Universal Design Mobile Interface Guidelines for Mobile Health and Wellness Apps for an Aging Population Including People Aging with Disabilities

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Abstract—**The usability of mobile interfaces for older adults is becoming more important as the population ages and their use of technology increases. Whereas a few design strategies have been developed to guide the design of the mobile interfaces for an aging population, these strategies and their related principles and guidelines are focused on either older adults or individuals with disabilities. The size of the population aging with disabilities is growing. However, there are no guidelines that include this end-user population. Adaptation and integration of the existing strategies were necessary to create an inclusive and comprehensive set of guidelines for interactive mobile interfaces for older adults that includes people aging with disabilities. The paper presents an overview of the Universal Design Mobile Interface Guidelines, UDMIG, for an aging population and individuals aging with disabilities, and the related evaluation checklist. UDMIG v.2.2 and the checklist were developed to ensure usability of future mobile technologies by older adults through a universal design strategy that accommodates all users to the greatest extent possible. Moreover, the paper details the application of the guidelines to the design of the mobile health and wellness self-management app for individuals aging with multiple sclerosis, MS Assistant. Additionally, it reports the results of an expert review with the purpose of evaluating the effectiveness of implementing UDMIG v.2.2 in the design of MS Assistant.**

Keywords-aging; aging with disabilities; design; evaluation; guidelines; mobile interfaces.

I. INTRODUCTION

This research paper is based on the previously reported contribution on the design and evaluation of mobile interfaces for an aging population [1].

Older adults encounter many barriers while interacting with mobile applications [2]-[5]. Lack of physical space (e.g., small touch and physical buttons), confusion with their location within the context, use of menus that require precise movements, use of small fonts, content placement, and use of large contents that require memory recall, are some of the barriers that lead to longer and less successful task completion [6][7].

The usability of mobile interfaces for older adults is becoming more important as the population ages and seniors' use of technology increases. To ensure usability of new technologies for older adults, a number of design strategies have been proposed. While these strategies may adequately address the usability issues for people experiencing the normal aging process, they do not address the increasing number of usability barriers experienced by people aging with disabilities, a user population that is also growing at a rapid pace [8][9].

To be inclusive of people aging with and into disability in the design of interactive mobile interfaces, the Universal Design Mobile Interface Guidelines (UDMIG), was developed. The UDMIG is a comprehensive set of usability guidelines based on four established design strategies for desktop and mobile user interfaces, including, Universal Design (UD), Design for Aging (DfA), Universal Usability (UU), and Handheld Mobile Device Interface Design (MID).

This paper describes the development of the UDMIG and its associated checklist to ensure usability of future mobile technologies by older adults through a universal design strategy that accommodates all users to the greatest extent possible. In addition, it details the application of the guidelines to the design of MS Assistant, a mobile health and wellness self-management app for individuals aging with multiple sclerosis.

This paper is organized into six sections. Section II provides a background of the four design strategies that formed the basis of the UDMIG. In addition, it describes the current evaluation tools used for the assessment of mobile touchscreen interfaces for an aging population. Section III describes the three prototypes of the mobile interface guidelines for an aging population and their refinement, to include individuals aging with disabilities in UDMIG v.2.2. Section IV identifies the specific design criteria derived from UDMIG v2.2, which should be applied to the development of the mobile applications for older adults with disabilities. Section V describes the development of MS Assistant, a mobile health management application for people with Multiple Sclerosis (MS) based on the design criteria. Section VI presents the results of an expert review to evaluate the effectiveness of implementing the UDMIG design criteria in the design of MS Assistant. Finally, Section VII provides a discussion of the current state of MS Assistant and proposes future work.

II. BACKGROUND: DESIGN FOR AGING

There are four widely accepted strategies that are applied to the design of desktop and mobile user interfaces that are relevant for the target population. These include UD, DfA, UU, and MID.

UD is the design everyday products that are usable by everyone (to the greatest extent possible). By doing so, UD

facilitates usability, thereby eliminating physical barriers to usability (and inclusivity) that would be experienced by any individual, including older adults and people with disabilities [10][11]. The Principles of UD [12][13] consists of seven principles and twenty-nine guidelines. Although originally developed to apply to physical products, the Principles of UD are equally applicable to the design of digital technologies.

In contrast to UD, DfA [14] specifically addresses the specific functional limitations associated with aging and user interfaces. DfA identifies the factors that constrain the use of products and user interfaces by older adults, as well as aspects of human-computer interface design that accommodate older users with age-associated disabilities and limitations [15]. It has fifty-two design guidelines grouped into six categories that cover design of visual, auditory, and haptic presentation of information, input and output devices, and effective interface design.

UU is comprised of eight guidelines, called the Eight Golden Rules of Interface Design. Whereas UD was initially developed for the design of physical environments (e.g., buildings, spaces, products, graphics), UU is intended to support usability, inclusivity, and utility of information and communication technologies [16]. Based on UU, the MID [17] modified and extended the eight golden rules to provide general design guidance for the usability of mobile platforms (Table I).

TABLE I. DESIGN STRATEGIES, THEIR TARGET AUDIENCE AND DESIGN

Design Strategy	Target Audience	Target Design
UD	All Users	Physical Environments
DfA	Seniors	User interfaces
UU	All Users	ICT
MID	All Users	Mobile Interfaces

While each of the four design strategies is commonly used to guide the design of mobile interfaces, none are sufficiently comprehensive to ensure that mobile user interfaces will be usable by older adults. Clearly, the first three strategies, UD, DfA, and UU, which were developed prior to the proliferation of mobile interfaces, are not specific to this platform. In contrast, whereas the MID is the mobile platform-specific, DfA is the only population-specific (i.e., a focus on older adults) strategy. Moreover, it is also the only strategy that clearly links individuals' needs and abilities to design solutions. As such, it provides both an understanding of *what* the functional problems of older adults are and guidance on *how* design can be used to solve those issues. This person-environment (P-E) fit approach [18] not only provides an understanding of *why* interface design needs to be different to be usable by older adults but also the tools to create unique and innovative interfaces without relying on a rigid set of prescriptive rules.

