

USER-CENTERED DESIGN OF AN INTEGRATED SENSOR DATA INTERFACE
FOR REMOTE CARE COORDINATION

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by
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FOR REMOTE CARE COORDINATION

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DEDICATION

This work is dedicated to my family.

To my parents for giving me life and purpose: you showed me that it was possible to pursue a graduate degree while working full time and raising a young family.

To my children for your patience and love: being your mom is the best part of my day, even on the hardest days. You showed me how to set aside work and school to just be with you. You gave me things to look forward to, including soccer games, school performances, family movie nights, play days, craft time, and snuggle time.

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List of Abbreviations

| | |
|-----------------|---|
| AI | Artificial Intelligence |
| ASSETs | Age-Friendly Sustainable Smart and Equitable Technologies |
| ASSETs for AIP | Age-Friendly Sustainable Smart and Equitable Technologies for Aging in Place |
| CMS | Centers for Medicare and Medicaid |
| IoT | Internet of Things |
| IRB | Institutional Review Board |
| ML | Machine Learning |
| Precision START | Precision Smart Technologies for Rapid Translation |
| REDCap | Research Electronic Data Capture |
| SBD | Scenario-Based Design |
| SUS | System Usability Scale |
| UCD | User-Centered Design |

List of Definitions

ASSETs for Access Intervention Research Team – an interdisciplinary team of nursing, occupational therapy, social work and informatics researchers focused on multi-component, community-based digital health research and services to support independent aging.

ASSETs for Aging in Place – CMS-funded demonstration project in partnership with the State of Missouri Department of Health and Senior Services and ShowMe Home program to deliver strengths-based remote health coaching and care coordination services to older adults at home using digital health technologies.

ASSETs Site Management Interface – web-based dashboard prototype developed prior to ASSETs for AIP to remotely manage sensor projects and studies in the homes of clients and participants, including other sites unaffiliated with the ASSETs for AIP project.

ASSETs for AIP Care Coordination Interface – web-based dashboard developed during the ASSETs for AIP project to visualize sensor data and support workflows for delivery of digital health remote health coaching and care coordination services.

Co-Design – the inclusion of users as primary decision-makers in the design of prototypes.

Device – a sensor technology for collection of some type of data. Within the management of sensor technology, a device (or multiple devices) connects to a hub.

Home – within the concept of managing sensor technologies, a home is the specific location of data collection, which may be a physical location or an individual with wearable sensors only.

Hub – within the concept of managing sensor technologies, each home has one or more hubs where data is collected from devices.

Site – within the concept of managing sensor technologies, a site is a set of homes and residents. The ASSETs for AIP project is a site.

USER-CENTERED DESIGN OF AN INTEGRATED SENSOR DATA INTERFACE FOR REMOTE CARE COORDINATION

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Dr. Blaine Reeder, Dissertation Advisor

ABSTRACT

Innovative approaches to the management and support of healthy behaviors through the connection of health professionals to client sensor data requires the development of new tools for combining and viewing data. Though Internet-of-Things technologies have become ubiquitous, and opportunities abound for their use by health professionals to understand client or patient behaviors, few systems exist for this purpose. The web-based site management interface and care coordination data dashboard created in this research project bridge the usability gap between health professionals and their ability to use client sensor data for remote health coaching and care coordination.

Instrumental in this work was the inclusion of health professionals in care coordinator roles that provide remote health coaching for client self-management of their care. We took a user-centered design approach with care coordinators as co-designers that began with the discovery of information needs, workflow, and design requirements through contextual inquiries and focus groups to define interface design requirements. An iterative prototyping process incorporated usability and design principles to build and improve interface and data display designs. This process included care coordinators as the target users and co-designers in decision-making and finalizing a consensus low-fidelity prototype comprised of still images. The next step required engaging a developer to create a high-fidelity prototype that included interactive features for usability testing.

Care coordinators began using the high-fidelity prototype to perform their daily work with existing and new clients, reviewing and exploring client sensor data. Usability testing included: heuristic evaluation, administration of the system usability scale, cognitive walkthroughs, think-alouds, and interviews with design researchers, care coordinators, and other health professionals as usability testers to identify actionable items for interface improvement. Despite needed improvements, the interface is usable and has reduced care coordinator documentation and frustration in understanding client sensor data. The resulting interface opens the door for potential augmented cognitive enhancements and further additions of sensor data for more insightful clinical guidance and understanding of human behavior.

