

DEVELOPMENT AND COMPARISON OF CUSTOMIZED VOICE-ASSISTANT
SYSTEMS FOR INDEPENDENT LIVING OLDER ADULTS

A Thesis

presented to

the Faculty of the Graduate School
at the University of Missouri-Columbia

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

SHRADHA SHALINI

Dr. Marjorie Skubic, Thesis Advisor

DECEMBER 2019

The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

DEVELOPMENT AND COMPARISON OF CUSTOMIZED VOICE-ASSISTANT
SYSTEMS FOR INDEPENDENT LIVING OLDER ADULTS

presented by Shradha Shalini,

a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

Dr. Marjorie Skubic, Professor, Dept. of Electrical
Engineering and Computer Science

Dr. Dan Lin, Associate Professor, Dept. of Electrical
Engineering and Computer Science

Dr. Kari R. Lane, Assistant Professor, Sinclair School of
Nursing

To my beloved parents Sadhu Choudhury, Sukanti Choudhury, and my sister Sonali Choudhury for their constant support and care, and to my husband Anup Mishra, who always believed in me and inspired me every single day.

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to Dr. Marjorie Skubic, my adviser and committee chair, for her guidance, invaluable constructive comments and constant support in everything. From giving me an opportunity to work in the lab, to guide me throughout my study, to make her presence on my conference presentation, to support me with my interest in an internship, for all this and much more, I could not be more thankful. I constantly draw inspiration from her positive attitude. Without her guidance and persistent help, this study would not have been possible. It was a privilege to work under her supervision.

Special thanks to my committee member, Dr. Kari R. Lane, for her immense support, mentorship, and advice during the focus group study, dyad interviews, and helping me with rides to the interview locations. I would like to sincerely thank my other committee member, Dr. Dan Lin for serving on my committee and imparting her knowledge and expertise in the security aspects of the study. I am also thankful to Dr. Robinson for the valuable comments and suggestions throughout the focus group study and dyad interviews.

I would also like to express my sincere appreciation to all the seniors that I had the pleasure to interview for my research work. I would like to thank my lab members for their support in the Center for Eldercare and Rehabilitation Technology lab. I am thankful for my lab mate Trevor Levins who worked with me in our initial study. I am also thankful to Brianna for her help and assistance with conducting the dyad interviews and helping me with rides to the interview locations.

I owe the deepest gratitude to my father Sadhu Choudhury, my mother Sukanti Choudhury, and my sister Sonali Choudhury, without their motivation, faith, and continuous support this would not have been possible. Finally, I would especially like to

thank Anup Mishra, who always had my back. It was much easier to accomplish all that I have with his support.

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Abstract

Voice-controlled in-home personal assistants have great potential to assist older adults. This thesis explores the aspects of human-computer interface design, specifically a voice assistant, to help older adults manage their personal health, especially in the case of chronic health conditions. In our previous work, we have built a web interface for caregivers to monitor older adults' health changes based on in-home sensor data from motion sensors, bed sensors, and depth sensors. Data collected from these sensors are stored in servers and processed using several algorithms to obtain health and activity parameters including gait, fall risk, detect fall, motion patterns, sleep, heart rate, and respiration rate, as well as to generate health alerts. The sensor system with automated health alerts and care coordination has been shown to help seniors maintain better functionality. In our current research project, we focus on developing a consumer interface for older adults and their designated trusted others that can provide health information on-demand, based on spoken queries. The health information is presented as both audio and visual displays and uses graphical visualizations and linguistic summaries of the sensor data trends and changes. The goal is to present data in a form that is simple to understand. To accomplish our objective of creating an easy-to-use-and-understand health data interface for older adults, we explore voice-controlled, in-home personal assistants as a solution. Two voice assistant platforms with displays were selected for implementation and testing, namely, the Amazon Echo Show and the Lenovo Smart Display with Google Assistant.

An initial focus group study was conducted with older adults and their family members to get their feedback on different possible platforms that could be used to show their health information and health messages and different possible ways to present the data. The feedbacks from 23 older adult participants and 5 family members in the initial focus group study helped us in implementing a prototype of the voice-assistant application in both Amazon Echo Show and Lenovo's Smart Display with Google Assistant. During the development process, we discovered the advantages and limitations of both platforms. Both the voice-assistant platform's prototype application was presented to older adults and their family members or their trusted others. The feedback about the devices from 18 dyad interviews and the technical limitations of the devices helped us conclude that Amazon Echo Show is the appropriate platform for our study. We have used the Amazon Echo Show to develop the health information retrieval application and will deploy the system in the homes of older adults for further testing.

This thesis includes the feedback from the focus group study, the development process of the applications for both the Amazon Echo Show and Google Assistant. It also includes the feedback from the dyad interviews about the device preferences, the speech recognition accuracy of both the devices, the limitations of both the devices and the reasons for choosing the Amazon Echo Show as the device to do the final development. This thesis also elaborates on the development of the Amazon Echo Show's health information retrieval application and the deployment process of the application. The voice-assistant application will be deployed in 55 homes that include 40 independent living participants and 15 participants with mild cognitive impairment.

Chapter 1

Introduction

This chapter provides an overview of the motivation and primary goals of the development and comparison of customized voice-assistant systems for independent-living older adults.

Motivation

With the emerging of various health tracking systems, such as smartwatches and smartphone apps that provide continuous health information on-demand, there is a great potential for health tracking systems, specifically designed for older adults to monitor their own health. Voice-controlled in-home personal assistants can be leveraged to assist older adults in an easier, hands-free voice interaction that can provide their health information.

Several older adults at TigerPlace (an independent living facility for older adults with tiered levels of skilled care available to allow older adults to age in place) have in-home sensors, such as depth sensors, bed sensors and motion sensors to track their daily activities and health [1, 2]. Fig.1 shows an example of older adults living with the sensor system. The sensor data are analyzed through various algorithms to generate health alerts for the clinicians [3], Fig. 2(a) shows our on-going work. Studies show that the automated

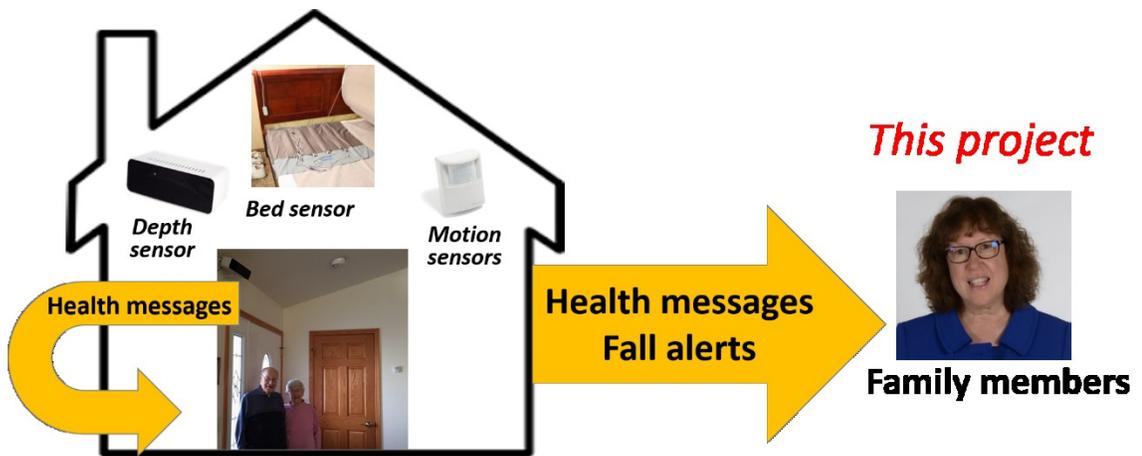
health alert system enhances the registered nurse care coordination delivery model at TigerPlace, increasing the length of stay of the older adults living with sensor systems nearly twice as compared to the older adults who do not live with a sensor system [4]. Our proposed method is to provide continuous, on-demand health information to independent living older adults and designated family or trusted other using a voice-assistant system, as shown in Fig 2(b). This could possibly help older adults to monitor and manage their own chronic health conditions and have a healthier aging trajectory. In case of increased health risks, as informed by the voice assistant systems, the older adults can potentially seek medical care and interventions from health providers to improve health.



Figure 1 In-home sensor systems.



(a)



(b)

Figure 2 Health alerts and messages generated using in-home sensor systems (a) for clinicians and social workers (b) for residents and their family members or designated trusted other.

Primary Goals

The primary goals of this study are:

- To explore data and health message representation in a simpler and more accessible form to the older adults and their designated trusted others, specifically for voice-assistant systems.
- To design and develop two prototype applications for Amazon Echo Show and Lenovo smart display with google assistant that can be used to access the older adult's health information by themselves as well as by their designated trusted others. Fig. 2 (b) shows the health alerts and messages that are generated by the in-home sensors can be received by older adults and their designated trusted others.
- Exploration and comparison of two different voice-assistant devices with built-in displays: Amazon Echo Show and Lenovo Smart Display that will be the best fit for our study to provide the health information through voice responses, text messages displayed on the screen, and data visualization graphs.
- Design, development, and deployment of a voice-assistant application based on dyad interview feedbacks and other technical factors. We used the Amazon Echo Show platform, Amazon Developer Console, Amazon Web Services (AWS) cloud platform, and a customized data processing pipeline to automatically process sensor-based health data and generate health information plots.

The remainder of this thesis is structured as follows. In chapter 2, we discuss the background and related work. In chapter 3, we discuss the initial older adults' input from

a focus group study, developing voice-assistant prototypes for dyad interviews, we also describe the comparative study of the two voice assistant prototypes using the Amazon Echo Show and Lenovo smart display with google assistant. This section also includes a brief description of the voice-assistant platforms, test scenarios for using the voice-assistant applications, and a comparison of the speech recognition capabilities of the two devices. In addition, we describe the application development process and deployment process for the Amazon Echo show devices. In Chapter 4, we discuss the results of the speech recognition test, feedback from the dyad interviews, reasons for choosing Alexa as the platform for deployment, usage, and the advantages and limitations of each platform. Chapter 5 includes contribution to the voice-assistant systems for older adults.

Chapter 2

Background and Related Work

This chapter provides a review of the interactive interfaces, voice assistant platforms, and healthcare-based interface designs for older adults.