With the lack of an aging-relevant set of usability guidelines for mobile interfaces, there is a similar lack of a comprehensive evaluation tool to assess the usability of mobile touchscreen interfaces for this population. Existing assessment tools were either designed for other scales of design (e.g., products, services, spaces, buildings), developed to support the design of web interfaces for individuals with disabilities, or created for an evaluation of user interfaces for the general population. Five tools, the UD Checklist, Universal Design Performance Measures for Products, Product Evaluation Countdown, Universal Design Assessment Protocol and GUDC Guidelines are intended to assess the physical environment based on the UD principles.

The *UD Checklist* [19][20] assesses design based on both UD principles and ranges of users' abilities (i.e., vision, hearing, speech, cognition, dexterity, communication, balance, stature, upper and lower body strength and mobility, lifespan) to indicate the degree to which the outcome met the criteria for each design principle and each type of ability, respectively. This tool was intended to evaluate architectural spaces. It does not assess the specific design features, and it only evaluates the proposed design, not actual designs in use. The *Universal Design Performance Measures for Products* [21] uses twenty-nine UD guidelines as performance measures, and the five-point rating scale from strongly disagree to strongly agree, with a choice of not applicable to identify strengths and weaknesses of a product. It is intended to evaluate the usability of products throughout their life cycle, develop usability testing and focus groups, and identify and promote UD features of products. The second version of this tool called the *Product Evaluation Countdown* [22], was developed for use by end-users with their ranges and levels of abilities to test the actual demands of products. *Universal Design Assessment Protocol* (UDAP) [11][23] assesses UD principles by ability as well as across the range of abilities, evaluating design at the level of each UD guideline, thus providing a more precise analysis. However, the tool proved to be very complex and impractical to quantify UD with its six hundred and twelve-cell matrix. The Global Universal Design Commission, Inc. (GUDC) created *GUDC Rating System* that covers design process, site and building elements, customer service, and facilities management, which is building-type specific [11].

In addition to UD-derived evaluation tools for the physical environment, the *Web Content Accessibility Guidelines (WCAG) 2.0 Checklist* was developed by the Web Accessibility Initiative (WAI) of the World Wide Web Consortium (W3C) [24] to evaluate the accessibility of web pages and HTML content for users with disabilities. However, the tool is neither specific to mobile devices nor does accessibility necessarily equate to usability. Finally, although a number of other evaluation checklists and frameworks for testing the usability of mobile apps have been proposed [25]-[28], these tools are intended for the general population and do not recognize a variety and ranges of limitations an aging population faces.

III. UNIVERSAL DESIGN MOBILE INTERFACE GUIDELINES, UDMIG

The first version of the guidelines, UDMIG v.1.0, which has been previously reported [29][30], was created by applying DfA, UU, and MIG to the seven Principles of UD. This version relied too much on principles and guidelines of

universal design as the underlying basis for the UDMIG. As such, it failed to incorporate P-E interaction approach that was a unique contribution of DfA, contained inconsistent language and level of specificity, and needed further refinement.

A. UDMIG v.2.0

To overcome problems with UDMIG 1.0, UDMIG v.2.0 [31] was developed within a framework based on the P-E fit model [18] as an organizing principle (Fig. 1).

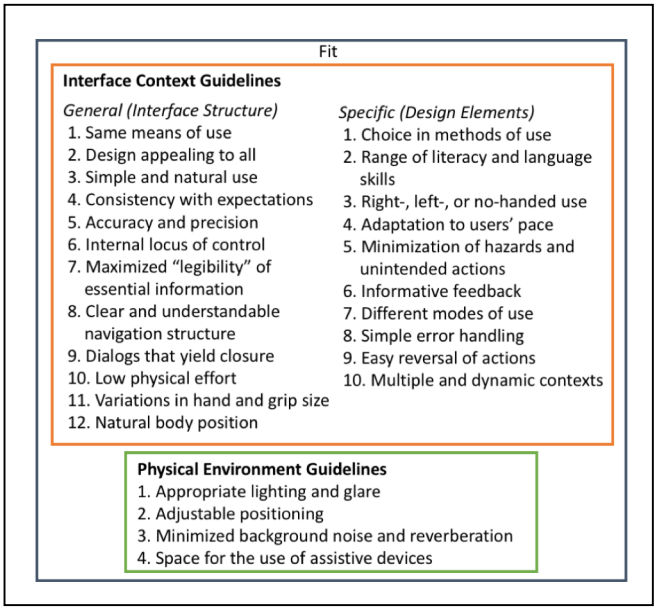

Figure 1. Structure of UDMIG v.2.0 based on P-E Model and its person, environment, and fit components.

The P-E fit approach [18] assesses the match or fit between a person's ability and the demands of the environment to promote healthy aging. Usability of mobile applications is achieved when there is a match between a person's ability and the design of the interface. In UDMIG v.2.0, the fit between the range of human abilities and the environment is manifested as a set of performance guidelines. These guidelines cover both the contextual environment of the interface and the physical environment in which the interface is used. For purposes of designing interfaces only guidelines specific to the interface environment, itself, were considered in the development of UDMIG. Moreover, the interface environment can be further differentiated by those guidelines that address the design of the interface structure (e.g., layout and navigation), as well as those that guide the design of the specific design elements (e.g., buttons and text) (Fig. 1).

B. UDMIG v.2.1

UDMIG v.2.0 failed to include the people aging with disabilities. Whereas data indicate that this is a growing population of potential users [8][9], the guidelines did not address the types of impairments and comorbidities experienced by these individuals.

To expand UDMIG v.2.0 to include individuals aging with disabilities, a study with people with multiple sclerosis (MS) was conducted [32]. MS was taken as an example of aging with disability. People with MS were chosen as an ideal end-user population as they represent a diverse user group that has symptoms that vary widely from an individual to an individual, but also within individuals over time. Moreover, MS presents with chronic symptoms that share many of the functional limitations associated with aging, including a decline in muscle strength, problems with balance, weakness, fatigue, reduced sensation, vision impairments, bowel and bladder dysfunction, cognitive impairment, pain, osteoporosis and sleep disturbances [33]-[36]. In addition, a majority of individuals diagnosed with MS experience major decline in their abilities due to the progression of MS after five years post-diagnosis [37]. Following this period, they need to learn how to cope with the functional limitations caused by the disease and how to age with MS.

