Evaluating an Evidence-Based mHealth Application, MS Assistant, for Individuals Aging with Multiple Sclerosis

Ljilja Ruzic, Harshal P. Mahajan, and Jon A. Sanford
The Center for Assistive Technology and Environmental Access (CATEA)
Georgia Institute of Technology
Atlanta, GA, USA
e-mail: ljilja@gatech.edu, harshal.mahajan@design.gatech.edu, jon.sanford@design.gatech.edu

***Abstract*—A majority of individuals diagnosed with MS experience major decline in their abilities due to the progression of MS, five years post-diagnosis and after age 40. Following this period, they need to learn how to cope with the functional limitations and disabilities caused by the condition and how to age with MS due to an early onset of age-related problems. In addition to the signs of early aging caused by MS symptoms and consequent impairments, these individuals experience increased disability due to the physical effects of aging and comorbidities. As a result, they have to manage the effects of the condition on their lives every day. Self-management can help mitigate the symptoms associated with MS. mHealth applications offer potential holistic support for self-management of the condition as they represent more robust technologies that have potential to include all the interventions proven to be useful to manage multiple health problems. This research paper describes the evaluation of the mHealth app, MS Assistant, an evidence-based app that provides the daily support and self-management of the condition to individuals aging with MS, which was developed based on the Universal Design Mobile Interface Guidelines, UDMIG v.2.1. mHealth application was evaluated by the expert reviewers. Moreover, the paper presents an app refinement based on the suggestions of the experts who tested the effectiveness of the app and its design features and provided possible recommendations for its redesign.**

Keywords- aging; mHealth; multiple sclerosis; universal design.

I. INTRODUCTION

This research paper details the evaluation of the mobile health (mHealth) application for individuals aging with Multiple Sclerosis (MS) by the expert reviewers. The study tested the effectiveness of the mobile app and its design features and resulted in the recommendations for the user interface redesign [1].

MS is a complex inflammatory disorder of the Central Nervous System (CNS) [2]. This chronic and progressive disease is affecting around 400,000 individuals in the US and 2.5 million people worldwide, with approximately10,000 newly diagnosed cases of MS annually [2]. MS is characterized by a large number and variety of symptoms [3]. Cognitive changes and mobility limitations (e.g., spasticity, weakness in one or more limbs, gait difficulties) are the most significant ones related to disability [3].

A majority of individuals diagnosed with MS experience significant declines in their abilities due to the progression of MS after five years post-diagnosis and especially after age 40 [4]. Following this period, they need to learn how to cope with the functional limitations and disabilities caused by the condition and how to age with MS due to an early onset of age-related problems [4][5]. In addition to the signs of early aging caused by MS symptoms and consequent impairments, these individuals experience increased disability due to the physical effects of aging and comorbidities [6][7].

As a result, these individuals have to manage the effects of the condition on their lives every day [3]. More specifically, they need a continuous disease, symptom, and medication management, coupled with education and effective strategies for addressing the exacerbations (i.e., a worsening of old symptoms or an onset of new symptoms for at least 24 hours, also called a relapse) [8]. They need to understand their condition to take charge of managing MS and related impairments [8].

Self-management can help mitigate the symptoms associated with MS [8]-[12]. To support self-management, access to pertinent information, resources, and education about the nature of MS, the treatment, and methods for improving quality of living (QOL) delivered in an appropriate way could considerably improve lives of individuals with MS [13]. Additionally, research studies [14]-[16] suggested that self-management interventions using telehealth (i.e., remote-patient monitoring) have a potential for overcoming access barriers in MS. Social support is another way of enhancing the QOL in people with MS. Moreover, the World Health Organization (WHO) [13] and the Consortium of Multiple Sclerosis Centres [17] advise that individuals with MS take control of decisions affecting their wellness and life and self-manage their condition as often as possible. As a result, there is a great need for efficient tools to support the health and wellness self-management of daily activities for individuals with MS.

mHealth apps offer potential holistic support for self-management of the condition as they represent more robust technologies that have the potential to include all the interventions proven to be useful to manage multiple health problems [18]. These health and wellness self-monitoring applications offer a range of tools to assist with health and wellness daily organization, communication with healthcare providers, and education [18].

This research paper details the evaluation of the mHealth app, MS Assistant, an evidence-based app that provides daily support and self-management of the condition to individuals aging with MS. mHealth application was evaluated by the expert reviewers, who provided recommendations for app redesign. Moreover, a summary of an app refinement based on the suggestions of the expert reviewers is presented here.

The paper is organized into six sections. Section I provided a background. Section II reviews the related work about technological support for people with MS and other chronic conditions that share similar symptoms with MS. Section III describes the initial design of MS Assistant. Section IV summarizes the evaluation of the effectiveness of the design features and the app through an expert review. Section V presents the refinement of MS Assistant based on the recommendations of the experts. Section VI provides a conclusion and proposes future work.

II. Related Work

The majority of individuals with MS use modern communication technology regularly (i.e., personal computer, internet, email, mobile phone) [19]-[21]. They have high levels of acceptance for using electronic communication methods for exchanging information with health care providers. Ninety-six percent of them possessed mobile phones, and older participants used it less frequently. However, there is a lack of relevant previous research on the needs and concerns of individuals aging with MS [6] to inform the design of the mHealth apps for this group of end-users.

There are only nine current mobile applications (described below) available to this group of users, which primarily focus on providing basic information about latest research, news, and practical tips on health, nutrition, and fitness, self-recording of health status, medication adherence, daily activities, symptoms, mood, and similar, and/or sharing the data with healthcare providers. Multiple Sclerosis Association of America (MSAA) released a mobile phone app for health self-reporting, My MS Manager, for individuals with MS and their caretakers [22]. Similarly, MS self app offers a journal that can be later easily accessed by the user who can share their data with the healthcare team [23]. Another self-reporting app is called MySidekick for MS [24], which also provides medicine reminders and a memory exercise. My MS Conversations provides an interactive group session with experienced virtual patients on selected topics [25]. MS Journal is an injection reminder tool for individuals with MS and their caregivers limited to UK market only [26]. My Multiple Sclerosis Diary [27] is another injection reminder mobile app that offers injection location and time set up. SymTrack was designed as a health self-reporting tool that stores shares the health charts with healthcare providers [28]. Social app MS Buddy [29] pairs individuals with MS with another person with MS to chat daily. MS Attack app [30] helps users learn about MS symptoms, how these present themselves during the MS attack and provides a location of the UT MS Clinic and the Neuro Eye Center.

These nine mobile apps provide only basic functionality with the limited set of features compared to the other health and wellness apps for the general population and individuals with other chronic conditions (e.g., iHealth mobile app provides telehealth [31], Headspace: Meditation app introduces the users to the practice of meditation [32], Mango mobile application gamified the medication adherence [33], Syandus provides simulation learning technology for patients and students [34]).