Studies have shown that designing user interfaces for older adults bring unique challenges [5]. The information provided through these interfaces must be simple to understand by older adults [6]. Previous studies have explored the human-computer interaction (HCI) challenges in developing different user interface options for older adults and their designated trusted others. In [7], Skubic et al. have presented challenges in two user interfaces for consumer health applications. The first is to provide sensor data information for detecting early signs of health detection, and the second is an interactive remote physical therapy (PT) system that can be used for remote PT sessions between a client and a therapist. The study provides insights for developing interactive user interface systems that can be used to engage older adults effectively to manage their health conditions.

Several studies show the use of interactive robotic devices could assist in healthcare management[8-10]. A survey by Fong et al. shows that socially interactive robots can potentially assist in health care, rehabilitation, and therapy, by working in close proximity to humans[9]. The study also predicted that social robots can engage, entertain, and

enlighten their users. Additionally, studies show that people interact with technology in a similar fashion as they interact with other humans [9, 11]. Voice-assistant systems are experiencing huge growth worldwide, and are a popular way of interacting with a range of applications[12]. A recent analysis shows that by the year 2023, about 8 billion voice-assistant devices will be in use [13]. In the year 2018, voice assistant users on smartphones and on smart speakers reached 90.1 million and 57.8 million, respectively [14]. There has been significant predicted growth in adopting voice assistants in other parts of the world, including East Asia [15]. Social robots and conversational agents have also been the focus of research with older adults [16-22]. Bickmore et al. conducted a longitudinal study involving 21 adults aged 62-84. In this study half of the older adults interacted with a simulated agent daily for 2 months in their homes and the other half served as a control group. Results show that the agent was liked and significantly more efficient at increasing physical activity than the control. There have been studies on voice-assistant interfaces for older adults [23-27]. Alexandra et al. and Giuseppe et al. have explored custom designed voice assistants for older adults [23, 24]. Alexenko et al. have discussed the benefits of using voice-assistive technology to control an assistive robot and conducted a speech recognition accuracy test for younger versus older adults [25]. Anderson et al. have also conducted a speech recognition test for voice-driven document retrieval for the elderly [28]. In [26], Schlögl et al. have shown that voice-assistant devices can be used effectively by older adults, though an adequate fall back modality is a necessity should errors arise. Sayago et al. have discussed the necessity of including older adults in research activities such that the voice assistants could be tailored for their needs [27]. Voice-assistant usability has been studied with older adults in the context of the Smart Home using the Sweet-Home

system [29]. The authors have reported that the users were disturbed by the rigid grammar structure of the voice-assistant and were eager to adapt it to their own preferences.

Several studies have also explored the usability of voice-assistive technologies in different fields of healthcare and health management [30-34]. In [30], Carroll et al. have designed a routine management system using the Amazon Alexa. They found that the system was simple yet effective for individuals with early and middle-stage dementia. In [31], Pradhan et al. show the effectiveness of the voice-assistant Amazon Echo for users with a range of disabilities.

In the recent years, there has been significant growth in natural language processing technologies that have enabled the development of several voice-assistant devices for consumers, such as, Google Home and Amazon Echo [35, 36]. There have been several studies in developing interactive user interfaces for older adults using the voice-assistant devices [37-40]. Ma et al. have developed a personalized healthcare application using Amazon Alexa [37]. The voice-assistant application provides health information collected through a wearable sensor. In this study, the authors have also performed a speech recognition accuracy test. In [18], Ennis et al. have designed a smart cabinet system that includes an Amazon Echo device and a bathroom cabinet. The system can track objects in the cabinet and provide relevant information upon asking with a voice command. Their findings show that the system received a positive usability score. However, they have highlighted a few limitations of using an off the shelf voice-assistant, e.g., Amazon Echo cannot proactively speak. In [19], Cheng et al. have explored the potential and limitations of using a Google Home application for diabetes self-management for older adults when

compared to a mobile application. Results show that the participants were inclined towards using the Google Home application over the mobile application.

In [40], Choi et al. have conducted a study with nineteen older adult participants (age: 65+) over a two month time period to explore the feasibility of using voice-assistant devices to support aging in place. The authors have conducted semi-structured interviews to gather their overall attitude towards using the voice-assistant devices. Results show that the participants had a positive experience using the voice-assistant devices and expressed their interest in using this technology as a health management device to keep track of their health data, such as blood pressure or blood sugar. Kowalski et al. conducted a pilot study with Google Home to understand how older adults interact with voice assistant systems [41]. They identified a number of reasons for which voice assistant interfaces combined with smart home devices are well adjusted to the needs of several older adults for accessibility and convenience. The group of older adults in this study could naturally identify several already available applications of the voice assistant and accept them as generally useful and empowering.

Liao et al. did a survey of users and non-users of voice-controlled intelligent personal assistants to understand the motivations and barriers of adopting this technology and their concerns about data privacy [42]. Results show that the users tended to report lower levels of general privacy concerns. The users also reported high confidence that the technology providers ensured their use of voice-assistant devices as private, safe, and secure. Only seven percent of the non-users articulated privacy concerns as their primary reason for not using voice-assistant technology. This survey demonstrates the general acceptance of people for voice-assistant technologies. Beirl et al. studied how voice

assistant technology influences dynamic family interactions in the home over time [43]. The study included six family homes over three weeks. Results show that family readily appreciate voice-assistant technology into their family lives, playing, singing, performing, and even asking questions to resolve family disputes. The voice-assistant was found to encourage much laughter and helping each other but also triggered sibling rivalry, teasing and family arguments. However, the authors suggest that voice-assistants may help children learn the art and joy of conversations in the presence of humans and machines. This idea contradicts with the previous research articles including Turkle's concerns about the digital age [44-46].

Chapter 3

Methodology

This chapter describes the methodology used to develop, evaluate, and deploy the voice-assistant systems.

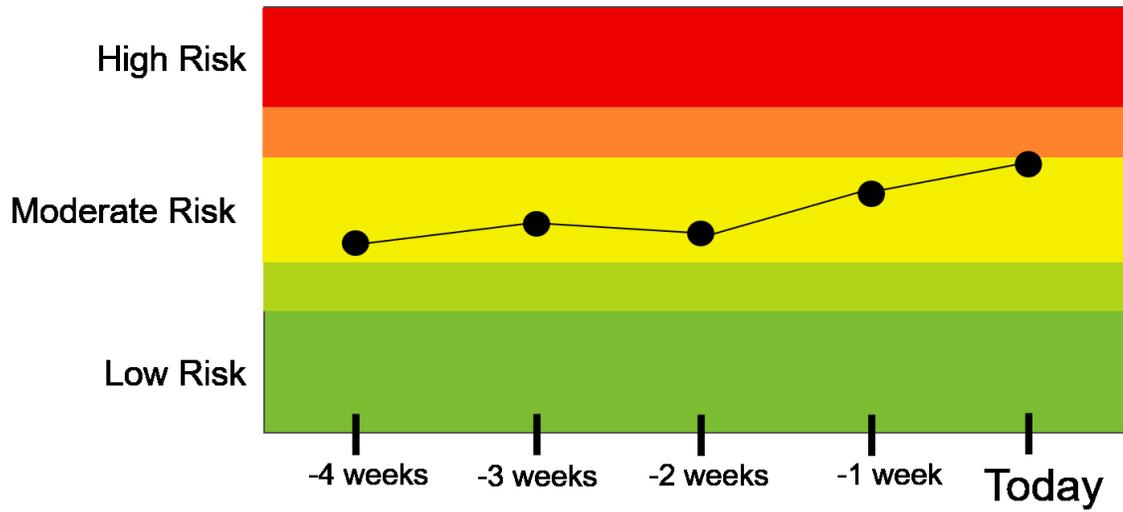
Focus Groups Studies

As an initial study, twenty-three older adult participants (Mean age=80; 85% female) and five family members (Mean age=64; 100% female) were recruited to get their feedback on different possible platforms that could be used to show their health information and health messages to themselves or to their family member [47]. The participants were informed about the health and wellness system that the University of Missouri Center for Eldercare and Rehabilitation Technology (CERT) has developed to track the health of older adults. The system primarily includes three different sensor systems, including a depth sensor system to track gait and fall risk and detect falls, a noninvasive bed sensor system to track heart rate, respiration rate, sleep patterns, and restlessness in bed, and a motion sensor system to track daily activity patterns. Sensor information is accessible via a web portal for the clinical staff in senior housing sites [7]. The participants of this focus group study were then asked about the idea of using a personal health system, specifically

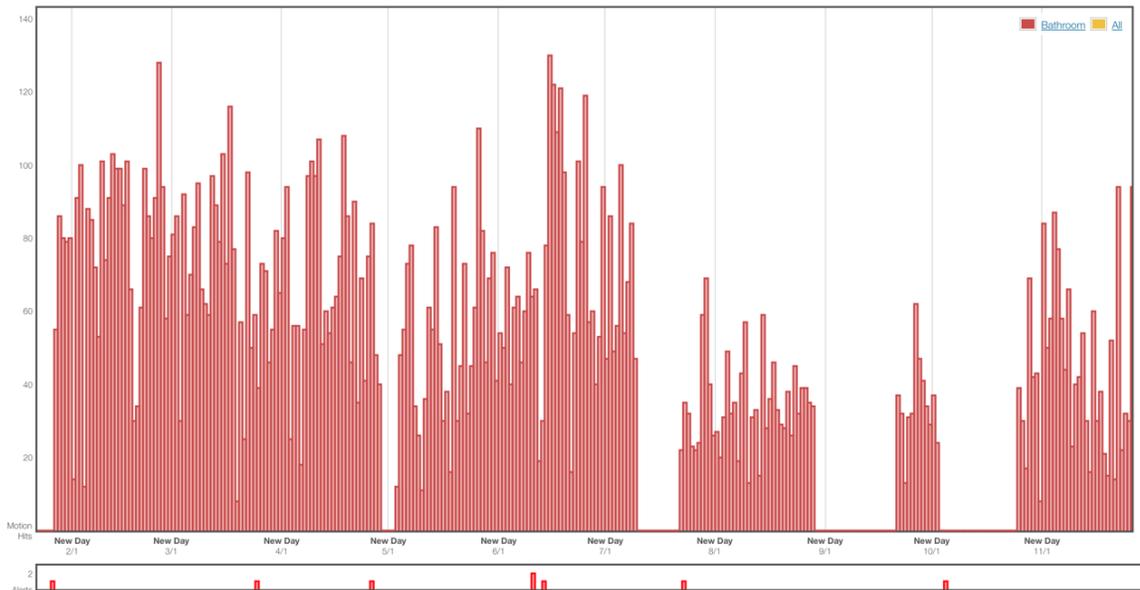
designed for older adults and their family members to visualize the same sensor data in a format designed for them.

