Creating a Smartphone Application for Image-Assisted Dietary Assessment among Older Adults with Type 2 Diabetes

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Abstract

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In the United States, the population of those aged 65 or over numbered 44.7 million in 2013 and is anticipated to reach approximately 74 million people by 2030. More than one in four people in the United States aged 65 years and older have diabetes. For diabetes care, medical nutrition therapy (MNT) is recommended as a clinically effective intervention. For personalized MNT, it is essential for dietitians to assess the nutritional status of patients with a variety of dietary data (i.e., meal patterns, food choices, and overall dietary balance). However, it is difficult to obtain accurate information because traditional dietary assessment methods (e.g., 24-hour dietary recall (24HR), food records) are based on self-reported data. In particular, those methods might be inappropriate for older adults because they have special considerations with diminished functional statuses (i.e., diminished vision and memory loss). To address this problem, previous researchers have developed and validated dietary assessment methods using images of food items for improving the accuracy of self-reporting over traditional methods. Nevertheless, little is known about the usability and feasibility of image-assisted dietary assessment methods for older adults with diabetes and their

satisfaction with the methods. To my knowledge, no studies evaluated the image-assisted dietary assessment methods with both health providers (i.e., dietitians) and patients (i.e., older adults with diabetes), though both are essential stakeholders in the dietary assessment process. Further, little is known about the usability and feasibility of smartphone applications for an image-assisted dietary assessment, though a smartphone is the device that can perform multiple tasks (i.e., capturing, viewing, and transmitting images) required for an image-assisted dietary assessment. Filling these gaps may reduce errors in self-reporting by older adults with diabetes and result in more accurate dietary assessments. The overall aim of this research is to assess whether a smartphone application can improve the accuracy of traditional dietary assessment methods among older adults with type 2 diabetes. To achieve the overall aim, I created a food record app for dietary assessments (FRADA), a smartphone application for capturing, viewing, and transmitting images of food and beverages, and I evaluated the usability and feasibility of FRADA and the satisfaction of older adults with diabetes with the application. Further, I evaluated the satisfaction of dietitians with an image-assisted, 24-hour dietary recall interview. The findings of this research support the evidence that image-assisted dietary assessments using FRADA could be potentially used to improve the accuracy of a traditional dietary assessment method by reducing errors in self-reporting. Also, this study reveals design opportunities to facilitate communications between older adults and dietitians for better dietary assessments. To my knowledge, this is the first attempt to evaluate a smartphone application with both older adults and dietitians through a lab-based and deployment study based on 24-hour dietary recall interviews.

The aims of this study are:

- **Aim 1**: To create a smartphone application for image-assisted dietary assessments and determine the usability of the application for older adults with diabetes.

- **Aim 2**: To determine the feasibility of the smartphone application in older adults with diabetes for image-assisted dietary assessments.
- **Aim 3**: To determine the satisfaction of older adults with diabetes with the smartphone application for image-assisted dietary assessments and determine the satisfaction of dietitians with image-assisted 24-hour dietary recall interviews.

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DEDICATION

To my parents and brother.

Chapter 1

EXECUTIVE SUMMARY

1.1 Statement of the Problem

In the United States, the older population aged 65 or over numbered 44.7 million in 2013 [39] and is anticipated to reach approximately 74 million people by 2030 [50]. More than one in four people in the United States aged 65 years and older have diabetes [9]. Diabetes is known as one of the most fatal diseases in the United States. In 2013, it was reported that diabetes was the seventh leading cause of death [3]. The American Diabetes Association reports that diabetes is "a complex, chronic illness that requires continuing medical care with multifactorial risk reduction strategies beyond glycemic control" [3]. Nutrition therapy is recommended for individuals with diabetes as part of the overall treatment plan [3]. In particular, medical nutrition therapy (MNT) is recommended as a clinically effective model to take care of people with diabetes [19, 36, 40, 42]. For personalized MNT, it is essential for dietitians to assess the nutritional status of patients with a variety of dietary data (i.e., meal patterns, food choices, and overall dietary balance) [42]. Dietitians have used various methods, such as food records, 24- hour dietary recall (24HR), and a food frequency questionnaire to assist with the needed assessment. However, it is difficult to obtain accurate information because all of these methods are based on self-reported data [23, 28]. In particular, conventional methods for dietary assessment might be inappropriate for older adults because they have special considerations with diminished functional statuses [35, 52]. One study showed that older adults did not report energy intake adequately during 24-hour dietary recall interviews [12].

Researchers have developed and validated dietary assessment methods using images of food items for improving the accuracy of self-reporting over traditional methods [13, 20, 24, 34, 37, 41]. Not only did the use of images of food items lead to identifying unreported foods and misreporting errors [20, 24, 41], but the dietary information from the images also enabled researchers to identify additional energy intake of the given food items [20, 24, 41]. Although 11.8 million older adults with diabetes [9] may have special considerations, such as loss of vision, diminished taste and smell, and poor hearing, little is known about the usability and feasibility of image-assisted dietary assessment methods for older adults with diabetes and their satisfaction with such methods. To my knowledge, no studies have evaluated the image-assisted dietary assessment methods with both providers (i.e., dietitians) and patients (i.e., older adults with diabetes), though both were essential direct stakeholders in the dietary assessment process. Further, little is known about the usability and feasibility of the image-assisted dietary assessment methods using smartphone apps, though smartphones could perform multiple tasks (i.e., capturing, viewing, and transmitting images) required for an image-assisted dietary assessment. Filling these gaps may reduce errors in self-reporting by older adults with diabetes for more accurate dietary assessments.

1.2 Purpose of the Study and Aims

The purpose of this study is to assess whether a smartphone application can improve the accuracy of traditional dietary assessment methods among older adults with type 2 diabetes. To achieve the goal, I created a food record app for dietary assessments (FRADA), a smartphone application for capturing, viewing, and transmitting images of food and beverages, and I evaluated the usability and feasibility of the application and the satisfaction of older adults with diabetes with the application. Further, I determined the satisfaction of dietitians with image-assisted 24-hour dietary recall interviews.

To achieve the goal of this study, I pursued three aims:

- **Aim 1**: To create a smartphone application for image-assisted dietary assessments and determine the usability of the application for older adults with diabetes
- **Aim 2**: To determine the feasibility of a smartphone application in older adults with diabetes for image-assisted dietary assessments
- **Aim 3**: To determine the satisfaction of older adults with diabetes with a smartphone application for image-assisted dietary assessments and determine the satisfaction of dietitians with image-assisted 24-hour dietary recall interviews

1.3 Research Questions

In this section, I present the research questions related to each aim. The questions for Aim 1 are as follows: What is the usability of FRADA with older adults with diabetes? Would FRADA be usable for older adults with diabetes performing the required tasks (i.e., capturing, viewing, and transmitting images) to collect images of food items? Would it be easy for older adults with diabetes to follow the instructions, such as including all the food items in one single photograph and holding the phone at a 45-degree angle when taking pictures of food items? Would older adults with diabetes want to use FRADA in the future? What are the potential benefits of using FRADA for older adults with diabetes? What are the concerns of older adults with diabetes when interacting with FRADA? What are the potential target populations of FRADA? The research work undertaken to address the first aim is illustrated in Chapter 3.

The following research questions are related to Aim 2: What is the feasibility of FRADA with older adults with diabetes? Would the images of food items reduce errors in self-reporting during a 24-hour dietary recall interview? How much would the 24-hour dietary recall using food images reduce errors in self-reporting? Chapter 4 presents the research

work undertaken to address the second aim and its questions.

For Aim 3, I explored the following questions to understand the population of older adults with diabetes during a 24-hour dietary recall interview using images of food items: Would FRADA be usable for older adults with diabetes to perform the required tasks (i.e., capturing, viewing, and transmitting images) for collecting images of food items in real-world settings? Would it be easy for older adults to follow the instructions (i.e., including all the food items in one single photograph, holding the phone at a 45-degree angle when taking pictures of food items, and capturing images of food items before and after every single eating event)? What are the challenges older adults with diabetes face when capturing images of food items in real-world settings? What are the privacy issues of older adults with diabetes when sharing images of food items with other people? What are the trust issues of older adults with diabetes when sharing the images of food items with other people? Next, I explored the following questions to understand the population of dietitians during a 24-hour dietary recall interview using images of food items: What are the benefits of using images of food items during the 24-hour dietary recall interview? What are the needs of dietitians when reviewing images of food items? What are the potential use cases of FRADA for dietitians? In Chapter 5, I describe the research work undertaken to address the third aim and its questions.

1.4 Significance of the Study

The findings of this study contribute to advancing knowledge about image-assisted dietary assessment in the field of Biomedical and Health Informatics and the field of Nutritional Sciences by creating a smartphone application for improving the accuracy of image-assisted dietary assessments and evaluating it with older adults with diabetes.

1.4.1 Significance to the Field of Biomedical and Health Informatics

The significance of this work lies in its potential to create a smartphone application for improving the accuracy of image-assisted dietary assessments for further research in the field of Biomedical and Health Informatics. First, my methods based on a user-centered design (UCD) approach [10] can be used to reflect the needs of users with special considerations (e.g., people with cognitive disabilities and people who are visually impaired). The findings through the methods will expand knowledge about how to design smartphone applications for image-assisted dietary assessments in older adults. While the majority of image-assisted dietary assessment methods are targeted for young adults or adolescents [11, 20, 21, 27, 32, 44], my study aims to address the needs and barriers of older adults with diabetes in designing an assessment tool. Thus, designers, developers, and researchers could use the findings of my study for creating smartphone applications targeting older adults with diabetes.

1.4.2 Significance to the Field of Nutritional Sciences

This study will fill important gaps in the field of Nutritional Sciences. Although my study is focused on collecting images of food items using a smartphone, the findings of my study suggest that both health providers and patients using smartphone applications can actually collect various types of data, such as text, voice, and biological signals that represent patients' blood pressure, and physical activity patterns. Ultimately, the findings from this dissertation could improve the accuracy of a traditional dietary assessment method by reducing errors in self-reporting. A smartphone-based image-assisted dietary assessment could be used as an enhanced dietary assessment methods that would reduce errors, which occur with self-reporting tools. For instance, images of food items support recall for older adults with diabetes with diminishing memories. In addition, UCD approaches [10] could enable validated dietary assessment methods to be used in practice. Little is still known about the

satisfaction of both health providers (i.e., dietitians) and patients (i.e., patients) with the dietary assessment methods, though dietary assessment methods have been validated.

1.5 Outline of the Dissertation

Chapter 2 provides background information and considers prior related studies: the characteristics of the population of older adults with type 2 diabetes, the process of medical nutrition therapy (MNT), and how MNT can be used to improve diabetes care. I summarize traditional dietary assessment methods and discuss pros and cons of the methods. After presenting examples of image-assisted dietary assessment methods, I describe the tasks required for advancing knowledge about image-assisted dietary assessment to address gaps in the prior studies.

Chapter 3 focuses on the development of FRADA for collecting images of food items and evaluation of usability of FRADA with older adults with diabetes in a lab-based setting. After describing the process of developing FRADA, I present the usability of FRADA with older adult participants through surveys and interviews and offer potential opportunities using FRADA.

Chapter 4 presents the deployment study that determines if FRADA may reduce errors in self-reporting when dietitians conduct 24-hour dietary recall interviews with older adults with diabetes. After describing the study procedure including the recruitment of participants of both older adults with diabetes and dietitians, I report the findings of the study with two perspectives: 1) how easy it was for older adults with diabetes to follow the instructions when older adults with diabetes capture images of food items, 2) how errors in self-reporting were reduced by using images of food items. Based on the findings of the study, I discuss its limitations and future work to be pursued.

Chapter 5 presents how I evaluated the satisfaction of two groups of stakeholders, older

adults with diabetes and dietitians when conducting 24-hour dietary recall interviews through a deployment study. I describe the study procedure using images of food items collected by older adults with diabetes when dietitians conduct 24-hour dietary recall interviews with them. Based on the results of the survey and interview study, I demonstrate that dietitians were satisfied with conducting 24-hour dietary recall interviews with older adults with diabetes using images of food items.

Chapter 6 summarizes the findings from each aim and demonstrates overall findings of this dissertation. After that, I demonstrate the contributions of my dissertation and discuss its limitations. Based on the findings from this dissertation, I present the directions of potential future studies for improving the accuracy of a traditional dietary assessment method through technologies that can be used by both older adults with diabetes and dietitians in real-world settings.

1.6 Key Findings and Conclusion

This dissertation offers three key findings. The first key finding is that that features and user interface of FRADA enable older adults with diabetes to accomplish tasks of capturing, viewing, and transmitting the images of food items successfully. Aim 1 study shows not only the usability of FRADA with older adults with diabetes, but it also demonstrates potential opportunities using FRADA for a deployment study. The second key finding is that using images of food items can improve the accuracy of a traditional dietary assessment method when dietitians conduct 24-hour dietary recall interviews with older adults with diabetes; nevertheless, little was still known about the feasibility of using a smartphone application when dietitians conduct 24-hour dietary assessment interviews with older adults with diabetes. The third key finding is that both older adults with diabetes and dietitians are satisfied with the process of using images of food items collected by FRADA, while no

previous studies evaluated the satisfaction of those stakeholders when using images of food items.

In brief, in this chapter, I presented the executive summary of this dissertation. After presenting the problem and purpose of the study and aims, I described research questions related to each aim. Moreover, I demonstrated the significance of this research to two fields of Biomedical and Health Informatics and Nutritional Sciences. After providing an outline of this dissertation, I identified three key findings. In the next chapter, I present the background information about this research and introduce relevant prior efforts using images of food items for improving the accuracy of a traditional dietary assessment method. After reporting the gaps in previous studies, I present three aims and research questions per aim to address the gaps.

Chapter 2

BACKGROUND AND REVIEW OF THE LITERATURE

2.1 Introduction

The overall aim of this research investigation is to improve the accuracy of traditional dietary assessment methods among older adults with type 2 diabetes by using images of food items collected by a smartphone application. As illustrated in the prior chapter, it is important to support growing older population with type 2 diabetes in the United States. In addition, I mentioned the significance of this study to the fields of Biomedical and Health Informatics and Nutritional Sciences. Building on the executive summary of this research in Chapter 1, the aim of this chapter is to provide background information about this research and consider prior related studies to this research. The characteristics of the population of older adults with type 2 diabetes are described in Section 2.2. In Section 2.3, I present the process of medical nutrition therapy (MNT) and describe how MNT can be used to improve diabetes care. Next, I summarize traditional dietary assessment methods and discuss pros and cons of the methods in Section 2.4. After presenting examples of image-assisted dietary assessment methods, I describe the tasks required for advancing knowledge about image-assisted dietary assessment to address gaps in the prior studies in Section 2.5.

2.2 Older Adults with Type 2 Diabetes

The reason I chose older adults with type 2 diabetes as my study population is the complexity prevalence and health burden of this disease. The American Diabetes Association (ADA) reports that diabetes mellitus is "a complex, chronic illness that requires continuous medical

care with multifactorial risk reduction strategies beyond glycemic control" [3]. About one in ten people in the United States has type 2 diabetes. More than one in four Americans aged 65 years and older has diabetes [9]. As the population aged 65 or over is anticipated to reach approximately 74 million people by 2030 [50], it is expected that the population of older adults with diabetes will increase accordingly.

Diabetes has a tremendous impact on the health of the U.S. population. Diabetes is known as one of the most fatal diseases in the United States. In 2013, it was reported that diabetes was the seventh leading cause of death [3]. Also, it is reported that diabetes increases the risk of heart attack and stroke [9], as well as increases the risk of cancer, especially colorectal cancer [15, 18, 25]. In particular, diabetes has influenced the health of older adults. Diabetes is known as the leading cause of blindness and kidney failure in older adults. Also, it is reported that older adults with diabetes are two times more likely to develop dementia than older adults without diabetes [29]. Furthermore, one in five people aged 65 years and older has vision problems [29], and one in three adults with diabetes may have chronic kidney disease. Moreover, it is known that people over 75 years old with diabetes are two times more likely to visit the emergency room for low blood sugar than younger population with diabetes [29].

Diabetes also takes a financial toll. The estimated total costs of diagnosed diabetes in the United States have risen to $245 billion in 2012 from $174 billion in 2007, which is a 41% increase for the last five years [2, 38]. The total costs in 2012 include $176 billion for direct medical costs and $69 billion for indirect costs, such as inability to work as a result of disease-related disability, reduced productivity while at work ($20.8 billion) for the employed population, and lost productive capacity due to early mortality [2, 38]. The estimated costs imply that diabetes produces explicit and inexplicit burdens to each individual and society as a whole.

2.3 Medical Nutrition Therapy

The reason I focused on a tool to support medical nutrition therapy is because such tool has great potential for helping diabetics. To improve diabetes care, the ADA suggests a strategy to support the following patients' behavior change efforts: "1) healthy lifestyle changes, 2) disease self-management (taking and managing medication and, when clinically appropriate, self-monitoring of glucose and blood pressure), and 3) prevention of diabetes complications (self-monitoring of foot health; active participation in screening for eye, foot, and renal complications; and immunizations)" [4]. The healthy lifestyle changes include "physical activity, healthy eating, tobacco cessation, weight management, and effective coping" (see Page S7 in [4]). For successful health, nutrition therapy is recommended for individuals with diabetes as part of their overall treatment plan [3] to achieve the goals of nutritional therapy as illustrated in Appendix C.1 [17]. In particular, medical nutrition therapy (MNT) is recommended as a clinically effective model to take care of people with diabetes [19, 36, 40, 42]. MNT is defined as "nutritional diagnostic, therapy, and counseling services for the purpose of disease management, which are furnished by a registered dietitian or nutrition professional." Since MNT is the application of the ADA's Nutrition Care Process (NCP) (see Figure 2.1), MNT consists of the following four steps of the NCP: 1) nutrition assessment, 2) nutrition diagnosis, 3) nutrition intervention, and 4) nutrition monitoring and evaluation. Researchers have shown that MNT is beneficial in older adults with diabetes [39]. In order to meet treatment goals, individuals with diabetes are required to receive personalized MNT from registered dietitians and nutrition professionals [3].

2.4 Traditional Dietary Assessment Methods

The challenges with traditional dietary assessments are what led me to assess whether a smartphone application could improve upon traditional methods for dietary assessments in

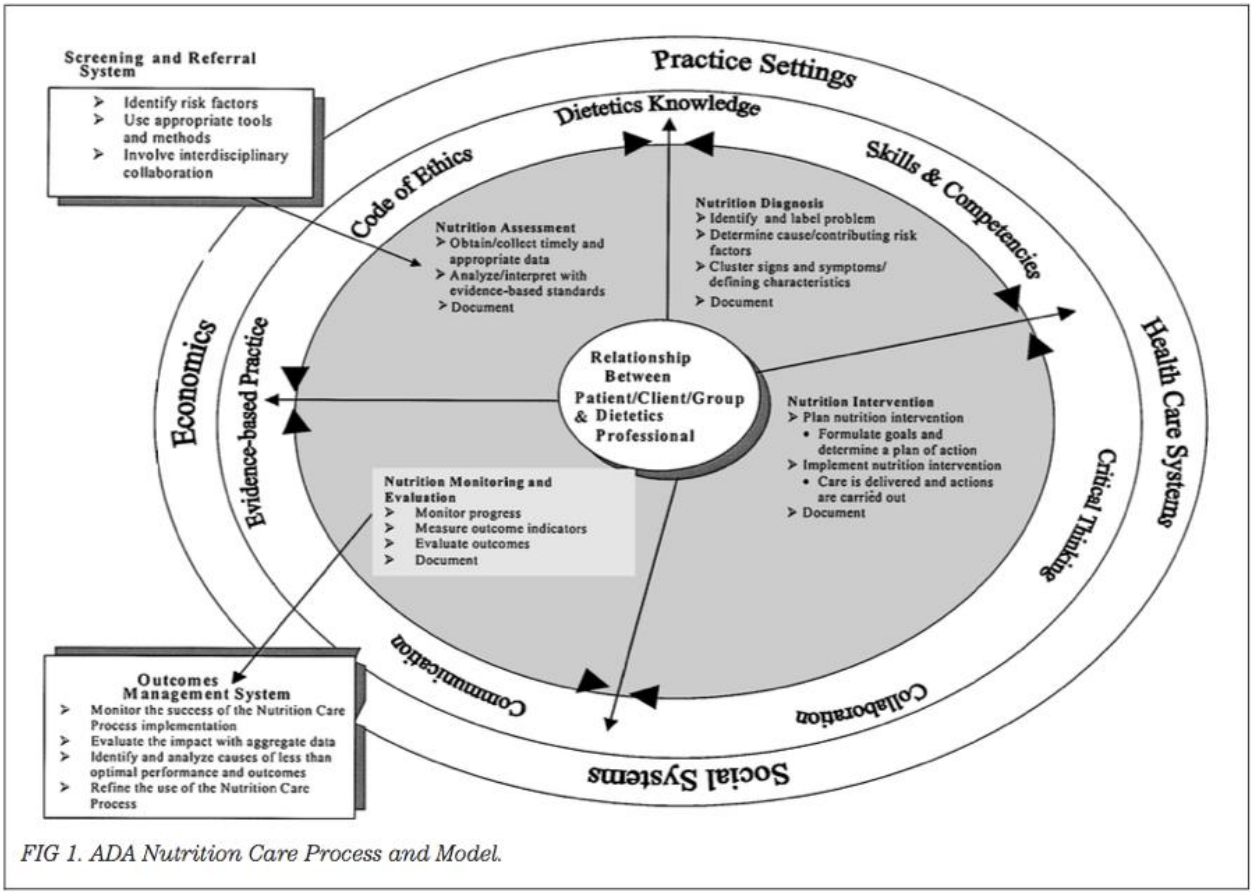

FIG 1. ADA Nutrition Care Process and Model.

Figure 2.1: ADA Nutrition Care Process and Model [31].

the context of MNT for older adults with type 2 diabetes. For dietary advice, it is essential for dietitians to assess the nutritional status of patients with a variety of dietary data, such as meal patterns, food choices, and overall dietary balance. To collect such dietary data from each patient, dietitians use methods such as food records and 24-hour dietary recall (24HR). The first method, food records, is an approach in which the patient is asked to write down all food items and amounts consumed over one or more days. The aim of this method is to obtain a detailed description of food intake, including types and amount of foods and beverages they have consumed. Since this method allows respondents to record their data right after they have consumed it, they do not have to rely on memory of their meals. The second method, the 24-hour dietary recall, is an approach to get retrospective information on food consumption patterns through interviews with the patient. While the food records method needs some level of literacy in recording, the 24-hour dietary recall method does not require knowing how to describe food items to dietitians because a dietitian speaks with a respondent directly during the interview.

However, it continues to be difficult to obtain accurate nutritional information because all of these methods are based on self-reported data. For instance, respondents would need to have strong motivation and literacy to keep recording their food intake using the food records method. They tend not to maintain regular performance on such tasks over long periods [23]. Instead, they might prefer recording the food items for three meals at the same time based on memory instead of documenting the information every single time. In addition, the 24-hour dietary recall method requires individuals to recall the food items they consumed and the amount of the food consumption [28]. Individuals might forget mentioning all the food items. Additionally, they might have trouble identifying the contents of the food items and estimating portion sizes.

It might be particularly difficult to collect reliable data from older adults using traditional

Method for Dietary Assessments	*Is literacy required?*	*Is memory required?*
Food records	Yes	No
24-hour dietary recall	No	Yes

Table 2.1: Comparison between two traditional dietary assessment methods: food records and 24-hour dietary recall.

methods for dietary assessment because they have special considerations with diminished functional statuses. For example, the 24-hour dietary recall method might be inappropriate because memory of older adults is more likely to be impaired than those of younger adults [35, 52]. In one study, older adults did not report an energy intake adequately during the 24-hour recall assessment [12]. Table 2.1 illustrates the comparison between food records method and 24-hour dietary recall method.

2.5 Prior Work

2.5.1 Examples of Image-Assisted Dietary Assessment Methods

To overcome the limitations of self-reporting by traditional methods for dietary assessment, previous researchers have developed and validated dietary assessment methods using images of food items for improving the accuracy of self-reporting over traditional methods. Prior studies demonstrated the benefits of using images of food items. For example, some studies showed that the use of images of food items led to identifying unreported foods and misreporting errors [24, 20, 41]. The dietary information from the images enabled researchers to identify additional energy intake of the given food items [24, 20, 41].

After searching for literature including a review paper [22], I identified six studies that evaluated image-assisted 24-hour dietary recall methods (see Table 2.2) using a variety of devices (see Figure 2.2). The majority of prior studies focused on evaluating the image-

Figure 2.2: (clockwise from top left) Devices used for collecting images of food and beverages: mobile telephone with a camera around his or her neck [11], digital camera [32], mobile device with a camera [27], Microsoft SenseCam [20, 21], Apple iPad2 [44].

Authors	*Participants (N)* *Age (mean)*	*Device for image collection*	*Capture*	*View*	*Transmit*
Arab et al. [11]	Healthy adults / N=14 (Age: 35±12)	Mobile phones with camera	✓	✓	✓
Lazarte et al. [32]	Healthy adult women / N=43 (Age: 35±9)	Digital camera	✓	✓	Not reported
Gemming et al. [20]	Healthy adults / N=10 (Age: 33±11)	SenseCam	✓	✓	✓
Ptomey et al. [44]	Adults with Intellectual and Developmental Disabilities / N=23 (Age: 26.4±9.7)	iPad 2	✓	✓	Not reported
Hongu et al. [26]	Healthy adults / N=54 (Age range: 19-28)	Smartphone	✓	✓	✓
Gemming et al. [21]	Adults / N=40 (20 males) (Age: 28±7, $females$ Age: 35±17, $males$)	SenseCam	✓	✓	✓

Table 2.2: Characteristics of image-assisted 24-hour dietary recall methods.

assisted dietary assessment methods with healthy adults. Four studies recruited healthy adults [11, 32, 20, 27] and the maximum mean age was 35 years old among the studies [11, 32, 20, 44, 21]. One study had adults with intellectual and developmental disabilities [44], but no studies recruited participants with any chronic diseases nor had participants aged 65 or older to evaluate the image-assisted dietary assessment methods. The sample sizes of prior studies were small. Four studies had between 20 and 54 participants [32, 44, 26, 21] and two studies had fewer than 20 participants [11, 20]. In regard to the approaches for capturing images, three studies used passive image capture with wearable cameras [11, 20, 21], while three studies used active image capture with a handheld digital camera [32], iPad [44], and smartphone [26].

