such as MS, we aim to address the following questions 1) What are the design principles of mobile app-based interventions associated with user satisfaction, and 2) What is the relative impact of the identified principles on user satisfaction. This is accomplished following a mixed-method exploratory approach comprised of a systematic literature review (SLR) and theoretical foundation for DP identification. Under the quantitative approach, a statistical analysis of user satisfaction and DP will be performed to validate the research hypothesis.

CHAPTER 2

LITERATURE REVIEW

DP have been seen in diverse terms such as - user interface enhancement and usability level (Seraj & Wong, 2012); persuasive systems design and self-management via personalized problem identification, goal-setting, decision-making, and action-planning (Lucero et al., 2022); and functional, user-interface, medical-knowledge, and patient-doctor routines (Legner, n.d.), etc. For the purpose of the proposed study, DP are as a broad set of rules for goals and contexts for app development and enhancement with both general and domain-specific aims such as those listed above. Importantly, design principles are "appropriate to a technological tool aimed at a specific goal or intervention can affect the usability and adoptability of the app, thereby affecting satisfaction" (Legner, n.d.).

Despite the ubiquity of mobile health apps, the practical use and success of the apps have been poor owing to a lack of user satisfaction (Serrano et al., 2016; T. Wang et al., 2022). The concept of DP for healthcare apps has been studied for several years to ensure favorable app usage. The relationship between DP and user satisfaction has rarely been studied. In absence of theory-based, user-centric principles with demonstrated association with user satisfaction, design professionals often find it challenging to articulate users' self-management health needs into app development requirements hindering user satisfaction (Ashritha et al., 2017; Kamaruddin et al., 2011). This gap is reflected in the literature (H. D. Nguyen & Poo, 2016a) as to what could constitute suitable DP for chronic health conditions from a user self-management perspective thereby improving satisfaction (Salimzadeh et al., 2019).

Wang et al., (2022) addressed the problem of what factors correlated with user satisfaction with mobile health apps for weight loss. They mined topics and themes from user reviews, which were then examined for a relationship with user satisfaction and dissatisfaction factors via Tobit regression as per Herzberg's 2-factor theory. They successfully identified factors that could be categorized into hygiene and motivating factors for user satisfaction. They acknowledged the availability of data from a short 2-year time span as a limitation. They pointed out that apps are frequently updated and necessitate accounting for user satisfaction over a longer period. There is a need for more stable constructs representing the factors affecting health app user satisfaction, consistent with Nguyen and Poo (2016), who supported the idea of a user-friendly design based on established design principles. Oh and Kim (2022) similarly examined what improves customer satisfaction in mobile app usage, though within the banking context. They also extracted factors that possibly affected user satisfaction from user reviews using text mining and topic modeling and then studied the relationship through panel regression. The authors suggested future research enabling greater assessment of more of the functional elements within the banking domain such as deposit, money transfer, or credit score management affecting app user satisfaction as opposed to generic app quality factors, such as ease of use, and convenience which were the focus of their study. Within the chronic health domain, similar functional factors identified in the literature include factors such as - diet management, self-monitoring, treatment alerts, disease knowledge, treatment decision support, etc. (Ambati et al., 2021; H. D. Nguyen & Poo, 2016b; Salimzadeh et al., 2019a; T. Wang et al., 2022). Such functional elements are essentially more responsive and revolve around self-management and care requirements. However, they may be subject to frequent changes, and thus can be better captured as DP. In essence, DP can encompass and absorb changes in user requirements over time and thus address a greater level of user satisfaction (Ferré-Grau et al., 2021). In the context of chronic health apps, design principles emphasis can lead to the development of more successful, sustainable, and responsive healthcare interventions (Al-Ramahi et al., 2017), for greater user satisfaction. It is important to establish the DP relevant to chronic healthcare app user satisfaction and study the underlying relationship to enable optimizing the nature and extent of such factors for various chronic health contexts.

This challenge exists despite a recognition of the applicability and significance of the DP already reported in the literature (Al-Ramahi et al., 2017b; Durst et al., 2017; Kamaruddin et al., 2011; Legner, n.d.; Seraj & Wong, 2012). Previous approaches to studying health app DP have focused more on technical aspects, rather than on end-user needs and social aspects. This results in often forcing new behaviors on users, rather than incorporating their needs into the app design (Durst et al., 2017; Er & Kay, 2005). The reported design principles often lack a strong theoretical underpinning. For example, (Good & Omisade, 2019) put forth User-Centered Design (UCD) as a basis for app design with a focus on user preferences with a developer lens but falling short of arriving at any set of design rules grounded in UCD. Similarly, (Camargo-Henríquez & Silva, 2022) pointed out that activity theory within a Human Computer Interaction (HCI) framework has been used to improve the development process based on activity analysis for rationalization of design. They demonstrated it as a tool to analyze and understand the complex socio-technical ecology while adapting the apps to their behavior and evolution. However, neither they nor any of the cited research in their work explicitly suggested these theoretical frames as bases for the development of DP particularly in the context of mobile app-based healthcare interventions. Further, (Wickramasinghe et al., 2020) proposed an activity-theory-based framework to analyze and design socio-technical systems for the analysis of app-based interventions. However, they did not elicit any rules for the effective design of apps for the future or even their immediate research context. Evidently, the application of these approaches was focused on divergent developer, procedural, and analytical perspectives, inconsistent with DP identification and articulation. The identification and establishment of a suitable and coherent theoretical basis for DP appropriate to the design of chronic health apps are also warranted.

There is limited literary evidence to suggest that different levels of design factors or principles can lead to variable user satisfaction outcomes (Frie et al., 2017; Oh & Kim, 2022; T. Wang et al., 2022). For example, Wang et al. (2022) explored and measured the correlations of identified factors of mobile health management apps pertaining to the chronic problem of weight loss and found differences in these correlations across and for different levels of satisfaction. Similarly, Oh & Kim (2022) quantitatively measured the impact of critical mobile app quality and design dimensions on user satisfaction, which showed that an increase or decrease in occurrence rates of such factors led to an increase or decrease in user satisfaction. Frie et al. (2017) arrived at correlations between the weight loss components of app design and user satisfaction measured through ratings, indicating that lower levels of these components could lead to lower satisfaction. This fact points to a need to quantitatively study the relationship between DP and user satisfaction.

CHAPTER 3

THEORETICAL FOUNDATION

From a theoretical perspective, the present research builds on extant theory regarding user-centric design, socio-technical systems, and user acceptance theories. The human-computer interactions (HCI) framework explains how the DP impact user engagement with chronic health apps (Good & Omisade, 2019; Kirwan et al., 2012; Lucero et al., 2022). A User Centered Design suggests that the chronic self-management activity of MS app users should be complemented by associated features facilitating the self-management (Good & Omisade, 2019). The Behavioral and Cognitively focused theories like Technology Acceptance Model (TAM) (Dou et al., 2017) and Self-efficacy Theory (Wulfovich et al., 2019) help explain user adoption and usage levels of chronic health apps developed with a DP emphasis. The Socio-Technical Systems (STS) framework (Wickramasinghe et al., 2020) helps explain the impact of the DP on user self-management in turn affecting the user satisfaction. The Socio-Technical Systems (STS) framework (Wickramasinghe et al., 2020) and Human Computer Interactions HCI propose the basis for design themes with the quality and value of the user-app interface features, which revolve around the user-preferences under the UCD framework (Good & Omisade, 2019; Lucero et al., 2022; Wulfovich et al., 2019). The applicability of the above theories to the proposed research has been reviewed thoroughly to arrive at a suitable theoretical foundation for this study. The DP, their associated theoretical premise and their theoretical relationship with user satisfaction are presented below. UCD (Barbaric et al., 2022; Cafazzo et al., 2012; Hsieh et al., 2021; L. Jibb et al., 2017; Reis et al., 2022), HCI (Good & Omisade, 2019; Huang & Benyoucef, 2022; Nardi, 1996), STS (Wickramasinghe et al., 2020) and TAM (Bhattacherjee, 2001; Knox et al., 2021) help enhance the satisfaction and continuance use of apps through the relevant DP in a chronic m-health app intervention context.

Ease of Use: A complementary design theme to ‘usefulness’ is ‘ease of use’ both of which come from the Technology Acceptance Model (TAM) (Dou et al., 2017; Knox et al., 2021) and Self-efficacy as their antecedent construct (Wulfovich et al., 2019), which help explain user adoption and usage levels of chronic health apps. Specifically, ‘ease of use’ when incorporated into chronic health apps through user friendly navigation, and design, will ensure improve perceived self-efficacy of the app users and will improve user satisfaction, as more and more users are able to easily access and navigate most features of the said apps. Since, this feature is also centered around user needs of self-efficacy, and aids in self-management, it falls under the purview of UCD (Good & Omisade, 2019; Wulfovich et al., 2019). Further, by virtue of increasing human-technology interactivity, towards greater user satisfaction, this DP is well within the ambit of HCI framework (Good & Omisade, 2019; Lucero et al., 2022).

Usefulness: One of the prominent DP in chronic health app design as a desirable feature is ‘usefulness’ also expressed as ‘utility’ in many studies (Iribarren et al., 2020; Øksnebjerg et al., 2020; Philips et al., 2018; Puig et al., 2021; Salim et al., 2021). It represents the perceived functional utility of the app, from a user perspective and when incorporated in the app design as an embedded aspect, helps enhance the app value. Enhanced utility helps increase the interactivity of the user with app, consistent with HCI framework, towards improved self-management, in turn increasing user satisfaction (Good & Omisade, 2019; Stinson et al., 2014; Turgambayeva et al., 2022; Wickramasinghe et al., 2020). In theoretical terms, ‘Usefulness’ of an app has been identified as an important construct under the Technology Acceptance Model (TAM), which proposes that user perceived ‘usefulness’ of a technology informs satisfaction for continuous usage (Bhattacherjee, 2001; Davis & Venkatesh, 1996; Ma & Liu, 2005). Since ‘usefulness’ in an app design context is akin to the ‘functionality’ construct of STS, this DP effectively also draws its basis from the STS framework, such that it helps design more user-friendly app system. Chronic health apps are such technology, which when designed with ‘usefulness’ feature in mind can help achieve improved acceptance, which translates into user satisfaction (Cheung et al., 2021; Davis & Venkatesh, 1996; Knox et al., 2021; Ma & Liu, 2005).

‘Social Support’ as a means of peer-help and connectivity (Heiney et al., 2020; Ledel Solem et al., 2020; Setiawan et al., 2019) has been identified as a recurring Design theme in the literature. Ledel Solem et al. (2020) in their App design and development study followed a user-centered approach to app design for chronic pain self-management and identified ‘Social Support’ as an important component of a user-friendly app design. As per their formative evaluation, they found users to rate the app as high on ‘satisfaction’ measured on the system usability (SUS) scale. Similarly, Adler et al. (2022) in their development study, pin-pointed social-media linking via the app for better sense of belonging and increased trust in the app. Peer-help via social-support helps improve user satisfaction for chronic health app users, who could share their experiences, and be better informed about the strengths, weaknesses, and suitability of the app to their needs. Social Support aspect of chronic health apps is entirely centered around the socializing belongingness needs within a system, which helps enhance their trust (Cafazzo et al., 2012; Kabeza et al., 2020; Reis et al., 2022; Slater et al., 2020). This incentivizes greater interaction between people via technology under a social-support environment consistent with STS. Users share their treatment details, personal disease progress and self-management performance, through the app technology enhancing user satisfaction (Good & Omisade, 2019; Woods et al., 2019).

Quality: Literature in the field of app design in general and chronic health app design in particular refers to usage and usability issues (Iribarren et al., 2020; Jeon & Park, 2018; Woods et al., 2019; K. Yu et al., 2021). Most of these pre-development studies point to the importance of enhancing what may be termed as user perceived app 'quality'. The prevention of such issues through effective app design, based on pilot studies, co-design, or re-design of apps based on real user feedback for future or potential users is a desirable design feature of apps. Apps which essentially account for 'quality' so as to prevent issues are likely to maximize user satisfaction. On the theoretical front, app quality being user centered and premised on increasing quality of interaction between app and user and thereby the frequency of usage, is consistent with the theoretical premises of UCD and STS frameworks (Good & Omisade, 2019; Iribarren et al., 2020; Wickramasinghe et al., 2020). The enhancement of 'quality' through prevention of usage issues enhances self-efficacy and ease of use.

'Privacy and Security' is also a theme, which emerges from HCI theoretical frames, and is a major user concern and design requirement (Abahussin et al., 2020; Adu et al., 2019). Privacy and security are a major user need, which if adequately fulfilled by chronic health apps through data protection, and privacy features, likely improves user security and *trust* in the app, thereby improving satisfaction (Abahussin et al., 2020; Good & Omisade, 2019). The data protection features help enhance the user *trust* and thus ensure greater interactivity between users and the app system, thereby complying with the HCI theoretical premises (Kamaruddin et al., 2011; Wickramasinghe et al., 2020).

'Technical Support' as a means to ensure smooth technical help (Abahussin et al., 2020; Philips et al., 2018; Puig et al., 2021) and prevent future technical hindrances in app based user self-management, and ensure smooth interactivity are also pertinent themes consistent with the UCD theoretical premises (Good & Omisade, 2019; Puig et al., 2021; Turgambayeva et al., 2022; Wickramasinghe et al., 2020; Woods et al., 2019). Technical support specifically pertains to the level and extent of user-support provided by app via human or technological means for the users reporting technical issues with app usage. Thus, there is an interaction between the social and technical aspects of the app system which include the user, technological support features, or human support provided through a technical support team. Apps which have strong Technical Support features are able to resolve more customer problems, thereby improving user satisfaction and enhancing retention (Turgambayeva et al., 2022; Woods et al., 2019).