We conducted two formative studies [35][37] that assessed the usability and utility of the current mHealth apps to understand the existing state of the arts and provide the recommendations for the design of mobile health and wellness apps for individuals aging with MS. The two studies revealed that the current mHealth applications were not usable to the end-user population and did not provide holistic health and wellness support for the self-management of the condition. Hence, there is a need for a new evidence-based mobile application for people with MS, which would provide all the functional features that would help with the comprehensive health and wellness self-management and address their specific needs.

III. MS Assistant

MS Assistant is an evidence-based app, which provides the health and wellness self-management-based functionality, allows for personalization, assists with medication adherence and other daily tasks with alert and reminder systems, and sends alerts to the caregivers, family members, and healthcare providers in a case of an emergency. mHealth app was developed based on the results of the two formative studies [35][37] that evaluated the usability and utility of the current mHealth apps for individuals aging with MS. Its eight functions were selected based on the findings of a previously completed qualitative study [35], which was conducted to identify the specific needs for self-management of health and wellness among people aging with MS and to recognize the opportunities to meet those needs through mobile apps. The functions include *diary*, *reports*, *MS friends*, *games*, *education*, *goals*, *vitals*, and *emergency*. In addition, profile and settings were designed to offer personalization and customization.

A. Functionality

Diary provides a comprehensive tool for understanding the disease on a daily basis and over time, and how best to manage it through everyday self-management tasks, such as mood, symptoms, energy level, activity, sleep length and quality, and diet. *Reports* allows users to compile their health management data into useful reports that can be shared electronically with healthcare providers and caregivers. *MS Friends* is a social support feature that connects users with other people with MS to share their experiences and everyday challenges. *Games* features VR games that would enable users to perform real-world activities that they might find challenging. In addition, this feature has cognitive and classic games that help people with MS with cognitive functioning, and physical games, which help them with the balance. *Education* provides the latest news and research

about MS as well as health and wellness tips. *Goals* enables users to set up their personal health and wellness goals to keep them motivated and inspired. *Vitals* offers remote health and wellness monitoring through the Bluetooth connected devices, such as blood pressure monitoring devices, scales, sleep and activity trackers (e.g., Fitbit), and similar. *Emergency* lets users place calls directly to their healthcare providers, caregivers, and emergency phone number (e.g., 911 in the USA).

The mHealth app sends alert messages to the caregivers, family members, and/or healthcare providers in a case of an emergency (i.e., when the values of certain vitals go above the threshold, such as blood pressure, self-reported depression, extreme values of the symptoms severity).

B. Navigation

MS Assistant provides two types of navigation: linear and random access. Linear interaction allows users to go through the pages by making or skipping a selection and pressing the Next button. Users can go through the whole interface in a linear fashion by using the Next and Back buttons on every page, which provides consistency and simplicity. After a selection is made, the Next button takes users to the following page of the interface. When the user taps on any button, the button changes to the selected colored background and white text that visually emphasizes the selection. To change the selection, user can tap the button again to deselect it (Figure 1). Random access allows skipping the options and provides a faster pace of the navigation through the direct selection (Figure 2).

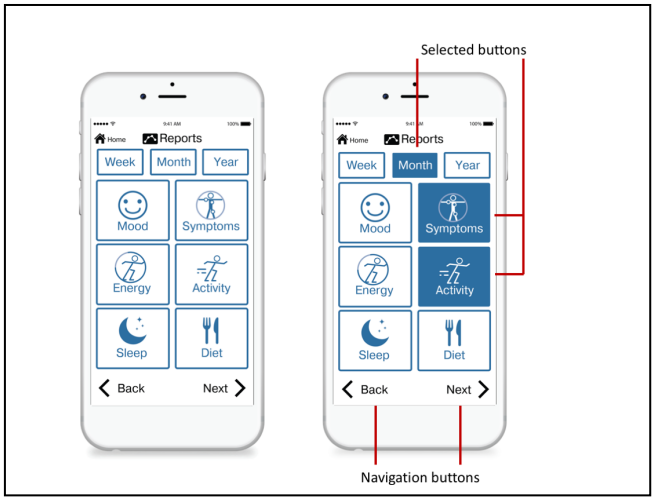

Figure 1. Linear navigation on Reports page.

C. Design Decisions

MS Assistant was designed based on the Universal Design Mobile Interface Guidelines, UDMIG v.2.1 and corresponding design criteria, which has been previously reported [36]-[39]. For example, the design goal was one mobile app for all users, rather than accessible design for people with disabilities, and avoidance of specialized design and language (*Same means of use*). Consistent sequences of actions are required in similar situations (*Consistency with expectations*). Complexity is eliminated by having simple screen designs that require a small number of tasks per screen (*Simple and natural use*).

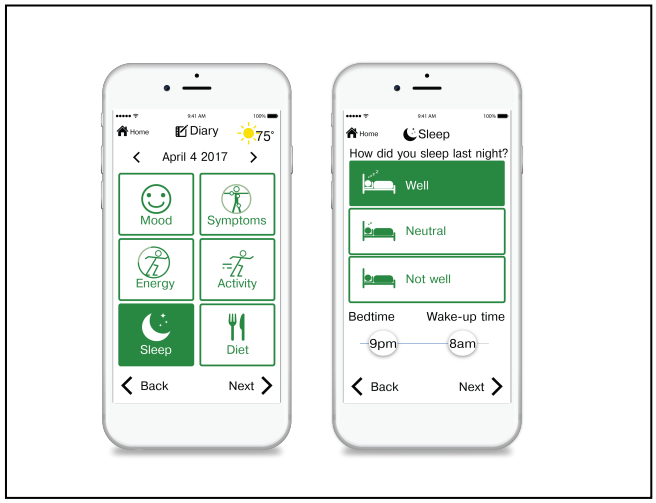

Figure 2. Random access on Diary page.

IV. Evaluation of the Effectiveness of the Design Features

For the purpose of evaluating the effectiveness of the design features as those were applied based on the UDMIG v.2.1 to the design of MS Assistant, we conducted an expert review in which expert evaluators rated the UDMIG-based design features that were implemented in MS Assistant, identified design elements that needed improvement, and recommended possible refinements. We collected user outcome measures, such as the ratings of the effectiveness of the application of the UDMIG design criteria to the app, and number and frequency of reported usability problems categorized based on their design features and characteristics. Additionally, we collected all verbally identified usability problems during the administration of the "talk aloud" protocol and categorized the data into the common themes to determine the main issues with the app [1][39].