Image-DietDay 24-Hour Dietary Recall Method (Arab et al. [11])

The aim of this study [11] was to evaluate the acceptability and feasibility of a web-based, self-administered, image-assisted 24-hour dietary recall method in 14 healthy adults. Each participant was asked to wear a mobile telephone around his or her neck for a week. The mobile phone captured images every 19 seconds during an eating event. The captured images were then transmitted wirelessly to a server and were filtered to remove blurry, poorly exposed, and unclear images. Further, Arab et al. created an application, ImageViewer, which allowed the participants to view and remove the images of the food and beverages. Next, each participant was asked to rate certain statements on the burden of wearing a mobile phone and the experience of using the overall system, including the ImageViewer. It was found that the image-assisted 24-hour dietary recall method overestimated energy intake by 7 percent, compared with the estimate of energy intake by the doubly labelled water technique [49]. There are some limitations to this study. First, wearing the mobile phone might have altered the usual eating behaviors of the participants. Further, since 71 percent of the

participants indicated that wearing the mobile phone was a burden, there might have been other unexpected potential biases that affected the findings of this study. For instance, the battery life of the phones was not enough to last an entire day. Additionally, the participants indicated that they were concerned about wearing the phone in public.

Since healthy adults reported that images were beneficial in identifying food items in this study, I hypothesize that images would be also beneficial for older adults with diabetes in recalling food items during a 24-hour dietary recall interview. Also, as participants stated that wearing a mobile device in public led to changing their eating behaviors, in my study, participants will not be asked to wear any devices in order to capture images.

Food Photography-Assisted 24-Hour Dietary Recall Method (Lazarte et al. [32])

This study [32] aimed to examine the use of the handheld digital cameras for assisting the 24-hour dietary recall method. The validity of this method was evaluated among a sample of 43 healthy Bolivian women for a single 24-hour period. For validating the method, Lazarte et al. compared the estimate of nutrient intake from the image-assisted 24-hour dietary recall method with the estimate of nutrient intake from the Weighted Food Record (WFR) method. To obtain the estimate of nutrient intake from the image-assisted 24-hour dietary recall method, Lazarte et al. asked each participant to capture images of food and beverages using a digital camera. Each participant was required to take two images per eating event: one at a 90-degree angle and the other at a 45-degree angle. After completion of the testing period, an interviewer conducted 24-hour dietary recall interviews with the participants. To calculate the estimate of nutrient intake from the WFR method, Lazarte et al. visited each participant's home and weighed all the food items during the testing period. Lazarte et al. demonstrated that the image-assisted dietary assessment method revealed acceptable validity compared with the estimate of energy intake from WFR.

Since this study was conducted in a free living condition to avoid the disruption of the eating behavior, I also aim to focus on a free living condition. However, in practice, participants in a study such as Lazarte et al. [32]) would need to take out the images from their digital camera and transmit them to somewhere manually. Instead, in my study, participants will be asked to use their smartphones to capture and transmit images of food and beverages.

SenseCam-Assisted 24-Hour Dietary Recall Method (Gemming et al. [20])

The aim of this study [20] was to determine if using a wearable camera can enhance 24-hour dietary recall in 10 healthy adults aged between 22 and 44 years. Each participant was asked to wear a wearable camera, the SenseCam, for two full days in a home setting. After the testing period, a dietitian conducted 24-hour dietary recall interviews with the participants and recorded their dietary details. Both the dietitian and the participants then viewed the images of food and beverages recorded by the SenseCam. The images revealed 17 additional food items; thus, Gemming et al. demonstrated that the images of food items increased the estimate of mean energy intake by 12.5%. Additionally, each participant was asked to fill out a questionnaire in order to get feedback on the use of the images of food items. The participants reported that the images helped them to recall unreported food items that could be used to provide more accurate information. Some participants mentioned that they felt uncomfortable using the wearable camera in public situations, such as riding a bus or purchasing food items. In addition to these negative responses from the participants, Gemming et al. found the following limitations: (1) the imaging frequency of the SenseCam was not strong enough to capture images of all food items, and (2) the image quality by the SenseCam was poor for conducting further analysis of the images.

In brief, this study demonstrated that viewing images of food items enabled healthy

adults to identify unreported or misreported food items. Based on the findings of this study, I hypothesize that older adults with diabetes may also be able to identify unreported or misreported food items by viewing images of food items. Further, as this study used a 7-point Likert scale survey asking for feedback about use of images, I used the same survey questions for evaluating the satisfaction of an image-assisted dietary assessment in this dissertation. However, this study showed that some questions in the survey were asking whether the camera was a burden to wear because this study focused on evaluating a wearable camera. Since a smartphone will be used in my study as an image-collection device, those questions related to the use of a wearable camera will not be included in my study.

Tablet-Assisted 24-Hour Dietary Recall Method (Ptomey et al. [44])

The objective of this study [44] was to determine if the 24-hour dietary recall method, which combines images of food and beverages, increases estimates of energy and macronutrient intakes. This method was evaluated among a group of 23 adults with mild-to-moderate intellectual and developmental disabilities. Each participant was asked to use an iPad 2 tablet to collect images of food and beverages for 24 hours. The next day, a dietitian recorded the food items on the form each participant consumed after conducting a 24-hour dietary recall interview with the participant. After the 24-hour dietary recall interview, both the dietitian and the participant reviewed the collected images of food and beverages and produced another form to correct any misreported or incorrect food items on the first form. The dietitian then entered the food items on the two forms, the one produced before reviewing images and the other recorded after reviewing images, separately into the Nutrition Data System for Research system and noted the estimates of energy and macronutrient intakes of the recorded food items from the system. Ptomey et al. found that the 24-hour dietary recall interview with images of food and beverages in adults with intellectual and developmental

disabilities improved the estimates of energy and macronutrient intakes.

This study demonstrated that all the participants completed the task of capturing images of food items successfully without assistance, though participants were adults with intellectual and developmental disabilities including limited cognitive abilities. This suggests that older adults with diabetes with diminished cognitive functions may also be able to capture images of food items without any support from their family members or caregivers. Nevertheless, this study did not evaluate the likelihood of the dietitians using the images to conduct a dietary assessment in the future, even though they were also direct stakeholders during the 24-hour dietary recall interview. In my study, I will conduct an interview with both older adults with diabetes and dietitians to evaluate the satisfaction of using the image-assisted dietary assessment tool.

Smartphone-Assisted 24-Hour Dietary Recall Method (Hongu et al. [26])

The aim of this study [26] was to evaluate the usability of a smartphone food picture app for assisting the 24-hour dietary recall method in 45 adults aged 19 to 28 years. The participants were asked to capture images of each of their meals and snacks before and after eating and send the images to the server for three weeks (six days per week). After that, a nutritionist conducted a face-to-face interview using the 24- hour dietary recall method. After the completion of the 24-hour dietary recall interview, both the nutritionist and the participant reviewed the transmitted images of food items on a website installed on the server. The participants were then asked to complete a questionnaire rating ease of use of the app, estimating the average length of time spent recording food intake each day using the app, and asking about the likelihood of the participant using the app to record food intake in the future. Although all the participants, except for two, reported that the app was easy to use, only half the participants responded that they would use the app daily to

record food intake in the future. This response was due to some potential challenges, such as forgetfulness or laziness with regard to taking images of food items. The participants also stated that they would like to see additional information in the app, such as calories and nutrients of consumed food intake.

First, this study showed that a smartphone application can be used as a device for collecting images of food items, as well as accomplishing the following: digital imaging, time stamps, location information, and note-taking to create a food record that includes images. Because of such benefits of using a smartphone app, I will also focus on creating a smartphone application for improving the accuracy of image-assisted dietary assessments. This study also reported that some participants (healthy college students) would not use the app in the future because they did not have any specific reason why they need to use this, though the app itself was easy enough to use. However, my study will focus on the population of older adults with diabetes who actually need to maintain healthy eating for managing their personal health. Additionally, this study found that participants were not able to record any images if they forgot to capture the images. I will incorporate those findings from this study into creating a app (e.g., features that remind users to capture images.)

Wearable Camera-Assisted 24-Hour Dietary Recall Method (Gemming et al. [21])

This study [21] aimed to determine whether wearable, camera-assisted 24-hour dietary recall method helped to identify unreported food items among 40 adults (20 males whose average age was 35 and 20 females whose average age was 28). To evaluate the validity of the image-assisted dietary method, Gemming et al. first calculated the magnitudes of under-reporting using a traditional 24-hour dietary recall method and an image-assisted dietary assessment method. The magnitude was the difference between the estimates of energy intake

and the estimates of total energy expenditure (TEE) over the estimates of TEE. Next, the difference by the traditional method alone was compared to the difference from the image-assisted method. Gemming et al. found that the image-assisted method reduced a greater magnitude of under-reporting than the traditional dietary assessment method. This was because viewing images enabled participants to recall unreported food items and identify errors caused by misreporting that were not captured by the traditional method alone.

Since viewing the images enabled adults to identify unreported and misreported food items, I hypothesize that older adults with diabetes may also be able to discover unreported or misreported food items. This study evaluated the feasibility of the image-assisted dietary method but not the satisfaction of participants. In my study, I evaluate both the feasibility and satisfaction in using the dietary assessment with two types of direct stakeholders: older adults with diabetes and dietitians. Also, this study showed that, in practice, people would need to purchase a wearable camera to follow the Gemming method; however, in my study, I focus on using the camera available in a smartphone that does not have to be purchased separately.

2.5.2 Tasks Required for Image-Assisted Dietary Assessment Methods

After reviewing prior studies [11, 20, 21, 26, 32, 44], I identified three fundamental features required for an image-assisted dietary assessment: 1) capturing images of food and beverages, 2) viewing images of food and beverages, and 3) transmitting images of food and beverages. Table 2.2 shows the characteristics of image-assisted 24-hour dietary recall methods.

2.5.3 Gaps

Prior studies showed how image-assisted dietary assessment methods reduced errors in self-reported data. In addition, prior studies validated the use of an image-assisted dietary as-

sessment methods with general populations. Nevertheless, I found three gaps after reviewing those studies.

1. No study evaluated the feasibility and usability of an image-assisted dietary assessment with older adults with diabetes.

2. None of the studies evaluated the feasibility of image-assisted dietary assessment methods with dietitians, even though dietitians were essential stakeholders in the dietary assessment process.

3. Little is known about the feasibility and usability of the image-assisted dietary assessment methods using smartphone applications, although a smartphone is the device that can perform all the three tasks required for image-assisted dietary assessments.

To addresses those gaps in the current literature around the use of tools to support MNT, my overarching aim is to assess whether a smartphone application can improve the accuracy of traditional dietary assessment methods among older adults with type 2 diabetes. I will address in three inter-related aims that specifically drill down into each of the gaps.

2.6 Conclusion

The overall aim is to assess whether a smartphone application can improve the accuracy of traditional dietary assessment methods among older adults with type 2 diabetes. Researchers developed and validated dietary assessment methods using images of food items for improving the accuracy of self-reporting of traditional methods. In this chapter, I presented background information about this research and introduced prior studies that proposed methods for improving the accuracy of image-assisted dietary assessments. After reviewing prior studies, I identified tasks required for image-assisted dietary assessments and gaps of the prior studies.

In the next chapter, I introduce FRADA that enables older adults with diabetes to collect the images of their meals and snacks. The chapter then demonstrates the usability of the application in older adults with diabetes in a lab-based setting. The findings of this study will show that it is usable for older adults with diabetes to interact with FRADA for accomplishing tasks of taking, reviewing, and transmitting images of food items for an image-assisted dietary assessment.

Chapter 3

USABILITY STUDY OF A FOOD RECORD APP FOR DIETARY ASSESSMENTS (FRADA)

3.1 Introduction and Overview

The literature review from Chapter 2 identified studies that evaluated image-assisted 24-hour dietary recall methods. As per Chapter 1, the overarching Aim is to assess whether a food record app for dietary assessment (FRADA) can improve the accuracy of traditional dietary assessment methods among older adults with type 2 diabetes. The goal of Aim 1 is to determine the usability of a smartphone application for improving the accuracy of image-assisted dietary assessments with older adults with diabetes. The subaims of Aim 1 are:

- **Aim 1.1**: To create a smartphone application that enables older adults with diabetes to collect images of food items
- **Aim 1.2**: To evaluate the usability of the smartphone application with older adults with diabetes

After reviewing the studies, I found a gap that no study created a smartphone application that addresses the needs of older adults. I also identified that no study evaluated the usability of image-assisted dietary assessment methods with older adults with diabetes, while prior studies evaluated it with general populations. Specifically, Aim 1 will address the gaps identified in the literature.

I explored the following research questions for Aim 1: What is the usability of FRADA

with older adults with diabetes? Would FRADA be usable for older adults with diabetes performing the required tasks (i.e., capturing, viewing, and transmitting images) to collect images of food items? Would it be easy for older adults with diabetes to follow the instructions, such as including all the food items in one single photograph and holding the phone at a 45-degree angle when taking pictures of food items? Would older adults with diabetes want to use FRADA in the future? What are the potential benefits of using FRADA for older adults with diabetes? What are the concerns of older adults with diabetes when interacting with FRADA? What are the potential target populations of FRADA?

To achieve Aim 1.1, I created FRADA, a smartphone application that enables older adults with diabetes to collect images of food items and evaluated the usability of the application with them. To develop FRADA, I used an Apache Cordova framework [5] through multiple web frameworks, such as HTML and JavaScript. I used this framework because it offers a set of APIs for implementing functions, such as capturing, viewing, and transmitting images collected by a smartphone. Furthermore, the codes generated in Cordova can be embedded to multiple platforms, such as Android and iOS. When designing interfaces of the application, I applied the design requirements developed to evaluate the usability of smartphone apps for promoting health and well-being of older adults [48] in order to address older adults' special needs (e.g., larger font sizes, increased contrast, and large buttons). To achieve Aim 1.2, I evaluated the usability of the application by using surveys and interviews with older adults with diabetes.

3.2 Development of FRADA

Aim 1.1 is to create FRADA that enables older adults with diabetes to collect images of their meals and snacks. Since collected images will be reviewed by dietitians, I developed two applications: one for older adults with diabetes to collect images of food items and the

other for dietitians to view collected images.

3.2.1 Development of Client and Server Applications for Older Adults with Diabetes

The application for older adults with diabetes consists of two sub-applications, client and server applications. The role of the client application is for older adults with diabetes to transmit collected images of food items to a server from their smartphones. Therefore, this application is embedded in their smartphones. On the other hand, I implemented another sub-application on the server, which receive transmitted images of food items, store them, and manage any request from the client side in the server. I used HTML and JavaScript languages to develop the client application using Apache Cordova [5], while using a PHP language [6] to implement the application on the server. In particular, I used the UW shared Web Hosting server [7] and its storage to store the transmitted images of food and beverages by smartphones. To reflect the special needs (e.g. large font sizes, big buttons, etc.) of older adults, I used design principles [48] to design the user interface on the smartphone application. I built the application using Apache Cordova [5], an open-source framework on the Mac OS X 10.11 machine. To facilitate communication between smartphones and the server, I used open source libraries provided by Apache Cordova [5]. Figure 3.1 illustrates the screen shots of the user interface in smartphones when study participants capture, review, and transmit images of food items.

3.2.2 Development of a Viewer Application for Dietitians

The purpose of this application is to enable dietitians to view images of food items transmitted by smartphones of older adults with diabetes during 24-hour dietary recall interviews. I used HTML and JavaScript languages in order to develop a web-based application. The application was designed to perform two tasks: 1) gathering the images having stored at the

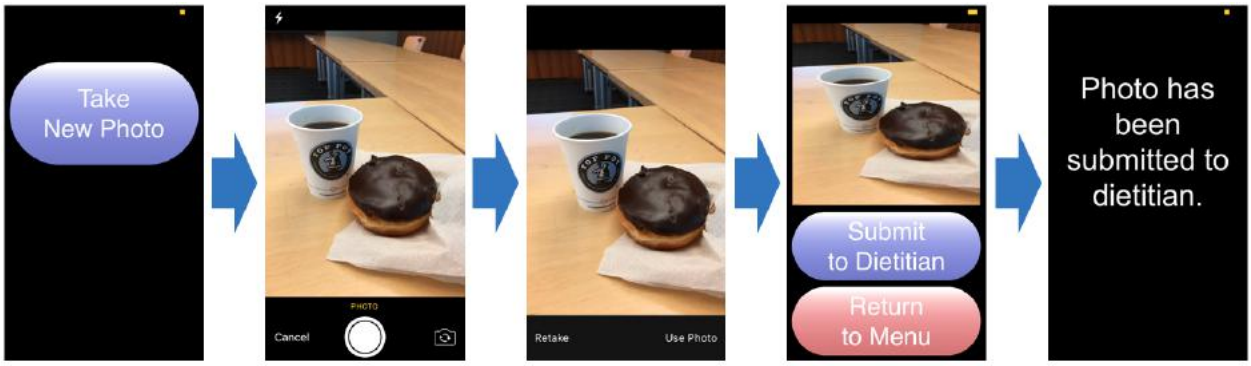

Figure 3.1: Screen shots of the user interface in the smartphone application.

UW shared Web Hosting server [7], 2) displaying the images to both dietitians and older adults with diabetes through devices (e.g., laptops, tablets, or smartphones) during 24-hour dietary recall interviews. As Figure 3.2 illustrates, the application displays a series of images transmitted by each older adult participant with diabetes. The date and time information were added to the top of each image as metadata for the images. In particular, the application allowed users to navigate the images taken more recently by scrolling down the page, as the images were organized in chronological order.

3.3 Methods

Aim 1.2 is to evaluate the usability of FRADA developed in Aim 1.1 with older adults with diabetes. In order to accomplish Aim 1.2, I recruited study participants (i.e., older adults with diabetes) and used surveys and interviews as methods to collect responses from the study participants.

Figure 3.2: Screen shots of the user interface of the viewer application for reviewing images of food items during 24-hour dietary recall interviews.

Figure 3.3: Food items used for usability study.

3.3.1 Participants and Inclusion and Exclusion Criteria

As inclusion criteria, participants were required to 1) be between 65 and 84 years old, 2) be diagnosed with type 2 diabetes or prediabetes for at least six months, 3) understand spoken English, 4) have their own smartphones with cameras, 5) live in independent living facilities, such retirement communities, retirement homes, senior centers, and senior housing, and 6) have experience with smartphone usage for at least six months. However, I excluded any participants who are legally blind or have severe auditory impairments to avoid any potential sample biases that might influence the study. All procedures were approved by the University of Washington Institutional Review Board.

As of 2015, only 27 percent of Americans 65 and older own a smartphone [1]. However, since 54 percent of Americans aged between 50 and 64 are smartphone owners, I anticipate that the population of older adults in the age group of 65 to 84 will increase. Further, among

assisted-living residents aged 65 and older, only 16 percent of the residents were in the age group of 65 to 84, which is less than 54 percent of the residents in age group of 85 years or older [8]. This supports that people who aged between 65 and 84 might need less help from their family members or caregivers than people in other age groups. Since I created an application designed for people who live in independent living facilities, I focused on the age group of 65 to 84.

3.3.2 Recruitment

To request recruitment of participants, I contacted senior centers, senior housing, and community centers located in the Greater Seattle Area, WA. I determined sites for recruitment as soon as a manager at the sites confirms my request. Under the permission from a manager, I posted recruitment flyers and arranged info-sessions at the confirmed sites.

I recruited twelve participants [51] from the three senior centers (i.e., Northshore Senior Center, Lynnwood Senior Center, and Edmonds Senior Center), two senior housing (i.e., Providence Vincent House and Northaven Retirement Apartments), and one community center (e.g., Center for Healthy Living), while two participants were recruited by my personal network through a mailing list of the Greater Seattle Dietetic Association and in person.

3.3.3 Study Procedure

To address Aim 1.2, I wanted to evaluate the usability of FRADA with older adults with diabetes via a lab-based usability session. In order to do this, I designed a test scenario consisting of pre-test survey, post-task survey, and post-test interview (see Table 3.1). Before each test, I prepared a smartphone (i.e., iPhone 6), a plate of food and beverages (see Figure 3.3), and instructions (see Appendix A.2) for the smartphone application. After that, I asked each study participant to fill out the pre-test questionnaire (i.e., demographics

Participants	*Before the test*	*During the test*	*At the end of the test*
Older adults with diabetes	Consent Pre-test survey Instructions (Appendix A.2)	Perform three tasks: capturing, viewing, and transmitting (Appendix A.3) Survey (ASQ) (Appendix A.4)	Interview (Appendix A.5)

Table 3.1: Study procedure for Aim 1.

questions) (see Appendix A.1) to get information about him or her, including age, gender, education level, and years of experience using a smartphone. I then proceeded with the lab-based usability session (see Table 3.1).

I provided each participant with instructions (see Appendix A.2) that include a list of rules that he or she should keep in mind when interacting with the application. The rules are as follows: 1) you should include all the food items in one single photograph; 2) to get the best images, you should hold the phone at a 45-degree angle when taking pictures of food and beverages.

During the test in the lab, I asked each participant to interact with the application in order to accomplish the tasks (i.e., capturing, viewing, and transmitting images of food items) (see Appendix A.3). Once the participant completed the tasks, I asked him or her to fill out the post-task questionnaire using the After-Scenario Questionnaire (ASQ) (see Appendix A.4), known as a valid and reliable scale for usability tests, to rate the satisfaction of the ease of completing each task and the amount of time it took to complete each task by using the smartphone application. The three statements of the ASQ, which uses a 7-point rating scale, are described in Appendix A.4. After the participant completed the post-task questionnaire, I conducted a post-test semi-structured interview with each participant.

The topics of the interview questions contained the participant's experience when he or she uses the application to perform each task. All interviews were conducted in person. Each interview lasted 20-30 minutes. All interviews were audio-recorded and transcribed.

3.4 Analysis

To analyze the responses from the ASQ, I summarized the numbers and percentages of ratings and responses. Regarding the qualitative data from the interviews, I collected statements from transcripts that described participants' experiences. I then applied an open coding method [43] to the statements as a single coder. After reviewing the statements repeatedly, I highlighted quotes on first pass. I bold faced recurring concepts on second pass and labeled the recurring concepts on third pass. The labeled concepts were then grouped into themes.

3.5 Findings

3.5.1 Participant Demographics

Participant demographics are illustrated in Table 3.2. 14 participants (11 female) took part in the study . The average age of participants was 73.6 years old (SD 5.0, range 65-80). Participants had a variety of highest degrees: Bachelor's degree (5 participants), Master's (3), High school graduate (3), Professional degree (2), and others (1). Participants used various mobile devices: Android (10 participants), iOS (3), and Amazon Fire (1).

3.5.2 Survey Results from Older Adults with Diabetes

Survey results revealed that participants were satisfied with the ease of completing the task of photographing, reviewing, and sending the images of food and beverages. In addition, they were satisfied with the amount of time it took to complete the task of photographing, reviewing, and sending the images of food and beverages. The average scores for completing

ID	*Gender*	*Age*	*Race/Ethnicity*	*Education*	*Number of Years Using a Smartphone*
P1	Female	76	White/Caucasian	Professional	2-3 years
P2	Female	80	White/Caucasian	Master's	>3 years
P3	Male	79	White/Caucasian	Bachelor's	<1 year
P4	Female	72	Asian/Pacific Islander	High School	>3 years
P5	Female	67	White/Caucasian	Bachelor's	Not reported
P6	Female	65	White/Caucasian	High School	>3 years
P7	Male	74	White/Caucasian	Professional	1-2 years
P8	Female	70	Asian/Pacific Islander	Bachelor's	2-3 years
P9	Female	76	White/Caucasian	Master's	>3 years
P10	Female	67	White/Caucasian	Bachelor's	>3 years
P11	Female	78	White/Caucasian	Bachelor's	<1 year
P12	Female	70	White/Caucasian	Others	>3 years
P13	Male	79	White/Caucasian	High School	1-2 years
P14	Female	77	White/Caucasian	Master's	1-2 years

Table 3.2: Participant demographics (P5 did not report the number of years using a smartphone).

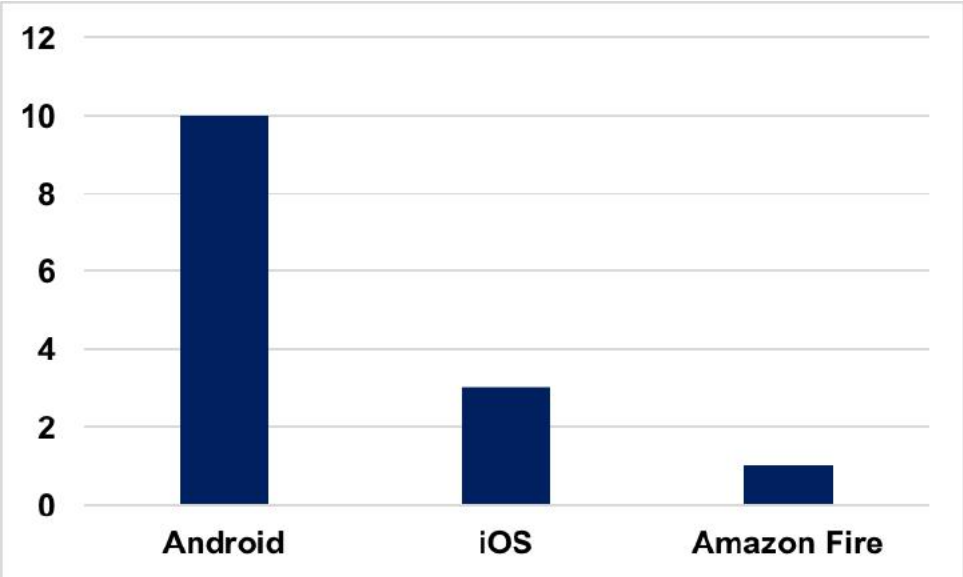

Figure 3.4: The number of participants across devices.