In this focus group study, different interface platforms were demonstrated. These platforms included smartphones, computers, televisions, tablets, voice-assistant devices, and smartwatches. Focus group participants were shown prototypes of smartphones, voice-assistant systems, and tablets that were connected to our research database containing data from an in-home sensor system for older adults living at TigerPlace [1]. The participants were informed about different health data presentation options for each platform, which include voice messages, text messages displayed on a screen, and text plus voice messages with data visualization graphs. The text messages are developed using linguistic summaries based on trends in the sensor data [48]. Fig. 3 shows the different data representation graphs that were demonstrated. The different data representation graphs include line graphs as shown in Fig. 3 (a), bar graphs as shown in Fig. 3 (b), risk meter visualization showing their health risk level in the form of a thermometer gauge as shown in Fig. 3 (c).

Your Fall Risk Trend



(a)



(b)

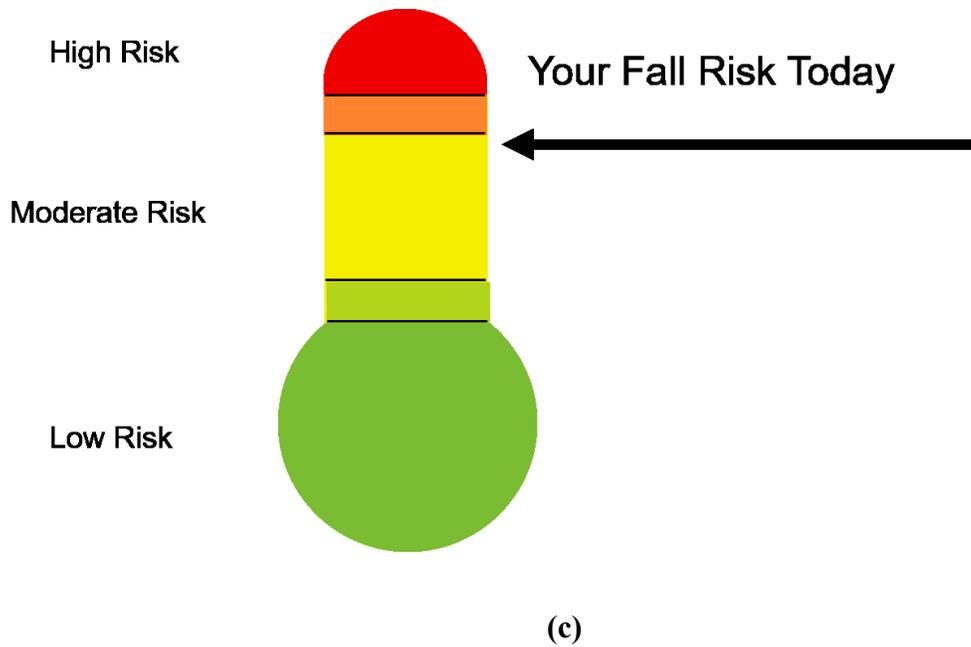


Figure 3 (a): Sample bar graph (b): Sample Line graph (c): Sample risk meter visualization showing their health risk level in the form of a thermometer gauge

Initial Feedback from Focus Groups Studies

Both older adult and family member participants preferred options in interacting with health information and receiving health alerts [47]. In the case of data visualization graphs, the participants preferred a simpler data graph that represents their health changes. However, they did not want to forgo important information about their health for simplicity's sake [47]. Most participants preferred a line graph as compared to bar graphs and risk meter visualizations showing their health risk level in the form of a thermometer gauge.

The focus group participants preferred to interact with sensor-generated health information using smartphones. Smartphone and computer use were highly preferred, but a combination of technology interfaces was desirable. Both older adult and family member

participants preferred options in interacting with health information and receiving health messages, e.g., emergency health alerts sent via text message and other health information accessible via computer. Most participants did not prefer television as a medium to get their health information. From their options of voice-assisted technology, they preferred a voice assistant with a visual display. In addition, since the voice-assisted platforms are relatively new and many participants had no prior experience with them, a more in-depth study was planned to investigate this further.

This initial focus group study helped us to understand the preferences of older adults and family members in receiving their health messages and other health information. The voice assistant systems described in this thesis were designed based on the input received from the focus group participants. The voice assistant platforms show the data in the form of simple line graphs with adequate information and simple text messages that summarize the data trends.

Voice Assistant Prototypes for Personal Health

Google Assistant and Amazon Echo voice assistant platforms were used to build the prototype for this study. For the evaluation of the voice assistant systems, four different test scenarios were designed. The details of the test scenarios are provided in the *Test Scenarios* section of the *Dyad Interviews* Section. A common prototype voice-command application was developed for both platforms based on these test scenarios. Considering the health literacy appropriate for an aging population, shorter and simpler messages were created to prevent an overburden of information to the older adults.

Therefore, to deliver useful health information in an easy to interpret format, the data visualization graphs were made simpler. Older adults and their trusted others were recruited in dyads for interviews to get their overall feedback towards these voice-assistant system prototypes. In a typical interview session, participants interact with the voice-assistant systems using the test scenario scripts listed in Tables 4, 5, 6, and 7 and provide feedback based on their experience. To make the voice-assistant interaction process easier for the participants, we placed a note with the application activation command on top of each device. The activation command can be followed by a set of health questions listed in the scenario tables. Speech recognition accuracies were also compared for both systems.

Voice-assistant devices

In this study, two-leading consumer-based voice-assistant platforms with displays were used: the Amazon Echo Show with a 10-inch display and the Lenovo Smart Display with Google Assistant, which also has a 10-inch display. Fig. 4 (a) shows the Lenovo Smart Display and Fig. 4 (b) shows the Amazon Echo Show. These platforms were selected because they have comparable displays and offer a multi-modal interaction between the voice assistant system and the older adult user. Table 1 shows the physical dimensions and specifications of the Amazon Echo Show and Lenovo Smart Display.

Both the devices function by staying in an always-listening mode once plugged in. The devices activate by listening to specific wake words. A user can ask a specific question to the voice-assistants by first speaking the wake word. The words spoken after the wake word are processed and voice response is delivered to the user. The built-in displays are

used in both devices to display the text of the device’s response as well as data visualization graphs as necessary. Both platforms can adjust the speech rate.

Table 1 DEVICE SPECIFICATION FOR AMAZON ECHO SHOW AND LENOVO SMART DISPLAY.

Device	Specification
Amazon Echo Show (2nd Generation) Display Resolution: 1280x800	10.1”
Lenovo Smart Display Display Resolution: 1920x1200	10.0”



(a)



(b)

Figure 4 (a): Lenovo Smart Display with Google Assistant (b): Amazon Echo Show.

Lenovo Smart Display with Google Assistant

By default, the wake word for Google Assistant device is “Ok Google” or “Hey Google”. The google assistant transcribes the question asked by the user and displays it on the screen. Fig. 5 shows a Lenovo Smart Display Device running the health app.

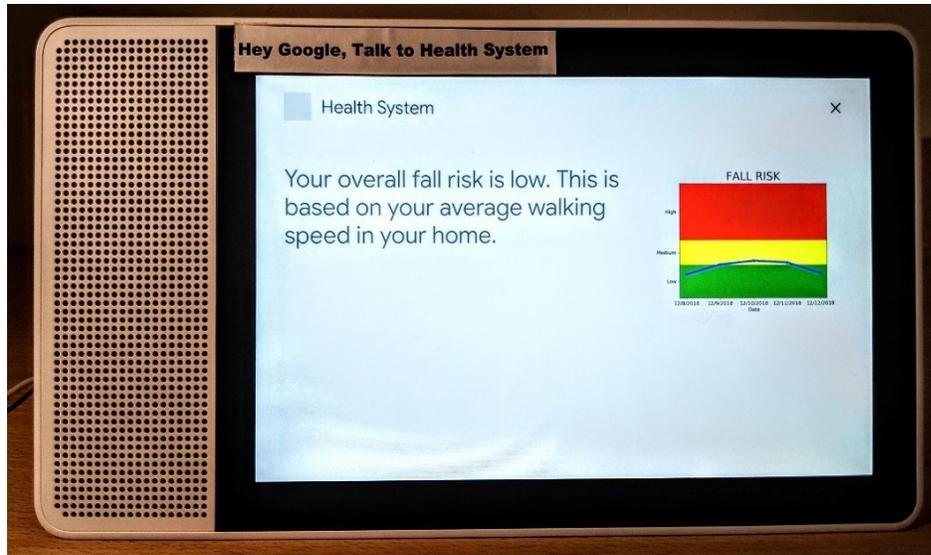


Figure 5 Lenovo Smart Display with built-in Google Assistant showing fall-risk information within the Health System App.

Amazon Echo Show with Alexa

By default, the wake word for Alexa powered devices is “Alexa”. However, this can be changed to “Echo”, “Amazon”, or “Computer”. The Amazon Echo device does not transcribe the question text as is done with the Google Assistant device. Fig. 6 shows a picture of the Amazon Echo Show display running the health app.

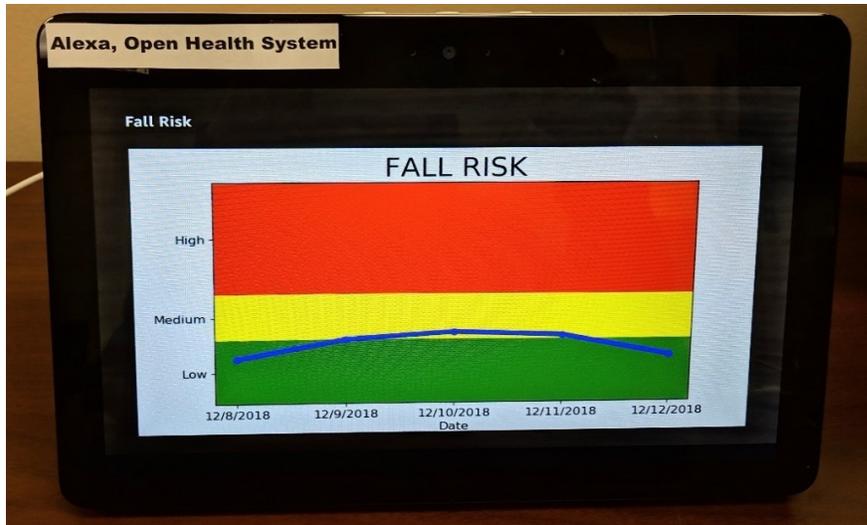


Figure 6 Amazon Echo show with built-in Alexa showing fall-risk information within the Health System App.