A. Methods

Ten researchers and/or designers with experience in aging, accessibility, human-computer interaction, human factors, industrial design, universal design, and/or usability participated in the study. Inclusion criteria were that participants be of age 18 and older and that they have more than three years of experience in one or more of the areas of expertise in accessibility, usability, aging, human factors, universal design, human-computer interaction, and/or industrial design. Participants' expertise included accessibility (n=8), usability (n=8), aging (n=7), human factors (n=6), universal design (n=6), human-computer interaction (n=5), and industrial design (n=2) respectively. The mean number of years of their working experience was 13±8.82 years.

Experts rated their familiarity with the user interface design for people with MS, dexterity, cognitive, and visual limitations from being "not familiar" to "somewhat familiar" to "very familiar" (Table I).

TABLE I. RATINGS OF FAMILIARITY WITH THE USER INTERFACE DESIGN FOR PEOPLE WITH MS, DEXTERITY, COGNITIVE, AND VISUAL LIMITATIONS.

Familiarity with the user interface design for:	Not familiar	Somewhat familiar	Very familiar
People with MS	3	10	0
People with dexterity impairments	1	5	4
People with cognitive impairments	0	8	22
People with visual impairments	0	3	7

1) Procedures

After signing the informed consent form approved by the Georgia Tech IRB, experts completed a demographic questionnaire about their areas of expertise and a number of years they have worked in the field. Experts rated their familiarity with user interface design for people with MS, dexterity, cognitive, and visual limitations on a scale from "not familiar" to "somewhat familiar" to "very familiar." They then performed directed tasks using MS Assistant without any training or assistance. Experts received a simple script with ten tasks that included entering health and wellness data (i.e., mood, symptoms and related difficulties, energy level, daily activity, sleep length and quality, and diet), emailing the reports, calling MS friend, finding virtual reality games, reading the MS news, setting up the weight goal, inputting the blood pressure, calling the healthcare provider, entering the personal information, and increasing the text size. Experts then used the UDMIG v.2.1 questionnaire to rate each guideline through its design characteristics, identified design elements needing improvement, and provided recommendations for their refinement.

a) UDMIG v.2.1 Design Criteria Questionnaire

Prescriptive design guidelines and standards are easy to interpret and to objectively assess. Assessment of performance guidelines is multidimensional since it incorporates both activity and participation [36]. All performance-based guidelines are subject to interpretation by experts as well as end-users to a certain extent, which makes objective measurement slightly difficult. UDMIG v.2.1 design criteria questionnaire rates agreement with achieving each of the design guidelines using the 5-point Likert scale where 1 = strongly disagree and 5 = strongly agree with each of the applicable design criteria. The versions of this questionnaire that correspond to the appropriate design criteria are intended to be used by end-users and to assist designers to think about the needs of the potential users who would interact with their mobile touchscreen applications.

The complete UDMIG v.2.1 design criteria questionnaire used for this expert review has 45 items (i.e., design criteria). An example of the questionnaire based on some of the design criteria (e.g., one design criteria per guideline) used for the expert review was previously published [35].

2) Data Collection and Analysis

We calculated the mean and standard deviation of the rating for each guideline and the mean and standard deviation of ratings for each participant. Fourteen ratings for one of the participants were excluded because they skipped the page with ratings of the guidelines.

Additionally, we analyzed the audio files during the participants' use of MS Assistant and administration of the talk aloud protocol to extract more usability problems they encountered during the interaction with the app. We used an inductive approach for data analysis.

As primary researchers, two authors independently coded the transcripts and generated a preliminary set of codes. We coded for the themes (i.e., design features and related characteristics based on the identified problems) that participants reported in the UDMIG v.2.1 design criteria questionnaire. Another research team member then reviewed the sections of the transcript and associated codes. Next, we met to discuss the themes and refine the coding taxonomy. Labels (miscategorization), buttons (layout), keyboard (on-screen verification), too many clicks (physical effort), and lack of direction (navigation) were added themes. The coding had inter-rater reliability (i.e., Cohen's kappa) of 79.0%. The team met again to discuss, further refine, and expand some of the themes and related categories. Buttons and pages (navigation) and layout of the buttons themes were expanded, and feature request, page layout (lack of consistency), and lack of confirmation of an activity (navigation) emerged as themes. For example, buttons and pages (navigation) included a problem with Next and Back buttons, in addition to other navigation problems participants talked about (e.g., confusion with going to the other News pages and suggestion to use "Page 1 of 2"). Moreover, the layout of the buttons theme incorporated the layout of the View Reports and Email Reports buttons category from the questionnaire in addition to the problems with the other buttons. We developed a list of themes, and each coder resampled an additional 20% of the data. Inter-rater reliability (i.e., Cohen's kappa) of 81.0% was achieved between the two researchers.

B. Results

The results reporting the effectiveness of the design features in MS Assistant, and the effectiveness of the mHealth app are detailed in this section.

1) Effectiveness of the Design Features

Ratings of the design features as those were applied to the design of the mobile app following the UDMIG design criteria and *usability problems*, which were identified and reported by the expert users following each rating, are detailed in this section.

a) Ratings of the Design Features

Ten participants rated 45 items on the UDMIG design criteria questionnaire. The total number of responses was 436, with 14 missing responses that were not used in the analyses. The range of ratings was 2 – 5 with the mean of all the ratings for design features was within a range of 3.90 (SD=1.10) – 4.89 (SD=0.33) (Table 36). Frequency of "Agree" and "Strongly Agree" ratings, which is a percentage of 4 and 5 ratings per design feature, was 60% - 100%. The design feature represented by DE6b (i.e., This app provides the system which can detect the error and offer a prompt message for handling it; if an entry for weight is skipped, provide a text message "Please enter a target weight") had the lowest mean of the ratings equal to 3.90 and the lowest frequency of 4 and 5 ratings, F=60%. This was the only mean value for design criteria that was lower than 4. Participants stated that the app provided a prompt message for handling an error. However, the prompt should "offer options to submit data without all responses submitted." Current prompts informed the users that they need to enter missing information and did not offer an option to skip certain fields. They made users fill out all the information on the page.

Out of a total of 436 ratings, 67% (n=292) of the design criteria was rated as 5 ("Strongly Agree"). An additional 27% (n=118) were rated as 4. The lowest rating for any criterion was 2 (1.3%, n=6) and an additional 4.6% (n=20) were rated as 3.

Among the 10 participants, mean ratings ranged from 3.87 – 4.91. The participant with the lowest overall mean ratings (M = 3.87) did not give a rating higher than 4 to any individual criterion with 39 rated as 4 and 5 rated as 3, and 1 as 2.