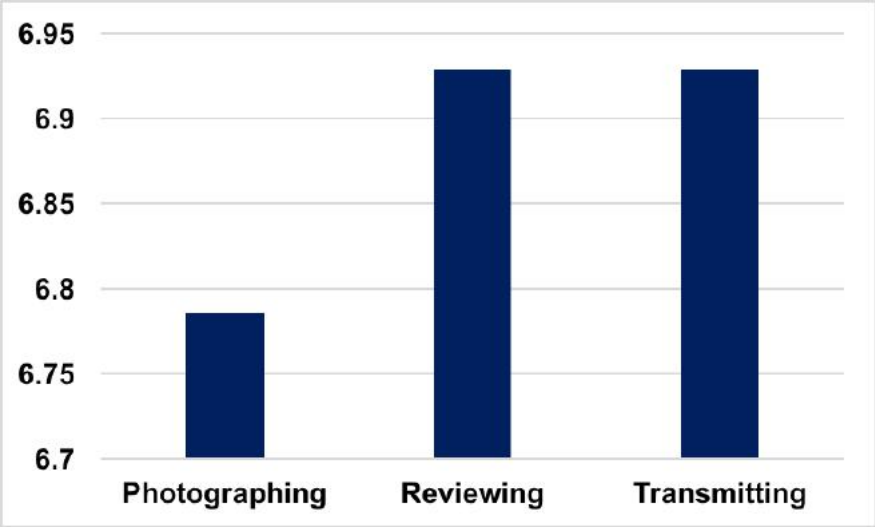

Figure 3.5: Scores for completing tasks of photographing, reviewing and sending food images.

the task of photographing, reviewing, and sending the images of food items were: 6.8 (SD 0.6), 6.9 (SD 0.3), and 6.9 (SD 0.3) out of 7 points, respectively (see Figure 3.5. In particular, 12 out of 14 participants reported 7 points for all the questions.

3.5.3 Interview Results from Older Adults with Diabetes

Usability of the Application

All the participants expressed that they were satisfied with efficiency when performing tasks for taking, reviewing, and transmitting images of food and beverages. First, participants stated that the application was quick and efficient to use. P9 stated, *"... there's only three moves basically, you know. Take a new picture, take the picture, and send the picture. It's very efficient. I can't think of any suggestions to make it better."* P4 was aware of the simplicity of the process when taking and sending a picture of food items: *"Well, probably just take a picture and sending it to a dietitian in one step."*

In addition, participants reported that the application was easy and simple to use to perform the tasks. P6 stated, *"A+, It's very simple and very easy to use."* P14 stated, *"So, I think it's very, very useful. I think it's very worthwhile and excellent thing that you've come up with. And, as with all things that are excellent, it's simple."* Moreover, P12 expressed the usability of the application by comparing with any other applications he had used: *"Oh, yeah, well, like I said, it's so much easier than anything that I've tried. I'm looking forward to seeing how you develop this app."* In particular, P1 and P11 reported that they did not have any difficulty in interacting with the app. P1 stated, "No, I didn't have any difficulty." P11 said, *"It's very easy to use. It's very intuitive. I had no problem with it at all."*

In addition to the efficiency of using the application, participants mentioned that they were satisfied with user interface on the application. For instance, the majority of the participants liked large font size of the letters on the application. P2 said, *"But, I did notice that your app has large letters, so it's easy to read. You don't have that little, teeny letter you have to look at."* P10 mentioned that the large print will help potential users of the application: *"It was very easy to use. And the large print, I think is very helpful to people who have a hard time seeing. It was, it was easy. I, I – it was easy to do."* Similarly, P11 enjoyed using big buttons on the user interface: *"... the app buttons, the big buttons, they were very large, which for me, another guy can see that for an elderly person because in texting with a phone I don't have small enough fingers or touchy enough fingers to do it well, but these buttons would make the app very easy to use for me..."*

To sum up, it was efficient for study participants to perform tasks, such as capturing, viewing, and transmitting images of food items by using FRADA. They also stated that it was easy to interact with user interface of FRADA.

Easy Instructions

Instructions of taking images of food items were: 1) including all the food items in one single photograph, 2) holding the smartphone at a 45-degree angle when taking the images of food items. Participants felt that it was easy to follow the instructions when performing tasks for taking, reviewing, and transmitting the images of food items using the application. P14 stated, *"Probably A [grade] because it's so clear. The instructions are clear. And the instructions on being able to accomplish the task is very clear. I feel like I could accomplish it with one request to do so."* P9 mentioned, *"Oh, I think it's great. It's very easy to learn and the instructions are good."* In brief, study participants felt that instructions of capturing images of food items by using FRADA were simple and easy to follow.

Tablet as an Alternative Device

Although most participants were satisfied with the user interface of a smartphone, three participants expressed their interest in using a tablet for performing the tasks of an image-assisted dietary assessment method. P10 said, *"I mean it's bigger, you know, but it's still easy. It's still easy to use. It's as easy to use as my phone is."* P2 stated, *"But, the tablet's bigger, but it still works. It would probably work the same."* P14 expressed her interest in using the application on both her smartphone and tablet: *"Well, the only change that I would like to make is I have both an Android phone and an Android tablet. And my tablet, I would hope that this app can be available on the tablet as well."*

Willingness to Use FRADA

Older adults with diabetes had various opinions about potential use of FRADA in the future. In particular, this study showed that it is important for older adults with diabetes to be aware of benefits of using FRADA to ask them to use FRADA continuously. Participants

mentioned that they would be willing to return to this application on their own in the future. P14 stated willingness to use the application by describing how she would use the application potentially: *"Sure, yes. I think it's a great idea. And I think that I would have a folder for it for the photographs that are specifically a meal that I actually ate. And I would also do a before the meal, before I ate it, and then, after the meal in case I left items that I didn't ever eat. Like I'm taking it with the packaging on it. Now, I take it eaten, but I never ate the apple. So, I show what would be left that actually was not consumed."* Similarly, P5 expressed interests, *"Sure, especially, you know, if I had a nutritionist or doctor who wanted me to send them pictures, I'd be happy to."* P10 mentioned potential opportunities of using the application when going out for dinner: *"I am interested in using the app when going out for dinner."*

Some participants expressed that they would like to use the application if asked by health providers. P1 said, *"If it was available, and the dietitian was available, it would be a great learning device and diagnostic device, for what you were eating, to how you could improve your diet habits."* P4 stated, *"I would use the app if dietitian asks me."* P3 stated that he would wish to use the application if there are any known benefits of using the application: *"I – well, I would return it, if it was part of a health, ongoing health procedure that I wanted to be involved with to, you know, to see that I was eating the right things, that's all, because I presume when this goes in you get feedback on it, saying this ice cream cone here may not be a good idea. I don't know."*

Nevertheless, P2 stated that they do not want to use the application in the future because she was still satisfied with the process of writing down food items using a food diary: *"I think it's easy to use. I personally probably wouldn't use it because I don't mind writing things down."* Even though P2 does not want to use it in the future, she was satisfied with the usability of the application: *"It's a very easy, it's a really easy app to use because once you*

understand it and, as I said, it probably would work for some people. Not necessarily for me, that's all."

To conclude, older adults with diabetes expressed a variety of opinions about possibility of using FRADA in the future. The responses from them indicate that it might be significant to inform benefits of using FRADA to older adults with diabetes for potential use of FRADA.

Potential Benefits of Using FRADA

Participants reported a variety of benefits of using the application. Most of the participants stated that the application may facilitate interactions with health providers. P11 stated, *"Apparently this is going to send data to a dietitian and the dietitian then can give the person using it feedback on what they might do to correct their diet to, I guess that's what it is... So it's an ongoing relationship between the patient and the dietitian."* P10 said that the images from the application may support the practice of dietitians: *"... because sometimes we don't tell the dietitian everything, but this way she can see everything we ate... It would be something that would be very helpful to people when, when discussing their, their eating habits with a dietitian."* Similarly, P6 mentioned that health providers will benefit from the images collected by the application: *"... Because it'll help people deal with their dietician and their doctor at the same time. So that everybody can get together and see what you're doing."* P12 mentioned that dietitians will be able to provide service by using the collected images of food items: *"...And then it goes to the dietician, and the dietitian's gonna be able to give me information..."* P1 also mentioned that the application will be beneficial to meeting with a dietitian: *"But if I – as I go through the day, if I just clicked a picture each time, I think that would be valuable, so not only meeting with the dietitian, but just for my own..."*

Further, participants stated that using the app will allow improving their personal health. P9 said, *"In helping somebody to decide how to change their diet for optimal health."* Similarly,

some participants expected improved health after using the application. P5 stated, *"You know, if they asked me to take pictures, if they were asking me to use the app, I think I'd eat even better."* P14 said, *"But this has a function that's directly related to promoting my health. So, that's a clear, pragmatic use."*

Two participants mentioned that the application allowed keeping track of meals and snacks efficiently. P9 stated, *"This would be faster if I use that. Take a picture of what you normally eat or what you just ate for your lunch and tell me if that's a good example of what you would have... In that case, I could do it and it would be very fast. Much faster than seeing a handwritten or a computer-generated list of what they had."* P1 described the process of taking pictures of food items by comparing with her existing practice of keeping a food diary: *"Like I said, keeping a food diary is just so boring, but if I could take a picture several days in a row — then I could just right all those things down, in my food diary."* In particular, P9 mentioned that the images captured by the application provide information describing the actual project: *"Instead of serving size, then you see the product, the actual product."*

In addition to direct benefits of using the application, P14 stated that the action of using the application enabled him to learn taking pictures using his smartphone as an indirect benefit: *"Well, I like it because it gives me practice taking pictures with my smartphone because I generally use a camera and not a smart phone. But here, I'd be doing it frequently. So, I would have experience doing it. And I like that sort of side effect of the app that it's teaching me."*

The conclusions I came from the analysis above regarding the potential benefits of FRADA are facilitating interaction with health providers, improving personal health, tracking meals and snacks, and a secondary finding of learning how to manipulate a smartphone.

Potential Features to be Added to FRADA

Participants reported multiple features to be added to FRADA. P14 was eager to have the option to store pictures taken by FRADA: *"Well, I'd like the option to be, I don't know if it was there or not, I'm not sure because I was following instructions. I don't know if the option was there to save it, rather than send it to save it. And so, if there were an option of saving file, something like that."*

Participants wanted to have a space to receive information from health providers, as well as supply additional information to health providers. P3 and P12 wanted to view any feedback on the images of food items from health providers. P12 stated: *"Right, right, well, what we've got now, but then having your app that you just have to snap the picture without having to do the labels, just take your picture. And I'm not sure how you would do that with the dietary feedback from the dietitian. I'm not sure how that would work, but it would make it easy."* In particular, P3 emphasized the importance of getting a feedback from health providers: *"I mean if you don't get any feedback the whole thing is worthless because if you keep sending it in –"*

While participants wanted to get feedback from dietitians, P2 wanted to provide dietitians with additional information about the portion size of the food items. To supply accurate information of food items, P2 stated, *"...I think you've got about the right size of plate, but I would definitely check that out....I don't have that knowledge. I'm sure that being – this is kind of a national brand to it, so they probably have a pretty good idea what's in that too."* Similarly, P10 was eager to supply additional information by leaving comments on the images of food items. P10 stated, *"And if there was maybe a place on the app where you could put in a comment.... – a comment would be nice, I only ate half of this meal..."*

From the analysis of responses from participants, I identified potential features to be added to FRADA that would allow older adults with diabetes to store images captured by

FRADA and to exchange messages with health providers.

Concerns of Older Adults

Participants expressed concerns toward use of the application. Most participants were concerned about potential costs, such as scheduling a meeting with a dietitian and purchasing the application, that might occur by using the application. P11 stated, *"Right, right, yeah. I mean, that, that, I can see that if that's going to be a continuous thing it would have to be almost, like, a doctor's relationship where depending upon how much time the dietitian spends on your particular diet."* P5 mentioned, "My only concern was how much would it cost you to have to have a nutritionist or doctor look at it, see." P1 was aware of how expensive it is to invite dietitians although she uses the application: *"Well, I just wondered how you would get the dietitian involved. You know dietitians are expensive..."* Also, P12 was concerned about the cost of the application itself. P12 said, *"That's huge. That's huge. We're seniors. You know, we live on Social Security, so I don't have a lot of money. Any of the apps that I have are free."*

In addition, participants mentioned trust issues on the food images collected by the application. For instance, P7 did not agree with that all the images tell the truth: *"You don't know what's in there (Cup) ... Vodka..."* Similarly, P2 said, "You're going to end up picking your own favorite foods anyway. I mean, just like you have your favorite foods." In addition to the accuracy of the images of food items reported by patients, P7 was suspicious about what patients would actually do while interacting with health providers: *"A lot of patients aren't cooperative. Patients do what they want. When I prescribe drugs for a patient what percentage of them do you think take the drugs like they're supposed to? What percentage of patients follow the instructions, for example with pharmacy, what percentage would you guess?"*

Furthermore, participants were concerned about other issues, such as privacy issues, learning how to use the application, and dietitians' concerns. Regarding a privacy issue, P2 stated, *"Yes. And, truthfully, to me that would be eventually, for some people it's going to work, for me it's invasion of my privacy... it's just personal. That's a personal thing"* Although P2 was concerned about the privacy issue, she still wanted to use the application if needed: *"I would probably share now and then. If I was really having a problem, I probably would be more willing to share."* P7 was particularly concerned about whether other older adults could use the application. P1 was worried about dietitians' concerns. *"The only thing I might wonder about is if the dietitian would like to be able to see the ingredients on anything instead of just looking at the title, especially if she wasn't familiar with that particular item."*

To sum up, the analysis of responses from participants indicates several concerns of older adults, such as potential financial cost, trust issues on images of food items, privacy issues, learning how to use FRADA, and dietitians' concerns when dietitians review images of food items.

Potential Target Populations

Participants suggested that this application may benefit a variety of potential target populations. First of all, participants agreed with the statement that this application will support patients with diabetes. P1 stated, *"I would recommend it to people with diabetes. I don't know what other people would use for it, but people with diabetes, pre-diabetes, or..."* Also, P2 expressed her recommendation: "I would recommend that diabetes patients use this app."

Participants mentioned that this application could be more beneficial to newly diagnosed patients with diabetes. P11 stated, *"... already a long time ago and then if the people who recently were diagnosed, they might be more interested in ..."* P2 also said, *"I guess, it's very useful, as I say. I think for a new diabetic, it would be very useful. A person that's been*

newly diagnosed with diabetes."

Older adults reported that the potential target users might be individuals who are sensitive to food intake in addition to patient with diabetes. P2 said, *"Especially if they were, again, I'm talking about new diabetics or people who are trying to, or even people who are trying to lose weight and need to work with a dietitian."* P10 suggested that this application could benefit people after surgery: *"... so, people after surgery, they – because they need to manage their diets and they need to talk with their nutritionists..."*

3.6 Discussion

The primary goal of this Aim was to create FRADA, a smartphone application that enables older adults with diabetes to collect images of their meals and snacks and determine the usability of FRADA. To do this Aim, I evaluated the usability of the smartphone application in older adults with diabetes through a lab-based usability session. By surveys and interviews, this study revealed that participants were satisfied with usability of FRADA and its instructions by performing three tasks (i.e., taking, reviewing, and transmitting images of food items) successfully. Even though responses from participants revealed their concerns when interacting with FRADA, they indicated willingness to use FRADA based on their needs in the future, as well as additional target populations who will benefit from use of FRADA. Based on the findings of this study, there remain topics to discuss: Would other existing or emerging modalities be appropriate for older adults with diabetes? How can we improve instructions for better use of FRADA? What are preferences of older adults with diabetes regarding a device, such as a smartphone and tablet computer? What are the needs of other potential target users (e.g., high blood pressure and chronic kidney disease)? How can we redesign FRADA to meet the needs of multiple stakeholders (e.g., family members, caregivers, and friends)? How can we deal with potential financial costs in real-world settings?

3.6.1 Appropriateness of Existing or Emerging Modalities for Older Adults with Diabetes

While this study focused on recording images of food items as logs, there still exist a variety of modalities, such as wearable cameras, voice-recording, and sensor technologies that would be appropriate for older adults with diabetes to record their meals and snacks. First, wearable cameras may be appropriate for the older adult population. Since images are captured automatically by wearable cameras [20, 21], older adults might not have to learn how to manipulate the devices. Similarly, older adults do not have to follow the instructions (e.g., including all the food items in one single photograph, holding the phone at a 45-degree angle when taking pictures of food items, and capturing images before and after eating events) when collecting images of their meals and snacks. Instead, older adults would only need to learn basic functions, such as how to turn on and off and how to charge the camera. Even though wearable cameras may reduce burdens of older adults, users might still need to screen collected images prior to analyzing the images. In particular, low-income older adults might not want to use wearable cameras because they would need to purchase wearable devices as additional devices.

Next, a voice-recording strategy might work well to support the older adult population. Similar to wearable devices, older adults do not have to follow the instructions, which are required for collecting images of food items. Instead, they would just need to turn on the video recorder when logging food intakes they consumed. Although a voice-recording strategy may help older adults record food items and their portion size, there remain challenges older adults might face when recording their voices. For instance, older adults would still need to turn on their video recorders before eating events. Also, it might be difficult for older adults to describe every single food item and its portion size accurately.

Lastly, sensor technologies (e.g., jaw motion sensor [47]) may be appropriate for older adults. For example, by monitoring chewing, a jaw motion sensor can detect periods of food

intake automatically while people consume food [47]. This might be particularly beneficial to older adults because they do not have to perform any tasks to record food items and their portion size during eating events. However, it is still questionable whether such sensor technologies monitoring individuals' eating behaviors might be socially acceptable for the older population.

3.6.2 Instructions

Participants were required to follow two instructions when taking pictures of food items. Although the instructions were based on the findings of the previous studies, this study showed that there are still rooms to revise the instructions by reflecting the needs of health providers. For example, dietitians might want to view the images taken at multiple angles for better understanding of the food items and their portion sizes.

3.6.3 Device Preferences

This study showed found that some participants were interested in using the application on a tablet device whose screen is larger than the screen of smartphones. Since this study focused on evaluating the usability of the smartphone application, the findings of this study do not tell if older adults with diabetes prefer a larger screen. Nonetheless, it would be valuable to conduct additional experiments to determine the acceptability of other types of devices (e.g., tablets, laptop, desktop, and smartwatches).

3.6.4 Target Users

I noticed that some participants did not want to use the smartphone application in the future because they were already familiar with how to manage their diabetes. Instead, they suggested that this application might benefit newly diagnosed patients with diabetes. This

implies that researchers and designers might need to consider unique needs of patients with other types of chronic diseases, such as high blood pressure and chronic kidney disease when asking them to use technologies with mobile devices.

3.6.5 Understanding Multiple Stakeholders for Better Tool Design

This study focused on evaluating the usability of the application with a single population of older adults with diabetes. As a result, I was able to identify potential features to be added to the application based on the feedback from older adults with diabetes, as well as benefits of using the application. Future work would need to incorporate the needs of other stakeholders, such as dietitians, family members, friends, and caregivers when devising features to be added to the application. Also, future studies could reveal the benefits of multiple stakeholders who interact with older adults with diabetes, such as family members, friends, and caregivers when using the application.

3.6.6 Cost-Sensitive Population

I noticed that most participants were sensitive to potential costs when using the application. This might represent the characteristics of participants in this study because they were mainly recruited at senior centers and senior apartments. There are more likely to be more low-income older adults in those facilities than retirement communities requiring relatively high living cost.

To sum up, I demonstrated multiple topics to discuss for better FRADA design. The topics include appropriateness of existing or emerging modalities for older adults with diabetes, what to address when updating instructions, device preferences of older adults, the needs of other potential target users, how to incorporate the needs of multiple stakeholders into

FRADA design, and how to deal with financial costs.

3.7 Contributions

The goal of Aim 1 was to create a smartphone application that enables older adults with diabetes to collect images of food items and determine the usability of the application. I achieved this goal via development of FRADA and lab-based usability sessions with older adults with diabetes. Achieving this aim demonstrates three contributions. First, I created FRADA for an image-assisted dietary assessment based on design requirements that reflect the special considerations of older adults, while other applications used in previous studies did not reflect such considerations. Therefore, designers, developers, and researchers could use the findings of my study for creating smartphone applications targeting older adults with diabetes. Second, I obtained structured feedback about the application from participants through three types of questionnaires: pre-test, post-task, and post-test using surveys and interviews. The findings through this strategy will expand knowledge about how to design smartphone applications for an image-assisted dietary assessment in older adults. Finally, I demonstrated potential opportunities of evaluating the feasibility and validity of FRADA in a deployment study. Ultimately, the findings from Aim 1 could improve the accuracy of a traditional dietary assessment method by reducing errors in self-reporting in real-life settings.

3.8 Conclusion

The work presented in this chapter supports the overall Aim of assessing whether a food record app for dietary assessments (FRADA) can improve the accuracy of traditional dietary assessment methods among older adults with type 2 diabetes. Specifically, the focus of this chapter is Aim 1 of developing FRADA that enables older adults with diabetes to collect images of food items and evaluating the usability of FRADA with older adults with diabetes.

Aim 1 fills gaps in knowledge from literature review by reflecting the needs of older adults when developing FRADA and evaluating the usability of FRADA with older adults with diabetes. The key findings of this study demonstrate that FRADA and its instructions for capturing, viewing, and transmitting images of food items were usable for older adults with diabetes. The findings also show that FRADA offers potential benefits to older adults with diabetes, as well as other patients (e.g., newly diagnosed diabetes, high blood pressure, and chronic kidney disease). In addition, by incorporating reported concerns of older adults when interacting with FRADA from this study, the findings suggest implications for creating technologies to support potential users of FRADA. In brief, Aim 1 study demonstrates not only the usability of FRADA with older adults with diabetes in a lab-based setting, but it also demonstrates potential opportunities using FRADA in real-life settings.

In the next chapter, I describe an evaluation of the feasibility of FRADA with multiple stakeholders involving older adults with diabetes and dietitians. I will report the extent to which the images of food items collected by older adults with diabetes using FRADA reduced errors in self-reported data.

Chapter 4

FEASIBILITY STUDY OF FRADA FOR AN IMAGE-ASSISTED DIETARY ASSESSMENT

4.1 Introduction

In the preceding chapter, I demonstrated the development of FRADA for the image-assisted dietary assessment. I then evaluated the usability of the application for older adults with diabetes. The goal of Aim 1 was to create a smartphone application that enable older adults with diabetes to collect images of food items and determine the usability of the smartphone application with older adults with diabetes. One of the key results of Aim 1 was that FRADA and its instructions were usable for older adults with diabetes. Participants were satisfied with usability of FRADA. Next, FRADA offered potential benefits to older adults with diabetes. older adults with diabetes reported that FRADA could be used to facilitate interaction with their health providers, as well as to improve their personal health by tracking their meals and snacks. In addition, the findings of Aim 1 showed that FRADA can be potentially used by other patient populations (e.g., individuals with high blood pressure and kidney chronic disease). Since FRADA was designed for collecting images of food items, it is applicable to any individuals who would need tracking a history of their meals and snacks. Last, Aim 1 revealed that tablet devices can be an alternative device to a smartphone for older adults with diabetes. It was because tablet devices provide a large screen that makes them easy to use FRADA.

The goal of Aim 2 is to determine the feasibility of FRADA for an image-assisted dietary assessment with older adults with diabetes and dietitians. The literature review from Chapter

2 revealed no study evaluated image-assisted dietary assessment methods in older adults, nor in diabetes, nor did any studies focus on dietitians as well as patients.

The questions for Aim 2 are as follows: What is the feasibility of FRADA with older adults with diabetes? Would the images of food items reduce errors in self-reporting during a 24-hour dietary recall interview? How much would the 24-hour dietary recall using food images reduce errors in self-reporting?

Having demonstrated the usability of the application, the goal of Aim 2 is to assess whether FRADA is feasible for an image-assisted dietary assessment. I first describe the methods used for collecting data (e.g., the images of food items and food list) in Section 4.2. Next, I explain the methods used for analyzing the collected data in Section 4.3. I then present the findings of the study in Section 4.4 and discuss the limitations of this study in Section 4.5. Finally, I conclude this chapter by summarizing the contributions of this work.

4.2 Methods

4.2.1 FRADA for the Study

Since FRADA described in Chapter 3 provides essential functions (i.e., capturing, viewing, and sending images) for collecting images of food and its usability was demonstrated in the previous chapter, I used FRADA as a tool for study participants to collect images of food items to evaluate the feasibility of an image-assisted dietary assessment. The goal of doing this was to examine whether FRADA is feasible for an image-assisted dietary assessment in support of Aim 2.

4.2.2 Participants and Inclusion and Exclusion Criteria

The 24-hour dietary recall interview requires both a dietitian and patient. In this study, I recruited both dietitians and older adults with diabetes to simulate the 24-hour dietary

recall interview as part of a deployment study.