Chapter 1: Introduction

Applications, websites, and many physical objects are designed with interaction as an expectation, however some designs are more useable, useful, and pleasing to interact with than others. A focus on how people interact with the artifact during the design phase will ultimately produce a better product. As Don Norman discussed in his book *The Design of Everyday Things*, Steve Krug expressed in *Don't Make Me Think*, and Jakob Nielsen described in *Usability Engineering*, the value of usability in technology design has implications in the success of any product.¹⁻³ If we were to create a Venn diagram of design, usability should overlap with other design variables, such as functionality and aesthetics.

When it comes to data visualizations and interactive dashboards, designers and developers should also consider that users may have varying levels of data literacy, a barrier to full comprehension. Data visualization design includes considerations alongside usability, functionality, and aesthetics. As Edward Tufte put it, “Visual representations of evidence should be governed by principles of reasoning about quantitative evidence. For information displays, design reasoning must correspond to scientific reasoning. Clear and precise seeing becomes as one with clear and precise thinking.”⁴ Knowledge of preattentive processing, an understanding of how the human brain processes information prior to cognitive awareness, and standard principles of design become keystones to creating effective and clear representations of data.^{5,6} While all researchers should try to follow these principles when presenting their data, it is a particular interest of mine.

This research project aligned with my background in graphic design and data science, as well as an interest in creating data dashboards that optimize clarity for users.

Within this project and alongside fellow researchers, I endeavored to design a web-based interface and data dashboard for sensor-based technologies in support of new digital health services. The project followed a typical user-centered design process with the following key objectives:

1. Characterize information needs

Design of a usable and useful system begins with understanding target users' information needs, workflow and design requirements. We used interviews and observations to engage health professionals in their care coordinator roles for this purpose.

2. Iteratively design and assess prototypes

Designing in increments and evaluating low-fidelity prototypes with small groups of usability testers provides opportunities for quick improvement. We used Gestalt principles, preattentive processing, and web usability guidelines in iterative designs and evaluation sessions with care coordinators and interdisciplinary health researchers.

3. Evaluate high-fidelity prototype

Evaluating the interface for usability issues helps identify whether design goals were met. We applied the standardized System Usability Scale, heuristic evaluations, cognitive walkthrough, think-aloud and interviews with care coordinators and other health professionals for this purpose. Usability testers included care coordinators, health interventionists, and health researchers. Testers included new users who were previously unfamiliar with the interface, design team members, and daily users of the prototype interface.

Fulfilling a need to incorporate disparate data

While Internet-of-Things (IoT) technologies have become prevalent in daily life, and opportunities abound for client and patient self-management of health using personal technologies, design research that integrates these technologies for use by health professionals is lagging and sporadic. IoT technologies include wearable devices, such as smart watches, heart rate monitors and accelerometers. They also include unobtrusive environmental sensors such as infrared motion detectors, passive door sensors, carbon monoxide detectors, wireless weight scales and bed sensors, among others.⁷⁻¹⁰ One reason these technologies have not been widely adopted in support of new digital health services is the difficulty of incorporating and assessing large amounts of personal technology data in information systems for decision-making and remote delivery of these services by health professionals. Further, such systems would require an interface to enable health professionals to view and explore combined disparate sources of data for whole-picture understanding. Developing a system that enables assessment of multiple collected data streams requires data visualization techniques to represent complex data combinations in simple ways and for rapid comprehension by health professionals. The broad goal of this work was to bridge the gap in this under-developed area of design research through the creation of a data visualization interface for health professionals to support remote care coordination and client self-management.

Beyond incorporating and displaying data as it exists, a system of this nature also presented opportunities for computer-aided decision-making in identifying patterns of behavior, deviations from normal behavior, and changes that may affect quality of life. As

future work expands to include results from causal discovery analysis, machine learning, or other computational methods, the ability to view the source material will increase transparency and clarity around system-generated behavioral insights. Therefore, this work was imperative to ensuring health professionals' trust in the system for confidence in their decisions that support their clients' wellbeing.

Focusing on the health professional as co-designer

A repeating motif throughout this work was that of the health professional in a care coordinator role as co-designer. While user-centered design and participatory design intentionally focus on and include the user in the design process, it was important in this project to include care coordinators as decision makers. Therefore, in this project, we called the care coordinators "co-designers" because they were the final arbiters of design decisions.