The study [32] evaluated the usability of two health and wellness self-management mobile applications for individuals with MS and one health app for the general population. The three apps were evaluated by older adults and individuals with MS to identify the effectiveness of app attributes.

Study participants reported a number of additional recommendations for the design of mobile health and wellness applications:

- Navigation needs to be clear, intuitive, consistent, and easy to understand;
- Locating pages needs to be easy and intuitive;
- Task completion needs to be evident and bold so that users know they have accomplished their tasks and they can continue with the subsequent activities;
- Provide specific and clear instructions for every step of the actions;
- Font, buttons, and icons size (screen characters and targets) should be large enough to be usable by the end-users;
- Color contrast needs to be very high to allow for ease of use and legibility of information;
- Avoid use of scrolling and spinner.

This set of evidence-based design recommendations is intended to assist with the future development of health and wellness mobile interfaces for older adults, including people aging with disabilities.

The recommendations represent the most important design elements that need to be considered for the development of mobile interfaces for an aging population and present the main considerations when designing for this specific population.

Based on the results of the reported study [32], the design recommendations were used to prioritize UDMIG v. 2.1 as eight essential guidelines and the rest as optional/advisory guidelines. Among these eight essential design guidelines, six refer to the interface structure and two to the design elements. In addition, Same Means of Use

guideline was added as the ninth mandatory guideline because it is the only UD principle that is essential to inclusivity and participation (Table II).

TABLE II. UDMIG v.2.1

Design Elements Guidelines	Interface Structure Guidelines
Essential Guidelines	
1. Accuracy and precision	1. Same means of use
2. Informative feedback	2. Clear and understandable navigation structure 3. Consistency with expectations
	4. Simple and natural use
	5. Dialogs that yield closure
	6. Maximized "legibility" of essential information 7. Range of literacy and language skills
Advisory Guidelines	
3. Choice in methods of use	8. Internal locus of control
4. Minimization of hazards and unintended actions 5. Different modes of use	9. Adaptation to users' pace
	10. Multiple and dynamic contexts
6. Easy reversal of actions	11. Design appealing to all
	12. Right-, left- or no-handed use
	13. Low physical effort
	14. Variations in hand and grip size
	15. Natural body position

These first nine design guidelines (i.e., the first two design elements guidelines and the first seven interface structure guidelines) should be used as the mandatory guidelines when designing for an aging population, including individuals aging with disabilities. The rest of UDMIG v.2.1 should be used as the recommended best practices.

IV. Design Criteria for Mobile Apps

Based on the UDMIG v.2.1, design criteria for a health and wellness self-monitoring mobile application for individuals aging with MS were developed. Each design guideline resulted in one or more corresponding design criteria, which were specified to be implemented in the app design.

UDMIG v.2.1 represent a set of performance guidelines. However, among the four founding design strategies, DfA is the only one that included prescriptive guidelines. Therefore, a number of design criteria are presented as prescriptive, and the majority as performance-based. Although the objective of both prescriptive and performance design criteria is to achieve usable design outcomes, they do so in very different ways. Prescriptive criteria focus on means and methods of achieving usability by dictating what must be done to achieve a usable outcome. This is largely achieved without specifying what the design of the outcome might look like. As a result, the more prescriptive design criteria are, the fewer design alternatives there are and therefore fewer ways to achieve a usable outcome. For example, DE guideline *Accuracy and Precision* provides a specific design criterion that the size of the buttons should be at least 16.5mm diagonally and 11.7mm square. In addition, it dictates the minimum contrast based on the WCAG 2.0 1.4.3 [24] level AA and level AAA. In contrast, performance design criteria focus on the product or results of the design process. Performance-based criteria suggest what the usable outcome should be without regard to how that outcome is achieved. As a result, performance design criteria provide greater flexibility in design outcomes by providing opportunities for designers to rely on their own interpretation and creativity to achieve a usable outcome. For example, IC guideline *Dialogs that yield closure* provides a design criterion that the related information should be grouped together and the most frequent operations should be highest on the menu structure. The later one focuses on the design outcome and leaves it up to the designer to determine what the related information is and how to group it, and what the most frequent operations within the design are.

A. Design Elements (DE) Guidelines and Criteria

Essential Guidelines

1. *Accuracy and precision*
    a. Size of the buttons is at least 16.5mm diagonally and 11.7mm square [38];
    b. Minimum contrast: the visual presentation of text and images of a text should have a contrast ratio of at least 4.5:1 (Level AA), preferably 7:1 (Level AAA) except for the following:
        i. Large Text: Large-scale text and images of large-scale text should have a contrast ratio of at least 3:1;
        ii. Incidental: Text or images of text that are part of an inactive user interface component, that are pure decoration, that are not visible to anyone, or that are part of a picture that contains significant other visual content, have no contrast requirement;
        iii. Logotypes: Text that is part of a logo or brand name has no minimum contrast requirement (WCAG 2.0 1.4.3) [24];
2. *Informative feedback*
    a. For every operator action, there is a system feedback, such as a beep when pressing a key or an error message for an invalid input value [16];

b. Provide a feedback about a confirmation of an activity and a current state [14][32];
c. For each icon provide a text description [38];

Advisory Guidelines

3. Choice in methods of use
a. Provide an option to select or deselect all user preferences such as voice input (e.g., Siri, voice control) in Settings, available as accessibility features in iOS [11][17];

4. Minimization of hazards and unintended actions
a. Provide text warnings as opposed to symbols and icons [14];
b. Avoid short-duration menu displays [14];
c. Frequent and important actions should be visible and easily accessible [11][14];
d. Tap targets on touchscreens should be at least 16.5mm diagonally and 11.7mm square [38];
e. Tap targets should be in colors that stand out, and arranged in linear order [30][39];
f. Avoid use of attention-catching techniques, such as flashing and scrolling text and images in the periphery [14];

5. Different modes of use
a. Use alternative interaction modes such as sound, vibration, and light [11];
b. Provide both tactile/haptic and auditory feedback with keypads [14];
c. Provide several alternative voices [17];
d. Provide redundant visual presentation of essential information (e.g., color, icons, and text) [11];

6. Easy reversal of actions
a. Provide "Are you sure?" prompts for important actions that can be disabled in Settings [11][14][30];
b. If an error is made, the system should be able to detect the error and offer a prompt message for handling the error (e.g., if an entry for weight is skipped, provide a text message "Please enter a target weight") [16].