Dietitians

To participate in the study, participants were required to 1) understand spoken and written English; 2) have a registered dietitian (RD) credential; 3) have experience with older adults for at least three months. The last criteria was in order to avoid any potential sample biases caused by study participants who were not familiar with interacting with older adults. I excluded any participants who are legally blind or have severe auditory impairments to avoid any potential sample biases that might influence the study.

Older Adults with Diabetes

To participate in the study, participants were required to 1) be between 65 and 84 years old, 2) be diagnosed with type 2 diabetes or prediabetes for at least six months, 3) understand spoken English, 4) have their own smartphones with cameras, 5) live in independent living facilities (e.g., retirement communities, retirement homes, senior centers, and senior housing), and 6) have experience with smartphone usage for at least six months. I chose these criteria to ensure that study participants could accomplish given tasks (i.e., capturing, viewing, and transmitting images of food items) using FRADA on their smartphones. I excluded any potential participants who are legally blind or have severe auditory impairments in order to reduce any potential sample biases. As illustrated in Chapter 3, the University of Washington Institutional Review Board approved all the study procedures.

Recruitment

To recruit dietitians, I identified the Greater Seattle Dietetic Association (GSDA) * after contacting a dietitian working as a nutrition counsellor in Seattle because GSDA provides people with networking opportunities with dietitians working in the Greater Seattle area. Next, I attended events organized by GSDA and spoke with attendees to identify potential participants. I then sent email messages to the dietitians who expressed interests in this study. Also, I used a GSDA mailing list to disseminate study participation opportunities to more potential participants.

To recruit older adults with diabetes, I invited each participant in the Aim 1 at the end of the session. I then contacted each participant to schedule sessions for the Aim 2 study if he/she expressed his/her interest.

Study Procedure

Older adults with diabetes took part in an orientation session and a field experiment in a home setting on the first day (Day 1), and an interview on the second day (Day 2), while dietitians only participated in the study on Day 2 (see Table 4.1). During the orientation session on Day 1, I described the research plan to each participant (see Table 4.1) and installed the application on their smartphones. I then provided each participant with instructions (see Appendix A.8) that include a list of rules that the participant should keep in mind when interacting with the application:

- Include all the food items in one single photograph
- Hold the phone at a 45-degree angle when taking pictures of food and beverages
- Capture images of food items before and after every single eating event

*http://www.eatrightseattle.org

Participant Groups	*Experiment (Day 1)*	*24HR Interview (Day 2)*	*Intervention (Day 2)*	*24HR Interview (Day 2)*	*Evaluation*
Dietitians	N/A	Consent Pre-test survey Create a food lists	Review images of food items	Make notes Create a food list	Post-test interview
Older adults with diabetes	Consent Pre-test survey Perform three tasks: capturing viewing, and sending Instructions	Recall food items	Review images of food items	Recall food items	Post-test survey and interview

Table 4.1: Aim 2 and 3 study procedure.

After the orientation session on Day 1, each participant was asked to perform the following tasks in order specified for the next 24 hours for each meal and snack:

1. Launch the application on his/her own smartphone
2. Capture images of food items before each eating event
3. Have meal (e.g., breakfast, lunch, dinner, and/or snacks)
4. Capture images of food items after each eating event
5. Review the images they have captured
6. Send the images to a dietitian using the application

On Day 2, I invited both a dietitian and an older adult with diabetes to be interviewed. I asked each dietitian participant to fill out the pre-test questionnaire (i.e., demographics questions) (see Appendix A.6) to get information about him or her, including age, gender, education level, and years of experience with older adults. I then asked the dietitian to use the instructions (see Appendix A.7) and conduct a 24-hour dietary recall interview with the older adult with diabetes. While the dietitian participated in a 24-hour dietary recall interview, she was asked to fill out the food list form (see Figure 4.1). After completing their initial 24-hour dietary recall interview, I gave the dietitian a tablet computer that allowed her to navigate images of food and beverages transmitted by the older adult with diabetes. While reviewing images using the tablet computer, the dietitian was asked to record any food items that were not reported previously, reported incorrectly, and were not captured by the smartphone on the right-hand side of the food list form using the following questions:

- Are there any other food items you did not report?
- Are there any food items you reported incorrectly?
- Are there any other food items you forgot to photograph?

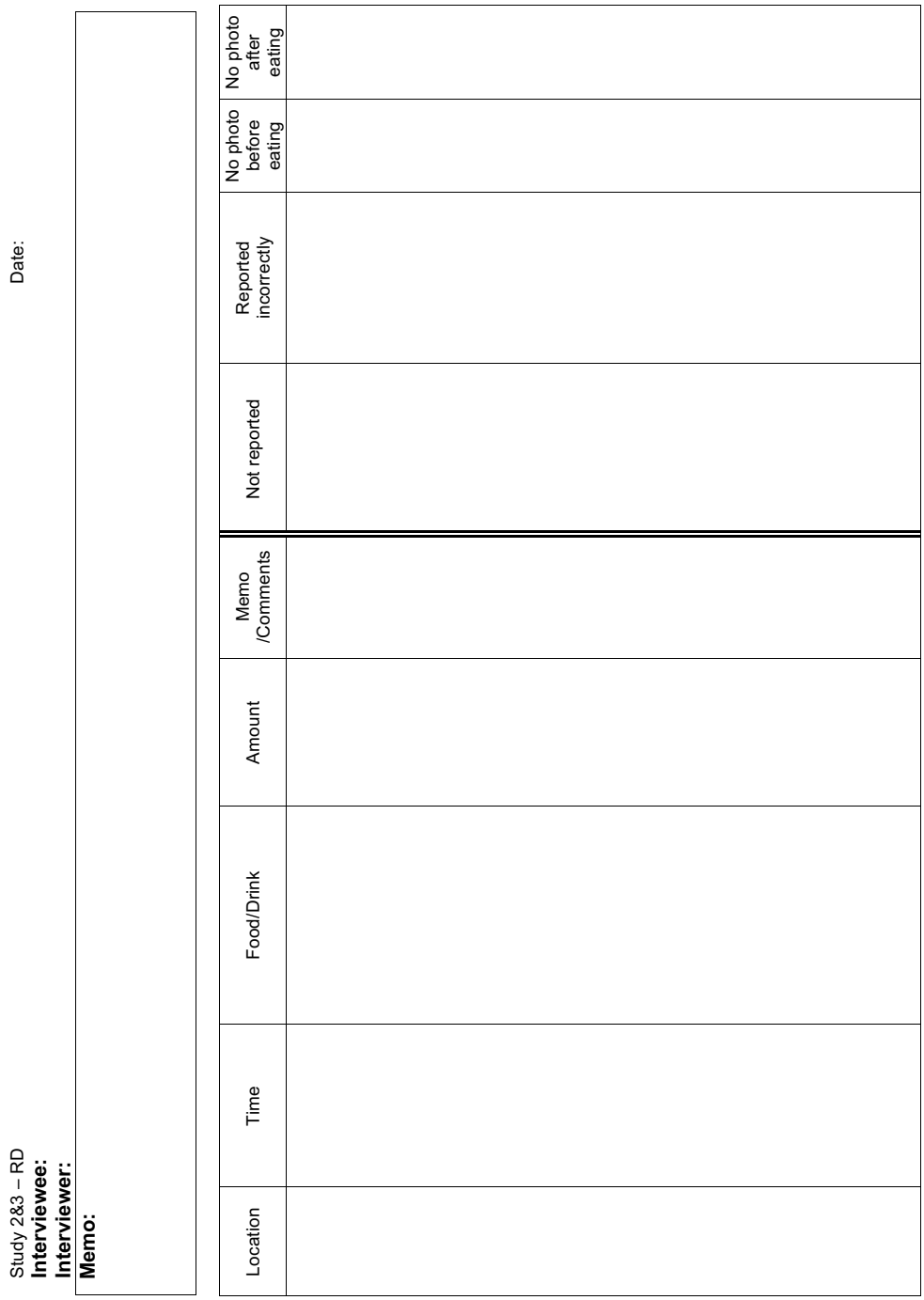

Figure 4.1: Food list form for dietitians to record the history of food intake of older adults with diabetes.

4.3 Analysis

4.3.1 Analysis of the Images of Food Items

I evaluated the feasibility of FRADA by analyzing the images collected by older adults with diabetes. Using the collected images of food items, I examined how accurately older adults with diabetes performed the task of capturing images of food items with the three criteria: 1) whether they included all the food items in one single photograph, 2) whether they held the phone at a 45-degree angle when capturing images of food items, and 3) whether they captured the images of food items before and after every single eating event.

First, I estimated the ratio of the number of the images including all the food items to the total number of images (see Equation 4.1).

$$Ratio\ (All\ the\ Items) = \frac{\#\ of\ images\ including\ all\ the\ food\ items}{total\ \#\ of\ images} \tag{4.1}$$

Second, I estimated the ratio of the number of the images taken at a 45-degree angle to the total number of images (see Equation 4.2).

$$Ratio\ (45-degree\ Angle) = \frac{\#\ of\ images\ at\ a\ 45-degree\ angle}{total\ \#\ of\ images} \tag{4.2}$$

Lastly, I estimated the ratio of the number of pairs of two images captured before and after eating events to the total number of eating events recorded as at least one image (see Equation 4.3).

$$Ratio\,(Pairs\,of\,Images) = \frac{\#\ of\ pairs\ of\ images\ captured\ before\ and\ after\ eating\ events}{total\ \#\ of\ eating\ events\ recorded\ as\ at\ least\ one\ image} \tag{4.3}$$

4.3.2 Analysis of the Food List

For Aim 2, in order to examine whether reviewing images of food items collected by FRADA was feasible for an image-assisted dietary assessment, I analyzed the food list recorded by dietitians using the two criteria: 1) whether the images of food items enabled older adults with diabetes to recall events not reported previously, 2) whether the images of food items enabled older adults with diabetes to correct events reported incorrectly, 3) whether older adults with diabetes captured the images before and after their eating events.

First, I investigated if any eating events were reported additionally after older adults with diabetes reviewed the images collected by themselves. If any eating events were reported additionally, I estimated the ratio of the number of the eating events reported additionally after reviewing images of food items to the total number of eating events (see Equation 4.4).

$$Ratio\ (Reported\ Additionally) = \frac{\#\ of\ eating\ events\ reported\ additionally}{total\ \#\ of\ eating\ events} \tag{4.4}$$

Second, I examined if any eating events were corrected after older adults with diabetes reviewed the images they had collected. If any eating events were corrected, I determined the extent to which how many eating events were corrected by estimating the ratio of the number of the eating events corrected after reviewing images of food items to the total number of eating events (see Equation 4.5).

$$Ratio\ (Corrected) = \frac{\#\ of\ corrected\ eating\ events}{total\ \#\ of\ eating\ events} \tag{4.5}$$

Third, I investigated if older adults with diabetes captured required images of every single eating event during the field experiment. If they did not capture images of all the eating events, I determined how many eating events were recorded as images by estimating the ratio

ID	*Gender*	*Age*	*Race/Ethnicity*	*Education*	*Period Working with Older Adults*
DP1	Female	34	Asian/Pacific Islander	Master's	2-3 years
DP2	Female	29	White/Caucasian	Master's	1-2 years
DP3	Female	38	White/Caucasian	Master's	>3 years

Table 4.2: Dietitian participant demographics.

of the number of eating events with the images captured before and after each eating event to the total number of eating events (see Equation 4.6 and 4.7).

$$Ratio\,(Before\,Eating\,Events) = \frac{\#\ of\ eating\ events\ with\ images\ captured\ before\ the\ events}{total\ \#\ of\ eating\ events} \tag{4.6}$$

$$Ratio\,(After\,Eating\,Events) = \frac{\#\ of\ eating\ events\ with\ images\ captured\ after\ the\ events}{total\ \#\ of\ eating\ events} \tag{4.7}$$

4.4 Findings

4.4.1 Participant Demographics

Dietitian participant demographics are shown in Table 4.2. All the dietitian participants were female and held a Master's degree as a highest degree. The average age of dietitian participants was 33.7 (SD 4.5, range 29-38). All the participants had at least 1-year experience working with older adults.

Older adult participant demographics are illustrated in Table 4.3. Six female study participants took part in this study. The average age of participants was 71.0 (SD 4.6, range 65-76). Participants had a variety of highest degrees: Bachelor's degree (2 participants), Professional degree (2), and High School graduate (2). Participants used various mobile devices, including Android (3 participants), iOS (2), and Amazon Fire (1) devices.

ID	*Gender*	*Age*	*Race/Ethnicity*	*Education*	*Period Having Smartphones*
OP1	Female	67	White/Caucasian	Professional	Not reported
OP2	Female	72	Asian/Pacific Islander	High School	>3 years
OP3	Female	70	White/Caucasian	Bachelor's	>3 years
OP4	Female	76	White/Caucasian	Professional	2-3 years
OP5	Female	65	White/Caucasian	Bachelor's	>3 years
OP6	Female	76	White/Caucasian	High School	>3 years

Table 4.3: Older adult participant demographics.

4.4.2 Ease of Use of Instructions for Capturing Images of Food Items

After reviewing images collected by older adults with diabetes (see Appendix A.9), this study showed that older adults with diabetes tended to follow the instructions successfully: including all the food items in one single photograph, holding the smartphone at a 45-degree angle when taking images of food items, and capturing images before and after eating events. Table 4.4 illustrates the ratio of the number of the images including all the food items to the total number of images (see Equation 4.4). The average ratio was 97.7 (SD 5.7). Table 4.5 illustrates the ratio of the number of the images taken at a 45-degree angle to the total number of images (see Equation 4.5). The average ratio was 94.9 (SD 7.8). Similarly, Table 4.6 reports the ratio of the pairs of images captured before and after eating events to the total number of eating events where at least one image was taken (see Equation 4.3). The average ratio was 71.0 (SD 37.2).

As the findings of Aim 1 supports that instructions were easy to use, the key finding of Aim 2 is that instructions were feasible for older adults with diabetes to follow for the 24-hour period in their home settings. This shows potential opportunities of using the instructions for a longer period.

ID	*# of Images*	*# of Images Including All Food Items*	*Ratio (%)*
OP1	36	31	86.11
OP2	7	7	100.0
OP3	15	15	100.0
OP4	20	20	100.0
OP5	5	5	100.0
OP6	10	10	100.0

Table 4.4: Ratio of the number of the images including all the food items to the total number of images

ID	*# of Images*	*# of Images Captured at a 45-degree Angle*	*Ratio (%)*
OP1	36	29	80.6
OP2	7	7	100.0
OP3	15	15	100.0
OP4	20	19	95.0
OP5	5	5	100.0
OP6	10	10	100.0

Table 4.5: Ratio of the number of the images taken at a 45-degree angle to the total number of images.

4.4.3 Reduced Errors in Self-Reporting

Identified Additional Eating Events

This study revealed that reviewing images of food items helped discovering missing or correcting items. As shown in Table 4.7, four older adult participants with diabetes reported additional food items after reviewing images of food items. The average ratio for older adults with diabetes who reported additional food items was 26.9 (SD 9.2).

ID	*# of Paired Images*	*# of Eating Events Captured Before and After Eating Events*	*Ratio (%)*
OP1	19	16	84.21
OP2	4	3	75.0
OP3	7	7	100.0
OP4	10	10	100.0
OP5	5	0	0
OP6	6	4	66.67

Table 4.6: Ratio of the pairs of images captured before and after eating events to the total number of eating events where at least one image was taken.

ID	*# of Eating Events*	*# of Eating Events Reported Additionally*	*Ratio (%)*
OP1	34	12	35.29
OP2	22	7	31.82
OP3	15	4	26.67
OP4	31	9	29.03
OP5	11	0	0
OP6	26	3	11.54

Table 4.7: Ratio of the number of additional eating events to the total number of eating events recorded as one image.

ID	*# of Eating Events*	*# of Corrected Eating Events*	*Accuracy (%)*
OP1	34	0	0
OP2	22	4	18.18
OP3	15	0	0
OP4	31	4	12.90
OP5	11	0	0
OP6	26	0	0

Table 4.8: Ratio of the number of corrected eating events to total number of eating events after reviewing images of food items.

Corrected Information of Eating Events

This study showed that images of food items helped correcting incorrect information related to the portion size of food items and time of eating events. First, the images enabled older adults with diabetes to correct the portion size of a food item. For instance, while OP4 reported one piece of pineapple, the images revealed that she actually consumed two pieces of pineapple. Similarly, while OP2 reported that she consumed one cup of rice, a dietitian found that OP2 actually consumed a half cup of rice instead of one cup. Two older adult participants with diabetes corrected the portion size of food items they consumed or eating time after reviewing images of food items (see Table 4.8). The average ratio for older adults with diabetes who corrected food items was 15.54 (SD 3.73). In particular, I noticed that the image helping clarify similar type of food items. For example, while OP3 reported initially that she drank water, the images enabled her to report tea instead of water. Similarly, while she reported tea for her dinner, reviewing images revealed that OP3 actually drank water instead of tea.

Furthermore, the images of food items enabled older adults with diabetes to correct the time when they started consuming their meals or snacks, though they reported the food

ID	*# of Eating Events*	*# of Eating Events with Images Captured Before Eating Events*	*Accuracy (%)*
OP1	34	27	79.41
OP2	22	22	100.00
OP3	15	15	100.00
OP4	31	31	100.00
OP5	11	4	36.36
OP6	26	26	100.00

Table 4.9: Ratio of the number of eating events with a pair of pictures captured before eating events to the total number of eating events.

items and the portion size of the food items correctly. For instance, although OP3 reported 10AM as one of her eating events, the images of food items enabled older adult to change the time from 10AM to 9AM. Similarly, OP5 changed time from 7:30AM to 6AM for one of her eating events after reviewing images of food items.

Performance Capturing Images of Food Items Before and After Eating Events

This study demonstrated that older adults with diabetes accomplished capturing images of their eating events before and after eating successfully. Table 4.9 illustrates the number of images older adults with diabetes captured before their eating events. The average ratio was 85.96 (STD 25.66). Similarly, Table 4.10 illustrates the number of images older adults with diabetes captured after their eating events. The average ratio was 71.55 (STD 35.73). The findings of study illustrated in Table 4.9 and 4.10 revealed that older adults with diabetes took at least one image of food items for more than 70 percent of their eating events. I discovered that older adults with diabetes captured fewer images of food items after finishing their meals and/or snacks than before they started eating.

To sum up, the key finding of Aim 2 is that reviewing images of food items collected by

ID	*# of Eating Events*	*# of Eating Events with Images Captured After Eating Events*	*Accuracy (%)*
OP1	34	19	55.88
OP2	22	15	68.18
OP3	15	15	100.00
OP4	31	31	100.00
OP5	11	1	9.09
OP6	26	25	96.15

Table 4.10: Ratio of the number of eating events with a pair of pictures captured after eating events to the total number of eating events.

FRADA was feasible for an image-assisted 24-hour dietary recall interview. First, reviewing images of food items enabled older adults with diabetes to identify additional eating events which were not reported. Table 4.7 demonstrates the ratio of the number of additional eating events to the total number of eating events recorded as one image. Second, reviewing images of food items enabled older adults with diabetes to correct incorrect information related to portion size of food items and time of eating events. Table 4.8 illustrates the ratio of the number of corrected eating events to total number of eating events after reviewing images of food items. Lastly, older adults with diabetes accomplished capturing images of their eating events before and after they have eating events successfully. Table 4.9 and 4.10 demonstrate the ratio of the number of eating events with a pair of pictures captured before and after eating events to the total number of eating events.

4.5 Discussion

I evaluated the feasibility of FRADA for image-assisted 24-hour dietary recall interviews with pairs of dietitians and older adults with diabetes. Through field experiments and 24-hour dietary recall interviews, this study revealed that older adult participants with diabetes performed capturing images of food items successfully. Furthermore, I discovered that collected

images of food items reduced errors in self-reporting. Reviewing images of food items not only helped older adults with diabetes identify additional eating events which were not reported previously, but it also allowed them to correct incorrect information related to portion size of food items and time of eating events.

4.5.1 Sample Biases

This study has sample biases to generalize the findings of the study. First, I focused on individuals who had previously interacted with FRADA by recruiting older adults with diabetes who participated in the Aim 1 study. In addition, as shown in Table 4.3, five out of six older adults with diabetes owned and had used their smartphones for at least 2 years. Therefore, future work remains to examine the feasibility of this approach with multiple populations, such as older adults with diabetes who have owned and used their smartphones less than 2 years and/or patients with other chronic diseases (e.g., kidney chronic disease, high blood pressure). For example, older adults who have less experience in smartphones might need additional effort into learning how to manipulate smartphones to perform required tasks (i.e., capturing, viewing, and transmitting images of food items) via FRADA.

4.5.2 Long-Term Deployment

This study focused on evaluating the feasibility of FRADA for an image-assisted 24-hour dietary recall interview. During the experiment, older adults with diabetes used the application from the time when they got up to when they went to bed. Though the assessment in this study was only for 24 hours, this was still felt to be very relevant since 24-hour dietary recall interviews are only 24 hours in duration. Nevertheless, little is still known about the feasibility of the application for longer periods. For example, this study did not investigate any long-term adherence issues, even though it is important to see how health of older adults

with diabetes would change if they were to use FRADA for longer periods. In addition, this study did not examine whether they would actually use it for longer periods, though participants expressed their interests in using FRADA in the future. While older adults with diabetes were able to perform tasks of collecting images of their meals and snacks successfully given a 24-hour time frame, it might not be comfortable for them to perform the tasks in a natural setting longitudinally. For instance, unexpected issues might occur more frequently during a long-term deployment study. Below are example scenarios individuals might face during the long-term deployment study:

- What would happen if there is no more battery?
- What would happen if older adults with diabetes need to travel?
- What if older adults with diabetes forgot to bring their smartphones when going out for dinner?

As for future work, a long-term deployment study would be needed to evaluate the feasibility of FRADA for longer periods.

4.5.3 Feasibility vs Validity

This study showed that it is feasible to use images of food items to identify missing food items, which would ultimately lead to reducing errors in self-reporting. Although this study showed the feasibility of using images of food items for 24-hour dietary recall interviews, it is still questionable whether this method could be used in a clinical setting because the proposed method using images of food items with older adults with diabetes still has not been validated. Since the Aim 1 and Aim 2 studies showed that FRADA is usable and feasible for older adults with diabetes, the application could be potentially used as a tool for older adults to collect the images of their food and beverages. In order to use this approach

in a clinical setting, future work remains to validate multiple dietary assessment methods, such as food records, 24-hour dietary recall, and food frequency questionnaire, using images of food items with older adults with diabetes.

4.5.4 Relevance to Recent Studies

The findings in Aim 2 presented that reviewing images of food items helped older adults with diabetes identify unreported food items and correct food items reported incorrectly. They are aligned with the conclusion of a recent review article [14] that image-assisted methods can improve the accuracy of traditional dietary assessment methods. Nevertheless, none of the studies reviewed in this article used a smartphone as a device for collecting images of food items to improve the accuracy of image-assisted 24-hour dietary recall interviews, while some [53, 16, 45] used smartphones as devices for collecting images of food items as part of image-based dietary assessment methods.

4.6 Contributions

This study reveals that an image-assisted dietary assessment using FRADA with older adults with diabetes is feasible, whereas no previous studies have evaluated the feasibility of an image-assisted dietary assessment with older adults with diabetes. The findings of Aim 2 demonstrate the extent to which older adults with diabetes can follow instructions when performing capturing, viewing and sending images of food items for an image-assisted dietary assessment: including all the food items in one single photograph, holding a smartphone phone at an angle when capturing images of food items, and capturing images of food items before and after each eating event. In addition, this study presents the extent to which older adults with diabetes can recall additional food items that were not reported, reported incorrectly, or not photographed after reviewing images of food items. This shows that a

smartphone-based image-assisted dietary assessment could be used as an enhanced dietary assessment methods that would reduce errors, which occur with self-reporting tools. To sum up, my study offers a proof of concept that it is feasible for older adults to use a smartphone application to collect images of their meals and snacks for an image-assisted dietary assessment.

4.7 Conclusion

This chapter demonstrates the feasibility of FRADA for an image-assisted dietary assessment. The study reveals that FRADA for collecting images of food items is feasible for older adults with diabetes. In addition, reviewing images collected by older adults with diabetes reduced errors in self-reporting during the 24-hour dietary assessment with dietitians. The images of food items not only enabled older adults to recall unreported food items, but they also helped them correct food items reported incorrectly. The work illustrated in this chapter supports the overarching aim of assessing whether FRADA can improve the accuracy of traditional dietary assessment methods among older adults with type 2 diabetes. The focus of this chapter is Aim 2 of investigating whether reviewing images of food items collected by FRADA reduces errors in self-reporting of older adults with diabetes during 24-hour dietary recall interviews. In brief, Aim 2 shows that using images of food items can improve the accuracy of a traditional dietary assessment method when dietitians conduct 24-hour dietary recall interviews with older adults with diabetes.

In the next chapter, I describe an evaluation of the satisfaction of older adults with diabetes and dietitians' experience with the images of food items during a 24-hour dietary recall interview. I will illustrate the needs and barriers of older adults with diabetes when collecting the images of food items in a home setting using FRADA. In addition, I will describe dietitians' perspectives including concerns and potential opportunities using images

of food items collected by older adults with diabetes.