Based on the research problem and purpose of the preceding discussion in this section, this study sought to test the research hypothesis as presented below.

H1: There is a significant impact of one or more MS app design principles on user satisfaction.

This study examined the relationship between MS app design principles and user satisfaction. The relationships studied in this research under a regression modeling approach can be expressed as:

User Satisfaction (sat) = α + β*Design principles vector (DP) + e (1)

Where α is the intercept, β is the coefficient of the Design principles vector, and e is the error term.

CHAPTER 4

METHODOLOGY

The present study addresses the problem of the sparsity of identified design principles (DP) and associated challenges in the formalization of user requirements elicitation and the development of more sustainable and responsive healthcare interventions. The problem likely leads to lower adoption and usage of the apps affecting their success owing to low user satisfaction. The overarching purpose of this study is to identify design principles involved in the self-management chronic-health app design to explore their association with user satisfaction. Different levels of design factors may lead to varying levels of user satisfaction. Thus, the study further aimed to quantitatively study the relationship between the DP and user satisfaction.

The need to optimize the scope of research (Alekseev et al., 2021; Giunti et al., 2018; Koskie, 2020; Marziniak et al., 2018; Rudick et al., 1992) leads to focus on MS apps as a case study. MS is a chronic condition affecting millions of people worldwide ranked second only to congestive failure in direct medical costs, with no cure and an unknown cause (Marziniak et al., 2018). Digital intervention as a self-management tool has grown in popularity with an expansion of mobile health. However, research shows that the currently available MS self-management intervention apps do not fully meet the needs of the users owing to various design shortcomings (Giunti et al., 2018).

To address the above problem and purpose, the study adopted a mixed-methods approach. An exploratory and qualitative design for DP identification and a quantitative approach for studying the DP-satisfaction relationship was adopted. The remaining subsections provide details regarding the various elements of the methodology.

Identifying design principles

The need exists to identify suitable DP (Legner, n.d.; Lucero et al., 2022; T. Wang et al., 2022) with a suitable theoretical basis in literature (Camargo-Henríquez & Silva, 2022; Good & Omisade, 2019; Wickramasinghe et al., 2020). Notably, Wang et al., (2022) highlighted the need to explore what factors correlated with user satisfaction for mobile health apps, which they explored and extracted using a text mining approach. Similarly, Oh and Kim (2022) called for further research exploring a greater assessment of factors, which revolved more around user activity. They explored and extracted such factors, though in the banking domain, via text mining and topic modeling. Thus, the above needs to identify suitable DP called for an exploratory approach as detailed in the following subsections.

Systematic Literature Review (SLR)

A Systematic Literature Review (SLR) regarding DP for mobile app-based interventions for chronic disease management under a top-down approach. The SLR has been performed as an adjunct yet stand-alone study under the research. It provides a comprehensive and evidence-based literary assessment and identification of DP, as informed by suitable theoretical premises, notably the User-Centered Design (UCD) and Human Computer Interactions (HCI) (Good & Omisade, 2019). A Boolean search query (see Table 4.1) was employed for identifying literature in databases namely Web of Science, PubMed, IEEE Explore, and AB/Inform until December 2022. The studies for the SLR were selected based on a progressive screening process involving typical steps like finalization of inclusion and exclusion criteria, keyword selection and finalization for online bibliographic database search, removal of duplicates, assessment for eligibility based on above criteria, and finally the synthesis and analysis of the papers for DP extraction, theoretical premises as well as other pertinent bibliographic metrics based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al., 2009). The DP themes from the SLR were used to augment the theoretical foundation and to guide and were ultimately contrasted with the findings from the thematic coding of user reviews.

Inclusion Criteria considered for the SLR was, primary research papers demonstrating rules/ideas/principles for design of healthcare app interventions, with the goal of maximizing user satisfaction, under given domain and/or constraints. Review articles, and non-English articles were excluded. Moreover, additional articles were excluded including studies with no specific chronic disease but general health behavior focus, Studies with no specific app focus, but general app development framework or multiple apps concerned with different problems, Studies with participants other than patients as end users of app, Studies in which the app intervention is not focused on self-management but caregiver role, Ongoing, incomplete, or prospective though published studies, with final or conclusive results pending.

Table 4.1 Search query for the SLR

“design*”
AND
“chronic condition*” or “chronic health” or “chronic disease*” or “self-management” or “self management”
AND
“mobile app*” or “app”
AND
“satisfaction” or “usability” or “adoption”

Thematic coding of user reviews

Data collection

The user review data was collected from the two most popular online app stores namely Apple iOS and Google Play. Both these app stores were searched for mobile apps related to MS using the keywords “MS” and “Multiple Sclerosis” which resulted in an initial list of 77 mobile apps The apps were further investigated based on the pre-established inclusion and exclusion criteria. Mobile apps that were not related to MS, apps that did not support English language preferences, and apps that were specifically catering towards physicians and healthcare professionals were excluded. The key inclusion criterion was mobile apps specifically intended towards MS patients for self-management. Based on the mentioned inclusion and exclusion criteria, the app description was thoroughly reviewed, and 36 apps were excluded accordingly. The raw data primarily consisted of MS app user reviews and associated fields such as ratings, titles, updates to the apps, etc. with a total of 50 fields to choose from for a total of approx. 1,228 reviews for 41 MS apps (Appendix B).

Thematic Coding and scoring the user reviews

Initially, open coding analysis was performed to identify the underlying themes associated with the user experience data (App user reviews). Thematic analysis proposed by Vaismoradi et al. (2016) was implemented for identifying the design themes. First, all 1,228 user reviews were manually coded to assign various design themes, then these themes were merged as deemed necessary to come up with meaningful design constructs that could be categorized and explained explicitly with respect to each other. This process of coding each review with various themes was performed by two researchers independently. Inter-rater reliability score was computed to evaluate the reliability of the coded themes. Any inconsistencies between the two researchers were resolved by discussing and finally agreeing upon the final design themes. The finalized design themes were considered as DP, which were further evaluated to assign DP scores.

The process of arriving at the scores data for the DP involved a manual assessment of the textual reviews data by two researchers for greater reliability. The inter-rater reliability score was computed to assess the reliability of the reviews scores arrived at by the two researchers. The original reviews dataset was provided to the two researchers to code and score the reviews on the given DP. Each researcher assigned the score codes separately, whereby a positive remark or content in the review concerning a specific design principle was coded as a '+1', while a clearly negative review on the given DP was assigned a '-1' value, and the rest were coded as '0'. After coding the reviews separately, the researchers came together to discuss the anomalies in the non-matching scores and finally agreed on one set of scores. Some of the reviews did not contribute to the data in any meaningful way, and the text was irrelevant to any of the DP. Such reviews were categorized as noise and were ultimately deleted.

Modeling the relationship between DP and user satisfaction

The need to quantitatively study the relationship between DP and user satisfaction (Frie et al., 2017; Oh & Kim, 2022; T. Wang et al., 2022) lends itself to statistical analysis, specifically ordinal logistic regression and Cramer's V correlation (da Silva et al., 2018). For example, Wang et al. (2022) explored and measured the correlations of identified factors of mobile health management apps pertaining to the chronic problem of weight loss and found differences in these correlations for different levels of satisfaction. Oh and Kim (2022) used regression methods to study the relationship between app design factors extracted from text mining and user satisfaction. The results showed that an increase or decrease in occurrence rates of such factors led to an increase or decrease in user satisfaction. This study adopts similar analytical approaches.

Operationalization of constructs

Dependent variable – User Satisfaction (sat)

Within the app usage context, user satisfaction may be seen as a fulfillment of user expectations driving enhanced participation, recommendation, adoption, and continuance (Oh & Kim, 2022; T. Wang et al., 2022). Apps in general and within the chronic health space have suffered with poor use and success owing to a lack of user satisfaction. As elicited earlier, a DP emphasis on app development may lead to a greater level of user satisfaction, which is one of the key research interests of this study (Awale & Murano, 2020; H. N. C. Fu et al., 2020; Huang & Benyoucef, 2022; Lucero et al., 2022; Seraj & Wong, 2012). Thus, user satisfaction is the dependent variable of the proposed study. The variable has been operationalized as user ratings from reviews for MS apps for the study. The user rating is a numeric variable measured on an ordinal scale. This variable is denoted as 'rating' for analysis purposes.

Independent variables vector – Design Principles (DP)

The DP though not consistently defined or applied in the literature, may be seen as a broad set of rules to develop and enhance chronic health apps (Al-Ramahi et al., 2017; Lucero et al., 2022). As a result of this research, DP were identified and extracted based on the process involving pertinent theories, SLR, and the thematic coding or user reviews, as noted earlier. The process also rendered the DP suitable for operationalization for this research as DP scores. The DP scores, which were computed as mentioned in the 'thematic coding and scoring the user reviews' section, represent the user-perceived value of different MS app design principles as affecting user satisfaction. Therefore, these DP scores are considered to quantitatively represent each DP respectively for further analyses purposes.

Statistical Analysis

The statistical analysis procedures include the descriptive univariate and bivariate analyses, data diagnostics, and regression modeling procedures for inferential analysis. While the statistical regression analysis is the focal analysis in the study, other forms of analyses may be considered supportive of or adjunct to the main analysis. Chronologically, the analytical procedures may be classified as descriptive statistics and regression analyses.

Pre-processing and descriptive statistics

During the preprocessing stage, the text from the reviews was cleaned from punctuations, stop words, URLs, and converted the titles to lowercase letters. Further, stemming and lemmatization were performed to convert all types of words to their respective root words. The preprocessing of the reviews was deemed necessary, especially when word cloud analysis was performed.

Descriptive statistics consisted of descriptive univariate and bi-variate analyses. Under univariate analysis, the frequency distribution by each category for each DP was tabulated. In addition to the frequency summary under univariate analysis, word clusters were plotted for each DP to analyze the most frequent words respectively. Under Bivariate analysis, correlation matrix was analyzed between all the DP including ratings (User Satisfaction) followed by standardized residual analysis for each DP against rating using mosaic plots.

Regression analysis

The DP data extracted and computed from the preceding methods as discussed above were used as input data for further analyses. Specifically, user satisfaction data from the user ratings were regressed on the DP to examine the relationship between all predictor variables that is the DP, and user satisfaction as the outcome variable.

We used ordinal logistic regression on the data as the dependent variable (user satisfaction) measured on an ordinal scale. For performing this regression, we needed to make sure that the following assumptions were checked as follows:

1. Two or more independent variables which were either continuous or categorical or a mix of both - assumption was met based on the current set of DP and rating variables.
2. No multicollinearity assumption needed to be met, which was verified by plotting Cramer's V correlation values which is a variation of Pearson's Chi-square test.
3. Presence of proportional odds assumption was verified by performing a brant test.

CHAPTER 5

RESULTS

Design Principles (DP)

The Design Principles were arrived at, based on a three-pronged process including grounding in pertinent theory as the theoretical foundation of the research, a systematic review of the literature and thematic analysis. The DP identified are presented under the relevant process subsections below. Some of the themes were renamed, merged, or eliminated and the most recurrent and relevant theses were finalized from all these intermittent DP results. The final number of DPs extracted was 11 as described further below.

Systematic Literature Review (SLR)

As described in the Methodology section, a search query from Table 4.1 utilized to search the databases namely ABI/Inform (21 articles), IEEE Xplore (62), PubMed (314), and Web of Science (383) resulted in a total of 780 articles. Out of these 780 articles, 271 were identified as duplicates and removed accordingly, which resulted in 509 articles. Keeping the inclusion and exclusion criteria in mind, these 509 articles were further reviewed by title and abstract, where 163 articles were excluded resulting in 346 articles. Finally, the full text of these 346 articles was further reviewed to exclude 273 articles based on the exclusion criteria which resulted in the final set of 73 articles. Based on the PRISMA approach, a total of 73 articles were finalized for further analysis. Figure 5.1 illustrates the PRISMA chart of which there are five quantitative studies, 18 qualitative studies, and 50 mixed method studies.

Upon further analysis, the SLR identified 15 Design themes/variables through extraction of design features based on user preferences from the included papers. These themes were reviewed and categorized into 15 thematic categories. Table 5.1 illustrates the occurrence of each DP among the finalized set of 73 articles obtained from the SLR. Tracking stood to be the most popular DP which was recognized in 45 articles (61.6%), followed by Ease of use with 31 articles (42.5%), Education with 28 articles (38.4%), Notifications with 24 articles (32.9%), Charts and Reports with 15 articles (20.5%), Usefulness with 14 articles

(19.2%), Communication with Clinicians with 12 articles (16.4%), Behavioral Change with 11 articles (15.1%), and rest of the DP being under 15%.