Researcher's biases

As a researcher, I come to this work with formal training in graphic design and data analysis. After two decades working as a graphic designer, art director, and data analyst focused on visualization, I recognize that I both need and desire feedback on artifacts I design. As an art director, it was my job to critique designers work, ensuring that design principles were utilized to best advantage. As a data analyst and graphic designer, I regularly sought feedback from individuals with and without design expertise. I am very comfortable receiving feedback and not taking it personally. Ideally, in the design lifecycle, an unbiased party rather than the designer would lead usability tests. Due to the focus of this dissertation following the entire design lifecycle and the project's need to rapidly and inexpensively move through the design process, it was not possible

for a third party to lead usability tests. In critique meetings with co-designers, I encouraged the team to talk about how they would read a data visualization artifact, how they would like to use the interface, and reiterated that this interface belongs to them so they couldn't hurt my feelings if they wanted something different. With usability testers, I did not disclose that I was the designer and opted to wait in silence and encourage participants to talk about what they were seeing rather than provide input myself, or I would reiterate what they said to validate opinions and thoughts. Despite my best efforts to keep my biases out of the work, they may have influenced some of the results.

Significance of the work

A user co-designed digital health interface for sensor data allows health professionals to focus their attention on areas of client or patient need more quickly and precisely. Including health professionals as co-designers in the design process strengthened the design by including their ideas and clinical knowledge into the interactivity and data visualizations. The iterative design process supported the recognition of lessons learned from previous iterations and incorporated results into each new version of the interface. Iteration also encouraged the inclusion of multidisciplinary knowledge and analysis exploration opportunities in the data gathered as part of this project. The data visualizations designed through the iterative process support care coordinators in understanding client behavior rapidly, accurately, and clearly. Only with their collaboration could we identify visualizations that provide valuable insight for tailored health coaching to identify, measure, and recognize client goal attainment. Ultimately, digital health support for coaching and care coordination aimed to assist clients to self-manage their health, live independently and enjoy better quality-of-life.

No generative artificial intelligence tools were used within this research or the writing of this dissertation.

Chapter 2: Discovery of Design Requirements to Support Remote Care Coordination

This chapter is refined from our publication in the proceedings of the 2024 American Medical Informatics Association Annual Symposium.

Boles KK, Young L, Emezue C, Lee K, Popejoy L, Reeder B. Discovery of User Requirements to Support Remote Health Coaching and Care Coordination in a CMS Demonstration Project. In: AMIA Annual Symposium Proceedings. San Francisco, CA; 2024.

Introduction

From a plethora of data collection devices in the world, and widespread adoption into everyday lifestyles, emerged an opportunity for researchers to incorporate Internet of Things (IoT) technology into health and behavioral intervention studies. Sensor technology, particularly environmental and person-based sensors, provided a unique opportunity for remote monitoring of behaviors.¹¹ A population that could greatly benefit from this integration were aging individuals, particularly in rural and underserved areas.¹² When professionally trained care personnel contributed their expertise to remote monitoring, the experience was life-changing for aging adults.^{13,14}

The Age-friendly Sustainable Smart and Equitable Technologies (ASSETS) for Access team at the University of Missouri was formed by interdisciplinary health researchers to address challenges at the intersection of aging and health (see the List of Definitions). One funded initiative of this group is the ASSETS for Aging in Place (AIP) CMS (Office of Sponsored Programs and Awards (OSPA) Contract #: 00076747) demonstration project (see the List of Definitions). The ASSETS for AIP project focused

on serving older adults living in rural or underserved areas through digital health services enabled by sensor technologies in the client home. The care coordinators included nursing, occupational therapy, and social work professionals that help older adult clients self-manage and live independently through remote health coaching and care coordination based on individual client strengths. The ASSETs for AIP demonstration project leveraged the expertise of the care coordinators who monitor individual clients' daily activity captured by smart home sensors and wearable devices. The sensor technology setup included at least four Fibaro passive infrared multi-sensors¹⁵ connected to a Raspberry Pi¹⁶ hub with a mobile internet hot spot installed in the clients home and a wearable device worn by the client (Garmin watch¹⁷ or FitBit smart watch,¹⁸ or Oura ring¹⁹). The sensor technology setup can be expanded to include additional multi-sensors, contact door sensors, or new sensors as identified to provide more context to reveal a client's lifestyle (Figure 1).