The mean values of the ratings were equal to 3.90 and above. Only one design feature had a mean rating of 3.90 (DE6b), and all other features had mean ratings of 4 and above. Therefore, expert users rated all design features highly usable in MS Assistant.

Design feature represented by DE6b "the system which can detect the error and offer a prompt message for handling it" was rated the lowest because some participants thought that the prompt informed the users that they need to enter missing information and did not offer an option to skip certain fields (N=4) and rated it very low (rating=2, N=1; rating=3, N=3). The second lowest mean rating was given to two design features because of the lack of tactile feedback in an app due to the lack of the Taptic Engine in iPhone 6 model (M=4.00). Two participants rated DE2a "feedback about a confirmation of my activity and a current state" low (rating=2, N=1, rating=3, N=1), and only one participant rated the design feature characterized by DE5a (i.e., different modes of feedback, such as sound or vibration) lower than 4 (rating=2, N=1). The next lowest mean rating was equal to 4.20 and was given to DE2b "system feedback for my actions, such as a beep when pressing a key," due to the lack of the tactile feedback as well (rating=3, N=1). Two design features had mean rating of 4.22: IC8 "choice of linear navigation vs. random access" was rated by two participants lower (rating=2, N=1; ratings=3, N=1), and IC13b "minimized steps (i.e., basic tasks)" was rated low by two participants (rating=3, N=2). Design feature represented by IC7b (i.e., the use of technical language is avoided) had mean rating of 4.33 (rating=2, N=1; ratings=3, N=1). All other mean ratings of the design features were equal to 4.40 and above.

The highest mean rating (M=4.89) was given to three design features: IC6d "cursive and decorative fonts and use of all uppercase letters are avoided," IC9 "personalization to change my skill level from a "novice" to an "expert" user," and IC10a "configuration of the display settings to my needs and preferences." The second highest mean rating (M=4.80) was given to eight design features: DE1a 'large enough button size," DE4c "buttons in colors that stand out, and arranged in linear order," DE6a "easy reversal of my actions if I make a mistake," IC4a "the use of the picker is avoided," IC4b "scrolling text, especially horizontal formats, is avoided," IC5a "clear indication on the top of the page where the user currently is at any point of time," IC14a "visible spacing between the small buttons," and IC15 "main navigation buttons of equal importance at the bottom of the screen."

The difference between the lowest mean rating (M=3.90) for DE6b and the highest mean rating (M=4.89) for IC6d, IC9, and IC10a was statistically significant (t(9)=2.951, p=.016). This result suggested a redesign of the prompt to allow users flexibility in navigation and an option to enter data they want, and not necessarily all data.

The second lowest mean rating (M=4.00) for two design features represented by DE2a and DE5a was significantly different than the highest mean rating (M=4.89) for IC6d (t1(9)=2.667, p1=.026; t2(9)=4.216, p2=.002, respectively), IC9 (t1(9)=2.667, p1=.026; t2(9)=4.216, p2=.002, respectively), and IC10a (t1(9)= 3.162, p1=.012; t2(9)= 4.216, p2=.002, respectively). Both design features that correspond to DE2a and DE5a were rated lower due to the lack of tactile feedback. Participants would appreciate having vibratory feedback implemented within an app, but they understood the limitations of iPhone 6 models and the lack of the Taptic Engine. The next lowest mean rating (M=4.20) for DE2b and the highest mean rating (M=4.89) for IC6d, IC9, and IC10a (t(9)=2.981, p=.015) were significantly different as well. This design feature was rated low due to the lack of tactile feedback in iPhone 6 model as well.

There was a significant difference between the mean rating (M=4.22) for IC13b "minimized steps (i.e., basic tasks)" and the highest mean rating (M=4.89) for IC6d "cursive and decorative fonts and use of all uppercase letters are avoided" (t(9)=2.434, p=.038) and for IC9 "personalization to change my skill level from a "novice" to an "expert" user" (t(9)=2.434, p=.038), respectively.

b) Usability Problems

After rating the design features, ten participants commented about the specific features and suggested design recommendations. We listed all usability problems with the app, grouped those issues into themes related to their design features and characteristics, and reported the number and frequency of participants reporting the problem (Table II).

Total of 3 participants (F=30%) reported low contrast on the instructions pages where white text on a grey background and "Do not show this again" button in a selected state with green text on a grey background did not provide high enough contrast (Table II).

1. Navigation: Seven participants reported problems with navigation due to having "to press on Next after a choice is made," (P1) which "was not clear at first." They either "expected to double click" (P6) or click on the selection to open that particular page. Moreover, 2 participants reported that "Next" and "Back" buttons look like a part of the specialized use and design. However, all of them understood that Next and Back buttons are typical of linear navigation, which is beneficial to an aging population that uses this app in a novice user mode only. Two participants were not sure whether there is more than one way to go to different pages (i.e., linear navigation using the Next and Back buttons and random-access).

2. Labeling: Labeling of buttons included a number of different usability problems and related suggestions. Four participants reported that "Education" should be renamed into "Digest," "Resources," or similar because "News" category did not belong in there. It was not clear that a healthcare provider would be listed under the functional feature named "Emergency" (N=2), but there was no agreement on the alternative location for it. P3 suggested that it should be moved under Reports as an additional sub-feature named Contacts. P1 stated they "didn't want to click on it because I thought it would call 911," but did not think any other location would be more suitable for it. Mood page had an "Energized" icon, which was confusing to 1 participant Diary had a category "Energy level." They suggested that "Anxious and Excited are missing" (P3) and that "Energized could be elsewhere." Another suggestion was to rename "Input" and "Output" categories of Settings into a non-technical language (N=2). 1 participant reported that "Speech" should be renamed into "Voice."

3. Design of UI elements: Design of a number of user interface elements included 3 participants who reported that Profile and Settings did not look like buttons (P9) and that those should be redesigned to "stand out" (P6) and look more prominent (P6, P9). Design in Adobe Illustrator presented in this paper followed the guidelines strictly and made a distinction between the name of the app, MS Assistant, and Profile and Settings buttons on the first page. However, because of the limitations of iOS and the size of the top navigation bar, there was no space for the Profile and Settings icons because of the minimum font size dictated by the UDMIG v.2.1. Participants suggested that those two buttons should "look like buttons" (P9) with possibly adding a black border to them, relevant icons, or background color so that those look like the other buttons on the home page. In addition, 2 participants reported that top navigation bar icons that represent a title of the current page, including the weather icon, "look clickable" (P6). During the design phase, Adobe Illustrator prototypes made a clear distinction between the design of the home button and the title of the current page (e.g., Diary, Mood, Vitals). However, since the iOS limited the size of the top navigation bar and there was no compromise on the side of the font size, those two looked the same. P4 recommended that "header should look different than the home button." Moreover, 2 participants commented that the design of the slider used on the symptoms, difficulties, and sleep pages probably needs a redesign because of the problems with motor control in individuals with MS, and their possible use of the stylus. 1 participant commented that the "numbers on the bottom should be on top of the slider" (P9).