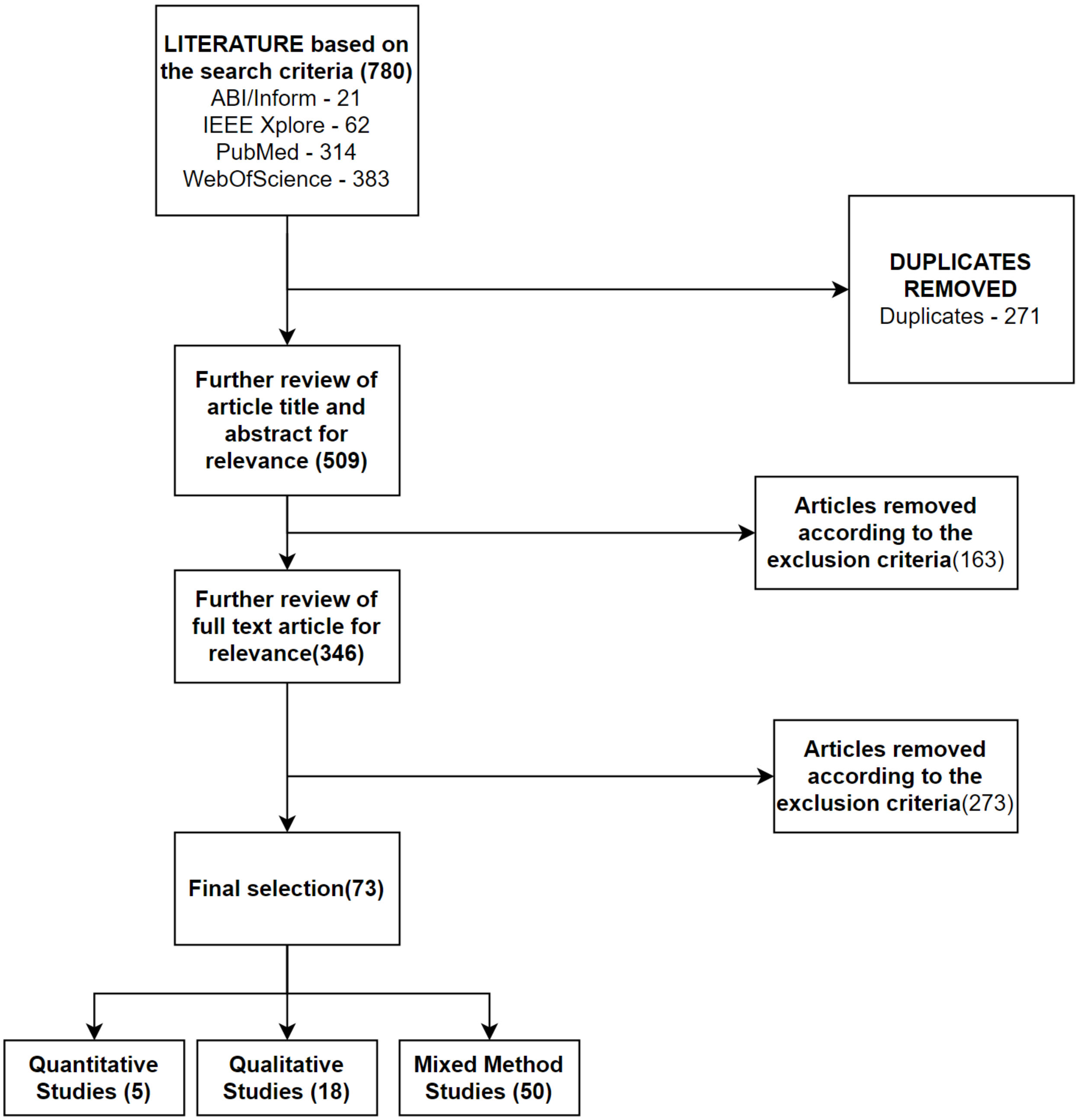


Figure 5.1. SLR PRISMA Results of finalized set of articles.

Among the 15 DP obtained from SLR, six of them seem to reflect constructs described in theoretical foundation section which are Ease of Use, Usefulness, Social Support, Quality, Privacy and Security, and Technical Support. Although Technical Support and Privacy and Security have weak frequencies in SLR, the literature regarding their relationship with user satisfaction remains consistent with theory. The following paragraphs elaborate on these DP as reflected in the literature beyond those captured in the theoretical foundation.

Table 5.1. Frequency distribution of the DP based on SLR

DP	Frequency	Percentage
Tracking	45	61.6%
Ease of Use	31	42.5%
Education	28	38.4%
Notifications	24	32.9%
Charts and Reports	15	20.5%
Usefulness	14	19.2%
Communication with Clinicians	12	16.4%
Behavioral Change	11	15.1%
Compatibility	10	13.7%
Quality	10	13.7%
Social Support	9	12.3%
Enjoyment/Fun	8	11.0%
Reward mechanism	7	9.6%
Privacy and Security	3	4.1%
Technical Support	1	1.4%

Tracking: Follow up and tracking of the user activity aids effective self-management support. Thus, 'Tracking' also emerged as a pertinent DP theme (Barbaric et al., 2022; Goyal et al., 2017; Kabeza et al., 2020). Barbaric et al. (2022) in their chronic heart failure study with 'tracking' as one of the major design features, contributing to high user satisfaction. (Goyal et al., 2017) in their Randomized Controlled Trial (RCT) cum survey study had the monitoring of blood glucose levels of adolescent Type 1 diabetes patients as a major design feature, similarly found high user satisfaction among users. Similarly, 'Tracking' emerged as a major design feature desired by asthma patients under a pre-development user-centered survey study by Schneider et al. (2016). 'Tracking' as chronic health app DP aids in monitoring and thereby improving self-management performance of the users (Barbaric et al., 2022; Giunti et al., 2018; Schneider et al., 2016). Consequently, such app aided tracking support improves user experience through enhanced user-system interactivity (Giunti et al., 2018; Good & Omisade, 2019; Wickramasinghe et al., 2020).

‘Notifications’ as means to alert the user for performing specific self-management tasks (Ambati et al., 2021; Torbjørnsen et al., 2019) aid in enhancing the user interactivity with the app system (Abahussin et al., 2020; Good & Omisade, 2019), and also smooth user-technology interaction. Design and usability survey studies with ‘Notifications’ as an important feature indicate that it likely contributes to high user satisfaction (Abahussin et al., 2020; Nordstoga et al., 2020; C. Roberts et al., 2018; Sage et al., 2017).

Education: Information, and educational materials provided by the app regularly, form a substantial chunk of chronic health app support. This emerged as a pertinent theme and was named as ‘Education' (Knox et al., 2021; Luiu et al., 2018; K. Yu et al., 2021). Chronic health apps make self-care knowledge and disease education more accessible to users than traditional intervention programs (K. Yu et al., 2021). ‘Education’ support has been identified as a one of the major design themes in chronic health development studies informing app design and development and also contributed majorly to user satisfaction under the respective usability and satisfaction testing (Farzandipour et al., 2019; A. Nguyen et al., 2018; K. Yu et al., 2021). On the theoretical front, such educational support achieved via apps being centered around the informational and instructional user needs, thus facilitates an effective self-management (Adler et al., 2022; Ledel Solem et al., 2020; K. Yu et al., 2021). The ‘Education’ design theme also involves creation of an interactive mechanism between the user or patient and the clinicians, which is facilitated by computing technology apps (Good & Omisade, 2019; Yu et al., 2021). App facilitated user education helps achieve more user-friendly self-management system, with high level of interaction and collaboration between users and the disease experts facilitated by the app (Ledel Solem et al., 2020; Wickramasinghe et al., 2020).

Communication with Clinicians: One of the important themes supporting the user self-management is ‘Communication with Clinicians’, which is critical for the users to manage their disease related activities with expert guidance and direction and critical feedback on self-management performance. ‘Access to Clinicians’ is thus, a construct which contributes to design, implementation and evaluation of interactive self-management systems (Good & Omisade, 2019). Incorporation of this feature in the design of Apps which provide such functionality, facilitate such expert help, help gain favor by users. Advice from doctors and communication with them has been found to receive the highest score from a user satisfaction perspective (Baek et al., 2018; Turgambayeva et al., 2022). Baek et al. (2018) explicitly concluded in their chronic m-health app design study that there is a demand for mHealth tools to include functions effectively supporting communication between patients and clinicians.

Compatibility: An important emergent construct 'compatibility' denotes the fit of the hardware and software to the user preferences and app support and also between various elements of the interface. Apps which provide a greater fit between different components of the overall app system, improve the user-experience through seamless navigation, and little or no software-hardware adjustment problems (Kidd et al., 2019). Thus, user-satisfaction for such apps is likely to be high.

Behavioral Change: One of the crucial themes especially in the case of self-management of most chronic disease conditions. This theme is responsible for improving health outcomes over an extended period of time. Underlying factors such as motivation and health feedback, outcomes for behavioral change can in turn affect the user satisfaction in the long run (Alessa et al., 2018; L. Lin et al., 2019).

Charts and Reports: This theme is responsible for the functionality of facilitating the user/care giver to summarize their health outcomes, physical activity, medications, symptoms, etc. This provides an overview of the essence of using the mobile app and is directly related to user satisfaction (Ledel Solem et al., 2020).

Reward Mechanism: This theme can be attributed to same as Behavioral change as this makes an attempt towards achieving the same goal of user satisfaction and user retention in the long run (de Ridder et al., 2017).

Enjoyment/fun: Consistent with the goal of user satisfaction, this is a more direct aspect that can influence the user satisfaction strongly for an intended continuance usage of mobile app (Tam et al., 2020).

The DP theme frequencies from SLR were one aspect in determining the overall fit of the DPs from SLR to qualify for the final list. For example, a DP with the lowest frequency could still qualify for the final list, based on theoretical relevance and manual assessment, and a DP with a very high frequency could fail to qualify for the final list if they are not reflected in theory and represented in the manual assessments.

Thematic coding

The manual thematic analysis by two researchers resulted in an inter-reliability score of 0.75 (Cohen's kappa). The resolution of inconsistencies among the raters as noted in the methodology resulted in the following 11 themes: 'Communication with Clinicians', 'Compatibility', 'Disease Knowledge', 'New Treatment Alert', 'Notifications', 'Tracking', 'Social Support', 'Ease of Use', 'Technical Support', 'Usefulness', and 'Privacy and Security'.

Derived design principles

Themes including *Tracking*, *Ease of Use, Education*, and *Notifications* were predominant in SLR. Also, they were consistent with Thematic Coding. Thus, these DPs, qualified for the final set although they are not present in theoretical foundation, with the exception of the *Ease-of-Use* DP. Further, tracking, education, and notifications would fall under 'Perceived usefulness' according to theoretical premises. *Communication with clinicians* and *Compatibility* did not draw their basis from the theoretical foundation of the study (although *Communication with clinicians* can be attributed to usefulness) however, they derived moderate evidence from the SLR and were quite consistent with thematic coding. Therefore, these two DP themes qualified for the final DP set. *Usefulness* was predominant in SLR, consistent with thematic coding as well as theoretical foundation, therefore it qualified for the final set of DPs.

Disease Knowledge and *Treatment Alert* themes derived from the manual thematic analyses were conceptually close to each other, from a user information and learning perspective. Both these themes were thus, when merged into – *Education* design theme was found to be quite consistent with the SLR. Thus, *Education* was retained for the final set. *Social support* found moderate support from the SLR, however, was quite consistent with theory, and thematic coding, therefore it qualified for the final set of DP. Although *Privacy and Security* and *Technical Support* did not draw strong support from the SLR, they were quite consistent with both theory and thematic analysis, therefore, they also qualified for the final set of DP. *Quality* drew moderate evidence from the SLR and was firmly consistent with theory, thus it qualified for the final DPs set, even though it did not derive its basis from thematic coding. The SLR yielded a prominent design theme named *Charts and Reports*.

However, a closer semantic look at the DP and the underlying paper contexts from the SLR revealed that this theme mostly denoted patients sharing their reports and information with the physicians and discussing their health accordingly. Therefore, *the Charts and Reports* can be considered as one aspect for supporting *Communication with Clinicians*. *Behavioral change* was an important emergent theme from the SLR. However, even though it may be relevant for many of the Chronic diseases, it does not apply well to MS. Further, it was not consistent with theory or thematic coding. Therefore, this theme was dropped. *Enjoyment/Fun* and *Reward mechanism* themes had a weak SLR basis. Further, they did not have a firm grounding in the theoretical premises nor were they consistent in thematic coding. Thus, these two themes were also dropped from the analysis and did not qualify for final DPs set.

As a result of the said three-pronged process including manual, theoretical, and SLR procedures described above, the following 11 DP were identified:

Tracking: The *Tracking* DP represents MS mobile app features fulfilling the need for the users to be updated about and enable them to track their symptoms, medications, treatments and follow-up (Ambati et al., 2021; Carmona et al., 2021; Kim et al., 2015).

Technical Support: The *Technical Support* DP represents technical help and decision making support provided by the app as a feature against the need of the MS app users to effectively use the app for self-management of their condition (Abahussin et al., 2020; Philips et al., 2018; Puig et al., 2021).

Education: The *Education* DP represents the educational features of the MS apps whereby the users get explicit knowledge about the disease, symptoms, treatment (current and prospective new treatment options), and other related information which helps them manage the problem better (Ambati et al., 2021; Carmona et al., 2021; P.-H. Lin et al., 2015).

Compatibility: The *Compatibility* DP represents the compatibility of various devices such as the mobile phone, tab, or medical devices, etc. in coordination with the mobile app as well as other platforms such as social media, google, apple, etc. (Ambati et al., 2021; Goyal et al., 2017; Kim et al., 2015).

Social support: The *Social Support* DP is representative of the MS mobile apps' facilitation of the users to interact and bond with the other MS patients or app users to share their experiences (Ambati et al., 2021; Heiney et al., 2020; Ledel Solem et al., 2020; Setiawan et al., 2019).