Chapter 5

SATISFACTION OF STAKEHOLDERS WITH IMAGE-ASSISTED 24-HOUR DIETARY RECALL INTERVIEWS

5.1 Introduction

In the preceding chapter, I evaluated the feasibility of an image-assisted dietary assessment using FRADA with dietitians and older adults with diabetes. As per Chapter 1, the overall Aim is to improve the accuracy of traditional dietary assessment methods among older adults with type 2 diabetes. The goal of Aim 3 is to evaluate the satisfaction of stakeholders (i.e., older adults with diabetes and dietitians) with FRADA and an image-assisted 24-hour dietary recall interview. The subaims of Aim 3 are:

- **Aim 3.1**: To evaluate the satisfaction of older adults with diabetes with FRADA
- **Aim 3.2**: To evaluate the satisfaction of dietitians with an image-assisted 24-hour dietary recall interview

The literature review from Chapter 2 revealed that none of the prior studies evaluated the satisfaction of both patients and health providers with image-assisted dietary recall assessment methods, even though health providers are also essential direct stakeholders for the process of a dietary assessment.

The questions for Aim 3 are as follows: Would FRADA be usable for older adults with diabetes to perform the required tasks (i.e., capturing, viewing, and transmitting images) for collecting images of food items in real-world settings? Would it be easy for older adults to follow the instructions (i.e., including all the food items in one single photograph, holding

the phone at a 45-degree angle when taking pictures of food items, and capturing images of food items before and after every single eating event)? What are the challenges older adults with diabetes face when capturing images of food items in real-world settings? What are the privacy issues of older adults with diabetes when sharing images of food items with other people? What are the trust issues of older adults with diabetes when sharing the images of food items with other people? Next, I explored the following questions to understand the population of dietitians during a 24-hour dietary recall interview using images of food items: What are the benefits of using images of food items during a 24-hour dietary recall interview? What are the needs of dietitians when reviewing images of food items? What are the potential use cases of FRADA for dietitians?

To achieve Aim 3.1 and 3.2, I present methods used for collecting qualitative data from two groups of stakeholders (i.e., dietitians and older adults with diabetes) during the image-assisted 24-hour dietary recall interview in Section 5.2. Next, I explain methods used for analyzing collected qualitative data in Section 5.3. I then demonstrate the key findings of Aim 3 in Section 5.4 and discuss the limitations and future work of this study in Section 5.5. In the end, I conclude this chapter by summarizing the contributions of this work.

5.2 Methods

Using surveys and interviews, I determined the extent to which older adults with diabetes are satisfied with FRADA for performing tasks (i.e., capturing, viewing, and transmitting the images of food and beverages) required for an image-assisted dietary assessment. In addition, I used interviews with dietitians to understand how dietitians interact with the viewer application and how they interact with older adults with diabetes when reviewing images of food items.

5.2.1 Participants and Recruitment

As the participants in Aim 2 were the same as the ones in Aim 3, I did not recruit additional participants only for Aim 3.

5.2.2 Study Procedure

After running the experiment conducted in Aim 2, I carried out the following two sessions: one session for conducting surveys and interviews with an older adult with diabetes and the other session for conducting interviews with a dietitian. During the first session, I asked each older adult with diabetes to respond to the questionnaires (see Appendices A.9 and A.10) to rate their satisfaction with the images of food items collected by FRADA. I conducted interviews with the older adults with diabetes. The interview questions covered three themes: 1) experience using the FRADA for collecting images of food items, 2) potential uses of FRADA for different purposes, and 3) suggestions for improving FRADA. Sample interview questions covering those themes are described in Appendix A.11. After completion of the interview with older adults with diabetes, I conducted interview with dietitians. In this study, one dietitian conducted 24-hour dietary recall interviews with two different older adults with diabetes in my study. The interview questions covered multiple themes: 1) experience of using images of food items for a 24-hour dietary recall interview, 2) potential uses of the images of food items for a 24-hour dietary recall interview, and 3) suggestions for improving an image-assisted 24-hour dietary recall method. Sample interview questions covering those three themes are illustrated in Appendix A.12.

5.3 Analysis

Two types of data were collected through surveys and interviews: 1) responses to Likert-type statements from surveys with older adult participants with diabetes, 2) audio-recorded

qualitative feedback from the dietitians and older adults with diabetes. To analyze the survey responses, I summarized the numbers by calculating the average scores for each question. Regarding the qualitative data from the interviews, I collected statements from transcripts that described participants' experiences. I then applied an open coding method [43] to the statements as a single coder. After reviewing the statements repeatedly, I highlighted quotes on first pass. I bold faced recurring concepts on second pass and labeled the recurring concepts on third pass. The labeled concepts were then grouped into themes.

5.4 Findings

5.4.1 Survey Results from Older Adults with Diabetes

The following seven statements were used to evaluate the satisfaction of an image-assisted 24-hour dietary recall with older adults with diabetes (see Appendix A.9 and A.10).

1. The images helped me to remember some foods I had forgotten about.
2. The images helped to remember extra details of how my foods were cooked, prepared, or purchased.
3. The images helped me to remember the portion size of the foods I age.
4. The images helped me to verify the portion size of foods I age.
5. The images allowed me to provide more accurate information about the foods I age.
6. The application was easy to use.
7. I would like to use the application to record food intake in the future.

The average scores for the each question were: 7 (SD 0), 6.5 (SD 0.84), 6.67 (SD 0.82), 7 (SD 0), 7 (SD 0), 7 (SD 0), and 6.5 (SD 1.23) out of 7 points (see Figure 5.1). In particular, the average scores for all the questions were above 6 points, which were between the level

of "agree" and "strongly agree" described in the questionnaire in Appendices A.9 and A.10 . Survey results revealed that the images of food items were helpful for older adults with diabetes to recall multiple things, food items they had forgotten about, extra details of how their food items were cooked, prepared, and purchased, and the portion size of the food items they consumed. In addition, the survey results showed that the images of food items helped them not only verify the portion size of food items they consumed, but they also enabled participants to offer more accurate information about the food items they consumed. Furthermore, participants agreed that FRADA was easy to use when collecting images of food items they consumed for the past 24 hours. They also expressed that they would like to use the application to record their food intake in the future.

In brief, the key finding of surveys is that older adults with diabetes were satisfied with reviewing images of food items collected by FRADA due to multiple benefits, such as recalling additional eating events and verifying reported food items. This finding supports the results of the feasibility study in Aim 2 that reviewing images of food items enabled older adults with diabetes to identify additional food items which were not reported previously.

5.4.2 Interview Results from Older Adults with Diabetes

Usability of FRADA during the Deployment Study

Older adult participants were satisfied with FRADA when using it for 24 hours at home. OP3 said that it was easy for her to capture the images of her meals and snacks at home: *"Yeah, it was very easy for me. We don't have a dining room or a table; we eat off of a coffee table. And, with the children all around, it made me keep a clean spot on the coffee table to take the picture."* OP2 mentioned that the process of capturing images of food items was easier than writing them. *"It's easier. Much, much easier than writing down everything."* OP5 was also satisfied with the user interface of FRADA: "Very easy to do and very easy to read...Very

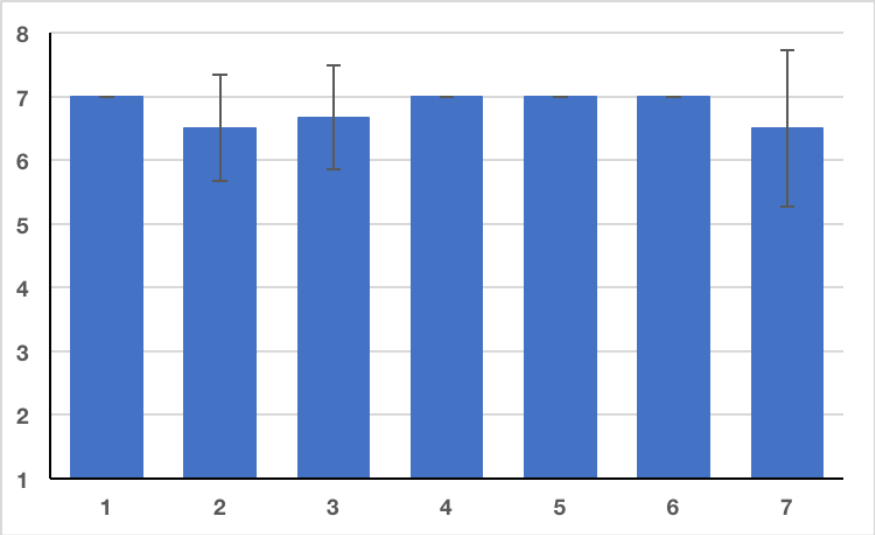

Figure 5.1: Average scores for each question illustrated in Appendix A.9 and A.10.

friendly and very informative and very helpful, too." In addition, they reported that FRADA worked functionally during the deployment study. OP5 stated, *"It worked pretty well. It did. It worked well. Took the pictures and submitted it to the dietitian and let me know that it was submitting to the dietitian, so it was, it did very well yesterday."* Similarly, OP6 said, *"it's pretty easy to do. Just take a picture and then wait and save it and send it to the dietitian."*

Satisfaction of Older Adults with Instructions

Older adult participants mentioned that the instructions were easy to follow. OP4 stated, "I thought it was very easy and I think especially because of the way you presented how to do it. You told me exactly how to do it. I think we went over that about three times, didn't we?" OP5 said, "Very easy. No problems at all." In particular, OP4 mentioned that it was very helpful to see how to hold FRADA for capturing images of food items prior to the deployment study: "And then also you telling me and showing me exactly how to hold the

camera at the 45-degree angle so I knew exactly how to do that and how to fit the pictures in the frame. As a result, I didn't have to take any of the pictures over again. I thought they all turned out just fine." Similarly, OP6 was satisfied with clear instructions: "But why I did a good job I think is because you, your good instructions. I knew exactly what to expect and I had planned for it."

Benefits of Using Images of Food Items for Older Adults

Recall Food Items Older Adults Did Not Reported. Most older adult participants agreed that the images of food items were helpful for recalling food items when meeting with a dietitian during 24-hour dietary recall interviews. OP3 stated that the images of food items helped her recall and verify food items she reported during the 24-hour dietary recall interviews: *"Really good. And it helps with recall... because I can't remember. And so, having pictures of it, it completely verified – more than just guessing...Well, I thought it was nice to have images because, as you observed, I had forgotten a couple items that I had eaten that we had pictures of."* OP6 also shared her experience when meeting with a dietitian during the study: *"Same with the picture. I forgot something, but I did have it in my journal and Megan notices it in the picture, so I looked back, yeah, I'd forgotten it to tell her."* Similar to OP3 and OP6, OP5 reported that the images reminded her of food items she had consumed: *"Well, it kind of reminded me of what I had eaten. I had forgotten. It reminded me of what I had."* In addition to reminding OP1 of the food items, she mentioned that the images of food items made her aware of the portion size of food items she had consumed: "Because of my memory. You know, I mean, I eat more than I think so I've seriously considered continuing this practice already because I think it's very beneficial to me...I'm just surprised I ate so much, especially chocolate." OP6 also stated that the images helped her estimate the amount of food items she had consumed: "if they sent me a picture, I could evaluate

what the amount was. If it's a decent picture, you can pretty much tell how much it is."

Leverage Images as an Alternative to Food Diary. Older adult participants were satisfied with the efficiency of recording food intake using FRADA. OP1 stated, *"Well, see, I've been writing it all down and I'm kind of tired. I don't know. I'd rather have the picture. A picture's worth a thousand words."* OP2 mentioned that it is easy and convenient to record food items: *"But when taking a picture, I don't need to do all those things, just take a picture, that's all. So, it's very easy, very convenient."* Similarly, OP6 indicated, *"But now I would use a picture. If anybody asked me again, I would ask for a picture of the meals that they had for one day, because that's a lot easier and faster than 24 hour recall."*

Help Diabetes Management and Health Behavior Change. Older adult participants mentioned that reviewing images of food items will support diabetes management. OP3 stated, *"I think it will help me a lot with my diabetes management... This is where the focus comes in. I'm going to pay attention to what I eat more. I know I had a dietitian set up my needs on."* OP1 mentioned that the images would motivate her to change her health behavior: *"I think it would be good for me to go back and maybe make up pictures of these that I can look at. And it really helps me to really be more motivated to measure how much I'm eating to better count my calories and stuff. Therefore, I really want to lose some weight. I'm really, really motivated now I think. And this is really a good spur on in that direction."*

Challenges Older Adults Face When Capturing Images of Food Items

Challenges in Different Environments. Older adult participants said that it is difficult to capture images of food items given some environments, such as at night or at restaurants. OP2 mentioned her challenges when taking the images food items with insufficient light: *"especially on last meal. That was at night at nine or ten, something like that. It wasn't enough light. I turned on every light, but usually in a camera they don't have enough light to*

take a picture. They need a flash." In particular, OP4 addressed challenges she faced when capturing images of her meal at a restaurant: *"I thought it was kind of a nuisance having to take the picture, especially in a restaurant. I had to move the other people's plates away sort of to get a good picture of my plate and then again take the empty plate. So, in a restaurant it's a little uncomfortable."* OP4 also mentioned that she needed to confirm that it is alright to capture the images in public prior to performing the task: *"I try never to use an iPhone in a restaurant when people are around and here I had to be sure and focus this properly. But it worked out fine and they were all very nice. And most of them had gone to the University of Washington so they kind of understood what I was doing. They thought it was a good thing to do."* Nevertheless, OP4 stated that she had to stop the conversation while capturing the images, though she was sitting next to her family members at a restaurant: *"But it kind of had to stop the conversation. "I've got to take a picture now, guys." You know, so we had to stop."*

Challenges in Performing Required Tasks. Some older adult participants felt that it was hard because they had to collect the images of all the eating events. Also, they were not accustomed to performing the task the first time. OP1 stated that she seemed to put her effort into performing tasks of collecting the images of her meals and snacks: *"And I had a full day. I was tired, but I did it."* OP2 mentioned that it was challenging for her to perform the task of collecting the images of food items at the beginning of the study; however, it became better to perform the task multiple times: *"In the beginning, when you explain to me and try to show me how to take a picture, everything in one frame, in the beginning, it was a little bit hard, but just a couple times and it was okay."* Similarly, OP5 also raised that there is possibility of educating older adults to use FRADA: *"I told her about the app study that you're doing and she was interested, but she doesn't really understand her phone that well, so I'm not sure."*

Potential Features of FRADA

Reminder. Older adult participants suggested that FRADA should have a feature for reminding them capture images of food items. Two older adults stated that they forgot to capture the images during the deployment study. OP5 stated, *"No. I forgot to do them last night."* OP6 also shared her experience about missing images: *"I didn't, it looks like I did not take the picture of the last, the cookies and the milk. It looks like I didn't take a picture of that but I didn't look to see. Like this one, there. I don't think I took another one. I forgot to take the one after I ate the cookies and milk. Obviously I didn't take it. So, it wasn't in there so I figured I must have forgotten."* OP4 tried not to forget to capture images of food items because it was part of the experiment: *"I think it would be easy to do that. I was focused on doing that all day. I thought, "Oh, I can't forget to take a picture because I don't want to screw your thesis up."* Nevertheless, she suggested that a reminder feature would help her perform the task of capturing images of food items in the future: *"Remembering to do it, you know. If you're going to eat something, you can't just grab something and eat it. Oh, I've got to take a picture of it. And then you wanted a picture of the plate afterwards to prove I ate it, I guess, or whatever."*

Support Diverse Populations. Older adult participants described potential challenges when people with special needs (e.g., tremors, language barrier) interact with FRADA. OP4 stated that it would be a good idea to address the needs of older adults who have trouble holding a mobile device: *"I think people that have trouble holding the iPhone or like my husband, he has essential tremors, he has diabetes, but he has a problem taking pictures with his camera so he doesn't take pictures simply because his hands shake. It takes him a long time. He has to put his arms against something so that they don't shake and the tremors don't obscure the picture."* Similarly, OP5 mentioned potential concerns of people speaking in other languages (e.g., Spanish) when they interact with FRADA: *"She's, she speaks Spanish,*

so I'm not sure that she really understands what I'm trying to tell her."

Use FRADA with Existing Tracking Applications. Older adult participants were eager to use FRADA in combination with existing tracking applications (e.g., MyFitnessPal *). OP4 said, *"MyFitnessPal for my diabetes management but I haven't been doing what I'm supposed to do. So, using this app in combination with the FitnessPal, I think it will be really helpful as well because I can't not remember what she said – how many grams of protein or carbs or whatever, and how they need to be spaced out. So, this is going to help me."* OP3 was also interested in using FRADA with MyFitnessPal: *"Also, I've done it – kind of like what we were talking about. When I was using MyFitnessPal, I would take a picture and use it to go back and enter everything on MyFitnessPal. And where it would talk about your lunch, and I'd say, "Okay. This is what I had for lunch" and I would enter it."*

Review Collected Images. This study showed that a feature for reviewing the collected images could be added to the next version of FRADA based on users' interest. OP2 was interested in reviewing the image she has collected: *"Yes, I think that's a good idea, just like taking a blood pressure measurement or sometimes they have a history, last history of blood pressure numbers and it's nice to look into what's changing in the blood pressure measurement. Just like that, dieting, it's changing a little bit. Usually, people only eat what they like so starting with taking all the instructions, following the instructions to cook or eating those meals, probably four of five months later or a couple months later, they are eating what they like. I think that's a good idea to look into what they eat."* Nonetheless, OP5 was not interested in reviewing images: *"If it's part of a study, I'll look at them and explain to you, but beyond that, I have no interest."*

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*http://www.myfitnesspal.com

Potential Use of FRADA

Older adult participants expressed that they are willing to use FRADA in the long term. OP3 and OP4 expressed that they are willing to capture images of food items frequently. OP3 mentioned, *"Normally, I would have gone maybe three times a week or more."* OP4 stated, *"I will keep this in mind and I may well use this idea of taking pictures of food more frequently."* On the other hand, other older adult participants stated that she would use FRADA only if she was asked to use it by her health provider. OP6 stated, *"If I were working with somebody at – I belong to Kaiser – and if I were working with somebody at Kaiser and they could also be plugged into the app, then yes, I would use it."* Similarly, OP2 said, *"Yeah, just once or twice a month and reporting it to dietitians and when we meet, they can suggest to me how I am eating or dieting."* OP3 wanted to use FRADA in the future because FRADA is much easier to interact with: *"And even if I don't do MyFitnessPal, I will do this – 100 percent. It's so much easier than anything else."* OP4 was also positive about use of FRADA in the future: *"I think it will be very interesting if this becomes a real app that people can use. And it will be interesting to see in the future if it's something that will be developed and available to people. If it works, it would be great."*

Nevertheless, OP6 did not want to use FRADA for now since she is satisfied with her current approach for recording her food intake: OP6 stated, *"But my method for journaling has worked for me and so I wouldn't be looking for another tool right now... Because the way I journal, I have a visual memory of what I've eaten so I don't really need the pictures. I already know what I ate yesterday and I know what my blood sugar was today. Actually, it was pretty good so what I ate yesterday translates with the amount of exercise I'm getting and what my blood sugar is fasting and what it is during the day."*

Older adult participants said that they would want to use the collected images as a memory aid when writing them down as their food diary. OP1 said, *"I would like to go*

back and update ... they call it a diary, which I have been doing for years. I didn't write them down because I thought maybe I could go back and write them down. So, I would like to do that." Similarly, OP4 mentioned that she can potentially use the images collected by FRADA when writing them down: *"Yeah. I thought it was kind of neat to do and I was thinking that I do want to keep a food diary and be more diligent about it. So, this would be a good way for me to do that. I would just take a picture of my meal and I wouldn't have to worry about remembering it. I could just go through my pictures and write it all down...even if you weren't associated with a study like this, you could take the pictures and then in the evening you could write down the food that you ate or the next day."*

Potential Target Populations

Older adult participants suggested multiple potential target users of FRADA. First, they said that FRADA would be useful for people with special needs for nutrition. OP2 mentioned, *"Any illness people live with. I think that's a good idea because they need a diet. They need specific diets to cope with the illness. I think that's a good idea to have this kind of thing, not only diabetes."* In addition, OP6 stated: *"Well I do have people that contact me every now and then for ideas and I have helped a number of family members and friends with special needs for nutrition, and it would be very helpful for them..."*

In addition, older adult participants mentioned that FRADA could help people who face challenges in keeping their food diary. OP4 said, *"Especially, it may be for people that are trying to keep a food diary but are having trouble remembering to write it all down, they might try this."* OP6 also mentioned that the approach using FRADA could be an alternative to writing down food intake: *"I think it's a good tool, especially for people who don't want to go to the bother of writing it down and if they're going to remember, they could either review their pictures or just the act of putting it together, eating it and then taking another picture*

might imprint on their memory better what they've eaten then if they just ate something randomly and not made a special note of what it was."

Additionally, OP6 mentioned that FRADA could support people who have memory loss that might bother 24-hour dietary recall interviews: *"but sometimes drawing it out for someone else, they just can't remember if they're not used to doing it. So, a 24-hour recall for some people does not work at all, so a picture definitely is a good idea."*

Privacy Issues by Sharing Images of Food Items

This study showed that older adult participants were not sensitive to any potential private issues by sharing their images of food items with family members. OP4 said, *"I wouldn't mind sharing them, but I don't think he would be interested in seeing them. My kids don't live at home anymore. They have families of their own and I don't think they would be interested in seeing my pictures of the food that I ate. I think it's a personal thing. I wouldn't mind if they wanted to see them."*

Taking Control While Reviewing the Food Images

Older adult participants did not have strong interest in leading the process of reviewing images during 24-hour dietary recall interviews. OP5 said, *"She was doing it, but I could see what they were, yeah. I was comfortable doing that."* In particular, she mentioned that it must be natural for her dietitian to take control: *"She took control. That's the way she should though. She's a dietitian....I was happy to let her do it."*

Trust Issues When Sharing Images of Food Items

OP5 stated that she did not want to share with other people food items she should not consume: *"Probably not. I want to look like I'm behaving myself. I don't want anybody to*

know that I'm eating something I shouldn't. That would be giving myself up." She also mentioned that she actually did not visit a fast food restaurant for that reason, though the place might be one of the restaurants she prefers to visit. *"I didn't want to go to McDonald's and get a Big Mac. I figured that wouldn't look good. It's not good for the study. Even though I love Big Mac's, but I try not to eat them very often."*

5.4.3 Key Findings from Interviews with Older Adults with Diabetes

Overall, interviews with older adults with diabetes in Aim 3 revealed several key findings for understanding the needs, preferences, and barriers of older adults with diabetes when they interact with FRADA. First, FRADA was usable for older adults with diabetes when they use it for 24 hours at a home setting. Similarly, the instructions for collecting images of food items were easy for older adults with diabetes to follow during the deployment study. This findings correspond to the results of Aim 1 where older adults with diabetes were satisfied with FRADA and the instructions for performing tasks using FRADA in a lab-based setting.

Next, I identified potential benefits of using images of food items for older adults with diabetes. For instance, reviewing images of food items helped older adults with diabetes recall any food items they did not report previously. Also, efficiency of recording food intake using FRADA enabled older adults with diabetes to consider collecting images of their meals and snacks as an alternative method to keeping a food diary.

Nonetheless, I found challenges older adults with diabetes face when older adults with diabetes capture images of food items. For instance, it was difficult for them to collect images of food items using FRADA at night because light was not enough to capture. Another example of the challenges includes issues when older adults with diabetes capture images of food items at a restaurant because they need to ask other people sitting around them to ensure that it is alright to capture images. Also, this study showed that some older adults

with diabetes faced a challenge in using FRADA at the beginning of the study as they were not familiar with how to manipulate it.

In addition, older adults with diabetes suggested potential features to be added to FRADA. For instance, they were eager to have a feature for reminding them capture images of food items as they forgot to capture the images during the deployment study. Also, they suggested that FRADA could have additional features to support other populations, such as people with hand tremors and language barriers, which were not reflected in the current version of FRADA. In addition, I discovered that the future version of FRADA could be used in combination with existing tracking applications including MyFitnessPal, as FRADA may fill the gap existing tracking applications have.

Furthermore, this study showed that it is important to consider trust issues when asking older adults with diabetes to share images of their meals and snacks through FRADA, although they are willing to use FRADA in longer periods. For example, one participant stated that she did not want to share with other people images of food items she should avoid.

5.4.4 Interview Results from Dietitians

Challenges in Current Practice

Dietitians stated multiple challenges in their current practice when meeting with older adults. First, dietitians expressed challenges they face when using food models to conduct 24-hour dietary recall interviews with clients. DP1 mentioned, *"sometimes I used food models to help them to provide a little bit better amounts of foods they ate, but they just helped them to provide more accurate amounts, but that doesn't really help seniors to recall the products what they had."* DP2 stated that *"But still the food models are not able to show me the food size or amount the patient ate contrary to images."*

In addition, dietitians reported challenges when conducting 24-hour dietary recall interviews with older adults in their current practice. DP2 shared her experience when meeting with older adults: *"We always complain or notice that 24 hour recalls are very helpful for each of us already conduct 24 hour recalls. When we meet patient especially for the first time, we all use them, but we all complain of the limitations the fact that people forget, under or overestimate. Especially older adults, YES."* She also raised the issue about older adults' willingness to report correct food items: *"So she or he wants to do presenting her information in good way to impress."* Similarly, she mentioned, *"... want to emphasize that you ate vegetables cause you are expected that dietitians want you to eat the vegetables."* In particular, DP3 stated that people with Alzheimer's disease might not able to report ingredients they consumed correctly because they did not cook but were given food items prepared by someone else: *"So they don't realize ingredients what's in it because they just eat what they were given but they don't focus on that or difficult to remember."* Additionally, DP3 reported challenges in estimating the portion size and nutrient content of food items when people had gone out to eat.