4. Buttons: Three participants reported a lack of vibration while tapping the buttons even though they understood the limitations of iPhone 6 due to the lack of the Taptic Engine, which provides the vibration while tapping the buttons that was included in later iPhone versions. P6 "expected to double-click" (N=1). However, the single tap was implemented throughout the app due to the design criteria IC13a (i.e., Use a single tap throughout the app instead of double-clicking).

5. Keyboard: One participant reported that spell check should be provided with the use of a keyboard. Lack of page scrolling while using a keyboard was found problematic to 2 participants. Participants recommended to "add scrolling where additional input is needed." Scrolling was disabled throughout the interface because of the IC4c design criteria requirement.

6. Page layout: Total of three participants had problems with the page layout. For example, P5 reported that "View Reports" button should be placed above the "Email Reports" button (N=1). Two participants reported that spacing between the top navigation bar and large buttons (e.g., Manual entry, Week, Month, Year buttons) should be increased.

7. Contrast: Two participants reported 3 times low contrast on the Instructions pages during the use of the app.

8. Prompt: Two participants reported that "Sometimes (it is) not clear what info is missing but did get a general message about missing info" (P5) after getting the prompt message, and that the app should "offer options to submit data without all responses submitted" (P7).

9. Font size: One participant thought that the font size of the News articles was too small.

2) Effectiveness of the app

While using MS Assistant, participants verbally identified specific *usability problems*, and *positive aspects* of MS Assistant via "talk aloud" protocol and in some cases recommended design solutions. Audio transcripts were used to identify usability problems and positive feedback.

a) Usability Problems

We categorized all the issues with the app into the themes to identify usability problems, and we reported related design features and their characteristics (Table III).

1. Navigation: Seven participants reported 12 times problems with navigation due to having to press on Next after a single choice is made and the appearance of Next and Back buttons as specialized use.

2. Labeling: Labeling of a total of eight buttons was not clear to a number of participants. Seven participants reported

7 times that "News" category did not belong in "Education" and that it should be renamed. It was not clear to 2 participants that a healthcare provider would be listed under the "Emergency" (n=2), but they could not think of an alternative location for it. Two participants thought that an "Energized" icon on the Mood page was confusing because Diary had a category called "Energy level" (n=2). Their suggestion for a replacement was to name it "Excited." Seven participants stated 9 times that "Input" and "Output" categories in Settings sound as a technical language and that those would be confusing to a regular user. Four participants thought that "Speech" should be renamed into "Voice" (n=4). In addition to these relabeling suggestions reported with the UDMIG v.21. questionnaire, there were 3 more labels reported during the interaction with the app. One participant suggested once to rename "News" into "MS News," another proposed once to rename "Diary" into "Daily feelings" or "Daily something" (P6), and the third one recommended to rename "Do not show this again" button into "Hide" (P10).

3. Design of UI elements: Participants had problems with the design of 5 user interface elements, which is 2 more than reported in the questionnaire. Five of them stated that Profile and Settings did not look like buttons and suggested to redesigned them to look more prominent and like buttons by adding a black border around them, icons, and/or a background color (n=5). Three participants thought that the top navigation bar icons that have a function of a header look like buttons (n=4). Five participants commented 7 times that the design of the slider should be changed. P3 and P6 thought that an easier design element should be used instead because the individuals with MS would have problems using it due to their limitations with motor control and the use of the stylus. P9 thought that the numbers on the slider should be on top of it, and P10 suggested to change the font of the selected number compared to the range provided (i.e., 1 to 5). In addition to these design elements present in the results based on the questionnaire, 3 participants reported 5 times problems with the design of the icons. For example, Output icon in Settings looked like a sound (P5) and audio (P9), P9 suggested to replace Input icon with Speech icon and to change Speech icon itself, and P10 stated that Seeing icon in Difficulties looks happy and that it should be changed. Moreover, P9 commented once that the comment section for MS type was not visible and that it could be replaced with a drop-down menu offering the names and abbreviations of the four types of MS.

4. Page layout: The total number of 6 participants commented 13 times about the problems with the layout of the buttons, including View Reports and Email Reports buttons. Two participants reported that the View Reports button should be above Email Reports button (n=2). In addition to the layout of the Email/View Reports buttons, 5 participants reported 11 problems with the layout of other buttons. For example, P3 thought that Tips would be of great importance and interest to the target population, and that Tips should be placed first on the list, followed by News and Research. They and P7 suggested having the listing of all the headlines of the articles on the News page. Week, Month, and Year buttons on the Reports page were not clear at first to this participant, and P6 suggested to "maybe change the color of the (Week,) Month, Year buttons." P4 suggested placing the "Read more" button on the News page on the bottom of the page. P10 said that the "names for the games are too long" and that we should "maybe change the layout to vertical buttons." They thought that "overall, the design is nice, but I would make it more dynamic." This participant did not understand the sequence on the 2 by 3 layout of the buttons on the Symptoms page. They thought that "if meditation (button) moves from the first place after a certain amount of (usage) time, would that be confusing?" in a case of a smart app. Reports pages should have "Page 1 of 2" on them. The small spacing between certain buttons (e.g., the Manual button in Vitals and Week, Month, Year buttons in Reports) and the top navigation bar was reported by 4 participants (n=4).

5. Keyboard: Five participants reported lack of page scrolling while using a keyboard 6 times.

6. Prompt: Three participants stated 4 times that when missing to fill out all the data on one page, the corresponding prompt makes them fill out all the information and lacks the flexibility to offer them the option to submit data without submitting all the responses. P10 suggested changing the text of the prompt to "Are you sure you want to skip X and Y?" The font size of the News articles was too small to 2 participants (n=2).

7. Other: Two participants thought that the font size of the News articles was too small. Two participants reported 3 times low contrast on the Instructions pages during the use of the app. One participant thought that the drawback of using a single tap is that it requires too many steps. P10 complained that the app requires too many clicks and that they are "wondering how much effort I am saving" (n=1).