Usefulness: The *Usefulness* DP represents the technical and result oriented efficacy of the app and its features, which create a favorable and smooth user experience and help achieve self-management objectives (Jeon & Park, 2018; C. Roberts et al., 2018).

Notifications: The *Notifications* DP represents a feature of the MS apps that provides notifications and alerts to the user or MS patient for performing specific self-management tasks (Ambati et al., 2021; Torbjørnsen et al., 2019).

Communication with Clinician: The *Communication with Clinician* DP represents ability to share the users' health related information with their doctors for getting a better understating of the disease progression (Ambati et al., 2021; Groat et al., 2018; Kim et al., 2015; Sage et al., 2017).

Ease of Use: The Ease-of-Use DP represents the sequence and process of browsing through the user interface of a given MS app which is related to a user friendly and visually appealing interface. (Ambati et al., 2021; Oh & Kim, 2022; T. Wang et al., 2022)

Security and Privacy: Security and Privacy represents data policies, and terms under which the user health data is secured and safeguarded by the MS mobile apps (Ambati et al., 2021; Cai et al., 2017; Groat et al., 2018).

Quality: Quality DP represents the robustness of the mobile app for the users' intended usage. In other words, it can be described as how well the functionalities in the apps are performing in terms of stability, speed, usability etc,. (Stutzel et al., 2019)

The DP identified were used to map with, code, and score the user reviews against each DP by two researchers, as described in the methodology section resulted in an inter-reliability score of 0.85 (Cohen's kappa). The DPs thus operationalized as scores were numeric scale variables. Upon coding, scoring, and exclusion of noise data, we arrived at 931 out of 1,228 reviews.

Statistical Analysis

Descriptive statistics

Figure 5.2 illustrates the Cramer's V correlation between DP along with rating. It is evident that there was no significant correlation among DP, the maximum correlation was seen between tracking and notification which was 0.07 indicating that they are mildly correlated with each other followed by tracking and social support, and tracking and quality by a 0.06 correlation. When the correlation between review rating and DP was analyzed, quality stood highest with 0.31 followed by tracking, social support, usefulness, ease of use, and education with moderate correlations while the rest stood Below 0.05.

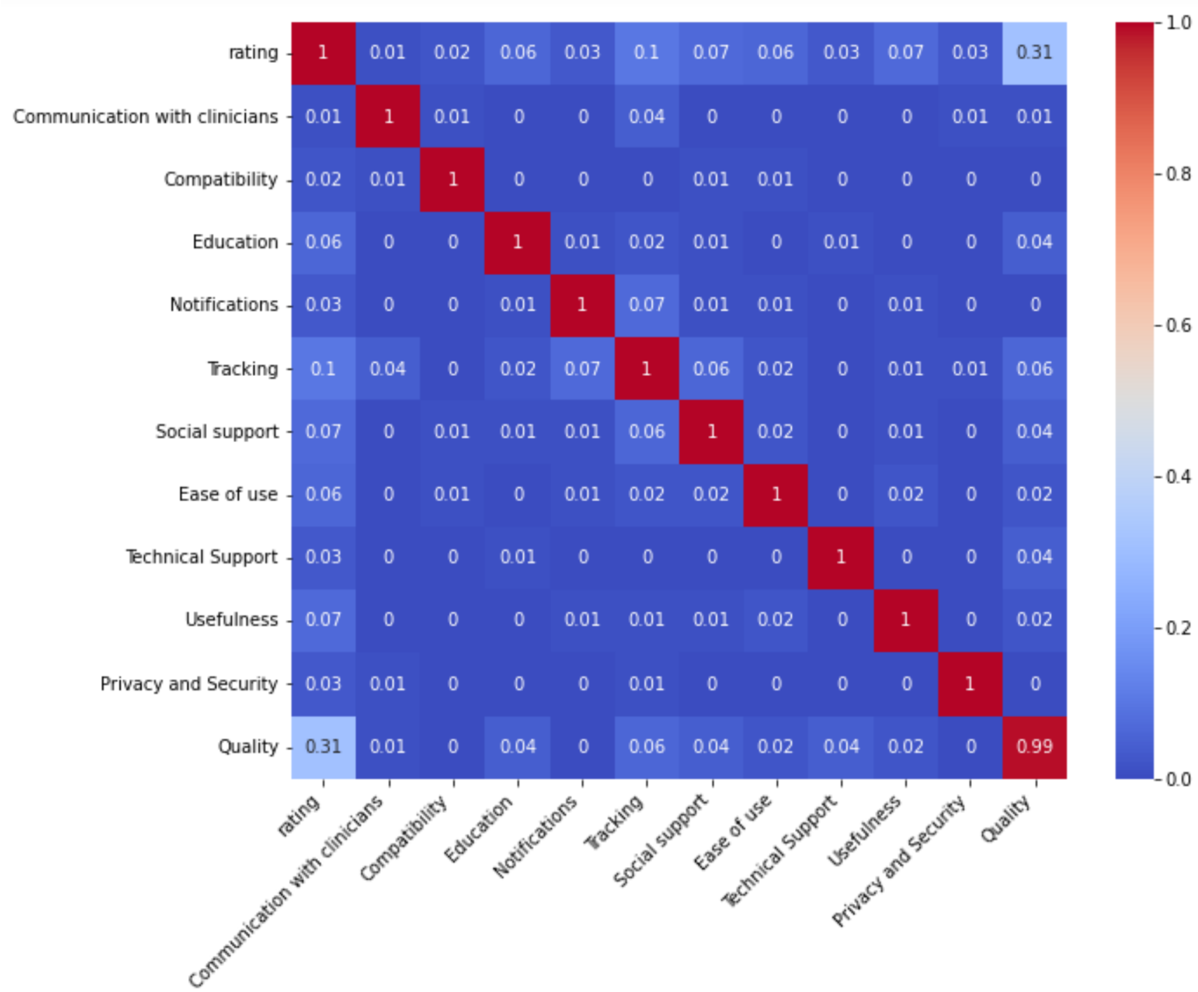


Figure 5.2. Cramer's V correlation matrix for the DP including rating

Table 5.2 illustrates the frequency distribution of each variable by category respectively. The distribution of the total 931 reviews is displayed by each category respectively. Ratings with '5' and '1' star were the most frequent among the users which is understandable as most of them post a review if they either like or dislike certain aspects of the MS apps. Overall, tracking (29%), Social Support (23%), Quality (23%) were most frequently mentioned followed by Education, General usefulness, and Ease of Use. When comparing +1 and -1 alone for a specific DP, Quality had a high data imbalance (no +1 reviews), followed by communication with clinicians, and privacy and security while the rest of them were moderately balanced.

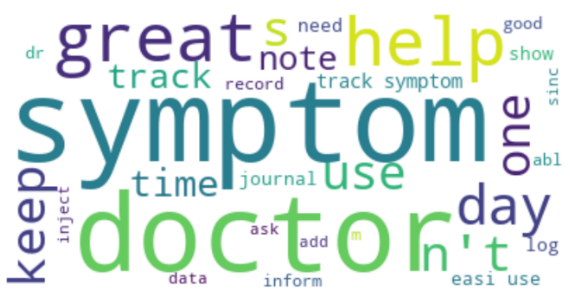
Table 5.2. Frequency distribution of all the DP and user satisfaction (Rating)

Variables	Categories	Distribution	%
Rating	1	200	21.5%
	2	74	7.9%
	3	90	9.7%
	4	126	13.5%
	5	441	47.4%
Communication with Clinicians (5% ‘+1’ and ‘-1’ response)	-1	2	0.2%
	0	885	95.1%
	+1	44	4.7%
Compatibility (4% ‘+1’ and ‘-1’ response)	-1	29	3.1%
	0	894	96.0%
	+1	8	0.9%
Education (17% ‘+1’ and ‘-1’ response)	-1	7	0.8%
	0	771	82.8%
	+1	153	16.4%
Notifications (9% ‘+1’ and ‘-1’ response)	-1	37	4.0%
	0	843	90.5%
	+1	51	5.5%
Tracking (29% ‘+1’ and ‘-1’ response)	-1	45	4.8%
	0	660	70.9%
	+1	226	24.3%
Social Support (23% ‘+1’ and ‘-1’ response)	-1	25	2.7%
	0	713	76.6%
	+1	193	20.7%
Ease of Use (13% ‘+1’ and ‘-1’ response)	-1	39	4.2%
	0	814	87.4%
	+1	78	8.4%
Technical Support (4% ‘+1’ and ‘-1’ response)	-1	21	2.3%
	0	895	96.1%
	+1	15	1.6%
Usefulness (14% ‘+1’ and ‘-1’ response)	-1	94	10.1%
	0	799	85.8%
	+1	38	4.1%
Privacy and Security (2% ‘+1’ and ‘-1’ response)	-1	21	2.3%
	0	909	97.6%
	+1	1	0.1%
Quality (23% ‘+1’ and ‘-1’ response)	-1	217	23.3%
	0	714	76.7%
	+1	0	0.0%

Figure 5.3 shows the word clouds associated with the reviews for each DP respectively. The world clouds represent the most frequent words for each DP where the size of the word correlating towards the frequency of the respective word.

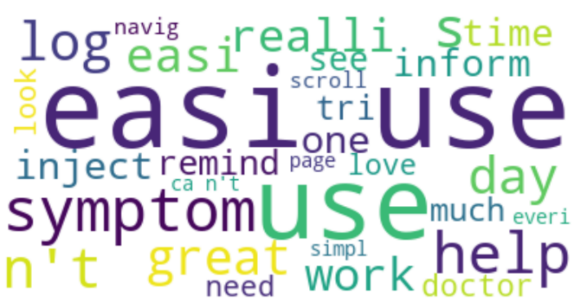
Among Communication with Clinicians, ‘symptoms’ and ‘doctor’ among others, seemed to be popular which were in line with the definition of the DP; the patients share their health data (symptoms, medication, etc.) with the clinicians. The word cloud for Compatibility with the most common words such as ‘use’, ‘not’, ‘phone’, ‘work’, etc,. reflected complains that the app was not working or not syncing with their phone. Moreover, terms like ‘iPad’ and ‘sync’ could suggest that there might be positive/negative reviews reporting the facilitation of iPad usage and synchronizing on multiple devices. The word cloud for Ease of use can be interpreted that people were referring to easy to use, navigation, scroll and user interface related topics which is in line with its definition. Education word cloud captures patients interest learning and being informed about their symptoms, disease, etc. Notifications word cloud illustrates the topics related to topics such as injection reminders, reminders in general, and alerts for the planned schedule. For the privacy and security word cloud, it was more related to topics such as lost data, privacy issues, Facebook data access, and email data access. Similarly, quality word clouds represent topics such as malfunctions, login/sign in issues, and issues regarding performance of the app. Social support word cloud shows topics relevant to connection with people, community and mostly portray positive words. Technical Support word cloud illustrates negative connotations associated with words such as ‘fix’, and ‘try’. There were also weak remnants of positive words such as ‘great’ and ‘thank’ reflecting appreciation for good technical support. Tracking word cloud captures words associated with the ability to track injections, symptoms, and other disease related elements.