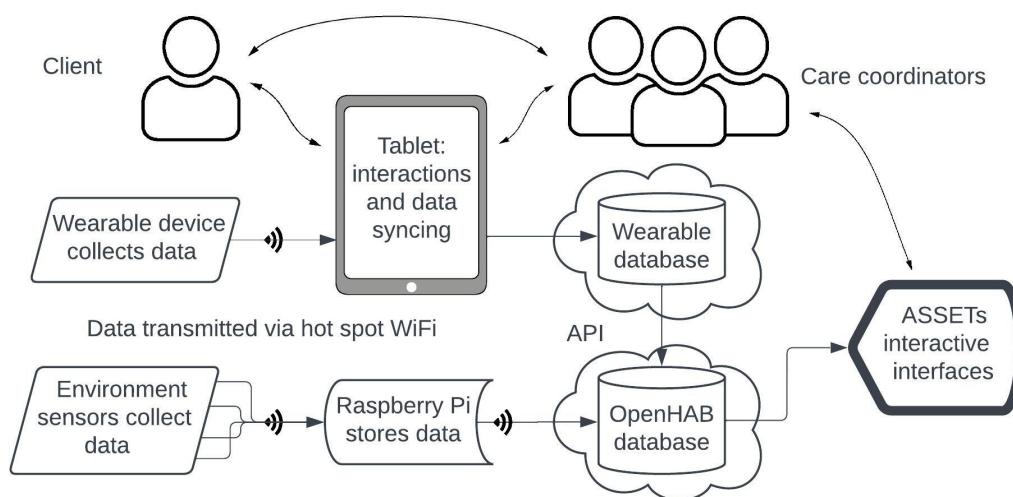


Figure 1. System setup for each ASSETs for AIP client

At the start of this project, care coordinators were using a web-based site management interface to monitor all homes of enrolled clients. The ASSETs site management interface for managing remote sensor projects and studies was developed prior to the formation of the ASSETs for Access Intervention Research Team and before funding for the ASSETs for Aging in Place CMS Demonstration Project was obtained (see the List of Definitions). The site management interface supported the care coordinators in setting up client homes with devices, and management of the setup, but it was limited in the data displays and functionality needed for client behavior monitoring and support (Figure 2).

An additional web-based interface and data dashboard for care coordination – the ASSETs Care Coordination dashboard (see the List of Definitions) – was necessary to address the care coordinators’ needs in displaying sensor data for rapid and informed decision making. Additionally, it would support algorithmic output of behavioral analysis for augmented intelligence.