Benefits of Using Images of Food Items

Dietitians mentioned several benefits of using images of food items when conducting 24-hour dietary recall interviews with older adults with diabetes. First, they mentioned that the images helped patients identify additional food items. DP3 stated, *"I think that it's really helpful. We did find one thing that she had completely forgotten about even though she was really detailed in her own journaling. And we talked through the 24-hour recall, but then when we brought up the photo, we realized that she had forgotten something. So, that was helpful."* This led dietitians to better estimate the portion size of food items older adults with diabetes had consumed. DP2 stated the benefits of using the images based on her

experience: *"It would be great if every single dietitian access to the images when conducting the food recall 24HR, because sometimes there might be some misunderstanding or patient can either overestimate or underestimate what they eat. So I think it would be really helpful."* Similarly, DP3 mentioned, *"It's also helpful from a sense of looking at portion sizes cause sometimes it's really hard for people to estimate how much…they don't have a sense of what is a cup? Or what's half a cup? So, it's nice to have images for that reason."* In addition, dietitians mentioned that reviewing images of food item can enable older adults recall food items they had not reported during the 24-hour dietary recall interview. DP1 said, *"It is a really good idea to use images to review older adults dietary history the day before because the images really help older adults recall what they ate the day before…the picture really helped them to recall what they had"* Similarly DP2 stated, *"Yeah, I think for example, patients forgot to mention specific food or underestimated or overestimated the portion size by reviewing images I could remind the patient that he or she had eaten something she didn't mention. Or that instead of two eggs, maybe patients ate eggs 3 eggs."* Furthermore, to identify more specific information about eating events of patients, the images enabled DP2 to hold longer conversation with patients: *"…use the images to continue to conversation and make it more detail, go deeper."*

Second, dietitians expressed that images of food items provide additional information to understand the dietary patterns of patients. DP2 indicated that the images offered extra information: *"So I noticed that when I reviewed the images after the food recall, there was lots of information that could have been helpful to know beforehand."* DP1 also agreed that images can be additional source of information: *"it's like a supplemental information."* DP1 used such additional information from the images to confirm food items older adults with diabetes reported. *"because the images confirm, kinds of confirm what the seniors recorded."* In particular, DP3 stated that the information from the images can be used to determine if

patients went outside for dinner: *"You can see the table cloth or with that client was out to eat – you could see she was out to each. So, that was nice."* Similarly, DP1 mentioned that reviewing images of food items helped her figure out dietary patterns of patients: "we can see their dietary patterns: how often they eat out. How often they tend to cook at home. I think that also may help."

Third, dietitians stated that it was efficient to conduct 24-hour dietary recall interviews using images of food items. DP3 said, *"The pictures especially though compared to just verbally describing. The pictures are quicker and they're a little bit more – I don't know – it's just easier to see and understand what they're talking about."* Also, she mentioned the efficiency of using the images when investigating the food items people had consumed: *"Yeah. I think that it's very helpful. I think that it's a useful tool. It's an efficient tool to be able to quickly see what people are eating and drinking."* In addition, she reported that the images helped her estimate the portion size of food items people actually consumed: *"the pre and the post to see how much they actually did eat... I think that's really helpful to see how much they actually ate."*

Lastly, dietitians reported that images of food items may improve awareness of patients for better eating health behaviors. DP3 mentioned, *"I think it's also just like any other tracking device or tracking method, it's really helpful for awareness because they then are able to kind of be more conscious and think about how much, and what they're having, and when they're having it... the biggest thing is probably the awareness because she was just so focused on doing it..."*

To sum up, dietitians reported that the images of food items collected by older adults with diabetes made the image-assisted 24-hour dietary recall interviews accurate and efficient, as the process of reviewing images met the needs of dietitians (e.g., understanding the dietary patterns of patients). Also, they mentioned that the images of food items may encourage

patients to have better health behaviors.

Viewer Application for Reviewing Food Images

Dietitians were satisfied with the usability of the application for viewing images FRADA generated, information provided by the application, the quality of images when reviewing them. First, dietitians reported that the viewer application was easy to interact with. DP1 said, *"It was easy. All the pictures were there. So, I can Just scroll down."* DP3 stated, *"I used a tablet and it was. Not difficult because it didn't require any particular computer skills or something too advanced... So the fact that I was able to do it without even doing any kind of rehearse out because you gave me the tablet and they just started."*

Second, dietitian participants liked date and time information because such information was essential for dietitians when conducting dietary assessment with patients. DP1 mentioned, *"I think actually the date and time is really helpful because especially for patients with diabetics sometimes also it is very important. Obtain what time they eat food. So that time tells me actually their diabetic patterns, too. For example, I can see interval between breakfast, lunch, and dinner, or snacks. If patients had snacks just after the meal, I maybe provide some advice that Why don't you have some space between meals and snacks? That would help her blood glucose management."* Similarly, DP2 said, *"I really like the fact that we have the date and time. I think date and time is really important."* In particular, DP3 was very interested in the possibility of accurate date and time information: *"Well, I like the date and the time. The time, especially because a lot of clients get the time wrong and – or they're just guessing. They're kind of estimating. So, it's nice to have the time in there as long as it's correct on their phone or in the app while they're doing that."*

Third, they liked the images captured at a 45-degree angle because the approach allowed them to identify any food items on dishes. DP1 stated, *"I can see the whole food, all the food*

and I can see little space here. So I think the strategy was really helpful." In particular, she was positive about this strategy, as this can be an approach to make the images standardized. For example, she mentioned, *"... make all the pictures standardized for individuals. Also, the meals. You had a really good strategic idea that make that Standardization."*

Fourth, they liked the process of reviewing images captured before and after each eating event, as those two images offer additional information (e.g., portion size of leftover). DP2 stated, *"I really liked the idea of taking a picture before and after. I liked it because you can see how much patients ate, this is important because especially someone goes out and they are given a very big portion of food they can choose all much to eat."* DP3 mentioned, *"Well, I think that this time around it was really nice to have the pre and the post. And to think about having my patients capture that. So, I'll probably actually do that in the future with my own clientele, is ask them to do pre and post. Because I think that's really helpful instead of just estimating or instead of just having them tell me how much they actually ..."*

Nevertheless, dietitians reported issues when reviewing images of food items. First, DP1 mentioned that some ingredients were not easy to detect from the images. *"Some ingredients didn't show in the image. Maybe that can be a still little limitation like example some ingredients may be hided by other big ingredients, but we cannot see in the picture."* Next, DP2 expressed that she would prefer the imaged located horizontally, while the images were displayed vertically (see Figure 3.2). DP2 stated, *"If they are placed side by side, I think it would be easier to look at cause so that I have to here and go down. But if I want to look at the before, I would go up again and p and down up and down."*

Potential Features of a Viewer Application

Dietitians wanted to obtain additional information that could potentially be used for better dietary assessments. DP3 emphasized how important it is to understand the environment

around patients: *"So, it's kind of nice to know, "Okay. Where is this from? And where are you eating?" Cause that's like a behavioral thing with food. Like are you eating on the run? Are you eating at somebody's house? Is it sitting in front of the TV?...Your environment affects what you're eating."* Dietitians were eager to obtain location information where patients consumed food items because location information is a relevant factor. DP1 stated, *"Maybe location if there is location information, that would be helpful too. So that we can see whether they may cook at home more or they may eat out more."* DP3 mentioned, *"Maybe a location. So, like home versus out to eat or being able to put in where they were at and where they were eating to help them remember."* She was very interested in additional data when meeting with patients with specific diseases (e.g., diabetes): *"if the app is specifically for patients with diabetes, I think it also would be also helpful in the future, it also could include some lab results for example like a blood sugar. So we could see blood sugar before the meal, and then blood sugar after the meal"*

Furthermore, dietitians wanted to have additional information to estimate the portion size of food items more accurately. DP1 was concerned about how to measure the size of containers on the images: *"Yea, for example, patients drink a cup of milk but I don't know how big the cup is. I don't know the size of the cup. I don't know. I cannot tell by the picture."* DP3 shared her experience about how a reference object can be used: *"to have some reference objects. So, like – for example – the Chobani, I know what size that is. So then, I can estimate the sizes of the glasses around it. But if that wasn't there, it would be hard to estimate"* In addition, for better estimating the portion size, DP3 suggested that dietitians use the images captured from the side rather by addressing the challenges when using the images captured from the top: *"Yeah. So, I think it's easier to not see it top down, but to see it form the side so you get a sense of depth...And not top down, ideally, it would be from the side so you get that height in there...Versus a top angle. Yeah. Which most people*

I think tend to do that, but yeah. I have had a couple people kind of like the whole plate. And then, when it's top down like that it's really hard to see …"

Dietitians were eager to have clear information about the images of food items. While the current application use military time to represent time information, DP2 wanted to see a 12-hour clock format when representing time information (e.g., 9:00AM instead of 9:00): *"I don't see here it's AM or PM, so I would suggest either way you know, I am not sure that's what I grow up with. I think it is called military time here in the U.S. For example, 9PM is 21 in my home country. So here I am not sure whether it is 9 in the morning or pm."* Similarly, dietitians wanted to see a description of the images to avoid any confusion. DP3 stated, *"if I didn't have their description – seeing the images without the description could sometimes be a little bit confusing."* In particular, DP3 expressed the value of descriptions of the images when patients were physically not available: *"Well, if I was going to get the pictures without having the client present, then I would want a description...If the images were going to be used without the client, it'd be nice to have a description of what it is."*

Dietitians wanted to be involved in the process of image-assisted 24-hour dietary recall interviews actively. DP2 was interested in a feature for sending a reminder to older adults to avoid any missing images: *"As patients know that as she or he has to see me, I would send the patients a reminder if it's possible to send me the picture."* While DP2 wanted to reduce any missing images before conducting 24-hour dietary recall interviews, DP1 was eager to supply information about the images after 24-hour dietary recall interviews. *"…the area where I can type some comments. That would be helpful … I may think too far, but if I use it in my practice, I may leave some advice or I would say this snack was OK, but this dinner may include this one, you may include this one. You may decrease something advice."*

Dietitians wished to use applications without any technical skills but based on their

preferences. DP2 stated, *"Only problem is that I am not very high tech person. I am not an expert in this area."* To overcome any potential challenges of using an application, DP3 suggested that an application should be easy to use: *"Especially with people who aren't quite as tech savvy, just making it a little more user friendly in that regard would be helpful."* DP2 suggested that user interface of the application be customized for each individual user to reflect his or her preference: *"You can choose other views. Probably, I think the option to choose could be better because for me it's the same, but there might be other person who don't like this view probably I don't know. So there was a possibility to change the view I think it would be a plus"*

Furthermore, dietitians were eager to organize the images collected by patients. In order to clarify the source of each image, DP2 wanted to see the name of patients who collected each image: *"Maybe the name of patient also as an identifier. If I add collection of photos in my computer, you know sometimes gets confusing, pictures get lost, you don't know who they belong to."*

Who to Control? Dietitians vs Older Adults

This study revealed that dietitians controlled the viewer application to review images collected by FRADA during 24-hour dietary recall interviews. They mentioned that they did not intend to control the process, but it happened naturally by their personal habits. DP1 stated that she had led the process of 24-hour dietary recall interviews to make the given time with patients efficient: *"I think it was just my habits. When I had limited time with patient to assess their diet, actually we usually have very limited time. So, I had to use our time effectively. So, I think I was not really patience with older adults. That's why maybe I would like to process more quickly. That's why I just control it. And then just ask the questions. Because if older adults control, it may take little longer time. So, I think it was my habit."*

Although DP2 agreed that she did not intend to lead the process of reviewing images, she expressed that she would like to involve patients in the process: *"It happened naturally. That was supposed to different? I think I was holding the tablet both times. Probably I would go back I would involve patients more. It would be helpful to maybe I don't recall how I was holding the tablet, but I am sure that I was leading that part."* DP3 also led the process of reviewing images in the situation where the tablet was located closer to her: *"because it was closer to me, and then I just ended up turning it to her and scrolling through."*

Although dietitians did not intend to control the process, they were aware of the benefits of leading the process. DP2 mentioned the benefits of the process of reviewing images led by dietitians: *"Probably conversation would be longer. In that case, that would be more room for the patient to comment to participate. I am thinking that case I will lead the conversation cause I was thinking about duties for activities which was putting the check. But in real life, I would love to involve the patient more."* DP3 also indicated the advantage of having the control, though she was not concerned about who to lead the process: *"I might have more to talk about one picture than another. So, it's kind of nice to be able to have that control to slow down and ask more questions...I think it could be either. So, from a patient's sense it's kind of nice because they're still in control. But from a clinician sense, I might want to pause longer."* Similarly, although DP2 expressed that it is better for her to lead the process, she emphasized the importance of patient involvement during the process: *"I still think that I should be the person in control, but I think the person could be involved more. And after reviewing every single picture, maybe there would be more time for conversation and comment."*

Dietitian-Patient Interaction

This study showed that dietitians wanted to involve their patients as stakeholders when reviewing the images of food items. DP2 wanted to interact with patients during the review process because she was eager to obtain specific information about eating events of patients: *"in real life, I would now exactly that kinds of diseases that this patient has. It would be really important to me to involve the patient when reviewing the pictures. If the patient has diabetes and she said that she didn't eat rice, then in the picture, it looks like she adds four cups, I would definitely love to share the tablet with the person and show her what I mean because I really need to know specific information."* In addition, she mentioned how important it is to make patients active during the process. DP2 stated, *"I think it is important in general to involve the patients in any kind of activity cause I don't want them to get board or lose track of what I am saying. So, I think what I did came natural but ideal would be also involve the patient and make sure she sees stuffs."*

To facilitate interaction between dietitians and older adults with diabetes during the process of reviewing the collected images, DP1 suggested a large screen as a tool: *"I think I would prefer a little bit bigger screen. Whatever device has bigger screen because then I can see the reviewed pictures with older adults together. If I have a small phone, it is very difficult to look at the pictures together. So, I would prefer whatever device has bigger screen."* DP3 also expressed her preference in using a large screen because the screen will be shared during the process of reviewing collected images: *"And get to it that way, that's what I would prefer as clinician. So, that we're looking at it together on a bigger…it would be easier to just make it larger and see the whole thing versus having to scroll back and forth."* She addressed that a large screen might make it easier for older adults to view the images together: *"you can make it larger for seniors, and to really see, and go through each one versus if you had the little icons, and then you'd have to click, and open each icon."* She described her

previous experience in practice when sharing the collected images with patients through a bigger screen: *"a lot of my clients track on their smartphones. But then I actually pull that information up through the web on my computer because it's a bigger screen. And then, we can look at it together."*

Potential Benefits of Using Images of Food Items

In addition to the primary benefits of using images of food items described in Section 5.4.4, this study revealed multiple potential benefits of using images of food items. This study showed that the images can be used as materials for educating patients. DP2 introduced a use scenario using the images to educate patients: *"...if I saw a picture that would present a meal that looks really balanced, really nice, I could use them without identifiers, show that picture to another patient. Even if the patient is different age or different needs, to show a picture of meal eaten to someone else...by showing them pictures of people who ate what I mean. I can tell them this is what I mean. This is just an example, but this person ate the meal. What could work for you do."* This scenario corresponded to her prior experience using the images available in the Internet: *"I google pictures of meals, and they show them what I mean when I say something like half of the plates should be filled with vegetables, the amount of fries shouldn't be more than a fist."* DP1 was also interested in collecting the images of meals to create materials for patient education: *"pictures also can be used for collecting like an example of good meals. I think it is a good resource. We can use the pictures to make our handout. Just good resources for practitioners to make a handout or book. That would be a good materials."* DP3 stated that the images could be used as intervention for health behavior change, though the images were used as materials for dietary assessment in this study: *"That also could motivate patients to maybe modify their diet. So, we could see that oh you had a lot of fruits in that meal or you had a lot of carbonates in that meal. No wonder*

why you had elevated blood sugar. That can be education tool for patients to encourage them to monitor their diet."

In addition, this study showed that collected images can be potentially used for future studies of dietitians. DP1 particularly mentioned potential opportunities of analyzing the images by integrating external data, such medical history of patients, to identify the correlations between dietary patterns and chronic diseases: *"I think that can be for future studies as a dietitian. Maybe possible studies. For example, we have all the images from many differed individuals. If we know their medical background, maybe we could do some study related to dietary patterns or dietary pattern with their chronic disease. We can see the pattern between what they eat and higher chance of these chronic disease. We could find some relationships between dietary patterns and chronic disease. I think that could be a future study material."*

Complementarity between Interviews and Images

Although dietitians wished to see descriptions about the images as additional information, they still considered the process of 24-hour dietary recall interviews to be valuable. DP3 mentioned that speaking with patients enabled her to identify information clarifying food items in images: *"Especially talking through it. It's not easy if I just had the images without the description of what it is. But yeah, talking with the patient, and having them point things out, and talking about portions. That was very easy."* Similarly, DP2 stated that the interview was helpful to identify food items not captured in images: *"The interview could complement information obtained by the pictures. So no problems if some pictures were not taken."*

Concerns of Dietitians when Using Images of Food Items

Dietitians reported multiple concerns when using images of food items. First, they were concerned about whether older adults would be able to perform tasks required for image-assisted 24-hour dietary assessment interview successfully. DP2 was worried about situations where older adults forget to capture images of food items: *"But I would imagine that people make forget to do it. It happens... if the patient forgot to take the picture of the rice, I could not comment on during the visit about the rice. So that would be still limitation the patient should remember that they should take a picture."* DP3 was concerned about how successfully older adults would be able to use a smartphone application to capture images of their meals and snacks: *"How easy it is to navigate that for the seniors cause this was very easy to just look at all the pictures and talk through it."*

Second, dietitians were concerned about sharing collected images via phones, as they would be considered as the private information of patients. DP2 stated, *"From what I know, as we are talking about information associated with patients, you are not supposed to have pictures with your personal on your personal phone. I am not sure if I would be allowed to review this picture from the phone unless the cell phone provided by hospital which is unlikely."*

Lastly, this study showed that dietitians would need training sessions to get accustomed to leveraging the images of food items during 24-hour dietary recall interviews. DP2 said, *"Because I remember the first time I was reviewing images, I was also trying to speak with the patient, so (I wanted to) make sure that all the images were there because I had to put the cross or a tick to show in your paper in writing if something is missing, so, I needed to pay attention to that. There was a speaking with the patient that so that's why it took more time. But I don't think it was a problem for everything for your first time is slow, and then second time you do it faster, and third time you are like wow you like it."*

In brief, dietitians were concerned about multiple factors, such as whether older adults could perform their tasks successfully, whether image collected by patient could be still shared by their phones, and whether they could use the images in real-life settings.

Best Time to Review Images of Food Items

Dietitians preferred reviewing images prior to meeting with patients. DP1 mentioned, *"I do prefer to have images before I meet the patient so that I can review first so that I can have some ideas about their dietary pattern even a little. When I meet the patient, I have better ideas where to start or what to provide in terms of advices. So, it would be better to have the images prior to maybe appointment time."* Also, DP2 expressed the same opinion that she would prefer reviewing images in advance: *"I think the day before or a few hours. It depends some dietitians screen."*

In contrast, DP3 mentioned that it is still important to review images of food items with patients together: *"However, with picture you really do need to talk through it and discuss what that is cause sometimes it's really hard to just see and know is this collard greens? Or is it spinach? Is it chicken? Is it pork? So, you really do need either that verbal or a written description of what the food is along with the picture. So, from an efficiency sense, it's fastest to just do it together. Look at the picture together and have the patient walk you through it."* Although she preferred reviewing images when meeting with patients, she was eager to receive the images in advance to make the process of the dietary assessment efficient: *"it'd be nice to have that information ahead of time, and then be able to plug it in, and do all the nutrient analysis to then have the feedback for the patient in the session…maybe sending the pictures in advance before the visit could be again a plus because it could save time."*

Potential Target Populations

Dietitians suggested a variety of potential target populations. DP3 mentioned that using the images would be helpful for people who are not going to journal or track anything: *"Specifically, with clients who aren't going to journal and are not going to use an app to track each thing, each food item, and plug that in. I think it's really helpful for them."* DP1 stated that the dietary assessment using the images would benefit people who cannot meet with dietitians in person: *"If we had a comment box, actually, for the future, a dietitian I think doesn't have to be there. I think maybe more convenient for some situations. For example, patients live far away, very difficult to access, came to the hospital or some limited accessibility. Then still they don't need to come. I can just communicate with patient with this picture and my advice. So, I think it would be also, can be used conveniently. We can break some limitations."* Also, she suggested that this process would be valuable for people with other chronic diseases: *"I think it can be helpful for people with other chronic diseases that are. Closely related influenced by their diet."* DP1 suggested that people with Asian backgrounds would benefit highly through the dietary assessment using images of food items because the images can be used to recall small but diverse ingredients included in Asian-style meals. DP1 stated, *"I think personally people with more Asian background may would benefit from these images because as long as I know that, Asian dishes usually had a lot of small ingredients. For example, chopped garlic, chopped onion,... images really help them remember a little ingredients like sesame seeds, but I realized that Western dishes are not as delicate as Asian dishes, so maybe more benefits for people with some Asian culture, background."*

While other dietitians suggested potential target populations by using images as a memory-aid material, DP2 mentioned that the images could be useful for communicating with people whose first language is not English: *"At the clinic where I work right now, I work with a lot of patients who don't speak English, and frequently almost every day, I use a phone interpreter.*

So Patients in front of me but interpret over the phone. But using this app which doesn't have any characters. I would. It would be really helpful because I could show to the patients in front of me the images which don't have any English characters or anything."

Potential Benefits of Using Automated Image-Assisted Dietary Assessment Methods

Dietitians were enthusiastic about potential benefits of using automated image-assisted dietary assessment process because such a process can make dietitians focus on their primary role of helping patients make changes: *"Most RD's would be happy to just have that done and then we can focus more on what really matter is helping the client make changes."* In addition, she was hoping that a manual process, such as plugging in all the data into the system, will be diminished by a potential automated dietary assessment system: *"If in the app there was also a place to plug in the info and have it do an analysis. If they want to take that to the next level... Also, the motivational interviewing. So, like helping people with behavior change cause we don't need to plug in all the data. I mean that's – a computer could do that, right?"*

5.4.5 Key Findings from Interviews with Dietitians

The overall key findings related to the interview results from dietitians were satisfaction of dietitians with the process of an image-assisted dietary assessment, benefits of reviewing images of food items, concerns of dietitians when reviewing images of food items, and potential features to be added to FRADA that would meet dietitians' needs. First, this study showed that the process of reviewing images of food items collected by FRADA met the needs of dietitians. For instance, they reported that they were able to conduct more accurate and efficient 24-hour dietary recall interviews with older adults with diabetes by reviewing the images, which would ultimately improve the accuracy of a traditional dietary assessment

method.

Second, the interview study revealed that potential opportunities of using images of food items for dietitians. For example, dietitians stated that the images of food items can be used as materials for educating patients. One of the proposed use scenario was to ask patients to review images of food items collected by other patients, as this strategy allows patients to prepare better meals. Also, one dietitian mentioned that such collected images would be useful for any potential future studies of dietitians, such as investigating the diet patterns of patients.

Third, I discovered that dietitians have concerns when using images of food items collected by older adults with diabetes. One of the concerns was that they were worried about reliability of the images collected by older adults. For instance, they had concerns about how successfully older adults would be able to use FRADA to collect images of their meals and snacks.

Lastly, one key finding in the interview study is that dietitians were highly motivated about improving accuracy of dietary assessments. For example, potential features proposed by dietitians were to obtain more accurate information for better dietary assessments. Dietitians were eager to see information about locations where patients had meals and snacks so that they may have better ideas to understand the environment around patients. In addition, to obtain more accurate information from patients, dietitians were interested in sending a reminder to older adults to avoid any missing information.

5.5 Discussion

5.5.1 Biases by Study Design

This study has potential biases related to generalizing the findings. For instance, it is possible that this application and process would require dietitians to put more effort into the meeting

with older adults. In this study, each dietitian conducted 24-hour dietary recall interviews with two different older adults. Dietitians with more extensive use of the system may become more familiar with the process of reviewing images of food items. DP2 actually spent more time with an older adult because she was not familiar with the process of reviewing images with the older adult participant, though she was aware of the study procedure.

In addition, this study did not evaluate the performance of each dietitian after performing their tasks of conducting 24-hour dietary recall interviews. According to eligibility criteria, all the dietitian participants held a Master's degree with a RD credential and had previous experience with older adults for more than at least 12 months. Although such eligibility criteria enabled me to collect reliable data from older adult participants, the differences in abilities in conducting 24-hour dietary recall interviews among dietitians were not measured in this study.

5.5.2 Methods for Understanding Perceptions of Older Adults with Diabetes

Overall, I used extensive assessment methods to understand perceptions of older adults with diabetes when they interact with FRADA. To evaluate usability of FRADA with older adults with diabetes in Aim 1, I assessed their report on what they liked or did not like about the use of FRADA through surveys and interviews (see Appendix A.4 and A.5) in a lab-based setting. In Aim 2, I evaluated the feasibility of FRADA by counting the number of images collected by FRADA in a natural setting: 1) the number of images containing all the food items in a one single photograph, 2) the number of images taken at a 45-degree angle, and 3) the number of before and after images they took (see Equation 4.1, 4.2, and 4.3 and Appendix B). Aligned with those two previous experiments, Aim 3 focused on understanding needs and challenges older adults with diabetes may have experienced when interacting with FRADA in a natural setting through surveys and interviews (see Appendix A.9, A.10, and A.11). For

future work, it would be worthwhile to see how quickly older adults with diabetes accomplish all the required tasks (i.e., capturing, viewing, and transmitting images of food items) using FRADA. The results of such experiment may confirm the efficiency of using FRADA as part of findings of surveys and interviews from Aim 3.

5.5.3 Disparities between Dietitians and Older Adults

Through interview studies with two different groups of stakeholders, this study showed that there exist disparities between dietitians and older adults.