Communication with Clinicians



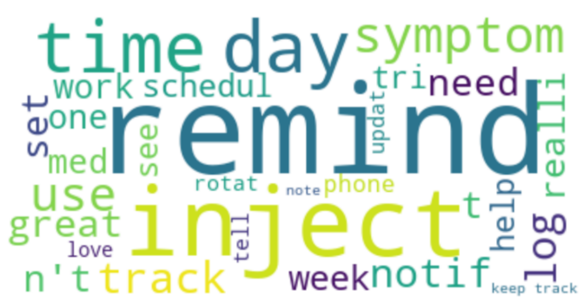
Compatibility

Ease of Use



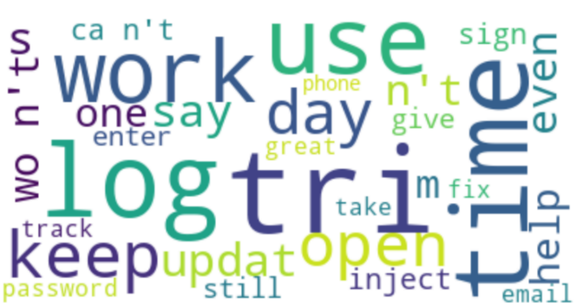
Education

Notifications



Privacy and Security

Quality



Social Support

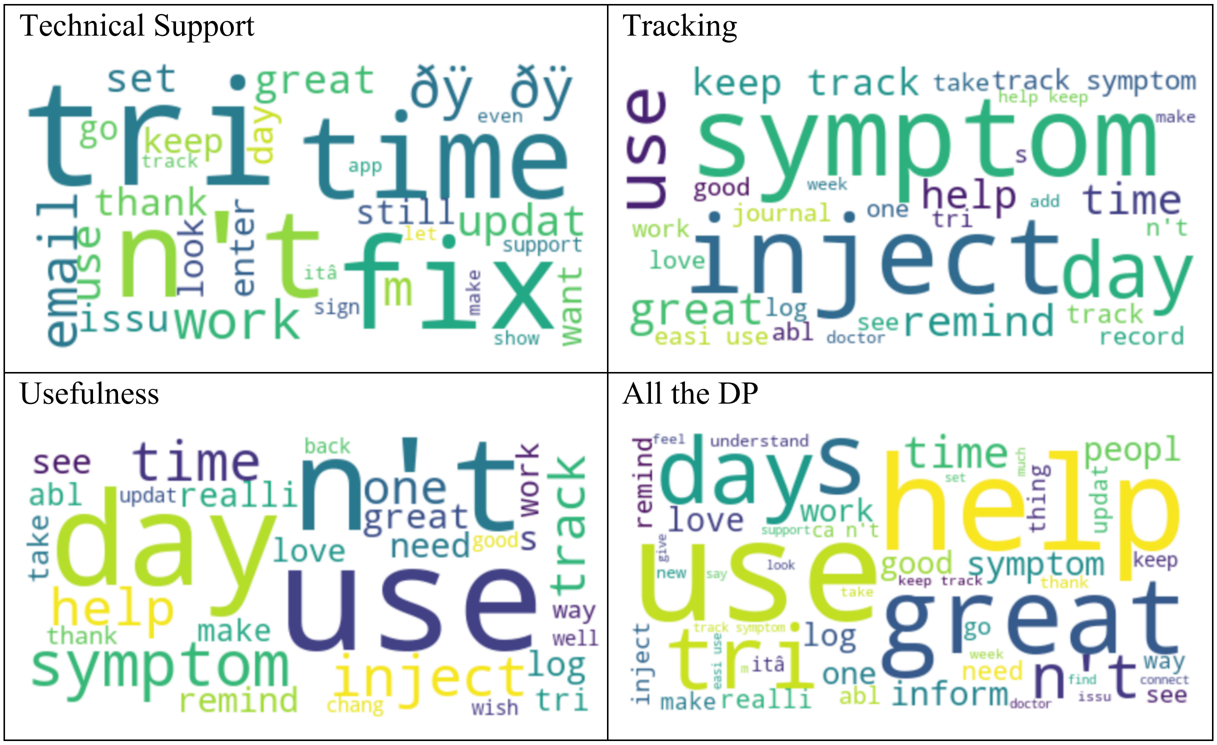
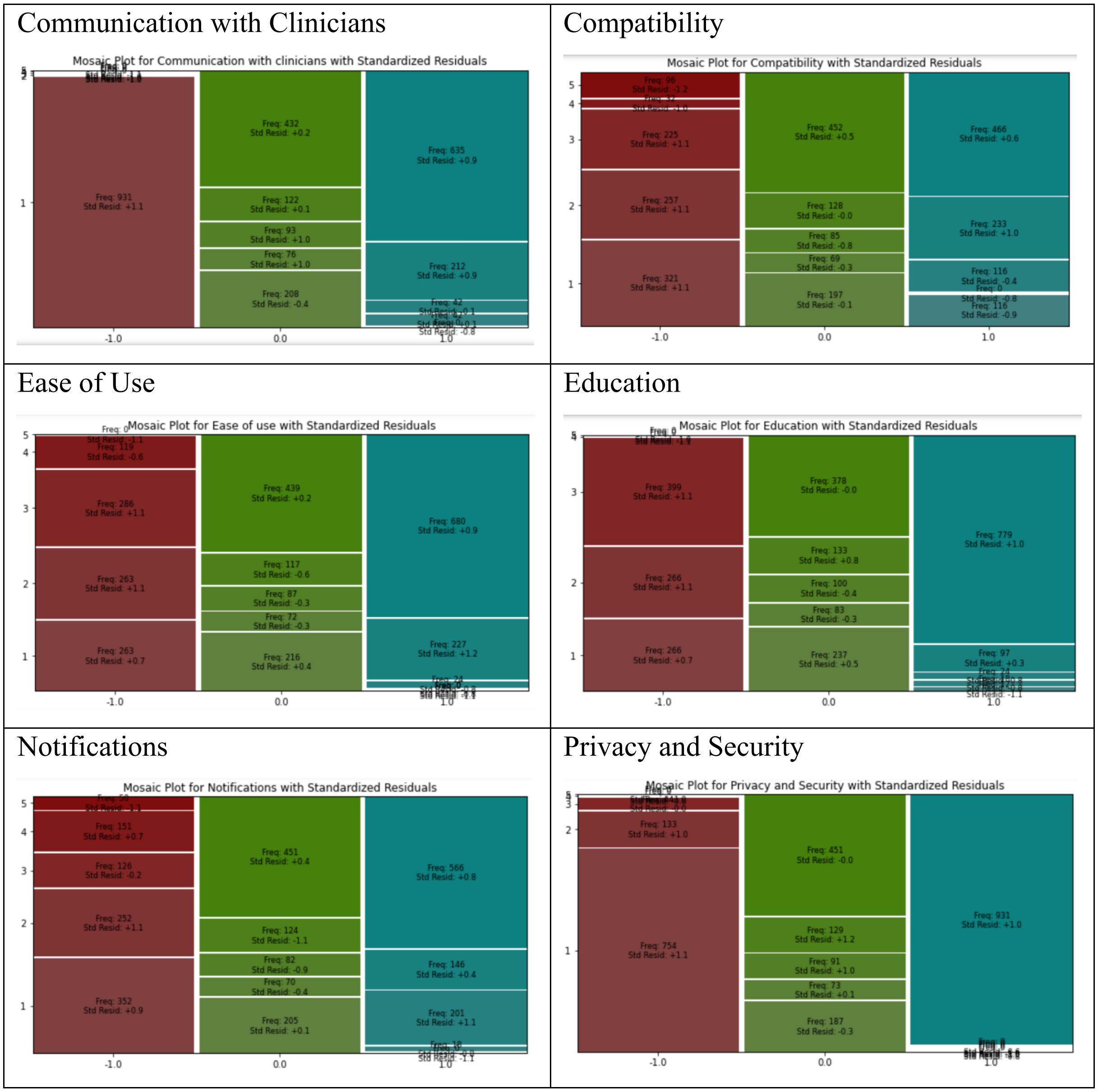


Figure 5.3. MS mobile apps reviews DP word cloud

Figure 5.4 illustrates the Mosaic plots of each DP with standardized residual values displaying the proportion of each category of the DP against the categories of rating respectively.



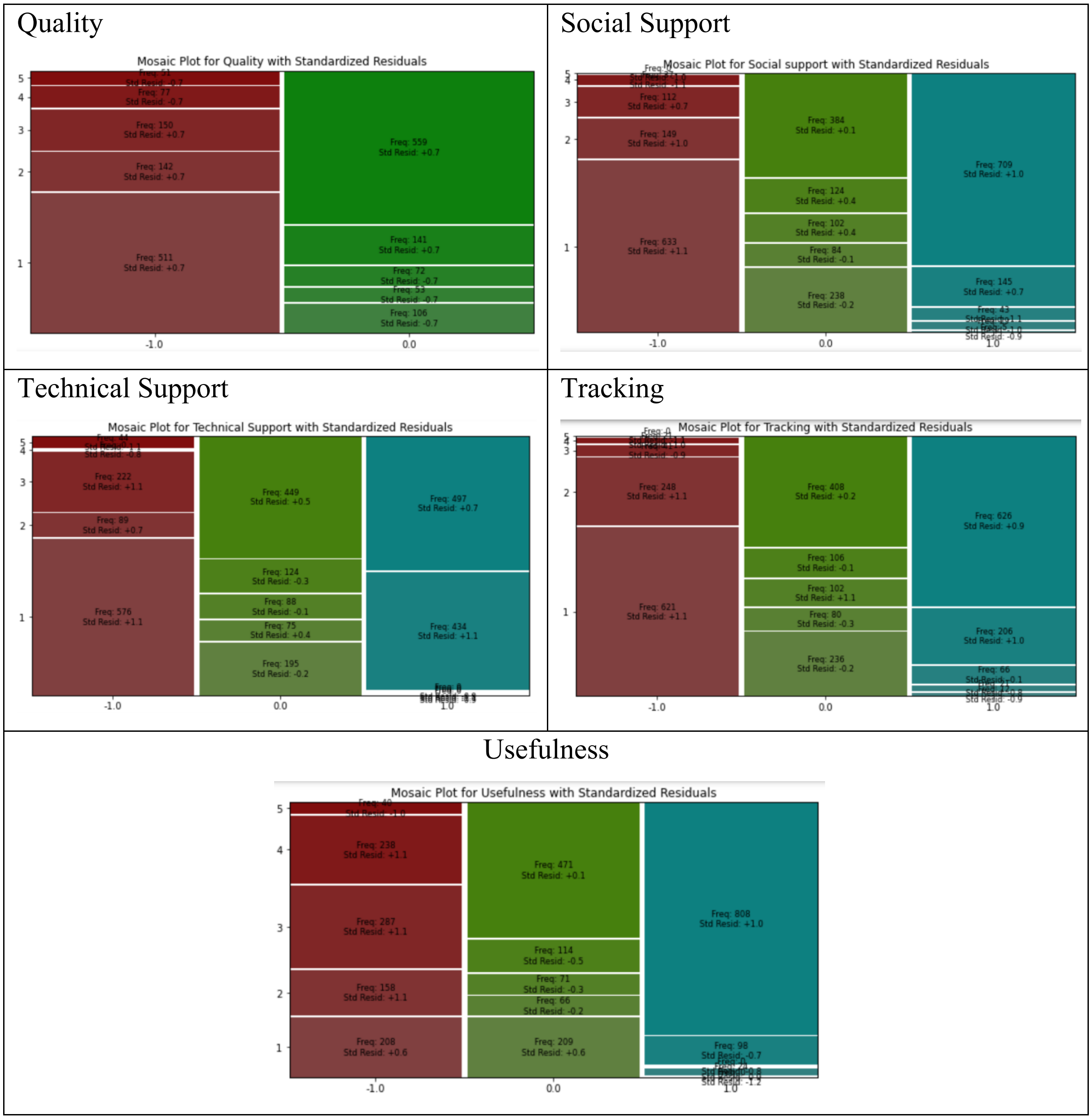


Figure 5.4. Mosaic Plots of DP with standardized residual values

Regression analysis

Based on the Cramer's V correlation matrix as illustrated in Figure 5.2, there was no significant correlation between the independent variables which verified the assumption of no multicollinearity. Similarly, the brant test showed an overall probability to be greater than alpha value of 0.05, which verified the presence of proportion of odds. The ordinal logistic regression model includes DP as the independent or predictor variables. The results of the regression model are shown in Table 5.3.

Table 5.3. Ordinal Logistic Regression Results

DV (Y)=Satisfaction IV (X) =DP	Coeff (S.E.)	t- value
Communication with Clinicians_-1	-17.231*** (9.4e-10)	-1.8e+10
Communication with Clinicians_+1	0.123 (3.8e-01)	3.2e-01
Compatibility_-1	-1.720*** (4.2e-01)	-4.1e+00
Compatibility_+1	1.220* (8.2e-01)	1.5e+00
Education_-1	-2.470*** (7.1e-01)	-3.5e+00
Education_+1	2.443*** (2.91e-01)	8.5e+00
Notifications_-1	-1.005*** (3.81e-01)	-2.7e+00
Notifications_+1	0.791** (3.61e-01)	2.2e+00
Tracking_-1	-2.342*** (4.21e-01)	-5.5e+00
Tracking_+1	1.801*** (2.31e-01)	7.9e+00
Social Support_-1	-3.576*** (4.91e-01)	-7.4e+00
Social Support_+1	2.337*** (2.51e-01)	9.3e+00
Ease of Use_-1	-1.276*** (3.51e-01)	-3.7e+00
Ease of Use_+1	1.112*** (3.21e-01)	3.5e+00
Technical Support_-1	-0.845* (5.11e-01)	-1.7e+00
Technical Support_+1	1.282** (5.61e-01)	2.3e+00
Usefulness_-1	-1.900*** (2.41e-01)	-7.8e+00
Usefulness_+1	2.330*** (6.11e-01)	3.8e+00
Privacy and Security_-1	-4.422*** (6.41e-01)	-6.9e+00
Privacy and Security_+1	14.295*** (1.21e-08)	1.2e+09
Quality_-1	-3.005*** (2.41e-01)	-1.3e+01
Intercepts		
1/2	-2.792*** (2.31e-01)	-1.2e+01
2/3	-1.884*** (2.31e-01)	-8.2e+00
3/4	-0.615***(2.31e-01)	-2.7e+00
4/5	0.966*** (2.21e-01)	4.5e+00
Log-Likelihood	-815	
AIC	1680	
Residual Deviance	1630	

* *p<0.1*
** *p<0.05*
*** *p<0.01*

The regression results showed that all DP significantly affect Satisfaction of the MS app users. This result showed support for the hypothesis of the study, which states that one or more design principles had a significant impact on user satisfaction. Communication with Clinicians coded as '+1' was not statistically significant while Communication with Clinicians coded as '-1' was statistically significant. Further the coefficients and *t*-values give an idea of the relative impact of the different MS app DP on Satisfaction. Social Support had the largest impact on user satisfaction, followed by Tracking, Quality, Education, and Usefulness.

CHAPTER 6

DISCUSSION

Identification of design principles

The DP were identified, extracted, quantified, and operationalized using a rigorous multi-modal, top-down approach employing SLR and a bottom-up in-depth analysis of user reviews with reference to pertinent theoretical foundations. Tracking, Education, and Notifications are reflected in SLR and user reviews. These can also be considered under perceived usefulness with respect to the theoretical foundation. Tracking and Notification themes are part of the review, and are functionally important, as reflected in the respective papers from the SLR. Barbaric et al. (2022) in their chronic heart failure study included 'tracking' as one of the major design features. Similarly, Goyal et al. (2017) also included it as an important aspect of their Type 1 Diabetes app as part of their randomized Controlled Trial cum usability survey.