8. Additional usability problems: Additionally, there are 6 themes of problems identified during the interaction with the app, which were not reported on the questionnaire. Six participants requested 11 times that certain features could benefit the app. For example, P1 asked if there is any way to specify the body area in Difficulties. P3 suggested that in a case of two selections in Symptoms, after making the one selection the app takes you to that symptom's page, and then it takes you to the one-screen selection again to make the second one. They added that the weight goals should have displayed the user's current weight with the text "This is what your weight is right now." P5 requested a louder sound feedback with the use of the buttons, adding the MS experience within the Profile, adding the Resources to the list of News, Research, and Tips because "older adults don't know where to find resources," and adding the info box to the View Reports page that would say "Select one or more buttons and choose whether you want Reports." P6 suggested to have the option to check the email address of the person who would get the reports sent by the user, to "make it clear in the description of a friend who he/she is by listing the symptoms or something else" in MS Friends, and to clarify on the top of the Instruction page "what this page is" by possibly adding "Getting started". P7 thought that after the prompt about sharing the personal information, Profile

page should have that information written again on the top of the page. P10 commented that in MS Friends "I would expect something about Mike to show up in a case of two people with the same name."

Five participants commented 10 times about the miscategorization of the certain labels. For example, P1 did not know where to enter data for numbness and where to find personal information. P6 thought that "Medications should be separate; not under Profile." P7 commented that it is "not intuitive" to look for "non-emergency contacts under Emergency; Emergency is 911", and that this "call should go under MS Friends." P9 "was not sure if Difficulty was on another page" and thought that Personal Information "would probably be in Diary." P10 added that "I would go to Diary for my Mood, symptoms. For energy level, because it is quantitative data, I would go to Reports." This participant stated that "I wouldn't link difficulty to symptoms." When looking for Reports, P10 said that "I could think also whether to go to MS Friends." P10 was not sure where to call a doctor, but after thinking about the available features, they thought that "Emergency and MS Friends makes sense."

Two participants reported lack of consistency in the page layout 2 times regarding the selections on two pages in the View Reports and Email Reports. P9 said that on-screen keyboard is problematic with verification because "I was looking for a back button. I don't see any indication that the focus is there (keyboard)."

Buttons and pages (navigation) theme was present 12 times in 6 participants. For example, P3 suggested that in the case of multiple selections, one at a time can be selected with a "loopback for more." P4 commented that it is "confusing to go from Symptoms to other screens if I want to skip something" and wondered if it is better "to go to the Home page from Symptoms or to go through all unwanted pages." They did not understand that Diary page offered random-access. The same participant complained that "when I went to Activity, Back (button) is taking me to the main (Diary) menu instead to Energy," which happened because the participant directly selected Activity from the Diary page. P5 thought that by tapping on the Next button on the News page, they were "going to the next page." This participant was not sure if they selected Mood "it would take me through everything," asked why Symptoms and Difficulties are not at the same level because these "are the same," and thought that "it should be clear there is no scrolling because of Back and Next buttons." P6 thought that we should "add another meal page after you go through one." P9 was confused that there is no "choice of eggs on the same page (with bread)," when both bread and eggs were selected. P10 commented when opened Diary Instructions page:

"I see a screen with a lot of text on it. When I first click on Diary, I would expect an input box. I see it's a prompt, but it doesn't look like a prompt."

The same participants thought that the comment section on the Symptoms page was not clear:

"I wouldn't think to put that information in here. I would enter numbness related to arm in one log, and for legs in another. Not both in one."

P10 also thought that "Email Reports would email reports by pressing (it)." The same participants reported a lack of confirmation of activity after entering the data on the Symptoms page (n=1).

b) Positive Feedback

Participants had some positive feedback throughout their usage of the app. P3, P4, and P10 loved the icons, which made sense to them and looked "expressive." P3 liked the sound feedback with the slider and with a tap on the buttons. Settings had a "pretty good mix there." P4, P6, and P7 liked "the color scheme a lot" (P6). P4 liked the font size. P4 and P8 appreciated the ability to deselect information which would be shared by using the switches on the Personal Information page, and P5 liked that on the switches have green color when selected because "green means go, so I guess green means sharing," and that there was a confirmation message (i.e., prompt) "especially when I was sharing the information.". P4 commented that the "buttons are refreshingly large," how "it is nice that it (linear interface) is making me log in everything this way," and that the app was "nice and easy to use." Both P5 and P6 appreciated that the user could choose from many items and make multiple selections on View Reports and Email Reports pages. P6 and P10 liked the design of the Sleep page, and P10 commented:

"I like the Sleep screen. It saved me a click. Once I am done, the screen itself looks like a confirmation. This screen is more confirmative to me than a Symptoms screen."

P10 thought that the Diet pages were designed consistent with the linear interface and that "if I am eating two different things I would not expect that Next would take me to both selections (on one page). It is pretty linear, the app, so I wouldn't expect that." The same participants thought that "Energy screen is really good and clear," and that" the slide bar is really good because the slider is big." P10 added that:

"Back and Home (buttons) both take me to the Home page, which is good. Home is a reference point. I would press Home button to go to the Home page."

P6 and P8 liked that there was a prompt before emailing the reports asking if the user wanted to email selected reports to selected contacts. P8 thought that "Reports is a great feature," because the user "can decide what I am going to let them know. I am not going to let them know about my diet because I had a lot of bacon." P6, P7, P8, and P10 thought that MS Friends is a nice and "straightforward" (P10) feature, on which P6 commented:

"I really like the idea that they can connect with people with MS."

P6 liked having the RPM via Bluetooth in Vitals. Games were "clear and easy to find" to P6 and "very simple" to P10. P8 thought that "this is going to be very cool. I like the News."

P6 commented on the overall design of the app:

"I like it. I like the nice simple design with large icons. It is easy to read. It has very nice feeling about so that I want to use it. It is nice. It looks like it can be useful."

P7 thought of MS Assistant as a consistent app with a great display:

"From UD perspective, it is really well done."

P8 thought that MS Assistant "is very well designed," it offers flexibility and a choice, and further commented:

"I think this is fabulous. Enormous utility. It is incredibly thought out. I love this."

P9 liked Home button and thought that the app was "very consistent" and "for someone with learning cognitive disability, it is accessible," and added:

"This is better than most apps that I have experienced. I am impressed."

C. Design Implications

As expected, audio transcripts revealed some additional usability problems reported by the participants and the existing problems were reported by a larger number of participants verbally, except in the case of the issues with the color contrast.