Ease of development in the two platforms

In this section, we describe the ease of programming and development on the Amazon Echo Show platform and on the Google Assistant platforms. We also describe development methods on these platforms with the goal of accommodating older adults. While voice-assisted technology may be accessible and easy to use for younger adults, there are several changes that must be made to give older adults a more accessible experience with the technology. The development of user interfaces for data visualization to present health data to older adults was done based on focus group results and recommended guidelines [6]. Guidelines for designing technology for older adults indicate that some fonts are more easily readable than others [6]. Sans-Serif font has been noted as preferred by older adults and perceived as more legible when compared to a Serif font. The default font family used for our data visualizations is Sans-Serif to ensure legibility. In addition, the same guidelines specify that brighter and clearer colors tend to stick out and bring attention to themselves, which in turn results in less effort to focus on a specific

image. By enhancing the contrast on the screen, a viewer may begin to use pre-attentive processes of searching for information. In pre-attentive searching, a bright and high contrast combination of colors bring attention to themselves and alleviate the user of using more effort to view the screen. As this type of searching helps older and younger adults, the data visualizations have been created with bright colors that offer a contrast to take advantage of pre-attentive searching. As a result, the line in the line graph is clearer to see, and the separations between each boundary on the graph are well known to a viewer. The contrasting colors utilized are commonly associated with other day to day phenomenon, such as a bold red for a stop sign being used to indicate a higher fall risk. In the earlier focus group study, the participants have preferred a simpler graph when shown several types of data visualizations. Therefore, the graphs used in the health app are simple. Also, the graphs have contrasting colors and the text messages are bigger [6].

The two health apps were configured on both the devices with a set of training phrases (Google)/Sample utterances (Amazon) listed in Tables 2 and 3. Training phrases/Sample utterances are the possible utterances that the user might say to invoke this intent. The apps were also trained with follow-up questions. Synonym and similar pronouncing words were included for better performance of the app, e.g., mom and mum for mother, and dad for father. More training data was added to the apps based on the information collected in the dyad interviews.

Finally, the third method of accommodation for older adults was done by slowing down the speed of the audio response on the voice-assistant devices. Both devices supported SSML tags to modify various aspects of an audio response. In this study, we elected to slow the rate of speech with SSML tags. The user interface development

guidelines for older adults indicate that as aging occurs, it becomes difficult to process faster rates of speech and that slower rates of speech are generally favored by older adults. In addition to the previous studies, our results from the initial focus group study show that older adults preferred a slow speech response.

Table 2 TRAINING PHRASES (GOOGLE)/ SAMPLE UTTERANCES (AMAZON) FOR SLEEP QUALITY.

Older Adult’s query	Family member’s query
Tell me about my sleep quality.	Tell me about my mom’s sleep quality.
Tell me about my sleep.	How did mom sleep?
How did I sleep?	Did my mom sleep well?
How was the quality of my sleep?	How’s the sleep quality of my mom?
Did I sleep well?	Tell me about my mother’s sleep quality.
	How did my mother sleep?

Table 3 TRAINING PHRASES (GOOGLE) / SAMPLE UTTERANCES (AMAZON) FOR FALL RISK.

Older Adult’s query	Family member’s query
Tell me about my fall risk.	Tell me about my mom’s fall risk.
What does my fall risk look like?	How does my mom’s fall risk look like?
Do I have any risk of falling?	Does my mom have a fall risk?

The complete list of training phrases or sample utterances for sleep quality and fall risk are provided in Appendix A.

Google Assistant

The google assistant app was developed using Google's Dialogflow API V2 platform. This technology is developed by Google and supports natural language conversations through devices with Google Assistant-enabled. The platform can be used to develop voice-assistant applications that can provide two-way continuous conversation between the Google Home device and the user, until the user's intent is fulfilled, or the conversation is finished.

The Dialogflow platform uses "Intents" as the unique identifiers that correspond to specific user utterances. Each intent has a set of training phrases. The training phrases consist of the many possible variations of a query that have the same intent. Each intent has a dedicated response to it. There are several types of responses to choose from [22]. In addition, each intent can have a set of follow-up intents. The device sends the user's utterance to the Google Assistant, which routes it to the fulfillment service via HTTP POST requests. The fulfillment for this application is developed using Node.js 8 programming. Several platforms were explored for deploying the fulfillment, including a University of Missouri server, the Inline Editor provided by the Dialogflow platform and the Heroku web platform. The prototype code was written in the Dialogflow Inline Editor, which is powered by the cloud functions for Firebase.

Alexa

An Amazon Echo application or "skill" is comprised of "intents" that each performs specific actions within the skill. An intent represents an action that can be performed by the skill and may contain optional "slot" values to accomplish more specific tasks requested

of it by the user of the device. To utilize an intent, the user speaks to the device, and the device matches the spoken words to an intent via an “utterance”. Utterances are phrases that contain words that Amazon looks for when deciding which intent to select after determining the words spoken by the user and may contain spots for slot values to be inserted. When the user of an Echo device speaks to the device, Amazon determines which intent to select by comparing the words it understands to the utterances of each intent. When an intent is successfully determined, the code written to handle that intent is run.

Development for Amazon Alexa was done in Node.js version 8.10. Amazon’s APL was used alongside Node.js 8.10 to deliver full-screen data visualizations. Additionally, Amazon’s AWS Lambda service was used to host the code required for the Alexa skill. Code uploaded to Lambda was done so in the form of a zip file containing the Node.js code to handle each intent and the imported modules that the code requires. At the current time of prototype implementation, Amazon's Alexa Presentation Language (APL), a JSON object used to format images, is in a public beta release and is utilized by the Echo Show devices to present full-screen data visualizations.

Dyad Interviews

We recruited dyad participants of age 65+ and one of their family members or designated trusted others for testing the two voice-assistant prototype applications and getting feedback on the two devices and the health app. Eighteen dyad interviews were conducted. The participants interacted with both the voice-assistant application prototypes. A Speech recognition test was also conducted, each person reads out a list of phrases to the

Amazon Echo Show and Google Assistant to test how well the devices recognize their speech. Participant's feedbacks were noted during the interview.

Test Scenarios

Two test scenarios were developed, with responses customized for the older adult and a family member. The older adult’s query produces a second person singular response, e.g., you or your. The family member’s query produces a third-person masculine/feminine singular response referring to the older adult, e.g., he or she. Tables 4, 5, 6 and 7 show the test scenario scripts. We also include test scenarios for husbands and wives to query health data of each other.

Table 4 SCRIPT FOR OLDER ADULTS FOR SLEEP QUALITY.

Older Adult	Voice Assistant
<p>Hey Google, talk to Health System.</p> <p style="text-align: center;">Or</p> <p>Alexa, open Health System.</p>	<p>Hi, Welcome to your personal Health System. How can I assist you today?</p>
<p>Tell me about my sleep quality.</p>	<p>Your sleep quality has been decreasing over the past few days. Would you like to know more?</p>

<p>Tell me more</p>	<p>This is what your sleep quality graph looks like. This graph uses several pieces of data to determine your overall quality of sleep. Overall, your sleep quality has been decreasing over the past few days. (Sleep quality graph will be displayed on the screen) (see Fig. 7)</p>
<p>How is my sleep quality calculated?</p>	<p>Your sleep quality is calculated by comparing your non-restlessness time in bed to your total time in bed.</p>
<p>How long was I restless?</p>	<p>You were restless for 1 hour 34 minutes and spent 7 hours and 20 minutes in bed.</p>

SLEEP QUALITY

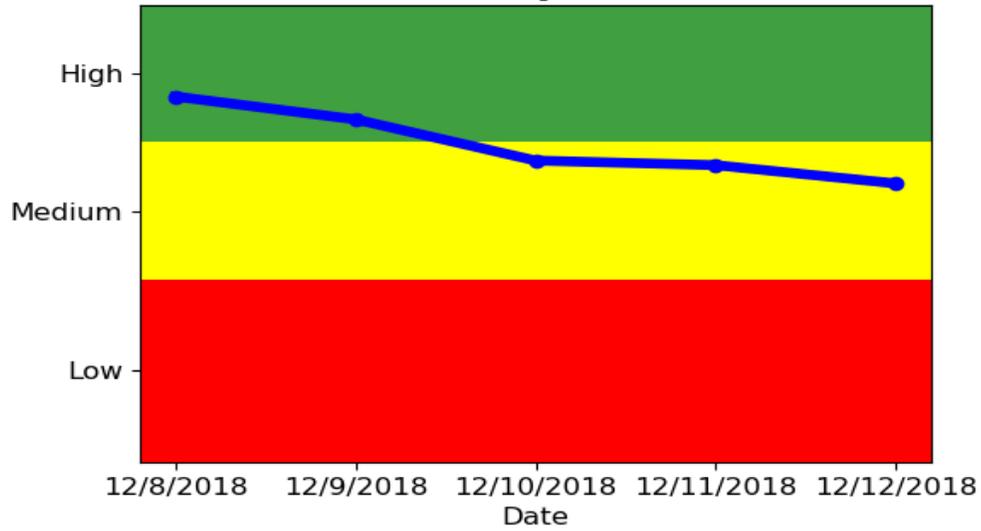


Figure 7 Sample data visualization for sleep quality.

Table 5 SCRIPT FOR FAMILY MEMBERS FOR SLEEP QUALITY.

Family Member	Voice Assistant
Hey Google, talk to Health System. Or Alexa, open Health System.	Hi, Welcome to your personal Health System. How can I assist you today?
Tell me about my mom's sleep quality.	Your mom's sleep quality has been decreasing over the past few days. Would you like to know more?
Tell me more	This is what her sleep quality graph looks like. This graph uses several pieces of

	<p>data to determine her overall quality of sleep. Overall, her sleep quality has been decreasing over the past few days.</p> <p>(Sleep quality graph will be displayed on the screen) (see Fig 3)</p>
How is her sleep quality calculated?	Your mom's sleep quality is calculated by comparing her non-restlessness time in bed to her total time in bed.
How long was she restless?	She was restless for 1 hour 34 minutes and spent 7 hours and 20 minutes in bed.