Ease of use and Usefulness were two DP which made it to the final set and also found support in theory, as well as featured prominently, in both the SLR and manual coding results. These two themes are theoretically well established constructs, which denote and help predict user-acceptance (Davis & Venkatesh, 1996; Ma & Liu, 2005) as well as continuance of use. Many of the SLR studies included these constructs as important design features (Iribarren et al., 2020; Øksnebjerg et al., 2020; Philips et al., 2018; Puig et al., 2021; Salim et al., 2021). Their prevalence in user reviews reflect the value users put on ease of use and usefulness.

Communication with clinicians as a DP also found a place in the final DP set since it was a predominant theme in the SLR studies (Baek et al., 2018; Turgambayeva et al., 2022) and also the manual coding results. Baek et al. (2018) underlined the importance of communication between users and their clinicians as part of the m-health tools development. The manual coding shows that the app users express their preference for and importance of keeping in touch with the doctors for discussion of their treatment, self-management performance, symptoms, and disease condition. This DP however, did not draw its basis from theory, though it could be considered under perceived usefulness.

Compatibility was included in the final DP list. While it featured prominently in manual thematic coding, and also SLR. User reviews reflect MS app users' challenges regarding the fit between the hardware and software supporting the MS app and also the various devices, which may impede use. Results of user surveys reported in the literature indicate that compatibility is a preferred feature (Kidd et al., 2019; Mohammadzadeh et al., 2022), wherein the compatibility plays an important role in improving user-experience via seamless navigation and minimal software-hardware adjustment problems. Compatibility is a functional feature rather than a conceptual construct. This DP however, did not draw its basis from theory, though it could be considered under quality.

Quality, Social Support, Technical Support, and Privacy and Security are three DP which find consistent support from all three aspects of the DP extraction process – theory, SLR, and manual coding. Social support helps fulfill the social needs of the users, thus finds voice in manual coding, further, it is elicited in the usability surveys of the SLR (Heiney et al., 2020; Ledel Solem et al., 2020; Setiawan et al., 2019). With respect to theory, social support construct may be seen as consistent with the theoretical premise which emphasizes greater interaction among people and between people and technology, such as STS (Good & Omisade, 2019). Technical support DP reflects the MS app users concern for the effective resolution of their technical problems. Privacy and Security reflects the trust needs of the users (Abahussin et al., 2020; Good & Omisade, 2019). It draws the theoretical basis from frames such as HCI, which emphasizes smooth user -technology interaction through enhanced user confidence (Good & Omisade, 2019). The manual coding support shows the significant security and trust concerns of the MS app users generalizable to other app context as also evident from the SLR support for the DP.

Disease Knowledge and New Treatment Alert were merged with Education. Charts and Reports and Behavioral Change were two DP themes identified in the SLR yet were not reflected in the user reviews. This may be attributed to their subtle yet functional contribution to chronic health app self-management in localized contexts such as Rheumatic disease self-management (Kristjansdottir et al., 2020) for Behavioral Change or customization of monitoring for Charts and Reports (Sage et al., 2017). The remainder of this section provides further insight and discussion regarding the identified DP.

Communication with Clinicians in the MS app context is indicated by manual coding results, pertains mostly to discussion of patient symptoms with the clinicians, and getting help and advice from them in chalking out their treatment plans, through sharing of reports. However in literature, communication with clinicians has been seen in terms of the physician's need to get a more comprehensive view of the patient health status, and towards enhancing greater self-management, and also communication of the self-management performance effort of the patients (Baek et al., 2018; Ledel Solem et al., 2020).

Within the MS app context, the *Compatibility* DP**,** as evident from the manual thematic analysis, shows that it revolves mostly around the fit of the phone device with the app. However, in SLR literature, especially within the general app context, the Compatibility construct denotes more generic aspects like compatibility of the app between different platforms including both hardware and software. It has also been seen in the context of compatibility of the app to frequent or stable change of platforms (Kidd et al., 2019; Mohammadzadeh et al., 2022).

Education in the MS app context reflecting the user views and preferences about the DP from the manual coding represents how education or information regarding disease can be used as a customer support tool. Accordingly, users on their part see it more as a tool for helping them manage their MS related self-management tasks such as medication, exercises, scheduling. In chronic health app literature, Education pertains to specific functional areas like enhancement of disease knowledge, and treatment alerts, which revolve more around direct technical aspects of the disease, though with the same end goal (Goyal et al., 2017; A. Nguyen et al., 2018; Singh et al., 2019; K. Yu et al., 2021). Thus, there is a slight distinction between the manual coding and literary analysis of the Education DP.

The *Notifications* DP as elicited in the chronic health app literature is focused on message alerts for medication and activity reminders, as well as disease levels (Abahussin et al., 2020; Mazuz et al., 2020; Sage et al., 2017), which in agreement with the view gained from the manual thematic analysis, which suggests that the Notifications DP connotes reminders of medications, injections, activity schedules, etc.

Tracking especially in most of the literature for SLR described in tracking the patients' health conditions, physical activity, goal tracking, medication etc. (Al-Ramahi et al., 2017) But in the case of MS, considering its own distinguishing features, the unique tracking difference in the case of MS is mostly symptom tracking compared to others (physical activity, goal tracking) as tracking symptoms is an important factor in the case of MS that can indicate relapses or progression.

According to theory *Social support* can be defined as the various means of support coming from friends, family, community, etc. (Good & Omisade, 2019; Wickramasinghe et al., 2020). Although this definition from theory does apply to our case scenario, in this study, social support is heavily relied upon facilitation of means to connect with other MS patients rather than family, healthcare providers, etc. This is moderately the case in the most of the chronic disease conditions (Ledel Solem et al., 2020; Salim et al., 2021; Stinson et al., 2014; K. Yu et al., 2021), although connection with healthcare professionals is a also equally weighted in these chronic conditions.

A theoretical view of *Ease of Use* shows it as user friendly navigation, and design of chronic health apps, which helps improve the perceived self-efficacy of the users. This view is mostly agreeable with the concept of this DP yielded from the manual coding analysis, wherein it pertains to ease of using the app for the purpose of medications, self-management activities of the users, and connecting with peers as well as healthcare providers. The view from the SLR suggests Ease of use in slightly more diverse terms, wherein functions and concepts such as ease of understanding, ease of reporting, readability, etc, define Ease of Use for the chronic health app context (Carmona et al., 2021; Heiney et al., 2020; Kim et al., 2015; A. E. Roberts et al., 2021).

Technical Support **-** from a manual coding context, is articulated as timely resolution of technical issues of the MS app users. As per theory, this DP is defined more generically in terms of computer supported collaborative work, and facilitator of community supported app functionality (Good & Omisade, 2019). The SLR suggests that technical support is means to ensure smooth technical help, prevent future technical hindrances in app based user self-management, and ensure better ongoing usability (Abahussin et al., 2020; Philips et al., 2018; Puig et al., 2021).

Usefulness is defined in theory as the perceived level to which a user believes usage of the app will enhance their self-management performance, within the chronic health app context (Knox et al., 2021). This definition strongly applies to the MS app context for this study as well, which reveals the underlying themes from the manual coding such as user need fulfillment, activity reminder, exercise help, daily log, etc. which cluster towards smooth user activity self-management. The SLR literature emergent view for this DP denotes it as the perceived functional utility of the app, from a user perspective, which helps enhance the app value (Stinson et al., 2014; Turgambayeva et al., 2022; Wickramasinghe et al., 2020).

Privacy and Security – connotes user trust in the app system according to theory, including both technological and human aspects (Wickramasinghe et al., 2020). From a manual coding perspective, the MS app context of the privacy and security DP is about data security and confidentiality of both patient identity and activity information, in agreement with the theoretical view. The SLR literature indicates a major user need, which if adequately fulfilled by chronic health apps through data protection improves user trust in the app (Abahussin et al., 2020; Good & Omisade, 2019). This view is also consistent with the theoretical view.

Quality - as a theoretical construct within the chronic health app design context is seen as the prevention of usage hindrances and issues through superior design, aimed at enhancing the quality of interaction between the user and the app system (Good & Omisade, 2019; Iribarren et al., 2020; Wickramasinghe et al., 2020). The manual coding analysis MS app context shows Quality as smooth and timely performance of all self-management activities and tasks by users. The SLR also suggests that quality may be seen as minimization of usability issues of an app, which helps improve user acceptance and frequency of usage (Iribarren et al., 2020; Jeon & Park, 2018; Woods et al., 2019; K. Yu et al., 2021).

Discussion of Statistical Analysis Results

The statistical analyses consisted of both descriptive and inferential statistics. As part of the descriptive statistics, the findings of the correlation analysis, the frequency distribution, and the mosaic plots complemented and supported the inferential statistical results.

As shown in the table 5.2, tracking, social support and quality received high response rates suggesting that these DP are predominant in terms of user satisfaction. If we take a closer look, there is a high number of ‘+1’ for both tracking and social support compared to the ‘-1’, therefore users seem to have an overall positive attitude towards these DP whereas for quality, there are no ‘+1’ reported. This may be because people are mostly biased to report issues with the usability of the functionality or usability. *Privacy and Security* also present a similar picture, which may be explained in a similar fashion to *Quality* for this data. Overall, Compatibility, Technical support usefulness, privacy and security, and quality have more '-1' coded than '+1' while it is the opposite for the others.

The correlation between ratings and quality seems to be significant with a value of 0.31. The rest of the correlation values seems to be very low which may be due to the presence of high number of zero values and correlation can be attributed only when there is a specific coding occurrence of '+1' or '-1' in both the DP at the same time. However, even though the magnitude of the correlation values is low, it is possible to glean some relations among DP. Moreover, there is moderate correlation between social support, tracking, usefulness, ease of use, and education with rating. Considering that these DP have larger numbers of '+1' when compared to '-1' except usefulness, most of the high values of rating (5 and 4) are attributed by these DP. Among the independent variables, correlation between notifications and tracking is moderate, which can be explained by the observation that most of the reviews contain a mention of both these DP in the same review suggesting that most of the apps that facilitate tracking also facilitate notifications and vice versa. This observed DP correlations between notifications and tracking finds support in the literature, whereby, these Design themes appear together as preferred features for user samples in user surveys and usability studies (Abahussin et al., 2020; Carmona et al., 2021; P.-H. Lin et al., 2015).

As illustrated in Figure 5.3, communication with clinicians and tracking have symptom as the most frequent word suggesting that MS app users utilize tracking feature for their symptoms and also share their tracked symptom data with their physicians. According to findings from the SLR, chronic disease related studies (A. Nguyen et al., 2018; Torbjørnsen et al., 2019; Woods et al., 2019) have tracking feature utilized to track physical activity, medication, and treatment. But considering the importance of identifying relapses and progression in MS, tracking and most of the health data shared with the physician is related to symptoms. Moreover, in word clouds, DP such as communication with clinicians, Ease of use, Education, notifications, social support, and tracking are associated with positive words such as 'great', 'help', 'easy', 'love', 'help', and 'good' whereas DP such as compatibility, privacy and security, quality, technical support, and usefulness are associated with negative connotations associated with words such as 'not', 'cant', 'lost', 'wont', 'issue', and 'fix'.

Based on the Figure 5.4, it is evident that in general DP which are coded '-1' have high proportions of 1-star ratings associated to them respectively, followed by 2-star and so on. The same goes for the '+1' coded DP having high proportions of 5-star ratings followed by 4-start and so on, associated with them respectively. This phenomenon is natural, as reviews reflecting negative attitude tend to have lower ratings and vice versa. But for compatibility, ease of use, technical support, and usefulness, the trend varied for their reviews which are coded as '-1'. This suggests that while users may perceive these DP negatively, other features of the app may have swayed their evaluation towards a more positive rating.

The inferential statistical analysis was based on an ordinal logistic regression model, as presented in the methodology chapter. The overall results of the study show that all the identified DP significantly affect User Satisfaction. The finding concerning 'communication with clinicians' DP is in contrast, Baek et al. (2018) who had underlined the importance of 'communication with clinicians' in their study citing need for mHealth tools to include the same in app design. While this construct may still be theoretically important from a user perspective, the reviews data were somehow unable to capture it owing to the fact that the users may not be expressing their concerns regarding this feature as frequently as it may deserve. To establish the theoretical impact of this DP, more empirical testing may be required in future.

The results demonstrate that 'Social Support' and 'Tracking' have the greatest impact on the MS app user satisfaction, followed by 'Quality', 'Education', and 'Usefulness'. Notably, these DP are informationally and socially intensive and are consistent with the preceding research vis-à-vis chronic health app user satisfaction (Beauchemin et al., 2019; Carmona et al., 2021; Heiney et al., 2020; Iribarren et al., 2020; Kim et al., 2015; Philips et al., 2018). At a theoretical level, 'Social Support' reinforces the user-centered basis of its incorporation in the chronic health app design (Cafazzo et al., 2012; Kabeza et al., 2020). This result also reaffirm its role in enhancing the interactivity between the user and the app system, (Good & Omisade, 2019; Woods et al., 2019). Significant impact of this DP on user satisfaction also implies that it significantly fulfill the socializing, belongingness, and trust needs of the users and help establish the balance between the social and technical aspects of app usage. From a practical perspective, 'social support' will help the users connect with user community as an extension of the app.