Dietitians' Concerns vs Older Adults' Abilities

First, while dietitians were concerned about the ability of older adults in performing the task of collecting the images of their meals and snacks, two studies (i.e., lab-based usability study and deployment study) with older adults revealed that FRADA was easy enough to interact with. Little is known about how much dietitians might trust the quality of the images collected by older adults.

Second, dietitians and older adults had different perspectives about the images of food items. Since dietitian participants considered the images as private patient information, they had concerns about using their personal devices to access to the images. However, older adult participants were not sensitive to sharing their images with other people.

Lastly, both dietitians and older adults agreed that they need training sessions to familiar with the process of 24-hour dietary recall interviews using images of food items. However, while dietitian participants wished for training sessions about how to review the collected images during the 24-hour dietary recall interviews, older adult participants were interested in learning how to manipulate FRADA to capture images of food items rather than how to interact with the collected images during the 24-hour dietary recall interviews.

Who to Control a Viewer Application

Although all the dietitian participants led the process of reviewing images of food items, they were eager to involve patients in the process. For example, they were willing to ask patients to navigate images, though they still wanted to take control to make the process efficient given the situations (e.g., limited time assigned to each patient). While dietitians wanted to encourage older adults to participate in the process, the interview study revealed that older adults tended to depend on the instructions from dietitians.

Potential Target Users of FRADA

Both dietitians and older adults mentioned that potential target users could be those people who are not good at journaling or tracking their diets. In other words, FRADA was considered as a tool to support recording food intake by both dietitians and older adults. While older adults considered people with chronic diseases, which are relatively common to older adults, as potential target users of FRADA, dietitian participants suggested populations with different types of needs, such as people who have language barriers and people who consume small but diverse ingredients.

5.5.4 FRADA as an Intervention Tool

The findings of this study demonstrated that FRADA was used as a valuable tool to support an image-assisted 24-hour dietary recall interview. While the findings showed potential opportunities of leveraging the images of food items for improving the accuracy of a traditional dietary assessment method, both dietitian and older adult participants expressed that there is potential to use FRADA as an intervention tool. For example, dietitian participants stated that the images of food items may potentially increase awareness of patients for better eating habits. Older adult participants reported that the images of food items enable them to think

what to eat next.

5.6 Contributions

To my knowledge, this study is the first attempt to evaluate the satisfaction of both health providers (i.e., dietitians) and patients (i.e., older adults with diabetes) with a smartphone application for improving the accuracy of image-assisted dietary assessments. The findings from Aim 3 suggest design implications for potential useful features to be added to FRADA. Ultimately, both health providers and patients using FRADA will be able to collect a variety of types of data (e.g., text, voice, and biological signals) that represent patients' blood pressure and physical activity patterns. Further, the qualitative feedback from participants offers insights in designing and developing image-assisted dietary assessment methods that address the needs of both dietitians and older adults. This finding may allow designers and researchers to incorporate such insights into tool design to support multiple stakeholders involved in the dietary assessment process. To conclude, this study is the first attempt to understand the satisfaction of both health providers and patients with a smartphone application for improving the accuracy of image-assisted dietary assessments.

5.7 Conclusion

The findings of the deployment study in Aim 3 provide an evidence that both dietitians and older adults are satisfied with the process of an image-assisted 24-hour dietary recall interview including the process of collecting the images of food items at reviewing images via a viewer application in real-life settings. Using FRADA not only enabled older adult participants to track their diets easily, but it also allowed them to use the collected images for health behavior change. In addition, the process of reviewing images during the 24-hour dietary recall interviews between dietitians and older adults facilitated interactions between those two stakeholders. Therefore, the findings in Chapter 5 suggest that there is

potential to design and develop technologies leveraging the images of food items for better dietary assessments. Furthermore, the findings revealed that each stakeholder has different perspectives that would potentially need to be incorporated into tool design to support both stakeholders.

To sum up, the deployment study using FRADA shows that dietitians are able to conduct image-assisted 24-hour dietary recall interviews with older adults. That is, the findings of Aim 3 show that both older adults with diabetes and dietitians are satisfied with the process of using images of food items collected by FRADA, while no previous studies evaluated the satisfaction of those stakeholders when using images of food items. I conducted surveys and interviews with two groups of stakeholders (i.e., dietitians and older adults) as part of this deployment study based on the findings of the lab-based usability study with older adults with diabetes in Chapter 3. In Chapter 4, I demonstrated that older adults with diabetes can use FRADA to capture images of their meals and snacks. Also, the images of food items were used for improving the accuracy of a traditional dietary assessment method. The work presented in this chapter supports the overall Aim of assessing whether FRADA can improve the accuracy of traditional dietary assessment methods among older adults with type 2 diabetes. This chapter focuses on Aim 3 of evaluating the satisfaction of older adults with diabetes with FRADA and dietitians with image-assisted 24-hour dietary recall interviews.

In the final chapter of this dissertation, I will highlight major findings from the three aims. Next, I will present contributions and discuss limitations of this study. In the end, I will propose future work that could potentially contribute to the fields of Biomedical and Health Informatics and Nutritional Sciences.

Chapter 6

CONCLUSION

6.1 Summary

Each subsection summarizes each aim I pursued in order to answer my research questions.

6.1.1 Aim 1: Usability Study of a Food Record App for Dietary Assessments (FRADA)

In the context of the overall Aim of assessing whether FRADA can improve the accuracy of traditional dietary assessment methods, the focus of Aim 1 was to create a smartphone application that enables older adults with diabetes to collect images of their meals and snacks and determine the usability of the application with older adults with diabetes. This aim addressed the gap in our knowledge that no study evaluated the usability of an image-assisted dietary assessment method with older adults with diabetes. Based on the gap, I explored the answers to following research questions: What is the usability of FRADA with older adults with diabetes? Would FRADA be usable for older adults with diabetes performing the required tasks (i.e., capturing, viewing, and transmitting images) to collect images of food items? Would it be easy for older adults with diabetes to follow the instructions, such as including all the food items in one single photograph and holding the phone at a 45-degree angle when taking pictures of food items? Would older adults with diabetes want to use FRADA in the future? What are the potential benefits of using FRADA for older adults with diabetes? What are the concerns of older adults with diabetes when interacting with FRADA? What are the potential target populations of FRADA?

Chapter 3 described the development of FRADA for older adults with diabetes to col-

lect images of food items and presents a usability study of FRADA with older adults with diabetes in a lab-based setting. When developing FRADA, I used design requirements that reflect the special considerations of older adults, while other applications used in previous studies did not reflect those considerations. I got structured feedback about FRADA from older adult participants with diabetes through three types of questionnaires: pre-test, post-task, and post-test using surveys and interviews (see Table 3.1). The key finding of Aim 1 is that participants using FRADA were satisfied with the ease of completing the task of photographing, reviewing, and sending the images of food and beverages. The majority of participants were not only satisfied with efficiency when performing tasks for taking, reviewing, and transmitting images of food and beverages, but they also felt that it was easy to follow the instructions when performing the tasks by using FRADA. In addition, I identified multiple perceived benefits of using FRADA, such as facilitating interactions among health providers and improving users' personal health by tracking meals and snacks efficiently. Nonetheless, older adults with diabetes were concerned about financial costs that might occur potentially when scheduling a meeting with a dietitian and purchasing FRADA. These findings address the gap in knowledge from literature review by reflecting the needs of older adults when developing FRADA and evaluate the usability of FRADA with older adults with diabetes.

In summary, it was easy and efficient for older adults with diabetes to use FRADA for collecting images of food items. There still remain questions to answer for future work: What are the needs and barriers of indirect stakeholders (e.g., family members, friends, and caregivers) of older adults with diabetes during the process of the image-assisted dietary assessment? What are the design principles for redesigning FRADA to address their needs? What is the usability of redesigned FRADA with multiple stakeholders of older adults with diabetes?

6.1.2 Aim 2: Feasibility Study of FRADA for an Image-Assisted Dietary Assessment

In the context of the overarching aim of assessing whether FRADA can improve the accuracy of traditional dietary assessment methods, Aim 2 focused on examining whether FRADA is feasible for an image-assisted dietary assessment. This aim addressed the gap in knowledge from literature review that none of the prior studies evaluated the feasibility of a smartphone application for improving the accuracy of image-assisted dietary assessments. The research questions based on the gap were: What is the feasibility of FRADA for image-assisted dietary assessments with older adults with diabetes? Would the images of food items reduce errors in self-reporting during a 24-hour dietary recall interview? How much would the 24-hour dietary recall using food images reduce errors in self-reporting?

Chapter 4 evaluated the feasibility of an image-assisted dietary assessment using FRADA through a deployment study with both two direct stakeholders: older adults with diabetes and dietitians. To evaluate the feasibility, I used the images collected by older adults with diabetes to determine the extent to which eligible images (i.e., all food items per eating event are in one single photograph) are collected. By comparing the food items recorded before viewing the images to ones recorded after viewing the images, I determined the extent to which viewing the images of food items help older adults with diabetes to recall any unreported, misreported, and forgotten food items to photograph. The primary finding of this aim is that use of images of food items collected by older adults with diabetes reduced errors in self-reporting. Reviewing images of food items helped dietitians identify missing information, such as portion size of food items and time of eating events. In addition, this study revealed that older adults with diabetes can capture images of their eating events before and after they eat.

To sum up, the findings from Aim 2 demonstrated that reviewing images of food items improved the accuracy of the 24-hour dietary recall interview, while no prior studies showed

whether it is acceptable for dietitians to use the image-assisted dietary assessment with older adults with diabetes. The findings from Aim 2 raised new questions: What is the validity of FRADA for image-assisted dietary assessments with older adults with diabetes? What would be potential features to be added to FRADA to support older adults with diabetes? Would the added features be usable, efficient, and effective for older adults with diabetes to perform tasks of capturing, viewing, and transmitting images of their meals and snacks in their real-life settings?

6.1.3 Aim 3: Satisfaction of Stakeholders with Image-Assisted 24-Hour Dietary Recall Interviews

In the context of the overall Aim of assessing whether FRADA can improve the accuracy of traditional dietary assessment methods, the focus of Aim 3 was to evaluate satisfaction of older adults with diabetes with FRADA and dietitians with image-assisted 24-hour dietary recall interviews. This aim addressed the gap in our knowledge that none of the previous studies evaluated the satisfaction of dietitians with image-assisted dietary assessment methods. The research questions related to Aim 3 are as follows: Would FRADA be usable for older adults with diabetes to perform the required tasks (i.e., capturing, viewing, and transmitting images) for collecting images of food items in real-world settings? Would it be easy for older adults to follow the instructions (i.e., including all the food items in one single photograph, holding the phone at a 45-degree angle when taking pictures of food items, and capturing images of food items before and after every single eating event)? What are the challenges older adults with diabetes face when capturing images of food items in real-world settings? What are the privacy issues of older adults with diabetes when sharing images of food items with other people? What are the trust issues of older adults with diabetes when sharing the images of food items with other people? Next, I explored the following questions

to understand the population of dietitians during a 24-hour dietary recall interview using images of food items: What are the benefits of using images of food items during the 24-hour dietary recall interview? What are the needs of dietitians when reviewing images of food items? What are the potential use cases of FRADA for dietitians?

Chapter 5 demonstrated the satisfaction of two stakeholders, older adults with diabetes and dietitians, when dietitians conduct 24-hour dietary recall interviews using images of food items collected by older adults with diabetes. Using surveys and interviews, I determined the extent to which older adults with diabetes are satisfied with FRADA for capturing, viewing, and transmitting images of food items required for an image-assisted dietary assessment. Moreover, as described in Table 4.1, I used interviews with dietitians to understand how dietitians interact with the application for viewing the images collected by older adults with diabetes. Also, by analyzing the interview data, I discovered how dietitians interact with older adults with diabetes when reviewing images of food items. One of the key findings of Aim 3 is that both older adults with diabetes and dietitians were satisfied with the 24-hour dietary recall interview using images of food items. In particular, this study revealed that both stakeholders reported perceived benefits of reviewing images of food items for better dietary assessments. Nevertheless, this study showed that there remain different opinions between older adults and dietitians. For example, while older adults were capable of performing the task of collecting the images of food items, dietitians were still worried about whether older adults can perform the task successfully.

In brief, the findings from Aim 3 demonstrated benefits of using images of food items when dietitians conduct 24-hour dietary recall interviews with older adults with diabetes. There remain questions raised for future work: How can we redesign FRADA to address the needs of potential target users with cognitive and physical disabilities (e.g., Alzheimer's disease and hand tremors) or users with language barriers (e.g., people speaking in Span-

ish)? What are the design principles to redesign user interface of a viewer application for dietitians? What are the long-term effects of using FRADA in real-life settings?

6.2 Limitations

There are five limitations of this study that will need to be addressed in future work. The first limitation is that the study sample was not representative of the target population (i.e., older adults with diabetes). This is because this study only focuses on older adults with diabetes who have prior experience with their smartphones; some older adults with diabetes do not own smartphones. Further, study participants (i.e., dietitians and older adults with diabetes) were recruited only in the Washington State in the U.S. This study has sample biases to generalize the findings of the study. First, I focused on individuals who have interacted with the smartphone application by recruiting older adults with diabetes who participated in the Aim 1 study. In addition, as shown in Table 4.3, five out of six older adults with diabetes have owned and used their smartphones for at least 2 years.

The second limitation of the study is that long-term effects from the deployment were not evaluated. While the feasibility of FRADA was evaluated for a 24-hour dietary recall interview, it is still questionable whether older adults with diabetes will be able to use FRADA for collecting images of their meals and snacks for a longer period due to unexpected issues. For instance, users might need to stop using FRADA due to lack of battery of their smartphone. Similarly, they might not able to use FRADA without the Internet connection, as the current version of FRADA asks users to transmit images of food items right after being taken. older adults with diabetes might forget to bring their smartphones when traveling. Another potential issue is whether older adults with diabetes would still be able to follow the instructions in real-world settings. In this study, participants were required to follow instructions when capturing images of food items for 24 hours in their home settings. This

study revealed that older adults with diabetes accomplished the required tasks successfully by following the instructions. The findings of Aim 1 and Aim 3 support that the instructions were easy to use for the 24-hour period. Nevertheless, older adults with diabetes might need additional motivations if they would need to follow the instructions for a longer period.

The third limitation of this study is that special considerations of older adults with diabetes with cognitive or physical disabilities (e.g., dementia and vision problem) were not addressed when I developed FRADA, though it is known that older adults with diabetes are twice as much likely to develop dementia than older adults without diabetes [29]. In addition, FRADA may not reflect the needs of older adults who have trouble holding a mobile device, as user interface of FRADA was based on the design guideline [48] that addresses the needs of a general population of older adults rather than addressing the needs of people who have any diseases (e.g., Parkinson's disease).

The fourth limitation of this study is that the process of the dietary assessment using FRADA was not validated with traditional validated dietary assessment methods, such as food records and 24-hour dietary recall, though this study showed that FRADA can be potentially used for better image-assisted dietary assessment with older adults with diabetes. In this study, I focused on investigating whether FRADA can be used in a real-life setting through a deployment study with both patients and health providers. For example, the findings of aim 2 revealed that reviewing images of food items helped identifying food items that were not reported or reported incorrectly when dietitians conducted 24-hour dietary recall interviews with older adults with diabetes.

The last limitation of this study is that there might be potential biases of having only one coder in qualitative data analysis. To analyze qualitative data from interviews in Aim 1 and Aim 3, I applied an open coding method [43] to collected statements from transcripts, identified recurring concepts, and grouped them into themes as a single coder. Nonetheless,

it is still possible for the single coder to only accept themes from his/her own perspectives but refuse themes from other perspectives.

6.3 Contributions

The findings of this study contribute to multiple domains. Despite the limitations of the study, it informs researchers about methods for creating smartphone applications for an image-assisted dietary assessment where special considerations of older adults with diabetes are addressed. The findings expand knowledge about how to design smartphone applications for improving the accuracy of an image-assisted dietary assessment in older adults. This study demonstrates the feasibility of a smartphone application for older adults with diabetes in practice (e.g., 24-hour dietary recall). For example, reviewing images of food items enabled older adults with diabetes to recall additional food items which were not reported previously. The findings from this dissertation shows that a smartphone-based image-assisted dietary assessment could be used for older adults as an enhanced dietary assessment methods that would reduce errors, which occur with self-reporting tools. Also, by evaluating the satisfaction of both older adults with diabetes and dietitians, this study provides researchers with design considerations for creating smartphone applications for an image-assisted dietary assessment. Such design considerations could be incorporated into tool design to support multiple stakeholders including indirect stakeholders (e.g., family members, caregivers, and friends of older adults with diabetes).

This research is innovative in two aspects. To my knowledge, this is the first attempt to understand users' needs using surveys and interviews involving multiple direct stakeholders including both health providers (i.e., dietitians) and patients (i.e., older adults with diabetes) to create smartphone applications for improving the accuracy of a traditional dietary assessment methods in Nutritional Sciences. While such an approach has been applied and

validated in other domains (e.g., Computer Science, Interaction Design, and Informatics), to my knowledge, few studies using UCD approaches in Nutritional Sciences have been conducted. Nobody has addressed the needs of multiple stakeholders (i.e., health providers and patients) in creating tools for dietary assessments. This shows that UCD approaches [10] can make existing validated dietary assessment methods usable for both health providers and patients in practice. Also, it demonstrates potential opportunities that UCD approaches can be applied to unexplored areas, such as designing other types of tools in Nutritional Sciences.

6.4 Future Research

Based on the key findings of this research and the identified limitations, I have identified five future areas of research. First, while this study focused on evaluating the usability and feasibility of FRADA with two direct stakeholders (i.e., older adults with diabetes and dietitians) to identify potential features of FRADA, further work still remains to identify the needs of indirect stakeholders, such as family members, friends, and caregivers, and incorporate them when enhancing FRADA.

Second, further work also remains to evaluate the validity of an image-assisted dietary assessment using FRADA with older adults with diabetes. While I evaluated the usability and feasibility of the dietary assessment using FRADA with older adults with diabetes, the method was not validated traditional dietary assessment methods (e.g., food records, 24-hour dietary recall interviews). By validating an image-assisted dietary assessment method using FRADA, I can determine if the method is clinically meaningful.

Third, FRADA could be enhanced by addressing the discovered needs of study participants. This study revealed user needs and demonstrated multiple potential features to be added to FRADA. One of the potential features was a reminder function that may enable older adults with diabetes to capture images of food items wherever they are. The analysis

of Aim 2 actually showed that some images were not transmitted to dietitians. The reminder function may enable older adults with diabetes to continue to collect images of food items.

Fourth, since there exist multiple potential target users of FRADA, it is important to identify the special needs of each potential population. For instance, people with hand tremors would need a feature that makes blurred images clear. In addition, people speaking in Spanish might need instructions for using FRADA written in Spanish. In brief, such identified needs could be used for developing future versions of FRADA.

Lastly, future work remains to analyze qualitative data from interviews in Aim 1 and Aim 3 with additional coders to avoid any potential biases (e.g., accepting themes from a single coder's perspectives). By doing so with multiple coders, inter-rater reliability could be addressed to assess the reliability of coding.

To sum up, there are multiple potential studies that would enhance the features of FRADA with older adults to improve the accuracy of image-assisted dietary assessment methods.

BIBLIOGRAPHY

[1] Pew Research Center Surveys Conducted December 4-7 and 18-21, 2014.

[2] Economic Costs of Diabetes in the U.S. in 2012. *Diabetes Care*, 2013.

[3] Classification and Diagnosis of Diabetes. *Diabetes Care*, 38(Supplement 1):S8–S16, 2014.

[4] Strategies for Improving Care. *Diabetes Care*, 38(Supplement 1):S5–S7, 2015.

[5] Apache Cordova. `https://cordova.apache.org/`, (accessed December 15, 2017).

[6] PHP. `http://php.net/`, (accessed December 15, 2017).

[7] UW Shared Web Hosting. `https://itconnect.uw.edu/connect/web-publishing/shared-hosting/`, (accessed December 15, 2017).

[8] Who Lives in Assisted Living? What Types of Residents Live in Assisted Living Facilities? `https://www.assistedlivingfacilities.org/resources/who-lives-in-assisted-living-/`, (accessed November 22, 2017).

[9] Statistics About Diabetes. `http://www.diabetes.org/diabetes-basics/statistics/`, (accessed October 25, 2017).

[10] Chadia Abras, Diane Maloney-Krichmar, and Jenny Preece. User-centered Design. *Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications*, 37(4):445–456, 2004.

[11] Lenore Arab, Deborah Estrin, Donnie H Kim, Jeff Burke, and Jeff Goldman. Feasibility Testing of an Automated Image-capture Method to Aid Dietary Recall. *European journal of clinical nutrition*, 65(10):1156–1162, 2011.

[12] Regan L. Bailey, Diane C. Mitchell, Carla Miller, and Helen Smiciklas-Wright. Assessing the Effect of Underreporting Energy Intake on Dietary Patterns and Weight Status. *Journal of the American Dietetic Association*, 107(1):64 – 71, 2007.

[13] Linda G Bandini, Dale A Schoeller, Helen N Cyr, and William H Dietz. Validity of Reported Energy Intake in Obese and Nonobese Adolescents. *The American journal of clinical nutrition*, 52(3):421–425, 1990.

[14] C. J. Boushey, M. Spoden, F. M. Zhu, E. J. Delp, and D. A. Kerr. New mobile methods for dietary assessment: review of image-assisted and image-based dietary assessment methods. *Proceedings of the Nutrition Society*, 76(3):283–294, 2017.

[15] Peter T. Campbell, Anusila Deka, Eric J. Jacobs, Christina C. Newton, Janet S. Hildebrand, Marjorie L. McCullough, Paul J. Limburg, and Susan M. Gapstur. Prospective Study Reveals Associations Between Colorectal Cancer and Type 2 Diabetes Mellitus or Insulin Use in Men. *Gastroenterology*, 139(4):1138 – 1146, 2010.

[16] Shanon L Casperson, Jared Sieling, Jon Moon, LuAnn Johnson, James N Roemmich, and Leah Whigham. A Mobile Phone Food Record App to Digitally Capture Dietary Intake for Adolescents in a Free-living Environment: Usability Study. *JMIR mHealth and uHealth*, 3(1), 2015.

[17] Alison B. Evert, Jackie L. Boucher, Marjorie Cypress, Stephanie A. Dunbar, Marion J. Franz, Elizabeth J. Mayer-Davis, Joshua J. Neumiller, Robin Nwankwo, Cassandra L. Verdi, Patti Urbanski, and William S. Yancy. Nutrition Therapy Recommendations for the Management of Adults With Diabetes. *Diabetes Care*, 2013.

[18] Andrew Flood, Lori Strayer, Catherine Schairer, and Arthur Schatzkin. Diabetes and Risk of Incident Colorectal Cancer in a Prospective Cohort of Women. *Cancer causes control : CCC*, 21(8):1277—1284, August 2010.

[19] Marion J. Franz, Jackie L. Boucher, Joyce Green-Pastors, and Margaret A. Powers. Evidence-Based Nutrition Practice Guidelines for Diabetes and Scope and Standards of Practice. *Journal of the American Dietetic Association*, 108(4, Supplement):S52 – S58, 2008. Emerging Trends in Diabetes Prevention Control.

[20] L Gemming, A Doherty, P Kelly, J Utter, and C Ni Mhurchu. Feasibility of a SenseCam-assisted 24-h Recall to Reduce Under-reporting of Energy Intake. *European journal of clinical nutrition*, 67(10):1095, 2013.

[21] Luke Gemming, Elaine Rush, Ralph Maddison, Aiden Doherty, Nicholas Gant, Jennifer Utter, and Cliona Ni Mhurchu. Wearable Cameras can Reduce Dietary Under-reporting: Doubly Labelled Water Validation of a Camera-assisted 24 h Recall. *British Journal of Nutrition*, 113(2):284–291, 2015.

[22] Luke Gemming, Jennifer Utter, and Cliona Ni Mhurchu. Image-Assisted Dietary Assessment: A Systematic Review of the Evidence. *Journal of the Academy of Nutrition and Dietetics*, 115(1):64 – 77, 2015.

[23] Mitchell Gersovitz, J Patrick Madden, and Helen Smiciklas-Wright. Validity of the 24-hr. Dietary Recall and Seven-day Record for Group Comparisons. *Journal of the American Dietetic Association*, 73(1):48–55, 1978.

[24] R Gregory, L Walwyn, S Bloor, and S Amin. A Feasibility Study of the Use of Photographic Food Diaries in the Management of Obesity. *Practical Diabetes International*, 23(2):66–68, 2006.

[25] J He, DO Stram, LN Kolonel, BE Henderson, L Le Marchand, and CA Haiman. The Association of Diabetes with Colorectal Cancer Risk: the Multiethnic Cohort. *British journal of cancer*, 103(1):120–126, 2010.

[26] Nobuko Hongu, Benjamin T Pope, Pelin Bilgiç, Barron J Orr, Asuka Suzuki, Angela Sarah Kim, Nirav C Merchant, and Denise J Roe. Usability of a Smartphone Food Picture App for Assisting 24-hour Dietary Recall: a Pilot Study. *Nutrition research and practice*, 9(2):207–212, 2015.

[27] Nobuko Hongu, Benjamin T. Pope, Pelin Bilgiç, Barron J. Orr, Asuka Suzuki, Angela Sarah Kim, Nirav C. Merchant, and Denise J. Roe. Usability of a Smartphone Food Picture app for Assisting 24-hour Dietary Recall: a Pilot Study. In *Nutrition research and practice*, 2015.

[28] Edgar Chambers IV, Sandria L Godwin, and Frances A Vecchio. Cognitive Strategies for Reporting Portion Sizes Using Dietary Recall Procedures. *Journal of the American Dietetic Association*, 100(8):891 – 897, 2000.