Table 6 SCRIPT FOR OLDER ADULTS FOR FALL RISK.

Older Adult	Voice Assistant
<p>Hey Google, talk to Health System.</p> <p>Or</p> <p>Alexa, open Health System.</p>	<p>Hi, Welcome to your personal Health System. How can I assist you today?</p>
Do I have any risk of falling?	Your fall risk is low. Your overall walking looks good. Would you like to know more?

Tell me more	Your overall fall risk is low. This is based on your average walking speed in your home. (Fall risk graph will be displayed on the screen) (see Fig 4)
What is my walking speed?	Your average walking speed was 2.2 feet per second.
How is the walking speed measured?	Your walking speed is measured using a sensor that is mounted on the wall in your home.

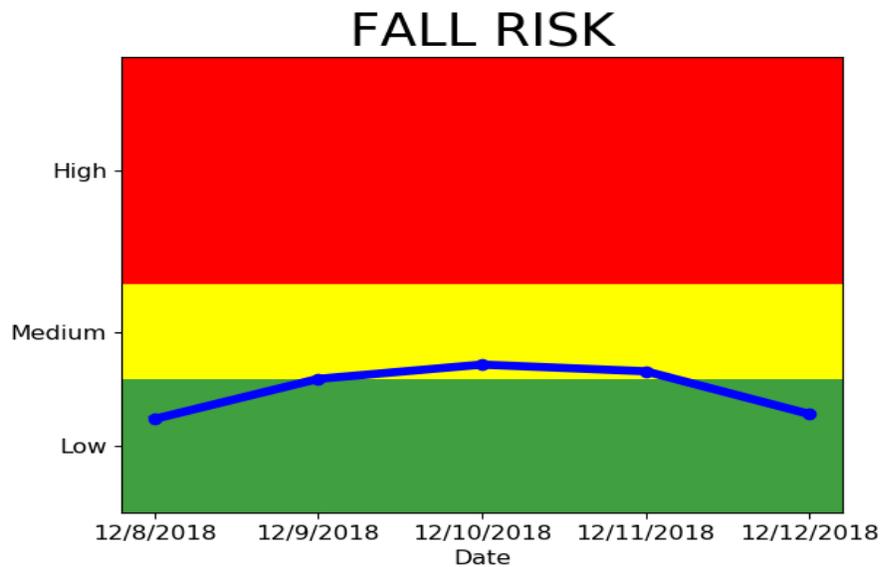


Figure 8 Sample data visualization for fall risk.

Table 7 SCRIPT FOR FAMILY MEMBERS FOR FALL RISK.

Family Member	Voice Assistant
<p>Hey Google, talk to Health System.</p> <p>Or</p> <p>Alexa, open Health System.</p>	<p>Hi, Welcome to your personal Health System. How can I assist you today?</p>
<p>Does my mom have a fall risk?</p>	<p>Your mom’s fall risk is low. Her overall walking looks good. Would you like to know more?</p>
<p>Tell me more</p>	<p>Your mom’s overall fall risk is low. This is based on her average walking speed in her home.</p> <p>(Fall risk graph will be displayed on the screen) (see Fig. 8)</p>
<p>What is my mom’s walking speed?</p>	<p>Her average walking speed was 2.2 feet per second.</p>
<p>How is the walking speed measured?</p>	<p>Her walking speed is measured using a sensor that is mounted on the wall in her home.</p>

Speech Recognition Test

We tested the speech recognition accuracy of both voice-assistants by using the “repeat after me” feature of Google Assistant and the “copycat” skill of Amazon Echo Show, to determine which platform could recognize the voice better. Twelve different sentences were used in this test, with each sentence having a different combination of words as listed in Table 8. Each person reads out a list of phrases to the Amazon Echo Show and Google Assistant to test how well it recognizes their speech. We found that some of the words in the sentences were incorrectly recognized by Alexa while Google Assistant recognized and repeated all the words correctly.

Table 8 PHRASES FOR THE SPEECH RECOGNITION TEST.

Phrases for the speech recognition test
What’s happening with my health?
What is my temperature?
Please tell me my pulse.
How many steps did I take?
Am I good to go for today?
Hang the air freshener from the rearview mirror.
The vacation was canceled on account of weather.
On numerous occasions she left early.
You can use your computer to program video games.
What are the chances we have a thunderstorm today?

Never do strenuous exercises close to bedtime because your body needs to relax before getting some shut-eye.

An hour of daily jogging will enhance your blood circulation.

Choosing a voice-assistant platform

Based on the feedback from the dyad interviews and technical advantages and limitations of both the platforms, we choose the Amazon Echo Show as the voice assistant platform that will be deployed at 55 older adult residents. Chapter 4 contains the details of this analysis.

Development and Deployment of the Amazon Voice-assistant Application

This section explains the steps to develop and deploy the Amazon voice-assistant application. The name of the application is “Health Assistant”. This application answers to health-related questions in the form of audio and visual response.

Application Overview

Fig. 9 shows the application overview. The in-home sensor system collects resident’s health data using depth sensor, bed sensor, and motion sensors. Data collected from these sensors are stored in servers and processed using several algorithms to obtain health and activity parameters including gait, fall risk, detect fall, motion patterns, sleep pattern, heart rate, and respiration rate. The processed data are then stored in database tables based on user Ids. When a resident opens the “Health assistant” skill, the most recent health

data are fetched from the CERT database tables. Personalized health information for each resident is delivered when a resident asks a health-related query to the voice-assistant. Fig. 10 shows the overall workflow of the application. The workflow is explained in detail in the following sections of this chapter.

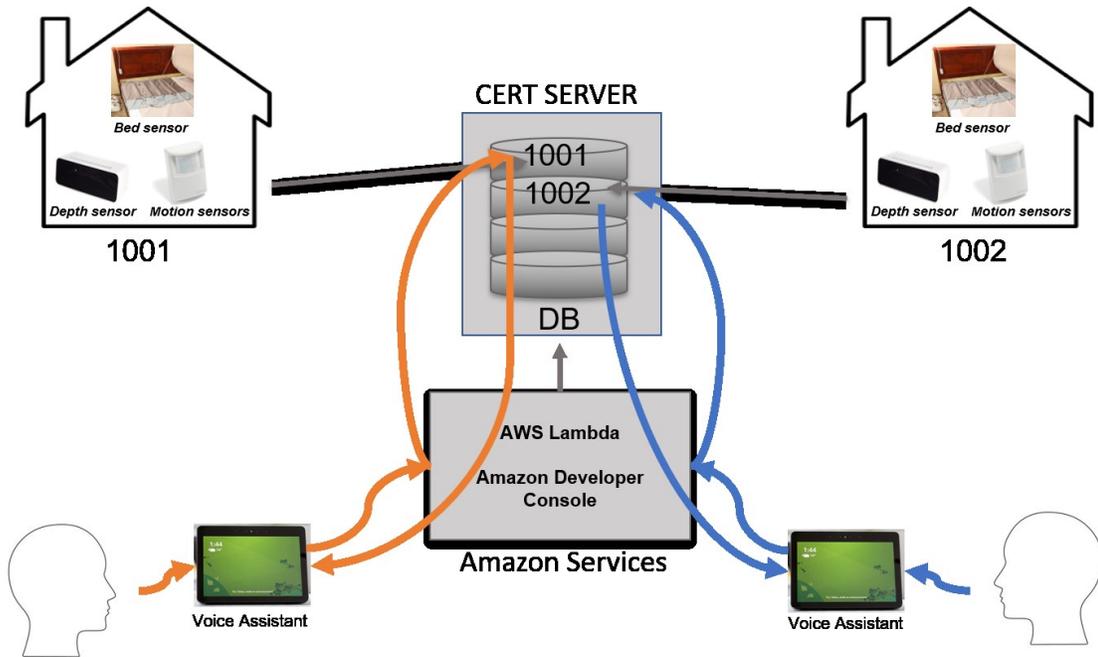


Figure 9 Workflow of users asking queries to the device, queries being processed, and personalized results being returned to the users.

Building Skills

Alexa's skills are a set of built-in capabilities. Skills are like apps for Alexa, enabling customers to perform tasks or engage with the content naturally with voice [49].

Steps to navigate to "Health assistant" skill on Amazon developer console

Visit "<https://developer.amazon.com/>". Click on the "Alexa" option. Select the "Skill Builders" dropdown menu from the top left. Select "Developer console" from the list. Then log in with your credentials. On the "Alexa Skills Kit Developer Console" page, you can see the list of all the Alexa Skills. Select "Health Assistant (status - In Development)".

There are two versions of this skill:

1. Health Assistant - In Development(status): Any update to the skill can be done in the development mode and can be made "Live" for production.
2. Health Assistant - Live(status): This is the "Live" production version.

Invocation name

Users say a skill's invocation name to begin an interaction with a custom skill. Our skill's invocation name is "Health Assistant".

Intents

An intent represents an action that fulfills a user's spoken request. Each intent will have sample utterances. Sample utterance is the possible utterances that the user might say to invoke this intent [49]. There is also a JSON editor where the code from utterances.json is found.

Endpoint

The Endpoint will receive POST requests when a user interacts with the Alexa Skill.

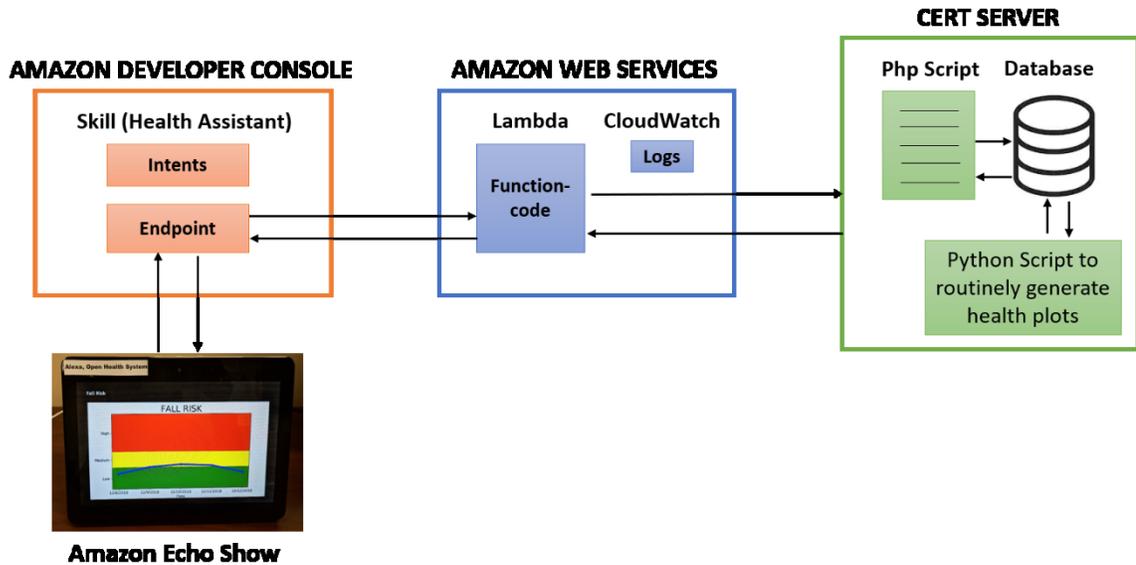


Figure 10 Workflow of amazon's voice-assistant application.