At a theoretical level, ‘Technical Support’ and ‘Social Support’ both reinforce the user-centered basis of their incorporation in the chronic health app design (Cafazzo et al., 2012; Kabeza et al., 2020). These results also reaffirm their role in enhancing the interactivity between the user and the app system, (Good & Omisade, 2019; Woods et al., 2019). Significant impact of both these principles on user satisfaction also implies that they also significantly fulfill the socializing, belongingness, and trust needs of the users and help establish the balance between the social and technical aspects of app usage. From a practical perspective, ‘technical support’ emphasis will help resolve more user issues with the app more frequently, while ‘social support’ will help the users connect with user community as an extension of the app.

The significant impact of ‘Education’, as a chronic health app DP on satisfaction has also reaffirmed the informational needs of the user towards effective self-management (Adler et al., 2022; Ledel Solem et al., 2020; K. Yu et al., 2021). Further, the results also affirm ‘Education’ DP as a means to achieve a more user-friendly app system facilitating better self-management of their chronic problem. ‘Tracking’ and ‘Notification’ have also been found to affect user satisfaction positively and significantly, both of which are highly user centered DP, with a focus on fulfilling the disease and symptom monitoring and self-management related informational needs of the users, thereby enhancing the smooth interaction between users and technology.

Another important finding is that Technical Support, Privacy, Ease of Use, and Compatibility, have a slightly lower impact on user satisfaction, which may be attributed to lower reference to such factors in user reviews. In this context, it is important to note that Oh & Kim (2022) found a similar construct – easy to use in a banking app scenario to be less strongly associated with satisfaction than its peers in their study from a user perspective. From a bank’s perspective, this factor did not have any significant impact, which resonates with our findings in the chronic health app context. From a theoretical perspective, the significant impact of ‘ease of use’ and ‘privacy and security’ as DP particularly reinforces the applicability of technology based theoretical premises to the chronic health app design (Davis & Venkatesh, 1996; Ma & Liu, 2005). At a practical level, the app developers may be able to gauge the level of user acceptance in proportion to the effect size of these DP on satisfaction, indicated by the regression results.

The impact of DP like ‘technical support’ and ‘compatibility’ on user satisfaction call for a user centered technical design of the apps to prevent any technical issues. Further, it signifies that addressing users’ issues as well as a proper fit between the software and hardware and various physical elements of the app system such as the mobile devices, etc. can ensure greater user satisfaction. This in turn ensures greater technological and thereby market success.

Overall, the regression results support the hypothesis of the study. The results also fulfill the overarching objective towards identification of DP and their impact on user satisfaction. As far as the theory is concerned, the results re-affirm the theoretical and empirical premises of the study particularly in reference to various DP including *Social Support, Ease of use, Technical support, Usefulness, Privacy and Security,* and *Quality*. The findings are largely consistent with preceding literature (Al-Ramahi et al., 2017b; Lucero et al., 2022), whereby the DP were emphasized as a broad set of rules to develop and enhance chronic health apps.

CHAPTER 7

CONCLUSION

This study addresses the problem of a sparsity of identified DP and associated challenges in the formalization of user requirements towards more sustainable and responsive healthcare interventions. The problem leads to user satisfaction which in turn could affect continuance of use and ultimately the efficacy of chronic m-health interventions. Accordingly, this study aimed to identify design principles for mobile apps for the self-management of chronic conditions that are associated with user satisfaction. Recognizing the need to optimize the scope of research (Alekseev et al., 2021; Giunti et al., 2018; Koskie, 2020; Marziniak et al., 2018; Rudick et al., 1992), this study focuses on MS apps as a case study, which affects millions of people worldwide, with high medical costs, no cure and unknown cause. Overall, the research identified a number of DP based on extant theory, a systematic review of the literature, and the thematic analysis of mobile apps for the self-management of MS. The DP are: *'Communication with Clinicians', 'Compatibility, 'Education', 'Notifications', 'Tracking', 'Social Support', 'Ease of Use', 'Technical Support', 'Usefulness', 'Privacy and Security', and Quality*.

The relationship between the DP and user satisfaction was explored using regression analysis, where it was found that all the DP except 'Communication with Clinicians' significantly affect user satisfaction. This may be attributed to the characteristics of the disease under consideration, namely MS, compared to mobile-based self-management interventions focusing on data-intensive conditions such as diabetes. Otherwise, the hypothesis of the study is largely supported. 'Social Support', 'Tracking', 'Quality', 'Education', and 'Usefulness' have the greatest impact on the MS app user satisfaction, which corresponds to their informationally and socially intensive character.

The findings re-affirm the theoretical premises of the study. The significant impact of 'ease of use' and 'usefulness' reinforce the applicability of TAM and the expectation-confirmation model (ECM) regarding adoption and continuance of use. Relevance of STS is supported via the significant impact of DP like 'social support' and 'technical support'.

From a theoretical perspective, the research improves our understanding of key design principles for the self-management of chronic conditions such as MS and the impact of such principles on user satisfaction. The findings are consistent with preceding literature, which recognizes DP as a broad set of rules for app development. However, the DP themselves were neither consistently defined nor applied in preceding chronic health app literature. This study in contrast has demonstrated a clear definition, extraction, and elicitation of DP. Thus, the most significant theoretical contribution of this study is the identification, elicitation, extraction, and quantification of suitable app Design principles for MS apps but with sufficient generalizability to other chronic m-health app interventions. The differential strength of relationship exhibited by different sets of DP such as those for socially and informationally focused ones, social support, tracking, quality and education, etc., as opposed to more obvious and expected, and embedded - usability and utility focused DP like 'ease of use' and 'usefulness' provides a clear theoretical contrast between the applicability of these principles. Such contrast may further be empirically tested for establishment of theoretical DP frameworks for chronic health apps.

From a practical perspective, the findings provide guidance to the user requirement elicitation process, potentially leading to the development of more successful, sustainable, and responsive healthcare interventions. Specifically, the study significantly contributes to practice whereby app designers are better poised to accommodate DP in the design and development of their apps. App developers may adapt and adopt the empirical framework to guide, assess and improve their app design and development process. Based on the results of the study, app designers are better informed regarding the most pertinent set of DP for their use cases.

Future research may aim to address limitations of this research. This study uses a cross sectional design owing to lack of availability of longitudinal data. It is thus particularly challenging to assess the impact of the identified DP with respect to continuance of use. Future research considering the temporal dynamics of the user preferences and changes in app technology and their effect on satisfaction and continuance of use is recommended. Researchers may consider panel data models to capture the effects of DP on satisfaction both across chronic health apps and over the years. There may also be time-lag effects in the DP-satisfaction relationships, which may effectively be captured by such panel models. Future empirical studies examining the contrast between the informationally and socially intensive DP like 'education' and 'social support' on one hand and more embedded and expected DP like 'ease of use' and 'compatibility' are recommended for greater practical applicability in app design scenarios.

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APPENDICES

APPENDIX A: SLR DATA EXTRACTION

Table A1. Illustration of Raw DP extracted from SLR

Sl.	Paper	DP
1	(Goyal et al., 2017)	• Automatic data transfer • Electronic log-book • Disease indicator level trends • Consecutive Out-of-range reading alerts • Rewarding mechanism • Peer comparison • Social media community • Secure personal health record
2	(Beauchemin et al., 2019)	• Medication reminders (tools) • Testimonial videos (social actors) • To-do-lists (medium) • Real-time medication monitoring
3	(Tacchino et al., 2015)	• Usability 1. Easy to follow instructions 2. Independent app use 3. Interesting exercises/activity 4. Useful training 5. Intention to use motivation • Motivation 1. Stress 2. Boredom 3. amusement
4	(Abahussin et al., 2020)	• Intuitive layout and navigation • Simplicity of design • Effectiveness of system's main functions • Clarifying design aspects and functionalities • Explaining aim and use of app • Explaining sub-metrics of disease. • Data protection and use policy. • Simple words and terminology. • Enhanced use and quality of captured clinical data • Capturing user disease pain-control strategies. • User notifications for reminders and disease levels. • Data reliability and accuracy • Data summaries

5	(Kabeza et al., 2020)	• Diabetes education • Desired information provision • Increased diabetes knowledge and awareness • Monitoring and reminder functions • Nutrition and physical activity • Coping with disease burden • App features – • Use behavior – • Usability – info delivery; available languages
6	(Sage et al., 2017)	• Customization of features like charting, notifications, alerts, and reminders • Personalization • Login and Home screen • Profile • Settings and info • Games and Quizzes • Asthma control quiz • Logging Medications, Symptoms and Triggers • Charting
7	(Heiney et al., 2020)	• Ease of use • Ease of reading messages • Length of message • Font size • Quick dial feature
8	(Kim et al., 2015)	• Personal info recording. • Blood sugar levels • Test records for comorbidities • Easy access to saved blood sugar history • Clinical outcome improvement • Structure and completeness of the app • Ease of use, Recommendable
9	(Mira et al., 2014)	• User-friendly interface to introduce text and images • Medication reminder alerts including sounds and flashing • Messages sent to relatives or caregivers • Complete list of caregivers • Summary of patient adherence behavior
10	(Puig et al., 2021)	• Technology acceptance features • Category classification features • Design requirements • Navigational features • Marketing preferences
11	(Øksnebjerg et al., 2020)	• Calendar • Diary notes

		• Memory aids • Search • Synchronize • Help • Adaptive
12	(Carmona et al., 2021)	• Ease of use • Ease of goal setting • Understandability • Enjoyment • Perceived helpfulness • Time commitment • Health tracking • Informative • simple
13	(Ledel Solem et al., 2020)	• Reliable, trustworthy, evidence based knowledge • Focus on psychological health • Activity pacing • Self-assessment • Communication • Social support Specific design features • Customization and personalization • Behavioral trackers • Feedback • Automatic tailoring • Visualization • Communicating with Health professionals • With peers • Avatar • Metaphors usage • Rewards
14	(P.-H. Lin et al., 2015)	• Food tracking • Calories tracking • Wireless scale • Motivational component and performance tracking • Engagement monitoring
15	(Luiu et al., 2018)	• Perceived helpfulness • Management of emotional issues • Ergonomics • Short messages • Less to read • Playful • Clinical information • Helpful tips

16	(C. Roberts et al., 2018)	• Ease of use • Visual appeal • Asthma Quizzes • Avatar • Inhaler Technique videos
17	(Setiawan et al., 2019)	• Accessibility • Customizable user interface • List of Avatars • Background pictures • List of themes • Appointment tracking • Pain management
18	(Phillips et al., 2019)	• Symptom monitoring and tracking • Health history information • Trying out learning feature
19	(D. Yu et al., 2019)	• New Accessibility feature • Using simple and common words for better understandability • Shortcuts in navigation • Reducing number of touches in navigation to minimize navigation burden • Contrasting colors • Short reminders • Large icons • Color differentiation of modules • Body map • Hiding unused modules from dashboard • Selecting display size, changing contrast and display theme for better personalization
20	(Iribarren et al., 2020)	• Education in the form of information and answers to FAQs • Side-effect/symptom reporting • Self-administration tracking • Exemplar functions – notes and a communication tool • Easier data transfer • Cost effective
21	(Hafdi et al., 2021)	• Goals • Measurements • Chats • News Items • Educational Material
22	(Groat et al., 2018)	• Maintaining a list of favorites • Flexible search • Descriptive interface • Ability to build favorite lists

		• Barcode scanning to search foods and nutritional content • Tracking meals and carbs counting
23	(Van Kessel et al., 2021)	• Font size, layout, color use, navigation, etc. • Use of calendars and quizzes • Underlying navigation structure • Exiting screens • Motor control • Content • Activity tracking • Video and animation
24	(B. Tulu et al., 2016)	• More button on main screen • Optimal task length • Consistent UI • Navigation and return to screen • Minimal user confusion points • Ease of data entry
25	(Barbaric et al., 2022)	• Voice features for better navigation • Reiteration of recorded data by voice app • Verbal feedback • Alerts • Self-Measurements • Symptom quiz
26	(Cafazzo et al., 2012)	• Fast, discrete transactions • Data collection • Decision making – support prompts • Overcoming decision inertia • Ad hoc information sharing
27	(Castensoe-Seidenfaden et al., 2017)	• App content • User interface • Technical issues
28	(Oksnebjerg et al., 2019)	• Tailor made calender • Individualized Activity Guiding • Cognition supporting features • GPS • Reminders • Picture messaging • Simple layout • Use of few contrasting colors
29	(Van Den Berg et al., 2022)	• Registration • Medications • Graph • Info about app goal • Font clarity

30	(Salim et al., 2021)	• Education about disease, symptoms, diagnosis, and medications • Self-monitoring of symptoms • Disease action plan • Medication and appointment reminder • Disease diary • Reward system • Social support
31	(Adler et al., 2022)	• Customizability/Personalization • Easy to search • Accessibility • minimal design • Favorite/save content • Profile creation • video animation • visualized progress • Different paths to end goal • Reminders • Social media linking
32	(Cai et al., 2017)	• Remote monitoring of systems, well-being and activities • Treatment adherence • Education and Support • Adapting a reward system • App interface design • Clinical practice integration
33	(Hsia et al., 2021)	• User engagement maximizing features • Peer support • Counseling
34	(Mazuz et al., 2020)	• Login and personal details • Password selection to complete login • Customization of the hour of notifications • Feedback loop
35	(Chiang et al., 2022)	• Interface design • Adequate Icons • Smooth operations • Clarity of Interface texts • Customization • Reset and return functions • Photo upload function
36	(Bellei et al., 2020)	• Appropriate element size • Daily graphs • Clickable controls and buttons • Easy Navigation