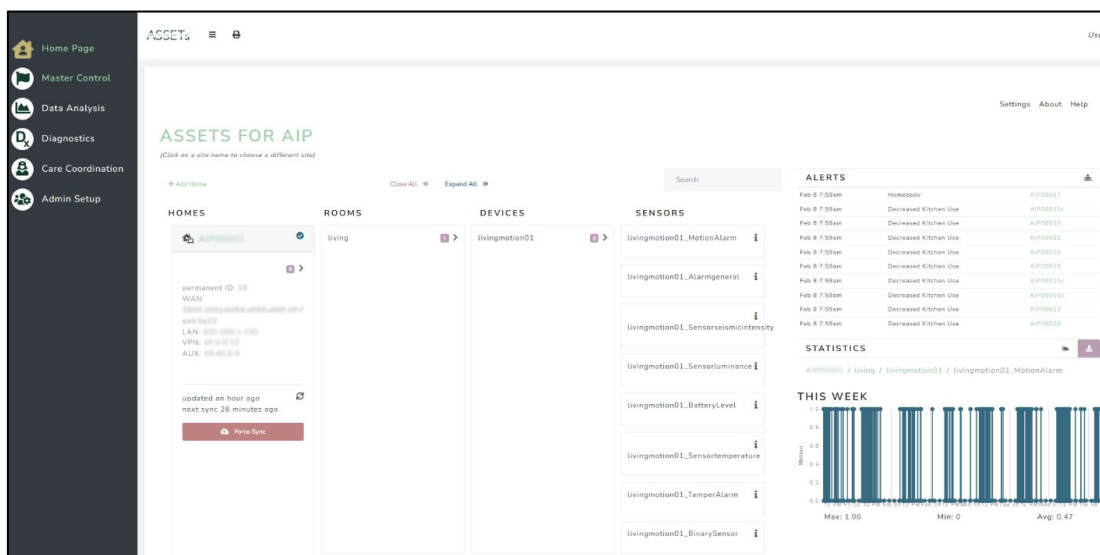


Figure 2. ASSETs site management interface main page

The primary goal of the ASSETs Care Coordination dashboard was to support care coordinators in optimizing their time monitoring and supporting clients in self-management of client behaviors. Within this goal, a high priority included displaying data for multiple sensors to the care coordinators so they could quickly discern what has happened in the lives of their clients and observe behavior change. Additionally, to reduce care coordinator cognitive load, the interface needed to provide information in the most user-friendly way possible. A user-centered approach provided guidelines for design and development of our interface and data dashboard designs.² Similar to other user-centered design projects,^{20,21} our process follows three general phases: 1. Characterizing information needs, 2. Iteratively design and assess prototypes, and 3. Evaluate prototypes. The first phase, characterizing information needs prior to prototype development, was crucial to user-centered design.^{3,21-23} These information needs were the basis for formally documenting design requirements for the interface. As pointed out by Norman: “The hardest part of design is getting the requirements right, which means ensuring that the right problem is being solved, as well as that the solution is appropriate.”³ As defined by the International Organization for Standardization, “A user requirements specification is the formal documentation of a set of user requirements, which aids in the development and evaluation of usable interactive systems.”²⁴ The documentation of design requirements based on characterized information needs was a deliverable from the first phase of the project. Additional information gathered also contributed to determining further iterations of the site management interface, the prototype care coordinators were using at the start of this project. Figure 3 represents the lifecycle for these two interfaces.

In this paper, we report on the focus groups and contextual inquiries part of this design lifecycle.

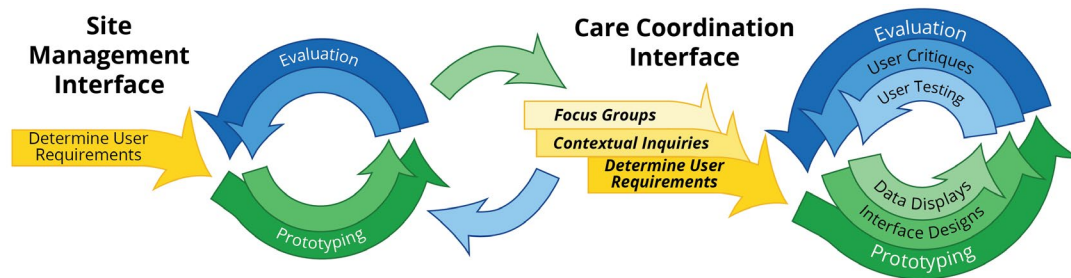


Figure 3. Design lifecycle of the ASSETs interfaces with user requirements stage identified by bold italics

Structured focus groups are a common method for gaining user input and are appropriate for the discovery of information needs of users.^{2,22,25} Additionally, focus groups provide a unique opportunity to encourage users to elicit additional thoughts from other participants.²⁶ Sedlmair et al. found that a combination of interview and observation methods is more successful for determining information needs and recommended contextual inquiries.²⁷ Contextual Inquiries have been used in many fields, including environmental science, clinical medicine, education, animal science, and information science. Contextual inquiry has been used in research to: assess existing technology, perform task analysis, and gather design requirements.²⁸⁻³⁰ Specific to requirements gathering, contextual inquiries were used in previous research on: understanding teachers' practices in their classrooms,³¹ understanding qualitative coding practices,³² observing animals interacting with technology,³³ and understanding challenges in completing tasks with visual impairment.^{30,34} A common method for data analysis of contextual inquiry results is affinity diagramming, completed by the design team mapping out themes together. Inductive qualitative analysis completed by individual coders is an alternative to

this method. Additionally, many sources discuss how contextual inquiry *could* be used effectively for requirements gathering without necessarily providing specific examples of use in research.³⁵⁻³⁹

In the contextual inquiry method, design team researchers observe and interview users with artifacts and systems in their real-world environment. There are three parts to conducting a contextual inquiry session: 1. Introduction and brief question and answer session, 2. Immersion with the interviewers acting as apprentices, and 3. Wrap-up discussion.^{40,41} We found many positive reasons to use contextual inquiry for requirements gathering.^{27,42,43} Contextual inquiry encourages interviewer interaction with, and interruption of, the user's workflow for more detailed understanding, while also mapping out a big picture workflow. Additionally, the interviewer perspectives become a useful part of the data collected. In this paper, we report on results from the discovery of information needs collected in two focus groups and four contextual inquiries.