Amazon Web Services (AWS)

Lambda

The nodejs code is hosted on AWS lambda.

Lambda Function

We used an AWS Lambda function for this project. To navigate to the Lambda function, Log in to “AWS”. From all services -> Compute-> select Lambda. You can view

or create your own Lambda functions. I created a function (with name db-connect) that this study uses. We can create a Lambda function by clicking on create -> browse serverless repositories so we could choose a template. The easiest one to do is the nodejs-fact-skill, and it configures everything for you as well.

The AWS Lambda ARN or HTTPS address for the skill should go in the Endpoints section in the Alexa skill build(in Alexa Developer Console). In Lambda, this function is located in N. Virginia.

Upload the zip file of the function code in the "Function code" section. Select Runtime as "Node.js 8.10" and Handler as "index.handler".

Function code

For this skill, this code is uploaded in a zip file on AWS Lambda (Function code section). The zip file includes just the index.js and the node_modules.

Index.js

Each Alexa's user id is mapped to one of the CERT database user id.

On launch, this skill connects to the database (initially I used php script to connect to the database, that was hosted in CERT server) and fetches various predetermined rows from the database and stores them in global variables.

When a user says a query, then the code matches the user's query with one of the "Intent Handler". If there is a matching "Intent handler" then it responds with the

corresponding intent's response. The response is via audio and visual response (displays the intents response). The visual response can sometimes have a plot to show. The plots are generated by the python script(aws-health-assistant-python).

CloudWatch

Cloudwatch has the log files. To keep track of the log, Log in to “AWS”. From all services -> Management & Governance -> select Cloudwatch. From the left menu, select Logs. Select the “db-connect” option to track all the log files.

Generating Plots

This script generates the plots that show the change in the health data over a period of time.

How it works

This script is scheduled to run every night at 12:00 AM to generate plots. The plots are saved in CERT's server.

Types of plots generated

The types of plots generated are: change in pulse rate, change in respiration rate, change in sleep quality, change in fall risk, and change in walking speed.

Steps involved in generating health change plots

1. The code reads the list of users ids.
2. It connects to University of Missouri (MU) CERT database.
3. It checks whether a folder with today's date exists. If not, it creates one. All the plots generated on that day will be saved inside that folder.
4. Log file will be generated every time the script is run. The log file is under `plots/current_date/current_date.log`.
5. For each user, a user folder is created with the name `currentDate_userId`.
6. For each user, 5 plots are generated including pulse rate, respiration rate, sleep quality, fall risk, walking speed. It is inside the folder `plots/currentDate/currentDate_userId/currentDate_userId_plotName.png`.
7. Close sql connection.

Publishing the Skill with Private Availability

Once the skill is ready, we used the developer console to publish the skill privately. We have two options; either we can publish it publicly or publish it only to Business organizations. Enabling public will give access to anyone who enables the skill, whereas, publishing it to Business organizations will give access to the selected business. When we publish it, its status changes to “Live”. A private skill is published “live”, but it is not available in the Alexa skill store.

After the skill is “Live”, we can give access to a business organization from the Live Health assistant app.

Linking Amazon Echo Show devices to Database User Ids

Each Amazon Echo Show’s user id is linked with a database user id in the function code.

Using the skill on Amazon Echo Show device

The name of this app is Health Assistant.

1. First, activate the device by saying the wake word “Alexa” followed by opening the skill by saying “Open health assistant”
 - E.g., “Alexa, Open Health Assistant”
 - Wait for the device to open the skill
2. Then ask your health-related question.
 - E.g., “Alexa, What is my risk of falling”
 - Wait for the device to respond
3. You can ask more questions.
 - E.g., “Alexa, How did I sleep”
 - Wait for the device to respond
4. You can exit at any time by saying “Exit”
 - E.g., “Alexa, Exit”
 - The device should exit from the skill.

List of Health Information queries

26 different questions that can be asked to the device. Table 9 shows the list of queries and responses.

Table 9 QUERY AND RESPONSE FOR PULSE RATE.

QUERY	RESPONSE
PULSE RATE	
Recent night time pulse rate	
what is my recent night time pulse rate	The most recent night time pulse rate for date August 7 2017 was 62 beats per
what is my most recent night time pulse rate	
Recent pulse rate	
what is my recent pulse rate	The most recent pulse rate for date August 7 2017 was 62 beats per minute.
what is my most recent pulse rate	
Recent day time pulse rate	
what is my recent day time pulse rate	The most recent day time pulse rate for date August 7 2017 was 62 beats per
what is my most recent day time pulse rate	
Change in pulse rate	
what is the change in pulse rate in the last few days	This graph shows the most recent change in pulse rate. A normal resting heart rate

show the change in pulse rate over the past few days	for adults ranges from 60 to 100 beats per minute (This response display a graph as shown in Fig. 11).
Normal pulse rate	
what is a normal pulse rate	A normal resting heart rate for adults ranges from 60 to 100 beats per minute.

Complete list of Queries and Responses are listed in Appendix B.

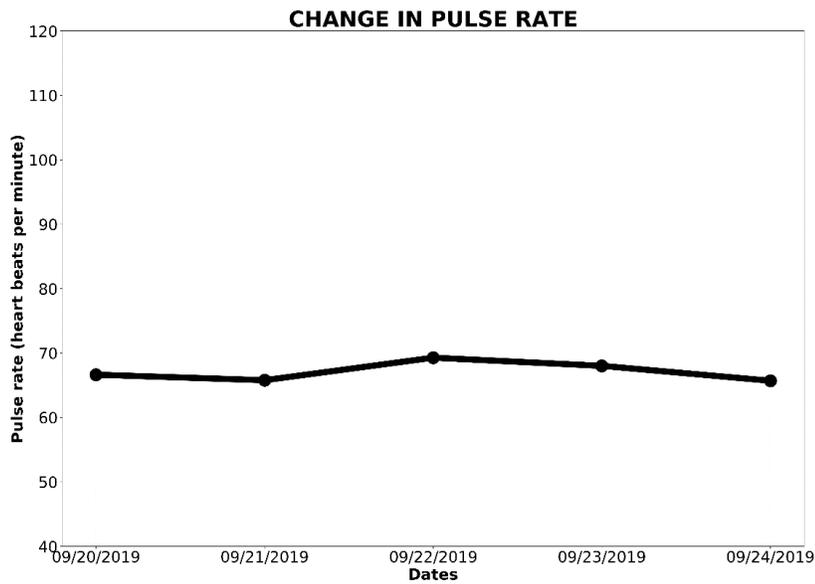


Figure 11 Change in Pulse Rate Plot.

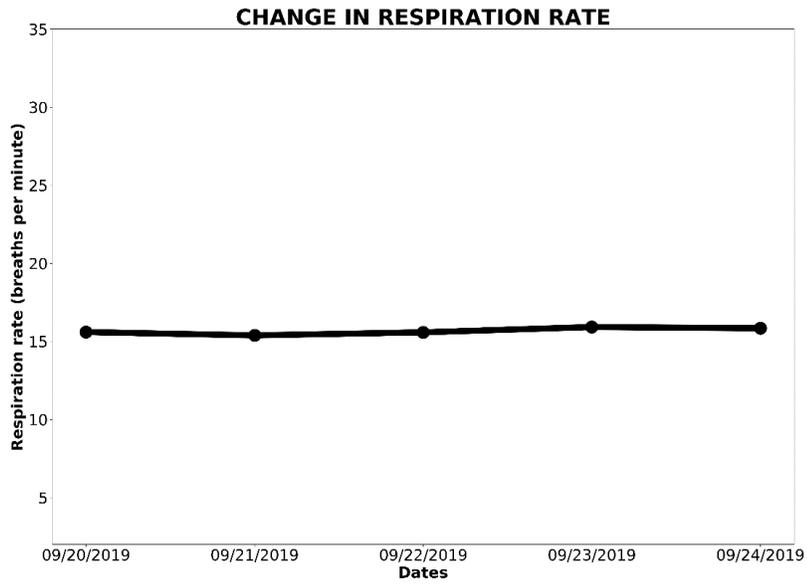


Figure 12 Change in Respiration Rate Plot.

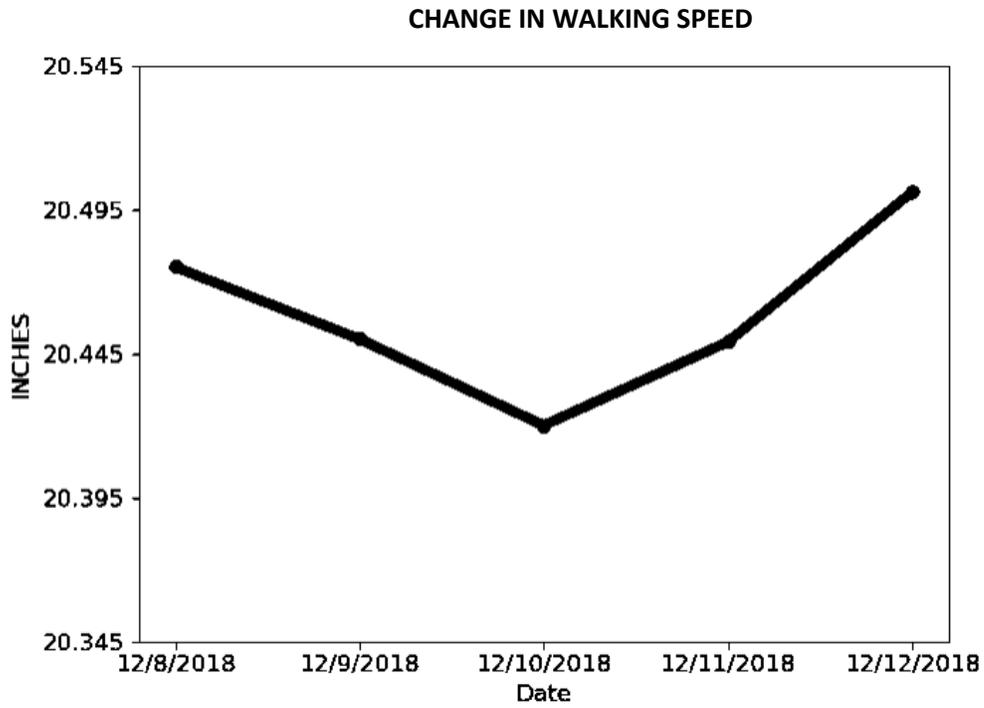


Figure 13 Change in Walking Speed Plot.