		• Easily understandable records • Quick usage learning • Interactive visualization
37	(Crosby et al., 2017)	• Interactive and Social features • Daily symptom tracking • Self-management goal choice • Visual progress tracking • Visual calendar • Peer support
38	(Casida et al., 2018)	• Self-monitoring and reporting • Daily reminders • Ease of Use • Readable display
39	(Petersen & Hempler, 2017)	• Overview of diabetes activities after diagnosis • Recording and knowledge about health data • Reflection games • Knowledge games • Recording of psychosocial data
40	(L. A. Jibb et al., 2017)	• Ease of use • Ease of understanding • Efficiency • Content • Navigation • Utility • Customizability
41	(Reis et al., 2022)	• Avatar • Information • Navigation Flow
42	(Jeon & Park, 2018)	• Vitals inputs • Activity inputs • Bulletin board • Interfacing glucometer • Personalized info • Reliable info • Goal setting • autonomy
43	(Mohammadzadeh et al., 2022)	• Information Acquisition • Psychosocial Management • Symptom management • Compatibility with changes
44	(J. P. Barros & P. Brandão, 2021)	• Tracking and Monitoring • Education • Feedback messages on data entry

		• Comment highlighting using different colors • Screen slide feature • Visualization
45	(Schneider et al., 2016)	• Asthma education via text or short videos • Messages • Reminders • Vitals and symptoms data entry • Automatic alerts in response to data entry • Visual aids
46	(Farzandipour et al., 2019)	• Graphical data display • Education • medication log
47	(Baek et al., 2018)	• communication with doctors • Self risk assessment • Exercise • tailored education • blood pressure management • Health status recording
48	(Slater et al., 2020)	• Realtime engagement and communication with other users • Symptoms check-in • An interactive tool-box for pain coping strategies • Tracking sleep, mood, functions, etc. • Setting realistic goals • Instructions for app access
49	(Ekezie et al., 2021)	• Interactive learning resources • Education materials • Chat forum • Virtual map routes • Leader board • Reminders • tracking
50	(Kidd et al., 2019)	• Ambient sound tester • Compatibility to different platforms • Newsfeed • Toolkit • Voice detector
51	(Van Der Kamp et al., 2021)	• Objective assessment • Visualization of trend data • Real-time tracking • Video assessment of symptoms • Individualized care plan
52	(Turgambayeva et al., 2022)	• Doctor appointment • Content visibility

		• Monitoring dynamics • Online consultation • Medication advice
53	(K. Yu et al., 2021)	• Disease information • Tracking • Reminders • Ease of use • Social support
54	(Stinson et al., 2014)	• Symptom tracking • Goal-setting • Training • Social Support
55	(H. N. Fu et al., 2019)	• Motivation • Competence • Autonomy • Connectivity with healthcare provider
56	(S. Wang et al., 2022)	• Health calendar • Testing results • Medication use • Education • Adding data • User guide
57	(A. Nguyen et al., 2018)	• Tracking • Diary • Disease facts • Diet tips • Schedule • Team
58	(Kristjansdottir et al., 2020)	• Strengths listing • Goal-setting • Linking strengths and goals • Sharing results easily with healthcare provider
59	(Salari et al., 2021)	• Monitoring • Logbook • Overview and analysis • Education
60	(Shah et al., 2014)	• Choices of symptoms including pain • Visual analog slider • Interventions including the use of medication • Medication reminder • Treatment reminder • Provider contact • Past pain diary

		• Provider feedback to patient
61	(Woods et al., 2019)	• Features weight and fluid restriction tracking • Data graphical representation • Entertainment • Interest • Interaction
62	(Singh et al., 2019)	• Medication tracker • Journal • Disease tracker • Goal-setting tool • Pain tracker • Nutritional planner
63	(Debong et al., 2019)	• Coaching • Bolus adviser • Feedback • Historical data
64	(Limmroth et al., 2018)	• Reminder function • Injection planning and recording • Injection data importing • History • Wellness tracker
65	(Adu et al., 2020)	• Information and feedback • Cloud storage • Data Protection • User information documentation • Analytics
66	(Song & An, 2021)	• Symptom measurement • Physical Activity Management
67	(Shin et al., 2019)	• Remote linkage • Avatar • Visualized reward system
68	(Nordstoga et al., 2020)	• Feedback • Navigation • Ease of Use
69	(Hsieh et al., 2021)	• Intuitive Navigation • Disease/outcome risk score • Efficiency • Perceived value
70	(Schnall et al., 2016)	• Food diary • Color key • Communication • Reminders • Logs

		• Lab reports • Pharmacy Info
71	(Tatara et al., 2013)	• Time recording • Feedback • Progress bar • Goal management
72	(Torbjørnsen et al., 2019)	• Reminders • Automatic tracking • Education • Detailed Feedback
73	(Knox et al., 2021)	• Information • Educational Resources • Diary • Symptom quiz

APPENDIX B: LIST OF MS MOBILE APPS

Table B1. List of MS Mobile Apps

App Name	Inclusion/Exclusion
Aby	Included
Basic MS Explorer	Included
BeCare MS Link	Included
BelongMS Improving life with Multiple Sclerosis	Included
Bike MS	Excluded
BLADDERUNNER	Excluded
Bloodwatch HCP	Excluded
Challenge Walk MS	Excluded
DIGITALBUDDY	Excluded
Disability Calculator	Excluded
Emilyn - My MS Companion (Multiple Sclerosis)	Included
Esclerosis MÃºltiple Consejos	Excluded
Finish MS	Excluded
Healthstories - Multiple Sclerosis (MS)	Excluded
icompanion â€“ track, test and understand your MS	Included
InnovSEPâ„¢ - MS Life Companion	Excluded
Momentum | National MS Society	Included
MS 3Dme	Included
MS AYUSHPRANA	Included
MS Bewegt	Excluded
MS Bike	Excluded
MS Care Connect	Included
MS CARES Augmented Reality	Excluded
MS COMPASS â€“ LietuviÅ¡kai	Excluded
MS Fatigue Fix	Included
MS Healthline	Included
MS Healthline: Multiple Sclerosis Chat	Included
MS Insider	Excluded
MS Journal	Included
MS Kognition	Included
MS MAYA	Excluded
MS Mosaic	Included
MS Notes Journal	Included
MS Ready	Excluded
MS Relapse Tool	Included
MS Relapse Tracker	Included
MS Shift	Excluded
MS Tagebuch	Included

MS Trust Conference	Excluded
MS Trust Publications	Included
MS Vacances	Excluded
MS Voice	Excluded
MSAAâ€"My MS Manager	Included
MS-APP	Excluded
MSCorner Health Manager: Track Symptoms & Meds	Included
MSGAN	Excluded
MS-Leitfaden fÃ¼r Neurologen	Excluded
MuckFest MS	Excluded
Multiple Sclerosis (MS)	Included
Multiple Sclerosis : Symptoms, causes, treatment	Excluded
Multiple Sclerosis @POC	Excluded
Multiple Sclerosis Advice	Included
Multiple Sclerosis App 1	Excluded
Multiple Sclerosis Chat	Included
Multiple Sclerosis Dx & Mgmt.	Excluded
Multiple Sclerosis Messenger	Included
Multiple Sclerosis Support	Included
My MS Managerâ„¢	Included
My MS-UK	Included
My Multiple Sclerosis Diary	Included
myBETAappâ„¢	Included
MyCareForMS	Excluded
Mylan Smart Injection TrackerÂ®	Included
MyMS Manager	Excluded
MyMS Manager - Doctors app	Excluded
myVUMERITY	Included
National MS Society	Included
Neuro-Compass Toolbox	Excluded
Noteness	Included
Pakistan MS Registry App	Excluded
Pear-006	Excluded
Pre-Meet: Multiple Sclerosis	Included
RealTalk MS	Included
TecTrack	Included
Understanding MRI: Multiple Sclerosis	Included
Walk MS	Included
Yoga vs. MS: Yoga against Multiple Sclerosis	Excluded

APPENDIX C: CODING MANUAL

Table C1. Criteria for DP scores

DP	Scoring Criteria	Examples
Communication with Clinicians	+1 given to reviews that have positive attitude regarding facilitation of (better) communication with clinicians.	"This allows me to keep track of my symptoms so I can show my Neuro when my memory isn't too good"
	-1 given to reviews that have negative attitude regarding facilitation of (better) communication with clinicians.	This app has been a great asset in the past, but I haven't been able to download data from the website for a long time now, and can't even use the app on my new phone because of the "Login failed" message. This is critical that I can access and share my data with my doctors. Please help!
Compatibility	+1 given to reviews reporting facilitation with multiple platform logins (google, FB, etc..), compatibility with multiple devices, compatibility with sharing or accessing multiple platforms through app (sharing progress in social media sites, etc...), compatibility to access the information through multiple places such as app as well as website access.	"Apple's iCal lets me record appointments, create reminders & sync everything between my laptop & desktop Mac & my iPhone."
	-1 given to reviews reporting issues or have negative attitude towards compatibility as defined above.	"It's not working on my Samsung galaxy s7. Very disappointed!"
Education	+1 is given to reviews that have positive tone towards information, disease knowledge, new disease alerts, etc.	"This app keeps you well informed providing you with different articles on the things that really matter."
	-1 is given to reviews that have a negative attitude towards the way functionalities related to education activities are handled in the app.	This has taken away all the amazing articles about MS news and research! This app is GARBAGE now!!

Notifications	+1 given to reviews containing positive tone towards facilitation of reminders, alerts, or notifications regarding MS self-management.	"It's so easy to use. I love how it reminds that is SHOT TIME!!"
	-1 given to reviews containing negative tone towards facilitation/functioning of reminders, alerts, or notifications regarding MS self-management.	"I depended on the old version that had the alert sound. The new version needs to upgrade, restoring the alert sound so I don't forget to shoot up. Thanks"
Tracking	+1 given to reviews containing positive tone towards facilitation of either tracking, logging, or monitoring their symptoms or medication.	"It helps me keep track of my daily symptoms easily."
	-1 given to reviews containing negative tone towards facilitation/functionality of either tracking, logging, or monitoring their symptoms or medication.	I keep losing all of my injection history after a week. The only reason I have this app is to track my injections and it canâ€™t even do the one thing itâ€™s supposed to do.
Social support	+1 is given for reviews that mention positive attitude regarding facilitation of access to other people with MS.	"I instantly felt the love, connection, empathy, etc., etc.. No one knows better than everyone in this community chat"
	-1 if any negative emotion regarding the access to other people or regarding the feature functionality itself.	others write to me but the app doesn't allow me to respond to them. what good is it?
Ease of use	+1 is given to reviews that have a positive attitude towards app usage, navigation, user interface, or other ease of use related concepts.	"Love this app so easy to use really helps me to get the most out of my dr's appointments especially when I am having an off day"
	11 is given to reviews that have a negative attitude towards app usage, navigation, user interface, or other ease of use related concepts.	"This app needs lots of work done to it. It is not user friendly at all."
Technical Support	+1 given to reviews where there is an interaction between the app user and the app support team or developers in a positive manner.	Had difficulty getting signed up at first, but got help from the developers and everything is working. Great program for keeping track of my MS

		symptoms daily. Just started, mire to explore.
	-1: given to reviews where the app user is unable to contact the app support team or developers. Moreover, if the app user is not satisfied with the app support team.	“Refuses to accept my valid login credentials.”
Usefulness	+1 if the reviewer says they loved the app, or app is helpful or useful or terrific or likes any features (other than current DPs)	“I love the app, just have what I need and nothing more or complicatedØŒ thanks”
	-1: If the review says they wishes there is a specific feature/functionality other than the current DPs (Note: for example, if they say that they wish they had tracking, then we would put -1 for tracking but no -1 for usefulness)	“You are better off looking onto the website. There is so much that cannot be done here and it’s a shame. Lots of lost opportunities”
Privacy and Security	+1 is given to reviews which complimented the measures taken by the app related to privacy and security related issues.	“This app is wonderfully lightweight with everything you need to schedule and keep track of injections and nothing you don't. I am not interested in using Copaxone's tracker where you have to be logged in to do anything. This app has no privacy issues but you can still export your data if you want. (This impressed my neurologist!) A few things I'd like to see if possible: if an injection is logged before the alarm, have the option for the alarm to reset for the next time instead of going off anyway. Ability to add custom injection locations as mentioned in another review. Addition of a setting for needle depth. (Currently I use the notes to handle those last two, which works fine but

		is a little clumsy.) Despite these notes, the app still rates 5 stars for design, utility, and reliability. I appreciate it every time I use it.”
	-1 is given to reviews reporting data loss, data storage concerns, privacy and security related issues.	“I do not have a FB account so this app is useless to me. And what about people who want privacy regarding their illness???”
Quality	+1 if the review has a positive tone on how the app functions in general (seamless, fast, smooth, or any other compliments regarding the app quality)	Did not find any reviews with positive intention towards quality of the app.
	-1 if the review has a negative tone on current feature performance. Moreover, if there is a quality issue with a specific DP, lets say tracking, then we would give -1 to BOTH tracking and quality	“I keep losing all of my injection history after a week. The only reason I have this app is to track my injections and it canâ€™t even do the one thing itâ€™s supposed to do”