B. Interface Context (IC) Guidelines and Criteria

Essential Guidelines

1. Same means of use
a. Eliminate specialized design and language [11];
b. Provide one hardware and software application that allows individualized preferences [11][40];

2. Clear and understandable navigation structure
a. Use the same design elements for the navigation from page to page, such as next and back buttons or similar [30] [32][39];
b. Have navigation assistance (e.g., menu, instructions) for how to navigate to specific points in the system, which includes navigation to not only the home page, but also any relevant page [14];
c. Provide specific, clear, and evident instructions for every step of the actions, and allow users to disable these instructions in Settings and on the instructions page [32];
d. Provide more than one way to go to different pages while keeping the consistency [32];

3. Consistency with expectations
a. Identical terminology is used in prompts, menus, and help screens [14];
b. Consistent commands are employed throughout (e.g., Next, Back) [14];
c. Ensure standardized format and keep consistent location of target items within (e.g., navigation buttons, Settings button, and error messages should always appear at the same location) [14];
d. Provide the icon with the title of the current functional feature at the top navigation bar on every page;

4. Simple and natural use
a. Frequent and important actions should be visible and easily accessible (e.g., Next and Back buttons on the lower left and right side, Home page button on the upper left corner) [14];
b. Avoid use of the picker [32];
c. Avoid scrolling text because it is difficult to process, especially horizontal formats; use a slow scrolling rate if it cannot be avoided [14][32];

5. Dialogs that yield closure
a. Group related information and have most frequent operations highest on the menu structure [14];
b. Indicate clearly on the middle of the top navigation bar where the user currently is at any point of time (e.g., diary, reports, games, symptoms) [14];
c. After users save any data, provide the information that their records have been saved and secured [16][32];
d. Make it clear how to navigate to all main points of the interface from the homepage (i.e., main functional features on the home page), and how to go back to homepage from any other page (i.e., home page button on every page) [32];
e. Provide an obvious feedback (visual, audio, and/or tactile) when a target is selected [14];
f. Make it clear which option is active (i.e., selected state) and what the consequences of an action are (i.e., by pressing the selected button and Next button the selected feature page will open) [14][32];

6. *Maximized "legibility" of essential information*
    a. Size of the buttons is at least 16.5mm diagonally and 11.7mm square [38];
    b. Whenever possible use 14-point and bigger serif or sans serif fonts (i.e., use Helvetica primarily, and use Arial and Times Roman as secondary options), and use at least 12-point when not [41];
    c. Avoid cursive and decorative fonts and use of all uppercase letters [14];
    d. Provide good structure (e.g., grammar) in spoken and written text [14];
    e. Provide video conferencing in addition to talking on a phone [14];
7. *Range of literacy and language skills*
    a. Avoid use of technical language [14];
    b. Keep reading level of text material at grade 10 or below [14];

Advisory Guidelines

8. *Internal locus of control*
    a. Provide a choice of linear vs. random access [30][39];
9. *Adaptation to users' pace*
    a. Profile provides personalization option for users' skill levels: novice to expert users [16][17];
10. *Multiple and dynamic contexts*
    a. Users can configure input and output to their needs and desires (e.g., text size, brightness) in Settings [17];
    b. Allow for a configuration of the context, such as environmental conditions (e.g., brightness, noise levels, weather), and presence of strangers and locations that restrict use of some app features (e.g., speech input and output in libraries) [17];
11. *Design appealing to all*
    a. Provide color palette that can be used by colorblind users [17];
12. *Right-, left- or no-handed use*
    a. Place main navigation buttons of equal importance accessible for both right- and left-handed users (e.g., Next and Back buttons at the lower left- and right-hand side) [39];
13. *Low physical effort*
    a. Avoid double-clicking and use single tap instead [14];
    b. Minimize steps (i.e., basic tasks) when possible [14];
14. *Variations in hand and grip size*
    a. If the targets are large enough (at least 16.5mm diagonally and 11.7mm square), a spacing between them can be zero [14][38];
    b. If targets are small, make spacing between them visible (e.g., 3mm) [14][38];
    c. If possible, place tap targets near the center or the bottom of the screen [38];
15. *Natural body position*
    a. Place main navigation buttons of equal importance at the bottom of the screen (e.g., Next and Back buttons at the lower left- and right-hand side) [39].

V. MS ASSISTANT: A MOBILE HEALTH MANAGEMENT APPLICATION

Based on the UDMIG v. 2.2 design criteria, a mobile health and wellness app, *MS Assistant,* was developed to enhance health self-management for people with MS. The app was designed to provide eight functions, to allow for personalization, and to assist with medication adherence and other daily tasks with alert/reminder systems. These eight functions were selected based on the findings of a qualitative study [40], which was conducted to identify the specific needs for self-management of health and wellness among people with MS and to recognize the opportunities to meet those needs through mobile apps. A number of preferred functions were identified and grouped into eight categories (i.e., daily self-reporting of health and wellness, keeping and communicating health and wellness records, education, social support, alert and reminder systems, virtual reality games, telehealth, personalization).

Functions. The eight functions include diary, reports, MS friends, games, education, goals, vitals, and emergency.

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 911.

Structure. 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 (Fig. 2). To change the selection, a user can tap the button again to deselect it.

For navigating through the pages, the user can tap on the Next and Back buttons located at the bottom corners of the screen (Fig. 2). For example, after tapping on the Diary button users are taken to the first Diary page where they can select the Mood. The selected state of the Mood button confirms the selection, and Next button takes users to the Symptoms page. Users are through all the Diary pages by tapping the Next buttons. After making the final selection on the Diet pages, users are taken to the Home Page. In addition, for the expert users and ones who prefer a direct selection, all of the functional features are accessible from the Home page. Moreover, every page has the Home and Back buttons to allow an easy random access. Back button takes users to the main Diary page and directly make selections.