Chapter 4

Results and Discussion

This chapter contains the Speech recognition results, feedback from dyad interviews, reasons for choosing Amazon Echo show, and Usage followed by discussion.

Speech Recognition Results

Table 10 shows a comparison of voice recognition performance between the Amazon Echo Show and the Google Assistant. A previous speech recognition test was conducted in 2016 using the Amazon Echo [37]. The first and second columns: Amazon Echo Show and Google assistant, shows the misinterpreted words by the two voice-assistants from 18 dyads (36 participants). These are results based on the comparison test.

Table 10 SPEECH RECOGNITION TEST RESULTS WITH WORD-LIST AND MISINTERPRETATIONS: PARTICIPANTS (2 STUDENTS, 18 DYAD) [represents Interpreted correctly, # represents Did not repeat the word, \$ represents Unclear word].*

Words/Phrases	Misinterpreted as	
	Amazon Echo Show (2018-19)	Google Assistant (2018-19)
Health	Heart, help, house, \$	*
Pulse	Pearls, #, pets, pause, voice, cost	*
Was	*	*

An hour	End our, In our daily, what an hour, In our, \$	I an hour
Vacation	Location, \$, Occasion, cat eye	*
Rearview	Review, View, #	*
Early	Hurly	*
Shut eye	Shark, Shut up, \$, shut up eye	Shut up
On	#, a	*
On account of	\$, counter, kind of, counted	Kinder, county
Your	\$	*
Jogging	*	job
Am I	*	I am I
An hour of	our	
Will enhance	Without \$	One hand catch, \$
Hang	Hang in, how many, \$	Hey there, *, turn
The	#	*
On numerous	No worse, #, numbers, \$	*
To	#	*, #
she	are	*
strenuous	Strangers, \$	*
Do strenuous	Two words	*
body	bot	*
My	A my	*
Good	Going	*
What	#, where	*
Occasion	Cat eye	*
The	*	A
The vacation	\$	\$
Cancelled	*	Cancelling
Never	*	A never
Numerous occasion	\$	*
Computer to program	Compute a	*
An hour of daily jogging will enhance	\$	*
Will enhance your	*, \$	\$
exercises close to bedtime because your	#	*

body needs to relax before getting some shut-eye		
Never do strenuous exercises close to bedtime because your body needs to relax before getting some shut-eye.	Never two words	*

Table 11 shows the overall speech recognition results for males versus females for both the device.

Table 11 SPEECH RECOGNITION TEST RESULTS for MALE VS FEMALE [10 Males, 26 Females, 94 words per participant].

	Female	Male
Alexa	199/2444 ^a	139/940
Google	23/2444	15/940

^aTotal misinterpreted words / total words

The total number of Female Participants were 26 and the total number of Male Participants were 10. Each participant spoke 94 words. The total number of words spoken by all participants were 3384. Out of the 2444 words spoken by the female participants, Alexa and Google missed 199 and 23 words, respectively. In case of Male participants, out of 940 words spoken by the participants, Alexa and Google missed 139 and 15 words respectively. Results show that google assistant performed better in speech recognition test.

Feedback from Dyad Interview

This section describes the feedback from the dyad interviews based on their device preferences, graph displaying ability of the devices, preferring a particular wake up word over the other, transcribe ability of the devices, and accuracy in speech recognition.

Device preference

The device preferences for each dyad interview are listed below.

Dyad 1 (husband/wife): Both prefer Google Home

Dyad 2 (husband/wife): Both prefer Amazon Echo

Dyad 3 (mother/son aged 55): Both prefer Amazon Echo

Dyad 4 (husband/wife): Wife prefers Amazon Echo and husband has no preference (however he prefers the larger graphs on the Amazon Echo)

Dyad 5 (mother/daughter aged 38): Mother preferred Amazon Echo device; Daughter noted pros/cons with each device, overall seemed to prefer the Google Home

Dyad 6 (father/daughter aged 62): Both did not necessarily prefer one device over the other, they thought both were easy to use and understand.

Dyad 7 (husband/wife): Both preferred the Google Home, however after the speech recognition test they noted issues with the Google Home device

Dyad 8 (husband/wife): Both preferred the Google Home

Dyad 9 (husband/wife): Both seemed to prefer the Google Home overall

Dyad 10 (husband/wife): Both preferred Amazon Echo

Dyad 11 (mother/daughter): Both preferred Amazon Echo

Dyad 12 (OA/friend): Both preferred Amazon Echo

Dyad 13 (OA/friend): OA liked Amazon Echo and Daughter doesn't mind or has no preference (the interviewer referred to her as daughter)

Dyad 14 (OA/friend): Both preferred Amazon Echo

Dyad 15 (OA/friend): Both preferred Amazon Echo, but friend also appreciates Google's speech recognition capacity

Dyad 16 (OA/friend): OA preferred Amazon Echo and friend is okay with either of the two

Dyad 17 (mother/daughter): Both preferred Amazon Echo

Dyad 18 (husband/wife): Not possible to determine who, but one of them preferred Amazon Echo [50]

Table 12 shows the summary of the device preference for older adults versus younger adults. 19 older adults preferred Amazon Alexa and 6 older adults preferred Google Assistant. Results show that most of the older adult participants preferred Alexa over Google. In case of younger adults, 2 participants preferred Alexa and 3 participants preferred Google, so most of the younger participants preferred Google over Alexa. Overall, 21 participants preferred Alexa, 9 participants preferred Google and 6 participants did not had a specific preference.

Table 12 DEVICE PREFERENCE SUMMARY

	Alexa	Google
Older participants (age: 65+)	19	6
Younger participants (age: below 65)	2	3

Graph

In designing displays with images, currently, Google Assistant cannot display full-screen images like Alexa can [51]. In our study, the application required an image to be easily seen or displayed across the screen; working with Amazon's Alexa proved easier. Moreover, most of the older adult participants also preferred a bigger graph in full-screen size in the Amazon Echo Show.

Wake up word

Google Assistant at this point in time lacks the ability to change its wake word to any other option other than "Hey Google" or "Ok Google", while Alexa's wake word can be changed from "Alexa" to "Computer", "Amazon", or "Echo". Moreover, most of the older adults preferred saying the wake-up word "Alexa" as compared to "Hey Google" or "Ok Google".

Transcribes

They liked the fact that the google assistant writes the text on the screen while they speak.

Speech Recognition

Speech recognition is better in Google Assistant.

Reason for choosing Alexa as the platform for deployment

Based on the technical advantages and limitations of both the device and based on the participant's preferences, we choose the Amazon Echo Show. The first reason for choosing the Amazon Echo Show was that Amazon's ability to display a full-screen size image, whereas in Google Assistant we could not display a full-screen size image [51]. Moreover, participants also preferred the bigger image in the Amazon Echo show as it was clearer to see a big image.

The second reason was, the wake word is customizable in the case of Amazon. The options for wake words are "Alexa", "Amazon", "Echo", or "Computer". Whereas, in the case of google the two options for wake words are "Hey Google" or "Ok Google". Most of the participants did like saying "Alexa" as a wake word as compared to "Hey Google" or "Ok Google".

The third reason was, connection to a new wifi network is easy in case of Amazon, to get connected to a new wifi network just connect the Amazon Echo Show device directly to the new wifi network. Whereas, in the case of google assistant, first we need to connect a mobile device/tablet (must have google home app installed) to the new wifi network then set up the google home device through the google home app on the mobile phone/tablet. So, this could be cumbersome for older adults to set up themselves.

Although, we have shown that Google Assistant scores better in speech recognition tests than Alexa does, Alexa was able to understand the health-related queries during the dyad interviews.

Usage

The older adults can ask about their health-related questions to the device for e.g., Fall risk, sleep quality, pulse rate, respiration rate, health messages. The family members or the designated trusted other could also use the “Health assistant” application on the Alexa app on their mobile phones to check the health information of the older adults. few older adults also liked the idea of checking on the weather forecasts on the Amazon Echo Show device. A list of other things that the older adults could use the Amazon Echo Show for are:

"Alexa, play my video Flash Briefing."

"Alexa, play some music."

"Alexa, set an alarm for 7 a.m."

"Alexa, set a pizza timer for 20 minutes."

"Alexa, what's the weather like?"

"Alexa, how do you make chocolate chip cookies?"

"Alexa, when is [holiday]?"

"Alexa, sing a Christmas carol."

"Alexa, what was the score of the [team] game?" [52]

Discussion

While the idea behind both the Amazon Echo Show and the Lenovo Smart Display with google assistant is the same, each has several advantages and disadvantages when compared to the other.

So far, we have interviewed 18 dyads of people aged 65+ and one of their family members or trusted others. In these interviews, some of the older adult participants have

preferred the Google Assistant, as they thought the voice of the Google Assistant is more natural. However, some of the other older adults preferred Amazon Echo, as they thought the wake word – “Alexa” is easier to use than “Hey Google”. Also, they preferred the larger graphs in the Amazon Echo Show as compared to the Google Assistant. Thus far in this dyad interview study, all 18 dyad participants liked the technology and they mentioned that they would like to use it. The results also show that our target users are enthusiastic about the voice assistant technologies as a healthcare information interface.

The limitation of this application is that the application can only answer to the queries that are listed in the sample utterances. The other limitation of Amazon devices is that a user has to open the particular app first in order to use it. For example, in case of the “Health assistant” app, the user has to say “Alexa, open health assistant” first to open the app and then ask the health-related queries.