Overall, the main usability problems were labeling of the buttons, use of Next and Back buttons for the linear navigation, design of a number of UI elements, lack of page scrolling with the use of a keyboard, layout of a number of the buttons, certain feature requests, miscategorization of a number of labels, and navigation related to the design of the buttons and pages. For example, problems with the labels for "Education," "Emergency," "Input," and "Output" buttons were reported by a majority of the participants (Appendix D). Labeling of the "Speech" button was reported by 40% of the participants and labeling of the "Energized" button on the Mood page was reported by 20% of the participants. Additionally, participants commented unfavorably on the use of Next and Back buttons for the linear navigation. However, they understood that the linear navigation using these two buttons might be more usable for the aging population of users. Moreover, they acknowledged that the smart interface and an option to switch from novice to expert user skips this way of the navigation for the more tech-savvy users. Design of certain UI elements was reported as well. For example, Profile and Settings did not look like buttons and the slider needed to be redesigned to half of the participants. Thirty percent of participants reported that Header looked like a button and that certain icons needed to be redesigned. Additionally, half of the participants reported that the page scrolling should be present while using the keyboard. Sixty percent of participants reported that the layout of the buttons needed to be changed (e.g., locations of Email Reports and View Reports buttons should be switched). Additionally, 40% of them thought that the spacing between the top buttons (e.g., Manual input button in Vitals, Week, Month, Year buttons in Reports) and the buttons below should be increased. Total of 30% of participants thought that after missing to fill out all the fields on one page, the prompt that follows should give them two options. First, it should let them go back to the previous page to fill out the missing content. Alternatively, it should allow them to go to the following page and leave certain fields empty. 20% of the participants stated that the font size of the MS News articles was small. In addition, 20% of the participants reported on the UDMIG v.2.1 questionnaire only that it was not clear that they can navigate through the whole interface in a linear fashion using the Next and Back buttons.

There were a number of problems that were found on the audio transcripts, which were not reported on the questionnaire. For example, 60% of participants thought that the app would benefit from the additional features (e.g., a place to specify the body area in Difficulties, the user's current weight with the text "This is what your weight is right now" in the weight goals, a louder sound feedback with the use of the buttons). Miscategorization of certain labels was a problem to half of the participants. Sixty percent of the participants reported problems with navigation due to the lack of direction, page design, and multiple selections. Additionally, 20% of the participants reported a lack of consistency on a page layout due to two pages with multiple selections within Reports.

Moreover, there were a number of problems that were reported by only one participant. For example, labeling of "News," "Diary," and "Do not show this again" was not clear to 1 participant per label. These problems were not addressed in the app redesign section, except for the "Do not show this again" button, which was renamed into "Hide this page." Design of UI elements category had the additional problems with the design of an input field for the MS type in Personal Information within the Profile (n=1). Problem with the keyboard spell check was not present in the audio transcripts, and one participant reported it on a questionnaire. One participant reported that the interface requires too many clicks. Although the app provides an on-screen verification within the input field, the lack of it was reported by 1 participant. Additionally, lack of confirmation of activity was reported once.

V. Refinement of MS Assistant

All the design features and related characteristics that needed to be redesigned based on the results of both the UDMIG v.2.1 design criteria questionnaire and audio transcripts were summarized, as previously reported [1]. The rationale for the design response was to make a design change if in agreement with UDMIG v.2.1, if at least two participants reported the problem, and if the suggestions were not already present in the prototype of MS Assistant.

Dark grey background on the instruction pages was changed into white to provide more contrast against the black and green (i.e., confirmation) text (Figure 3). "Education" was renamed into "Resources", "Emergency" into "Emergency Contacts" (Figure 4), "Energized" (in Mood) into "Excited", "Input" into "Speech Input", "Touch" into "Touch Input", "Output" into "Display and Sound", and "Speech" was replaced with "Voice".

Due to the lack of space on the top navigation bar, the name of the app, MS Assistant, was taken out of the Home page and the icons for Profile and Settings were added (Figure 4). The color of the icons for the current state (e.g., Diary, Reports) was changed from black into the color of that function (e.g., Diary icon in green, Reports icon in blue). In this way, the icon and the header look like the part of the page background and not like the buttons (Figure 3).

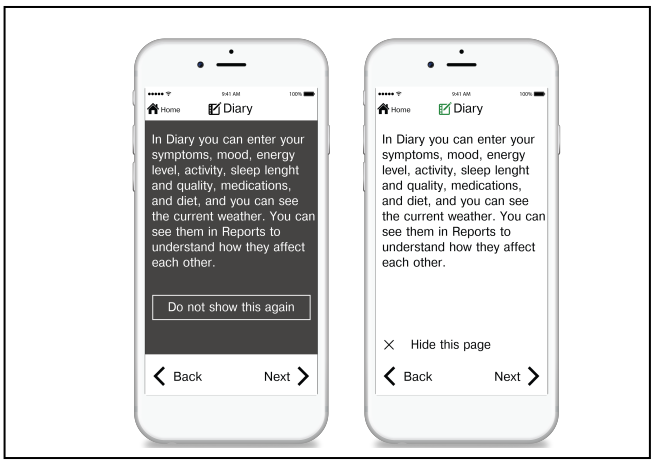

Figure 3. Before (left) and after (right) Diary Instruction page

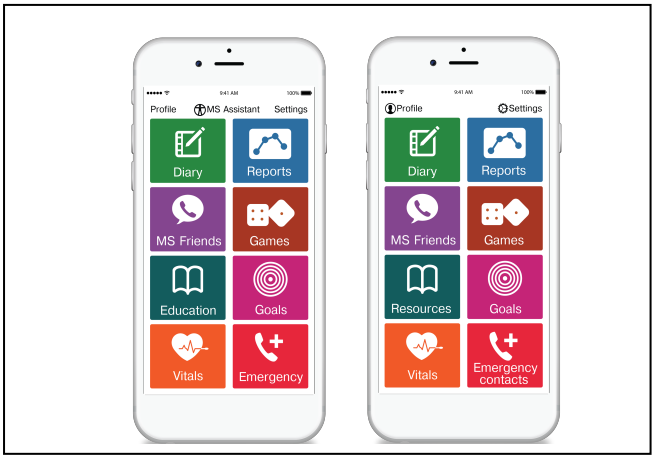

Figure 4. Before (left) and after (right) Home page

TABLE II. DESIGN FEATURES AND CHARACTERISTICS RELATED TO THE IDENTIFIED USABILITY PROBLEMS

Themes	**Usability Problems**	**Design Feature and Related Characteristic**		**Ability Required to Perform the Task**	**Number and Frequency of Participants, N, F (%)**
Navigation	Not clear whether a required action was taken due to having to press Next after a single choice is made	Next and Back buttons, Navigation		Cognitive	N=7 F=70%
	Lack of understanding that there are two ways of navigation	Two ways of navigation, Navigation			N=2 F=20%
Labeling	Not clear labeling of buttons	Buttons, Labeling	Education		N=4 F=40%
			Emergency		N=2 F=20%
			Energized		N=1 F=10%
			Input, Output		N=2 F=22.22%
			Speech		N=1 F=10%
Design of UI elements	Profile and Settings buttons not prominent and visible	UI elements, Design	Profile and Settings	Visual	N=3 F=30%
	Header looks like a button		Header		N=3 F=30%
	Slider hard to use by the target population, the font and location of the numbers		Slider	Physical/ Visual	N=2 F=20%
Buttons	Lack of vibration	Buttons, Haptic feedback		Physical	N=3 F=30%
	Expected double-tap	Buttons, Single tap			N=1 F=11.11%
Keyboard	Lack of page scrolling with use of a keyboard	Keyboard, Page scrolling			N=2 F=20%
	Lack of spell check with the use of a keyboard	Keyboard, spell check			N=1 F=10%
Page layout	Small spacing between the buttons	Button spacing, Layout		Visual	N=2 F=20%
	Layout, form, and location of View/Email Report buttons	View and Email Report buttons, Layout			N=1 F=10%
Contrast	Low contrast against the background (instruction page)	Background, Contrast			N=3 F=30%
Prompt	Lack of specificity and lack of flexibility (navigation)	Prompt, Content		Cognitive	N=2 F=20%
Font size	Small font size	Text, Font size		Visual	N=1 F=11.11%