[29] M. Sue Kirkman, Vanessa Jones Briscoe, Nathaniel Clark, Hermes Florez, Linda B. Haas, Jeffrey B. Halter, Elbert S. Huang, Mary T. Korytkowski, Medha N. Munshi, Peggy Soule Odegard, Richard E. Pratley, and Carrie S. Swift. Diabetes in Older Adults. *Diabetes Care*, 35(12):2650–2664, 2012.

[30] S Kroemer, J Frühauf, TM Campbell, C Massone, G Schwantzer, H Peter Soyer, and R Hofmann-Wellenhof. Mobile Teledermatology for Skin Tumour Screening: Diagnostic Accuracy of Clinical and Dermoscopic Image Tele-evaluation using Cellular Phones. *British Journal of Dermatology*, 164(5):973–979, 2011.

[31] Karen Lacey and Ellen Pritchett. Nutrition Care Process and Model: ADA Adopts Road Map to Quality Care and Outcomes Management. *Journal of the American Dietetic Association*, 103(8):1061–1072, 2003.

[32] Claudia E. Lazarte, Ma Eugenia Encinas, Claudia Alegre, and Yvonne Granfeldt. Validation of Digital Photographs, as a Tool in 24-h Recall, for the Improvement of Dietary Assessment among Rural Populations in Developing Countries. *Nutrition Journal*, 11(1):61, Aug 2012.

[33] James R. Lewis. Psychometric Evaluation of an After-scenario Questionnaire for Computer Usability Studies: The ASQ. *SIGCHI Bull.*, 23(1):78–81, January 1991.

[34] Corby K Martin, Hongmei Han, Sandra M Coulon, H Raymond Allen, Catherine M Champagne, and Stephen D Anton. A Novel Method to Remotely Measure Food Intake of Free-living Individuals in Real Time: the Remote Food Photography Method. *British Journal of Nutrition*, 101(3):446–456, 2008.

[35] MA McDowell, TB Harris, and RR Briefel. Dietary Surveys of Older Persons. *Clin. Appl. Nutr*, 1:51–60, 1991.

[36] Sara F. Morris and Judith Wylie-Rosett. Medical Nutrition Therapy: A Key to Diabetes Management and Prevention. *Clinical Diabetes*, 28(1):12–18, 2010.

[37] Alanna J Moshfegh, Donna G Rhodes, David J Baer, Theophile Murayi, John C Clemens, William V Rumpler, David R Paul, Rhonda S Sebastian, Kevin J Kuczynski, Linda A Ingwersen, et al. The US Department of Agriculture Automated Multiple-Pass Method Reduces Bias in the Collection of Energy Intakes. *The American journal of clinical nutrition*, 88(2):324–332, 2008.

[38] The Costs of Diabetes. `http://www.diabetes.org/advocacy/news-events/cost-of-diabetes.html`, (accessed October 26, 2017).

[39] US Department of Health, DC: US Department of Health Human Services. (2014). A Profile of Older Americans: 2014. Washington, and Administration on Aging. Human Services. `https://www.acl.gov/sites/default/files/Aging%20and%20Disability%20in%20America/2014-Profile.pdf`, (accessed October 26, 2017).

[40] Institute of Medicine. *The Role of Nutrition in Maintaining Health in the Nation's Elderly: Evaluating Coverage of Nutrition Services for the Medicare Population*. The National Academies Press, Washington, DC, 2000.

[41] Gillian O'Loughlin, Sarah Jane Cullen, Adrian McGoldrick, Siobhan O'Connor, Richard Blain, Shane O'Malley, and Giles D Warrington. Using a Wearable Camera to Increase the Accuracy of Dietary Analysis. *American journal of preventive medicine*, 44 3:297–301, 2013.

[42] Joyce Green Pastors, Hope Warshaw, Anne Daly, Marion Franz, and Karmeen Kulkarni. The Evidence for the Effectiveness of Medical Nutrition Therapy in Diabetes Management. *Diabetes Care*, 25(3):608–613, 2002.

[43] M.Q. Patton. *Qualitative Research & Evaluation Methods*. SAGE Publications, 2002.

[44] Lauren T Ptomey, Stephen D Herrmann, Jaehoon Lee, Debra K Sullivan, Mary F Rondon, and Joseph E Donnelly. Photo-assisted Recall Increases Estimates of Energy and Macronutrient Intake in Adults with Intellectual and Developmental Disabilities. *Journal of the Academy of Nutrition and Dietetics*, 113(12):1704–1709, 2013.

[45] M.E. Rollo, S. Ash, P. Lyons-Wall, and A.W. Russell. Evaluation of a Mobile Phone Image-based Dietary Assessment Method in Adults with Type 2 Diabetes. *Nutrients*, 7(6):4897–4910, 2015. cited By 16.

[46] Patrick Sanger, Andrea Hartzler, William B Lober, Heather L Evans, and Wanda Pratt. Design considerations for post-acute care mhealth: patient perspectives. In *AMIA Annual Symposium Proceedings*, volume 2014, page 1920. American Medical Informatics Association, 2014.

[47] Edward S Sazonov and Juan M Fontana. A Sensor System for Automatic Detection of Food Intake through Non-invasive Monitoring of Chewing. *IEEE sensors journal*, 12(5):1340–1348, 2012.

[48] Paula Alexandra Silva, Kelly Holden, and Phillip Jordan. Towards a List of Heuristics to Evaluate Smartphone Apps Targeted at Older Adults: A Study with Apps that Aim at Promoting Health and Well-Being. *2015 48th Hawaii International Conference on System Sciences (HICSS)*, 00:3237–3246, 2015.

[49] J Speakman. *Doubly Labelled Water: Theory and Practice*. Springer Science & Business Media, 1997.

[50] 2014 National Population Projections Tables. `https://www.census.gov/data/tables/2014/demo/popproj/2014-summary-tables.html`, (accessed October 25, 2017).

[51] Carl W. Turner, James R. Lewis, and Jakob Nielsen. Determining Usability Test Sample Size. 2006.

[52] Wija A van Staveren, Lisette CPGM de Groot, Ybel H Blauw, and RP Van der Wielen. Assessing Diets of Elderly People: Problems and Approaches. *The American journal of clinical nutrition*, 59(1):221S–223S, 1994.

[53] F. Zhu, M. Bosch, I. Woo, S. Kim, C. J. Boushey, D. S. Ebert, and E. J. Delp. The Use of Mobile Devices in Aiding Dietary Assessment and Evaluation. *IEEE Journal of Selected Topics in Signal Processing*, 4(4):756–766, Aug 2010.

Appendix A

STUDY MATERIALS

A.1 Demographics Questions

Please respond to the questions.

1. How old are you? _____
2. What is your gender?

   __ Female

   __ Male

   __ Prefer not to respond
3. What is your race/ethnicity?

   __ African American/Black

   __ Asian/Pacific Islander

   __ Hispanic/Latino

   __ Multiracial

   __ Native American/American Indian

   __ White/Caucasian

   __ Other ( )

   __ Prefer not to respond
4. What is the highest degree or level of school you have completed?

   If currently enrolled, highest degree received.

   __ No schooling completed

   __ High school graduate - high school diploma or the equivalent (e.g., GED)

__ Bachelor's degree (e.g., BA, AB, BS)

__ Master's degree (e.g., MA, MS, MEng, MEd, MSW, MBA)

__ Professional degree (e.g., MD, DDS, DVM, LLB, JD)

__ Doctorate degree (e.g., PhD, EdD)

__ Other ( )

5. How long have you used a smartphone?

__ Less than 6 months

__ 6 months to 11 months

__ 12 months to 17 months

__ 18 months to 23 months

__ 24 months to 29 months

__ 30 months to 35 months

__ 36 months to above

6. What type of smartphone do you have?

__ Android

__ iPhone

__ Window Mobile

__ Other ( )

A.2 Instructions

1. You should include all the food items in one single photograph.

2. In order to get the best images, you should hold the smartphone at a 45-degree angle when taking pictures of food and beverages.

A.3 Scenario

You have an appointment with your dietitian tomorrow to assess your diet. The dietitian wants to get the smartphone images of the food and beverages that you have consumed before the appointment for your dietary assessment. Now, you need to accomplish the following three tasks using your smartphone:

1. Capture an image of all the food and beverages served for your lunch.

2. Review the captured image to make sure the image complies with the pre-defined instructions.

3. Send your reviewed smartphone image of your lunch food and beverages to your dietitian.

A.4 After-Scenario Questionnaire (ASQ) [33] for Older Adults with Diabetes

Questions

Please respond to the following questions.

1. Please mark ✔after **photographing the images.**

"I am satisfied with the ease of completing the task of **photographing images** of food and beverages."

Strongly disagree O O O O O O O Strongly agree

"I am satisfied with the amount of time it took to complete the task of **photographing images** of food and beverages."

Strongly disagree O O O O O O O Strongly agree

2. Please mark ✔after **reviewing images.**

"I am satisfied with the ease of completing the task of **reviewing images** of food and

beverages."

Strongly disagree O O O O O O O Strongly agree

"I am satisfied with the amount of time it took to complete the task of **reviewing images** of food and beverages."

Strongly disagree O O O O O O O Strongly agree

3. Please mark ✔after **sending the images to your dietitian.**

"I am satisfied with the ease of completing the task of **sending images** of food and beverages."

Strongly disagree O O O O O O O Strongly agree

"I am satisfied with the amount of time it took to complete the task of **sending images** of food and beverages."

Strongly disagree O O O O O O O Strongly agree

4. Please share any comments, suggestions or thoughts that you have about the tasks.

A.5 Sample Post-Test Semi-Structured Interview Questions for Older Adults with Diabetes in Aim 1

- What are your overall impressions of the smartphone app?
- If you had to give the smartphone application a grade, from A to F, where A was exemplary and F was failing, what grade would you give it, and why?
- Name three words or characteristics that describe this smartphone app.

- What are the three things you like best about the smartphone app?
- What are the three things you like least about the smartphone app?
- If you could make one significant change to this smartphone app, what change would you make?
- Would you return to this smartphone application on your own in the future? Why/why not?
- What would entice you to return?
- Are there materials you would like to see added to the smartphone app? Which ones?
- Would you recommend this smartphone application to a colleague? To a friend?
- Do you have any other questions or comments about the smartphone application or your experiences with it?

A.6 Demographics Questions for Dietitian Participants

Please respond to the questions.

1. How old are you? _____
2. What is your gender?

   __ Female

   __ Male

   __ Prefer not to respond
3. What is your race/ethnicity?

   __ African American/Black

   __ Asian/Pacific Islander

   __ Hispanic/Latino

   __ Multiracial

   __ Native American/American Indian

   __ White/Caucasian

   __ Other ( )

   __ Prefer not to respond
4. What is the highest degree or level of school you have completed?

   If currently enrolled, highest degree received.

   __ No schooling completed

   __ High school graduate - high school diploma or the equivalent (e.g., GED)

   __ Bachelor's degree (e.g., BA, AB, BS)

   __ Master's degree (e.g., MA, MS, MEng, MEd, MSW, MBA)

   __ Professional degree (e.g., MD, DDS, DVM, LLB, JD)

   __ Doctorate degree (e.g., PhD, EdD)

   __ Other ( )

5. How long have you worked with older adults?

__ Less than 3 months

__ 3 months to 11 months

__ 12 months to 23 months

__ 24 months to 35 months

__ 36 months to above

A.7 Instructions for Dietitians

[Study 2&3 – RD]

Instructions

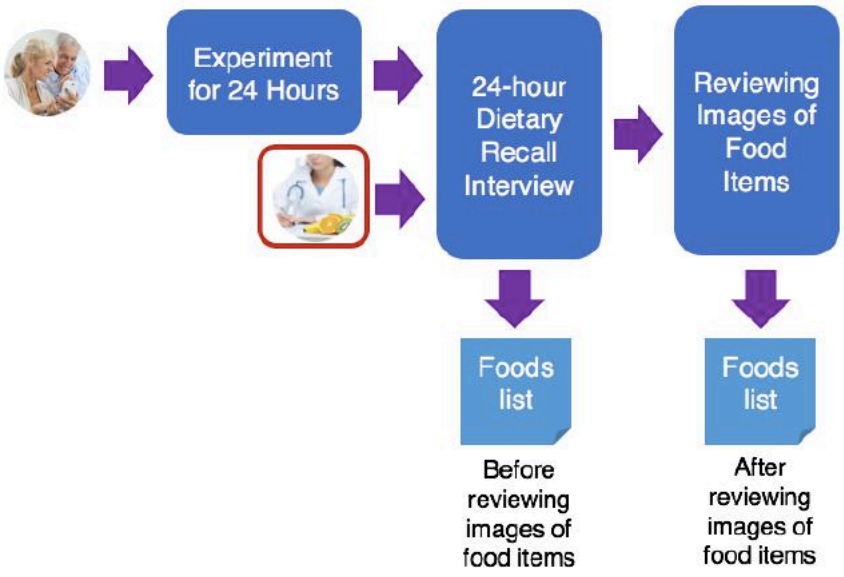
Roles

- Conduct 24-hour dietary recall interview with diabetic older adults
- Review images of food items with diabetic older adults
- Create foods lists before and after reviewing images of food items

Dietary recall questions while reviewing images of food items

- Are there any food items you did not report?
- Are there any food items you reported incorrectly?
- Are there any food items you forgot to photograph?

Procedure



A.8 Instructions for Older Adults with Diabetes

Study 2 for Older Adults

Scenario

You have an appointment with your dietitian tomorrow to assess your diet. The dietitian wants to get the smartphone images of the food and beverages that you have consumed before the appointment for your dietary assessment. Now, you need to accomplish the following three tasks using your smartphone:

1. Capture an image of all the food and beverages served for your lunch.
2. Review the captured image to make sure the image complies with the pre-defined instructions.
3. Send your reviewed smartphone image of your lunch food and beverages to your dietitian.

Tasks for 24 Hours

Capture images Capture images

1. Launch an app on your smartphone
2. Capture images of food items before each eating event
3. Have breakfast, lunch, dinner, and/or snacks
4. Capture images of food items after **each** eating event
5. Review the images you captured
6. Submit the images to the dietitian using the app

Instructions

1. You should include all the food items in one single photograph.
2. In order to get the best images, you should hold the smartphone at a 45-degree angle when taking pictures of food and beverages.

A.9 Participant Evaluation of Image-Assisted 24-Hour Dietary Recall Interviews [20] for Older Adults with Diabetes

Questions

Please mark ✓to respond to the following questions.

"The images helped me to remember some foods I had forgotten about."

Strongly disagree O O O O O O O Strongly agree

"The images helped me to remember extra details of how my foods were cooked, prepared, or purchased."

Strongly disagree O O O O O O O Strongly agree

"The images helped me to remember the portion size of the foods I ate."

Strongly disagree O O O O O O O Strongly agree

"The images helped me to verify the portion size of foods I ate."

Strongly disagree O O O O O O O Strongly agree

"The images allowed me to provide more accurate information about the foods I ate."

Strongly disagree O O O O O O O Strongly agree

A.10 Participant Evaluation: Ease of Use and Potential Uses of the Smartphone Application for Image-Assisted 24-Hour Dietary Recall Interviews [26] for Older Adults with Diabetes

Questions

Please mark ✓to respond to the following questions.

"The application was easy to use."

Strongly disagree O O O O O O O Strongly agree

"I would like to use the application to record food intake in the future."

Strongly disagree O O O O O O O Strongly agree

A.11 Sample Post-Test Semi-Structured Interview Questions for Older Adults with Diabetes in Aim 3

- We reviewed the images when meeting with dietitians. What are your overall impressions of using images of food items?
- Was it useful to review the images? Why/why not?
- What would you like to do using images of food items you collected?
- Any comments on this.
- What are your overall impressions of the smartphone app?
- Your task was to take images of every single meal and snack for the last 24 hours yesterday. Did you complete it successfully?
- What were the challenges in completing the tasks?
- How easy was it to follow the rules? (e.g., including all the food items in one single photograph, take 45-degree angle). Did you follow them?
- How easy was it to accomplish the tasks? (i.e., capturing, viewing, and transmitting).
- What are existing phone habits?
- What did you think after just one day?
- Is this something you could see yourself using long-term?

- Would you return to this smartphone application on your own in the future? Why/why not?
- What would entice you to return?
- Are there materials you would like to see added to the smartphone app? Which ones?
- Would you recommend this smartphone application to a colleague? To a friend?
- Do you have any other questions or comments about the smartphone application or your experiences with it?

A.12 Sample Post-Test Semi-Structured Interview Questions for Dietitians in Aim 3

Overall

- Have you conducted a 24-hour dietary recall interview with a patient using images of food items before?
- You reviewed the images when meeting with older adults. What are your overall impressions of using images of food items?
- Tell me about your experience when you reviewed the images of food and beverages collected by older adults with diabetes.
- Was it useful to review the images? Why/why not?
- Your task was to conduct a 24-hour dietary recall interview with an older adult. Do you think you accomplished the task successfully? Why/why not?
- Your task was to conduct a 24-hour dietary recall interview using images of food items with an older adult. Do you think you accomplished the task successfully? Why/why not?

Receiving images

- In this study, you received the images of food items during the 24HR. In real-life scenarios, when would you like to receive and review the images? Why/why not?

Reviewing images

- How easy was it to review images of food items with older adults with diabetes?
- What are the challenges in reviewing images of food items?
- I noticed that you navigated all the photos on the tablet, but was it what you intended to? If not, who do you think the right person to control the device to explore photos?

Presentation of images

- (By showing images), what do you think about information presented on the screen?
- Currently time and images are available, but what else would you be interested in?
- Do you have any thoughts about how to organize the images? Sorted by time?

Summary

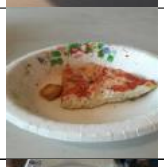
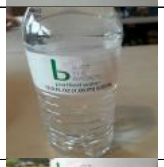
- If you could make one significant change to this process using the images, what change would you make?
- What else would you like to do using images of food and beverages for a 24-hour dietary recall interview?
- What other functions/features would you wish to use in the next image-assisted 24-hour dietary recall interview?
- Would you recommend this process to your colleagues?

- Would you like to recommend a 24-hour dietary recall interview using images of food items? Why/why not?
- Do you have any other questions or comments about the smartphone application or your experiences with it?

Appendix B

IMAGES COLLECTED BY OLDER ADULTS WITH DIABETES IN AIM 2

B.1 Images Collected by OP1

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
1		07:47:25	Yes	Yes
		07:51:38	Yes	Yes
2		08:28:51	Yes	Yes
		09:30:51	Yes	Yes
3		09:31:40	No	Yes
		11:17:45	No	No

Continued on next page

Table B.1 – continued from previous page

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
4		12:28:57	Yes	Yes
		13:29:38	Yes	Yes
5		12:54:31	Yes	Yes
		13:28:45	Yes	Yes
6		12:55:18	Yes	Yes
	N/A	N/A	N/A	N/A
7		13:24:29	Yes	Yes
		13:28:45	Yes	Yes
8		14:09:59	Yes	Yes

Continued on next page

Table B.1 – continued from previous page

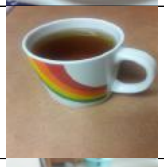
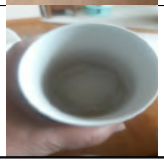
Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
		14:10:20	Yes	Yes
9		14:16:37	Yes	No
		14:17:21	Yes	Yes
10		14:17:55	Yes	No
		14:18:52	Yes	Yes
11		15:35:49	Yes	Yes
		16:09:15	No	No
12		17:25:09	Yes	Yes
		18:12:21	Yes	No

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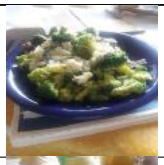
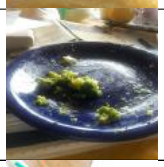
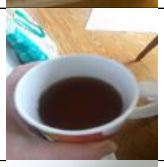
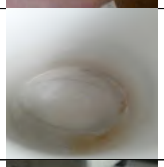
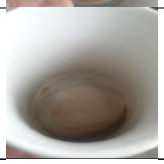
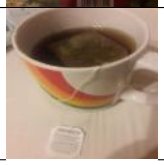
Table B.1 – continued from previous page

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
13		17:29:46	Yes	Yes
		17:45:19	Yes	Yes
14		18:12:54	Yes	Yes
		18:57:43	No	No
15		19:15:37	Yes	Yes
		19:18:36	No	No
16	**N/A**	19:29:02	Yes	No
	N/A	07:51:38	Yes	Yes
17		19:59:17	Yes	No

Continued on next page

Table B.1 – continued from previous page

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
		20:09:57	Yes	No
18		22:36:36	Yes	No
		22:38:23	Yes	No
19		22:37:18	Yes	Yes
	N/A	N/A	N/A	N/A

B.2 Images Collected by OP2

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
1		07:47:10	Yes	Yes
		08:00:09	Yes	Yes

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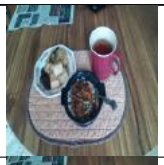
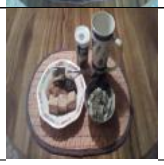
Table B.2 – continued from previous page

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
2		13:45:12	Yes	Yes
		14:30:45	Yes	Yes
3		18:46:01	Yes	Yes
		18:49:22	Yes	Yes
4		23:46:25	Yes	Yes
	N/A	N/A	N/A	N/A

B.3 Images Collected by OP3

Event ID	Image	Timestamp	All in One Image?	With an angle?
1		09:09:24	Yes	Yes

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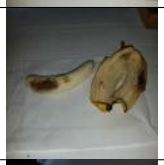
Table B.3 – continued from previous page

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
		09:30:17	Yes	Yes
2		11:27:44	Yes	Yes
		11:33:36	Yes	Yes
3		11:53:55	Yes	Yes
		11:54:42	Yes	Yes
4		12:24:11	Yes	Yes
		12:30:18	Yes	Yes
5		13:38:07	Yes	Yes
		14:17:29	Yes	Yes

Continued on next page

Table B.3 – continued from previous page

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
6		17:26:31	Yes	Yes
		17:42:21	Yes	Yes
7		17:26:31	Yes	Yes
		17:42:21	Yes	Yes

B.4 Images Collected by OP4

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
1		10:48:42	Yes	Yes
		11:44:55	Yes	Yes
2		10:57:42	Yes	Yes

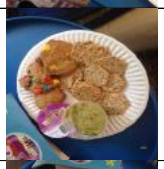
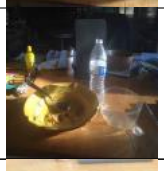
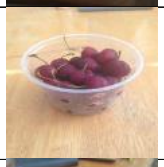
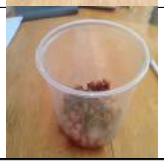
Continued on next page

Table B.4 – continued from previous page

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
		10:59:47	Yes	Yes
3		11:01:18	Yes	Yes
		11:03:35	Yes	Yes
4		11:05:18	Yes	Yes
		11:35:51	Yes	Yes
5		11:11:29	Yes	Yes
		11:40:30	Yes	Yes
6		13:12:51	Yes	Yes
		13:22:51	Yes	Yes

Continued on next page

Table B.4 – continued from previous page

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
7		13:49:25	Yes	Yes
		17:48:25	Yes	Yes
8		15:09:04	Yes	No
		15:24:34	Yes	Yes
9		18:45:01	Yes	Yes
		19:24:29	Yes	Yes
10		19:32:11	Yes	Yes
		11:35:51	Yes	Yes

B.5 Images Collected by OP5

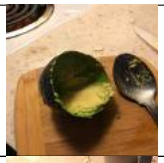
Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
1		10:48:42	Yes	Yes
	N/A	N/A	N/A	N/A
2		10:57:42	Yes	Yes
	N/A	N/A	N/A	N/A
3		11:01:18	Yes	Yes
	N/A	N/A	N/A	N/A
4	**N/A**	N/A	N/A	N/A
		11:35:51	Yes	Yes
5		11:11:29	Yes	Yes

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Table B.5 – continued from previous page

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
	N/A	N/A	N/A	N/A

B.6 Images Collected by OP6

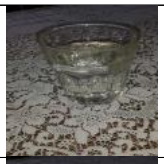
Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
1		10:56:00	Yes	Yes
		10:56:58	Yes	Yes
2		10:57:42	Yes	Yes
		10:56:58	Yes	Yes
3		11:11:29	Yes	Yes
	N/A	N/A	N/A	N/A

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Table B.6 – continued from previous page

Event ID	Image	Timestamp	All in One Image?	Taken at an Angle?
4		11:11:29	Yes	Yes
		11:35:51	Yes	Yes
5		11:11:29	Yes	Yes
		11:35:51	Yes	Yes
6		11:11:29	Yes	Yes
	N/A	N/A	N/A	N/A

Appendix C

OTHER MATERIAL

C.1 Goals of Nutrition Therapy that Applies to Adults with Diabetes [17]

1. To promote and support healthful eating patterns, emphasizing a variety of nutrient-dense foods in appropriate portion sizes, in order to improve overall health and specifically to:

- Attain individualized glycemic, blood pressure, and lipid goals. General recommended goals from the ADA for these markers are as follows:
  - A1C <7%.
  - Blood pressure <140/80 mmHg.
  - LDL cholesterol < 100 mg/dL; triglycerides <150 mg/dL; HDL cholesterol >40 mg/dL for men; HDL cholesterol >50 mg/dL for women.
- Achieve and maintain body weight goals.
- Delay or prevent complications of diabetes.

2. To address individual nutrition needs based on personal and cultural preferences, health literacy and numeracy, access to healthful food choices, willingness and ability to make behavioral changes, as well as barriers to change.

3. To maintain the pleasure of eating by providing positive messages about food choices while limiting food choices only when indicated by scientific evidence.

4. To provide the individual with diabetes with practical tools for day-to-day meal planning rather than focusing on individual macronutrients, micronutrients, or single foods.