Chapter 5

Conclusion

In this study, we have developed two prototype voice-assistant apps for the Google Assistant and Amazon Echo platforms, based on feedback provided in an earlier focus group study and previous literature. The applications can provide on-demand health information, such as sleep quality and fall risk to independent living older adults and their family members or designated trusted others. Four different test scenarios were designed for the dyad interviews to get the feedback of older adults and their family members or designated trusted others on the usability of the voice-assistant devices for managing and tracking health, their preferences of a device over the other. The speech recognition capabilities of the two voice assistant devices were also compared in the dyad interviews. Results show that the Google Assistant performs better than the Amazon Echo in accurately recognizing speech. However, Amazon Echo Show has the feature to display a full-screen size image, the wake word “Alexa” was preferred by older adults and wifi connectivity is easy in the Amazon Echo Show. So, we choose the Amazon Echo Show as the device that will be deployed in 55 older adults' homes. We did the final development of the “Health Assistant” application for Amazon Echo Show using Alexa Developer console, Amazon Web Services, nodejs, and CERT server database.

Contributions

- Explored possible ways to represent health data and messages in a simpler and more accessible form to the older adults and their designated trusted others.
- Conducted focus group study with older adults and their family members to get their feedback on data representation graphs and possible interfaces for displaying health information.
- Developed two prototype voice-assistant applications using Google assistant and Amazon Echo Show based on the focus group study feedback.
- Conducted dyad interviews for feedback on the prototype voice-assistant applications.
- Compared the two voice-assistant platforms based on voice recognition tests, user-interaction features, and feedbacks from the dyad participants.
- Based on the feedback from the dyad interviews and the device comparison analysis, an updated version of the “Health Assistant” app was developed for Amazon Echo Show.

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Appendix A: Complete List of Training phrases (Google) / sample utterances (Amazon)

Sleep Quality

Table 13 Complete List of Training phrases (Google) / sample utterances (Amazon) for Sleep Quality

Older Adult's query	Family member's query
Tell me about my sleep quality.	Tell me about my mom's sleep quality.
Tell me about my sleep.	How did mom sleep?
How did I sleep?	Did my mom sleep well?
How was the quality of my sleep?	How's the sleep quality of my mom?
Did I sleep well?	Tell me about my mother's sleep quality.
How did I sleep last night?	How did my mother sleep?
	Did my mother sleep well?
	How's the sleep quality of my mother?
	Tell me about my mum's sleep quality.
	How did my mum sleep?
	Did my mum sleep well?
	How's the sleep quality of my mum?
Tell me more	Tell me more
Yes	Yes
Sure	Sure

How is my sleep quality calculated?	How is my mom's sleep quality calculated?
How is my sleep quality estimated?	How is my mom's sleep quality estimated?
How is my sleep quality measured?	How is my mom's sleep quality measured?
How is my sleep quality captured?	How is my mom's sleep quality captured?
How is the sleep quality calculated?	How is her sleep quality calculated?
How is the sleep quality estimated?	How is her sleep quality estimated?
How is the sleep quality measured?	How is her sleep quality measured?
How is the sleep quality captured?	How is her sleep quality captured?
	How is the sleep quality calculated?
	How is the sleep quality estimated?
	How is the sleep quality measured?
	How is the sleep quality captured?
How long was I restless?	How long was my mom restless?
How long did I sleep?	How long did my mom sleep?
For how long I was restless?	How long was my mom in bed?
	How long was my mother restless?
	How long did my mother sleep?
	How long was my mother in bed?
	How long was my mum restless?

	How long did my mum sleep?
	How long was my mum in bed?
	How long was she restless?
	How long did she sleep?
	For how long she was in bed?

Fall Risk

Table 14 Complete List of Training phrases (Google) / sample utterances (Amazon) for Fall Risk

Older Adult's query	Family member's query
Tell me about my fall risk.	Tell me about my mom's fall risk.
Tell me about my walking data.	Tell me about mom's walking data.
Do I have any risk of falling?	Does my mom have a fall risk?
What does my fall risk look like?	How does my mom's fall risk look like?
How does my fall risk look like?	Tell me about my mother's fall risk.
Tell me about my walking.	Tell me about mother's walking data.
How's my walking?	Does my mother have a fall risk?
	How does my mother's fall risk look like?
	Tell me about my mum's fall risk.
	Tell me about mum's walking data.
	Does my mum have a fall risk?
	How does my mum's fall risk look like?

Tell me more	Tell me more
Yes	Yes
Sure	Sure
What is my walking speed?	What is my mom's walking speed?
What is my average walking speed?	What is my mom's average walking speed?
	What is the walking speed of my mom?
	What is the average walking speed of my mom?
	What is my mother's walking speed?
	What is my mother's average walking speed?
	What is the walking speed of my mother?
	What is the average walking speed of my mother?
	What is my mum's walking speed?
	What is my mum's average walking speed?
	What is the walking speed of my mum?
	What is the average walking speed of my mum?
	What is her walking speed?

How is the walking speed calculated?	How is my mom's walking speed calculated?
How is the walking speed estimated?	How is my mom's walking speed estimated?
How is the walking speed measured?	How is my mom's walking speed measured?
How is the walking speed captured?	How is my mom's walking speed captured?
	How is my mother's walking speed calculated?
	How is my mother's walking speed estimated?
	How is my mother's walking speed measured?
	How is my mother's walking speed captured?
	How is my mum's walking speed calculated?
	How is my mum's walking speed estimated?
	How is my mum's walking speed measured?

	How is my mum's walking speed captured?
	How is the walking speed calculated?
	How is the walking speed estimated?
	How is the walking speed measured?
	How is the walking speed captured?

Appendix B: Complete list of Query and Response for Pulse Rate, Respiration Rate, Sleep, Fall, Health Message and Help.

Table 15 Complete list of Query and Response for Pulse Rate, Respiration Rate, Sleep, Fall, Health Message and Help.

QUERY	RESPONSE
PULSE RATE	
Recent night time pulse rate	
what is my recent night time pulse rate	The most recent night time pulse rate for date August 7 2017 was 62 beats per minute.
what is my most recent night time pulse rate	
Recent pulse rate	
what is my recent pulse rate	The most recent pulse rate for date August 7 2017 was 62 beats per minute.
what is my most recent pulse rate	
Recent day time pulse rate	
what is my recent day time pulse rate	

what is my most recent day time pulse rate	The most recent day time pulse rate for date August 7 2017 was 62 beats per minute.
Change in pulse rate	
what is the change in pulse rate in the last few days	This graph shows the most recent change in pulse rate. A normal resting heart rate for adults ranges from 60 to 100 beats per minute. (includes graph as well)
show the change in pulse rate over the past few days	
Normal pulse rate	
what is a normal pulse rate	A normal resting heart rate for adults ranges from 60 to 100 beats per minute.
RESPIRATION RATE	
Recent respiration rate	
what is my recent respiration rate	The average respiration rate for date August 7 2017 was 14 breaths per minute
what is my most recent respiration rate	
Recent night time respiration rate	
what is my recent night time respiration rate	The average night time respiration rate for date August 7 2017 was 14 breaths per minute
what is my most recent night time respiration rate	
Recent day time respiration rate	
what is my recent day time respiration rate	

what is my most recent day time respiration rate	The average day time respiration rate for date August 7 2017 was 14 breaths per minute
Change in respiration rate	
what is the change in respiration rate in the last few days	This graph shows the most recent change in respiration rate. The normal respiration rate for an adult at rest is 12 to 20 breaths per minute. (This response display a graph as shown in Fig. 12).
show the change in respiration rate over the past few days	
Normal respiration rate	
what is a normal respiration rate	A person's respiratory rate is the number of breaths you take per minute. The normal respiration rate for an adult at rest is 12 to 20 breaths per minute.
SLEEP	
recent time in bed at night	
what is my recent time in bed at night	The time in bed on August 7 2017 night was 6 hours and 20 minutes.
what is my most recent time in bed at night	
recent restless time at night	
what is my recent restless time at night	The restlessness time in bed on August 7 2017 night was 1 hours and 15 minutes.
what is my most recent restless time at night	
recent time in bed at day time	

what is my recent time in bed at day time	The day-time time in bed on August 7 2017 was 6 hours and 20 minutes.
what is my most recent time in bed at day time	
recent restless time in day	
what is my recent restless time in day	The day-time restlessness in bed on August 7 2017 was 1 hours and 15 minutes.
what is my most recent restless time in day	
recent sleep data	
what is my most recent sleep data	The time in bed was 6 hour and 20 minutes and the restlessness time was 1 hour and 15 minute on August 7 2017.
what is my recent sleep data	
How did I sleep	
how is the sleep quality measured	
how is the sleep quality estimated	Sleep quality is calculated by comparing non-restlessness time in bed to total time in bed.
how is the sleep quality calculated	
display sleep quality graph	
show the sleep quality graph	This graph shows the most recent sleep quality data. 0 being the lowest and 1 being the highest. (This response displays a graph as shown in Fig. 7).
FALL	
recent fall risk data	
what is my recent fall risk data	

what is my most recent fall risk data	As of date August 7 2017, the fall risk is low
what is my recent fall risk	
what is my risk of falling	
recent walking speed	
what is my recent walking speed	Most recent walking speed as of August 7 2017 is 14 centimeter per sec.
stride length	
what is my stride length	Most recent stride length as of August 7 2017 is 14 centimeter.
stride time	
what is my stride time	Most recent stride time as of August 7 2017 is 14 second.
how is the walking speed measured	
how is the walking speed captured	The walking speed is measured using a sensor that is mounted on the wall at home.
change in fall risk over the past few days	
show me the change in fall risk over the past few days	This is what the fall risk graph looks like for the past few days. This is based on the average walking speed at home. (This response displays a graph as shown in Fig. 8).
what is the change in fall risk over the past few days	
walking speed graph	

show my walking speed trend for the last few days	This is what the walking speed graph looks like for the past few days. (This response displays a graph as shown in Fig. 13).
HEALTH MESSAGE	
what is my recent health message	The most recent health message on August 7 2017 says Night-time Bed Restlessness, Night-time Time in Bed have been decreasing for the past 10 days.
what is my most recent health message	
HELP	
help	You can ask me about pulse rate, respiration rate, sleep quality, fall risk and health messages. For example, you can say "Tell me about my fall risk" and I will tell your risk of falling.
give me an example	