TABLE III. USABILITY PROBLEMS (I.E., THEMES AND PROBLEM EXPLANATIONS) WITH RELATED DESIGN FEATURES AND CHARACTERISTICS

Themes	Usability Problems	Design Feature and Related Characteristic		Ability Required to Perform the Task	Number of Instances Problem was reported, n	Number of Participants, N
Navigation	Not clear whether a required action was taken due to having to press Next after a single choice is made; Specialized use	Next and Back buttons, Navigation		Cognitive	12	N=7
Labeling	Not clear labeling of buttons	Buttons, Labeling	Education		7	N=7
			Emergency		7	N=7
			Energized		2	N=2
			Input, Output		9	N=7
			Speech		4	N=4
			News		1	N=1
			Diary		1	N=1
			Do not show this again		1	N=1
Design of UI elements	Profile and Settings buttons not prominent and visible;	UI elements, design (form and color)	Profile, Settings	Visual	5	N=5
	The header looks like a button;		Header		4	N=3
	Slider hard to use by the target population, the font and location of the numbers;		Slider	Physical/ Visual	7	N=5
	Not adequate icons;		Icons	Cognitive	5	N=3
	Lack of MS types options		MS type		1	N=1
Page layout	Layout, form, and location of the buttons (including View/Email Report buttons); Page layout; Missing information about the selection and navigation; not dynamic enough; smart app feature	Buttons, Page Layout			13	N=6
	Too small button spacing	Button spacing, Layout		Visual	4	N=4
Keyboard	Lack of page scrolling with use of a keyboard	Keyboard, Page scrolling		Physical	6	N=5
Prompt	Lack of flexibility (navigation)	Prompt, Content		Cognitive	4	N=3
Font size	Small font size	Text, font size		Visual	2	N=2
Contrast	Low contrast against the background	Background, Contrast			3	N=2
Single tap	Too many clicks required (physical effort)	Buttons, Single tap		Physical	1	N=1
Feature request	Missing features	Feature, Feature request		Cognitive	11	N=6
Navigation	Lack of direction; Page design; Multiple selections	Buttons and pages, Navigation			12	N=6
Design	Wrong location and labeling of certain features	Labels, Miscategorization			10	N=5
Lack of consistency	Lack of consistency in page layout	Page layout, Lack of consistency			2	N=2
Keyboard	Lack of the on-screen verification with keyboard	Keyboard, On-screen verification			1	N=1
Lack of confirmation	Lack of confirmation that data was entered	Lack of confirmation of activity, Navigation			1	N=1

Numbers on the slider were placed on the top of it. Speech icon was replaced with Output icon, and Input icon with Speech icon. Output icon and Seeing icon (in Difficulties) were redesigned. Even though only one participant reported that there was no spell check with the use of a keyboard, this general feature was implemented because it is present in a majority of the apps. Page scrolling was added with the use of a keyboard. A prompt was redesigned to inform about the missing data in a way that allows users to go to the following page without having to fill out all information (i.e., "Do you want to fill out the missing information?" with Yes that takes them back to the previous page, and No that takes them to the following page). Text about the navigation (i.e., linear navigation using Next and Back buttons) was added to the first instruction page. The font size of the MS News articles was increased. The layout of the buttons was changed (e.g., View Report button was moved above the Email Report button, and the names of the VR games were shortened). The other layout changes were not made due to the inconsistencies with the page layout. A spacing between the top buttons and large buttons bellow (e.g., Manual entry, and Week, Month, Year buttons) was increased. There were a number of feature requests. For example, additional information about MS Friends is added on the calling page (e.g., friend's interests, MS type, and other information the person wants to share). No changes were made to the other feature requests due to the small number of participants reporting the problem (N=1 per problem).

Seven participants were reporting a problem with the navigation using Next and Back buttons. However, no change was made due to the design criteria IC2d. (i.e., Have more than one way to go to different pages while keeping the consistency). Next and Back buttons are typical of linear navigation and will be used in the novice user mode only. Additionally, 3 participants did not see that this prototype included alternative voices within the Settings and a problem with it. Similarly, 3 participants reported problems with the lack of the tactile feedback, which was not incorporated because iPhone 6 does not have the Taptic Engine that provides the vibration while tapping the buttons that was included in later versions. The total number of participants reporting the problems with the miscategorization of the labels was 5. However, no changes were made due to the small number of participants reporting the individual problem (N=1 per problem). No change was made to the second page of the Reports due to the lack of page space (N=2). Even though was there was a total of 6 participants who reported a problem with the navigation due to the design of the buttons and pages, no changes were made due to the small number of participants reporting the specific problem (N=1 per problem).

VI. Conclusion and Future Work

This research paper provides a detailed evaluation of the usability of MS Assistant by expert reviewers, which was previously reported [1]. The results of the expert review confirm the effectiveness of the UDMIG v.2.1 within the application to MS Assistant. Overall, this implementation of the guidelines to the design of the mobile app scored well. Most of the participants favorably agreed that the guidelines were effective. Ninety percent of the mean values of the participants' ratings were equal to 4 or higher. In addition, there was a small number of recommendations related to the minor usability problems in MS Assistant. Design changes addressed the usability-related suggestions made by the expert reviewers. One of the drawbacks of the study was its small sample size. However, all the experts had extensive and wide expertise applicable to the design of mHealth apps for people aging with disabilities. Another drawback of the study was that none of the experts was "very familiar" with the design of user interfaces for the target population. However, the majority of them were "somewhat familiar" with it.

Future work will include usability testing of the mHealth app with the individuals aging with MS to understand the usability of MS Assistant to determine the effectiveness of UDMIG v.2.1 in producing a universally usable product. This study will help with the analysis of the user-specific preferences for the specific design features and the resulting design implications.

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