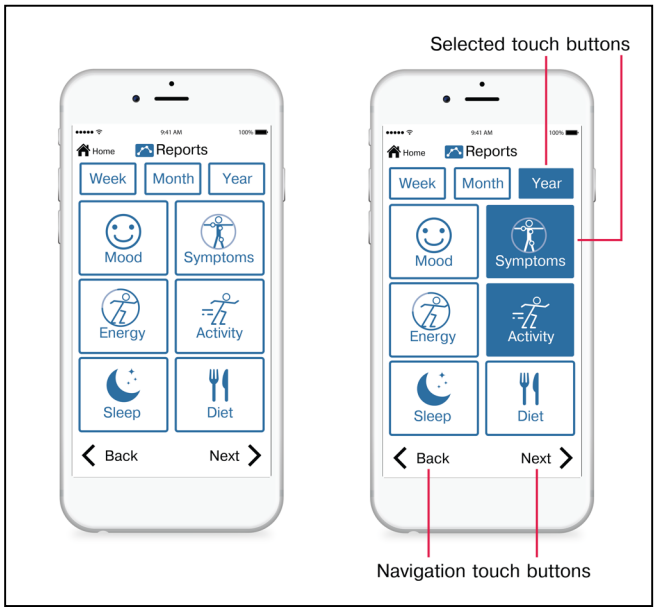

Figure 2. Linear interaction on the Reports page.

Design Decisions. Design decisions for MS Assistant were based on the UDMIG v.2.2 and corresponding design criteria.

A. *Design Elements (DE) Guidelines*

Essential Guidelines

1. Accuracy and precision

To facilitate the accuracy and precision required to accommodate different abilities, preferences, situations, contexts of use, ages, novice and expert users, and enhance users' experience, provided screen characters and targets are designed to be conspicuous and accessible (e.g., font size is at least 14-point and higher, the button size is at least 16.5mm diagonally and 11.7mm square [36]). In addition, every function is presented by its color of the touch buttons on the Home Page and throughout the app (Fig. 3a). The color scheme for the Home Page buttons (i.e., functional features) is chosen to pass the assessment against the WCAG 2.0 1.4.3 [20] color contrast success criteria. Contrast is maximized by using black on white text.

2. Informative feedback

When the user taps on any button to make a selection, the button changes to the selected state button with a colored background and white text that visually emphasize the selection. An error message shows up on the screen after the user creates an invalid input value. Top navigation bar provides information about the current functional feature by providing a title with an icon (e.g., Diary with its icon, Mood with its icon, etc.). After users finish all the tasks in the last section of the Diary, which is the Diet, they are taken to the Home page by tapping on the Next button.

Advisory Guidelines

3. Choice in methods of use

Different inputs and choices of input to accommodate variations in abilities, preferences, situations, and contexts of use are available in Settings as Input and Touch selections. For example, speech input through Siri and voice control is available for users.

4. Minimization of hazards and unintended actions

Text warnings, as opposed to symbols and icons, are provided in the form of prompts that can be disabled in Settings. Frequent and important actions are visible and easily accessible by placing the Home button on the navigation top bar and the Next and Back buttons on the bottom of the screen on every page (Fig. 3b).

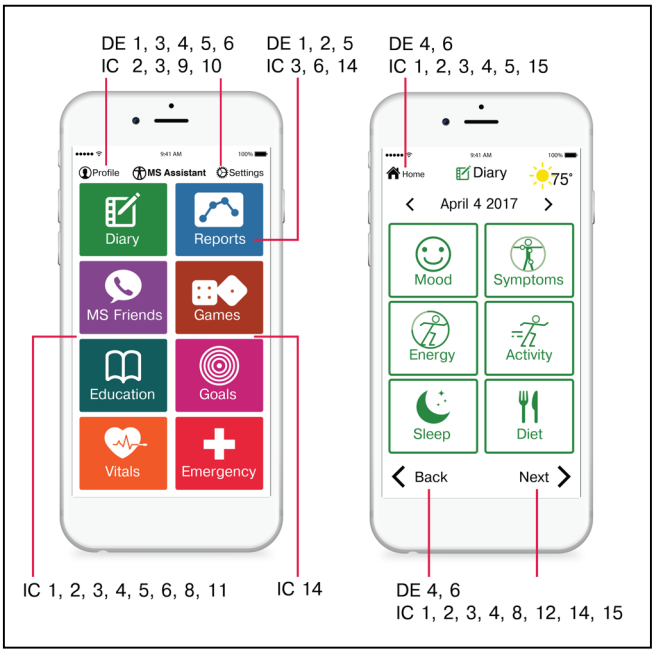

Figure 3. Homepage (3a) and Diary page (3b).

Short-duration menu displays are eliminated because of the slower processing speed of an aging population. Instead, after the user taps on any button, the button changes to the

selected state that lasts until the user taps on the Next button or he or she decides to deselect it.

5. Different modes of use

Different modes (pictorial, verbal, tactile) for redundant presentation of essential information to accommodate different abilities, preferences, and contexts of use are available and can be selected and deselected in Settings as Output and Touch accommodations. For example, alternative interaction modes such as sound, vibration, and light, haptic and auditory feedback with keypads, and several alternative voices can be selected. In addition, all touchscreen buttons provide redundant visual cues through color, icons, and text. Because of the limitations of iPhone 6, vibration (haptic) feedback is not available for this version and can be turned on for the iPhone 7 version and above.

6. Easy reversal of actions

Fail-safe features are provided to minimize hazards and errors. The units of reversibility are a single action, a data entry, or a complete group of actions. For example, "Are you sure you want to send the reports to the selected contacts?" is a confirmation message after a user selects the reports and contacts, with reversion back to the contacts screen when users press "No" (Fig. 4b). Easy reversal of an action is provided through the option to cancel unwanted task in this prompt message if the list of contacts is wrong. Similarly, if a target weight is skipped in the Goals, a text message "Please enter a target weight" shows up to remind the user to fill out the weight.

B. *Interface Structure (IS) Guidelines*

Essential Guidelines

1. Same means of use

The design goal is one mobile health and wellness app for all users, rather than accessible design for people with disabilities. As a universally designed system, the app design avoids segregating or stigmatizing users and provides participation by providing the same hardware and software application that allows individualized preferences.

2. Clear and understandable navigation structure

Users can choose to have linear navigation using the same type of linear navigation (e.g., Next and Back buttons) on every page or they can go back to the Home page and use random access navigation to go directly to a function. Navigation assistance is provided with instructions for how to navigate to specific points in the system and the Home page button on every page. Specifically, every functional feature has an instruction page that explains the content and interactions. For those who no longer need instructions, they can be disabled on the Instructions page itself and in the Settings.

3. Consistency with expectations

Consistent sequences of actions are required in similar situations. For example, users make a selection by tapping the button when the selected state of the button appears and navigate to the next page by tapping the Next button on every page. Identical terminology is used in all screens, prompts, error messages, text messages, and information screens. Consistent commands are employed throughout the interface (e.g., Next and Back buttons, Homepage button). Moreover, names, titles, color schemes, screen appearances, "look and feel," standard layouts, fonts, and font sizes are consistent throughout the app. In addition, consistency with pre-existing expectations is provided. For example, Next button is placed on the right-hand side, the Back button is located on the left-hand side, and selection is made by tapping a button. Information is arranged consistent with its importance by having the icon and the title of the current functional feature at the top navigation bar together with the Home page button (Fig. 4a).

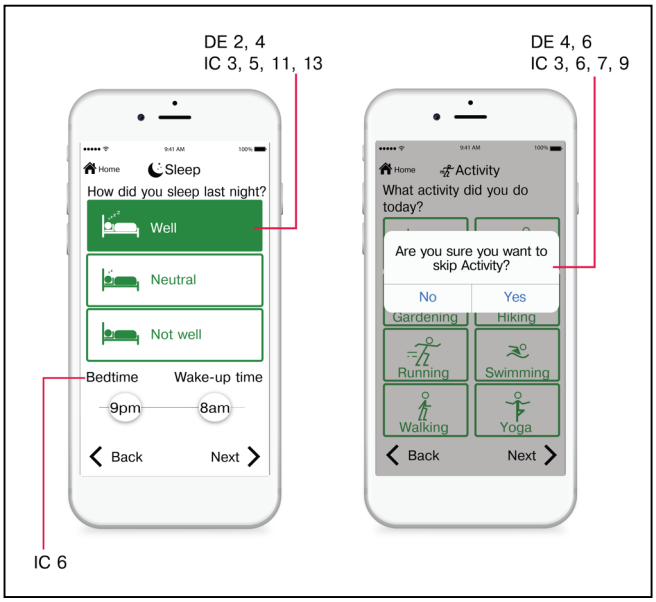

Figure 4. Sleep page (4a) and Activity page with "Are you sure?" prompt message (4b).

4. Simple and natural use

Complexity is eliminated by having simple screen designs that require a single task per screen (Fig. 5b). The Next and Back buttons are placed on the bottom of the page to allow for the natural use and navigation. Use of the scrolling is eliminated by having the single task on one screen. In addition, use of the picker is eliminated, and a slider, keypad, and buttons are used throughout the interface. Moreover, navigation is simple for novice users and those with cognitive limitations (linear navigation) as well as a for expert/advanced users (random access). Use of all attention-catching techniques is avoided.

5. Dialogs that yield closure

Screens are designed in a way that the related information is grouped, and the most frequent operations are placed highest on the menu structure. For example, on the Activity page, its icon and the title are highest on the screen and placed on the top navigation bar, start and end time is at the top of the page after the name of an activity, followed by the distance. The comments section is at the bottom of the screen. Related information is grouped, such that every functional feature has its own pages and colors that add to the differentiation between the selections. In

addition, it is clear and simple to navigate to all main points of the interface from the Home page (e.g., Diary, Reports, MS Friends, Games, Education, Goals, Vitals, and Emergency), and to go back to Home page from any other page (e.g., Home page button, Next and Back buttons). It is clearly indicated which option is active by having the selected state of the tapped buttons, and what the consequences of an action are. For example, by tapping on the Next button after making a selection, the next page will open. An obvious visual feedback is provided when a target is selected together by changing the color of the button to a color of the outline of the selected button. A vibratory feedback was not possible to implement on iPhone 6, which is a major drawback of this model. However, it is highly recommended, and it is possible to implement it on iPhone 6s and iPhone 7 devices.

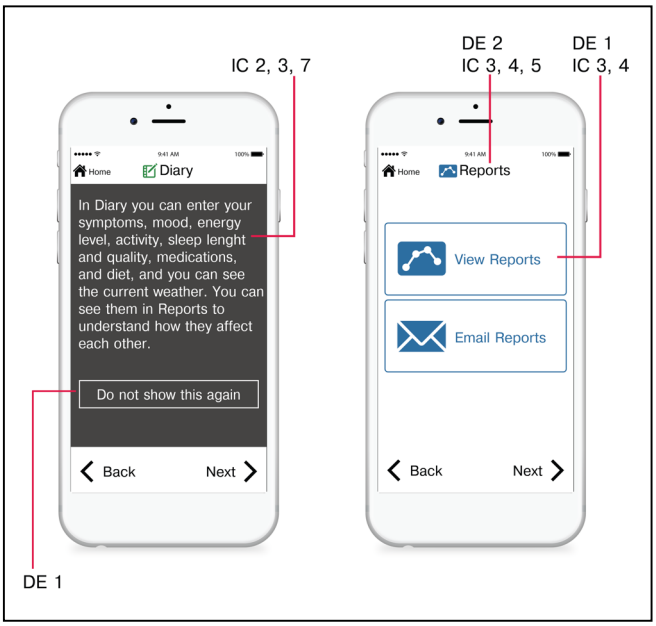

Figure 5. Diary Instructions page (5a) and Reports page (5b).

6. Maximized "legibility" of essential information

Screen characters and targets are designed to be conspicuous and accessible by designing the icons and buttons to be large enough to select easily. Helvetica 14-point font and bigger was the only font used.

7. Range of literacy and language skills

Research suggests that technical language might be difficult for older adults, as their educational attainment levels may be lower than that of younger adults [12]. Therefore, simple conversational language is used for all text material, and reading level of text material is kept at grade 10 or below (Fig. 5a).

Advisory Guidelines

8. *Internal locus of control*

The system should be designed such that users initiate actions rather than respond to them [14]. In addition, users can choose a navigation system and various preferences, such as linear vs. random access and novice vs. expert user navigation.

9. *Adaptation to users' pace*

The adaptable pace is provided in Settings and Profile to accommodate novice and expert users, different ages, abilities, preferences, situations, and contexts of use. Users can choose to navigate the app as novice or expert users, and they can personalize the app in the Settings. Pop-up menu durations are designed to be controlled by the user and require their confirmation (e.g., press "OK", "No", "Yes") to continue carrying out the commands.

10. Multiple and dynamic contexts

The Settings feature enables users to customize the input and output modalities to their needs and desires (e.g., text size, brightness) as well as the context, such as environmental conditions (e.g., brightness, noise levels, weather), presence of strangers and locations that restrict use of some app features (e.g., speech input and output in libraries) [39][40].

11. Design appealing to all

The app was designed to be appealing to all to enhance usability and marketability [14][15]. Color and its manipulation are important considerations for visual interfaces. MS Assistant has a color scheme that can be used by colorblind users.

12. *Right-, left- or no-handed use*

MS Assistant is designed to provide a right or left-handed access and use by having the main navigation buttons of equal importance at the lower left- and right-hand side (i.e., Next and Back buttons).

13. *Low physical effort*

The app is designed to minimize repetitive actions and sustained physical effort to provide ease of use, efficiency, comfort, and minimize fatigue [11] by using only single-tap [12] and by minimizing navigation steps.

14. *Variations in hand and grip size*

Large keys and appropriate inter-key spacing on a keypad are used to allow ease of use [12]. For the small targets (less than 16.5mm diagonally and 11.7mm square), a spacing between them is designed to be visible (e.g., 3mm) [12][36]. For the large targets, preferred is to provide the spacing between them although it can be zero. In addition, the tap targets are placed near the center or the bottom of the screen [36].

15. *Natural body position*

MS Assistant has the main navigation buttons at the bottom of the screen to provide comfort and minimize fatigue [37].

VI. EFFECTIVENESS OF THE IMPLEMENTING THE UDMIG V.2.2

For the purpose of evaluating the effectiveness of implementing UDMIG v.2.2 in the design of MS Assistant, we conducted an expert review to identify design elements that needed improvement to successfully apply the guidelines and recommend possible refinements.

A. Methods

Participants

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 individuals 18+ years of age who have more than three years of experience in one or more of the areas of expertise described above. 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 years.

Experts rated their familiarity with user interface design for people with MS, dexterity, cognitive, and visual limitations on a scale of "not familiar" to "somewhat familiar" to "very familiar." For familiarity with interface design for people MS, 3 respondents were not familiar and 10 were somewhat familiar. Regarding the design of interfaces for individuals with dexterity limitations, 1 expert was not familiar (n=1), 5 were somewhat familiar and 4 were very familiar. For interface design for people with cognitive limitations, 8 experts were somewhat familiar and 2 very familiar. Finally, 3 participants were somewhat familiar and 7 were very familiar (n=7) with interface design for people with vision limitations.

Procedures

After signing the informed consent form approved by the Georgia Tech Institutional Review Board (IRB), experts completed a demographic questionnaire about their areas of expertise and a number of years they have worked in the field. Experts then performed directed tasks using MS Assistant without any training or assistance. They received a simple script 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.2.2 checklist to rate how well each guideline was implemented, identified design elements needing improvement, and provided recommendations for their refinement.

UDMIG v.2.2 Checklist

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 [11]. 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.2.2 Checklist 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. It is intended to be used by end-users and to assist designers to think about the needs of potential users who would interact with their mobile touchscreen applications.

The complete checklist used for this expert review has 50 items (i.e., design criteria). An example of the checklist based on some of the design criteria (e.g., one design criteria per guideline) used for the expert review is presented in Table III.

TABLE III. UDMIG V.2.2 CHECKLIST

Design Elements Guidelines	Interface Context Guidelines
This application provides…	
1. The button size of at least 16.5mm diagonally and 11.7mm square.	1. The same means of use for all users, by eliminating specialized design and signage.
2. Feedback about a confirmation of my activity and a current state.	2. The same design elements for the navigation from page to page (e.g., Next, Back Home page buttons).
3. Alternate methods of input and use, such as speech input.	3. Standardized format and keeps the consistent location of target items within (e.g., navigation buttons, and error messages).
4. Text warnings as opposed to symbols and icons.	4. Visible and easily accessible frequent and important actions (e.g., a location of Next, Back, Homepage button).
5. Different modes of feedback, such as sound, vibration, or light feedback.	5. A clear indication on the middle of the top navigation bar where the user currently is at any point in time (e.g., diary, reports, games).
6. Easy reversal of my actions if I make a mistake, such as "Are you sure you want to send the reports to the selected contacts?", with reversion back to the contacts screen when I press "No."	6. The minimum contrast between the background colors against the images and text based on WCAG 2.0 1.4.3 Level AA, and preferably Level AAA.
	7. Reading level of text material at grade 10 or below.
	8. A choice of linear vs. random access.
	9. Personalization option to change my skill level from a "novice" to an "expert" user.
	10. A configuration of the output to my needs and preferences (e.g., text size, brightness).
	11. An aesthetically plausible color scheme that can be used by colorblind users.
	12. Main navigation buttons of equal importance accessible for both right- and left-handed users (e.g., Next and Back buttons at the lower left- and right-hand side).
	13. Use of a single tap throughout the app instead of double-clicking.
	14. The spacing between the small targets visible (e.g., 3mm).
	15. Main navigation buttons of equal importance at the bottom of the screen (i.e., Next and Back buttons).

Data Analysis

Mean and standard deviation for the rating of each guideline were calculated, as well as the mean and standard deviation of ratings for each participant. 16 ratings for the participant number 8 were excluded because they skipped the page with ratings of the guidelines IC5d to IC13d.

B. Results

10 participants rated 50 items on the checklist. The total number of responses is 484, with 16 missing responses that were not used in the analyses.

The mean of all the ratings for design criteria per participant is within a range of 3.90 – 4.89. The design criteria 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. This was the only mean value 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 484 responses, almost 70% (n=332) of the design criteria were rated as a 5. An additional one-quarter (n=126) were rated as a 4. The lowest rating for any criterion was 2 (n=6) and an additional 20 were rated as a 3.

Among the 10 participants, mean ratings ranged from 3.86 – 4.92. The participant with the lowest overall mean ratings (mean = 3.86) did not give a rating higher than 4 to any individual criterion with 44 rated as a 4 and 6 rated as 2 or 3.

In addition, participants identified specific usability issues with the design of some of the interface elements and structure, including navigation, labeling, scrolling while using a keyboard, color contrast, same means of use, page layout, and miscategorization. (Table IV).

Design of the elements of the user interface was the largest category with a total of 16 participants reporting usability problems in 3 subcategories. 8 participants stated that Profile and Settings should be redesigned to "stand out" and "look more prominent." 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 (Fig. 3). 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.2.2. Participants suggested that those two buttons should "look like buttons" with possibly adding a black border to them or a background color so that those look like the other buttons on the home page. In addition, 6 participants reported that top navigation bar icons that represent a title of the current page, including the weather icon, "look clickable" (Fig. 3b, Fig. 4, and Fig. 5). 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, etc.). 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. Thus, the current title of the page looked "like a button." Participants 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 redesign because of the problems with motor control in individuals with MS, and possible use of the stylus. 1 participant commented that the "numbers on the bottom should be on top of the slider."

TABLE IV. USABILITY PROBLEMS

Categories	Usability problems	Number of participants
Design of user interface elements	Profile, Settings not prominent	8
	Top navigation bar icons look like buttons	5
	Use of slider	3
Navigation	Having "to press on Next after a choice is made"	9
Labeling	Input, Output buttons	6
	Education button	5
	Speech button	4
	Emergency button	2
	Energized button	2
Lack of page scrolling while using a keyboard	Scrolling disabled	5
Color contrast	White on grey (instructions page)	2
	Green on grey (Do not show this again button in selected state)	1
Same means of use	Next, Back buttons	2
Page layout	Spacing between the top buttons and buttons below	2
	View Reports button is bellow Email Reports button	2
Miscategorization	Mood in Diary	1

9 participants reported problems with navigation due to having "to press on Next after a choice is made," which "was not clear at first." They either "expected to double click" or just click on the selection to open that particular page. However, all of them understood that this way of navigation is beneficial to an aging population that uses this app as a novice user.

Labeling was a category that included suggestions to rename "Input" and "Output" categories of Settings into a non-technical language (n=6). 4 of them thought that "Speech" should be renamed into "Audio" because it represents the settings for the sound coming from the device. Another suggestion was to rename "Education" into "Digest" or "Resources" because "News" category did not belong in there (n=5). It was not clear that a healthcare provider would be listed under Emergency functional feature (n=2), but there was no agreement on the alternative location for it. 1 participants suggested that it should be moved under Reports as an additional sub-feature named Contacts. The other participant stated they "didn't want to click 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 labeling to 2 participants because of Diary category "Energy level."

They suggested that "Anxious and Excited are missing" and that "Energized could be elsewhere."

Lack of page scrolling while using a keyboard was found problematic (n=5). Participants recommended to "add scrolling where additional input is needed." Scrolling was disabled throughout the interface because of the IC4c design criteria requirement.

Color contrast on the instructions pages with white on grey was not high enough to 2 participants, and "Do not show this again" button in a selected state with green text on grey background did not have high enough contrast to 1 participant.

Same means of use category has 2 participants who reported that "Next" and "Back" buttons look like a part of the specialized use and design.

Page layout category included a recommendation to move "View Reports" button above "Email Reports" button (n=2), and to increase the spacing between "Week", "Month", and "Year" buttons, and the other selection buttons on the Reports pages and between "Manual input" button and the rest of the screen on Vitals page (n=2).

Miscategorization was reported by 1 participants when they were not sure if Mood should be on Diary page.

VII. Conclusion

UDMIG v.2.2 and the related evaluation checklist were developed to ensure usability of future mobile applications by older adults, including individuals aging with disabilities. A universal design approach was used to accommodate all users to the greatest extent possible. Based on each UDMIG v.2.2 guideline and its design criteria, a representative statement with the 5-point Likert scale was created. The purpose of the checklist is to rate the agreement with each of the guidelines. It was developed for the end-users and usability experts to evaluate the usability and equitability of the mobile interfaces for an aging population.

The application of UDMIG v.2.2 to a mobile health and wellness app design was presented to illustrate and showcase the possible uses of the guidelines for a population of individuals aging with disabilities. eHealth mobile application for individuals aging with MS, MS Assistant was developed for this purpose. People with MS represent an ideal user group for application and evaluation of UDMIG v.2.2 and the checklist. They are a diverse user group with symptoms that vary widely from individual to individual and within an individual over time.

The study was conducted with the purpose to have expert evaluators rate the extent to which each guideline was implemented in the mobile app MS Assistant, to identify design elements that need improvement, and to suggest their possible improvements. Overall, this implementation of the guidelines to the design of the mobile app scored well. All mean values of the participants' ratings were equal to 4 or higher, except for the one equal to 3.86. The results of the study confirm that MS Assistant effectively implemented UDMIG v.2.2. There was a number of recommendations related to the minor usability problems found in the app.

The future work will require a refinement of the mobile app design based on those recommendations from the expert reviewers. Moreover, a usability testing of MS Assistant with individuals aging with MS will be conducted to assess the overall usability of the app to determine the effectiveness of UDMIG v.2.2 in producing a universally usable product. User outcome measures, such as a number of errors, completion time, and satisfaction ratings will be collected.

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