Methods

The visual design research team led by the lead author comprised two PhD students (including the lead author), two PhD-trained faculty, and a post-doctoral scholar. The design team's collective experience included design, data visualization, nursing, analytics, informatics, user-centered design, behavioral science, and qualitative data analysis. The visual design team sought to understand information needs, workflows, and design preferences of the care coordinators, as well as the broader goals of investigators from the larger ASSETs for Access Intervention Research Team as stakeholders (secondary users). These participants were interviewed in two separate focus groups. The inclusion of different types of users in the discovery process provided a more

comprehensive scope for the interface design and informed the boundaries of the initial design while helping us to plan for future features.

Focus Groups

The aim of the focus groups was to discover what features were required from a dashboard to support health coaching and care coordination responsibilities when engaging clients remotely through a digital health platform. The target users for this aim were care coordinators (nurses, occupational therapists, and social workers) who use technology (sensors) to tailor support to assist older adults (clients) with independence and monitoring their health status. We sought to discover the data points, frequencies, summary aggregates, and visual displays needed to identify patterns of behavior, deviations from those patterns, and potential critical health concerns associated with behaviors and deviations. Additionally, we were interested in documenting the care coordinators' current workflows using existing dashboard interfaces, and challenges they experience with the tools available to them.

Prior to scheduling focus groups, the five visual design team members defined the scope and broad intentions of the interviews and then independently compiled questions for information needs and dashboard requirements discovery. The lead author prepared a focus group protocol that included an introduction and questions. The focus group protocol was reviewed and approved by the remaining members of the design team.

Two focus group sessions were conducted. Participants were invited based on their roles in the ASSETs project and experience in other similar research projects. One member of the visual design team also belonged to one of the role-based focus groups and elected to only participate in that focus group, abstaining from being an interviewer.

Both focus groups included the same two in-person interviewers, including the lead author, and one virtual interviewer from the design team (Table 1). As suggested by Courage and Baxter, the interviewers used a slideshow that displayed the questions and provided printed copies of visuals for participants closer viewing.²² The interviews were video and audio recorded with the agreement of all participants with virtual meeting software provided by the University of Missouri (Zoom), and two audio recording devices.

Table 1. Focus group and contextual inquiry interviewers

| | Focus Group 1 (11/2022) | Contextual Inquiry 1 (2/2023) | Contextual Inquiry 2 (2/2023) | Contextual Inquiry 3 (2/2023) | Contextual Inquiry 4 (2/2023) | Focus Group 2 (4/2023) |
|----------------------------------|-------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|------------------------|
| Lead Author (in person) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Design team member 1 (in person) | ✓ | ✓ | ✓ | | | ✓ |
| Design team member 2 (virtual) | ✓ | | | ✓ | | ✓ |
| Design team member 3 (in person) | | | | | ✓ | ✓ |

All three ASSETs for AIP care coordinators and the care coordination manager, also a former care coordinator, participated in the first focus group. All four participated in-person. All members of the larger ASSETs for Access Intervention Research team (n=9), including co-investigators, investigators on other related research projects, and graduate students, were invited to participate in the second focus group. Of the nine intervention research team members invited, all five investigators of the ASSETs for AIP CMS demonstration project participated in the second focus group, two in person and three virtual.

Interviewers asked about participants' experience using sensors for care coordination, their familiarity with data dashboard and sensor technologies, and their perceptions of uses for several types of data. Additionally, interviewers asked about participants' familiarity with different data visualization display (chart) types and their thoughts on visual displays found by one of the interviewers,⁴⁴⁻⁴⁷ or preliminary data visualizations using ASSETs sensor data. Following the 90-minute focus group sessions, one interviewer transcribed the recordings.

Contextual Inquiries

The aim of the contextual inquiries was to understand interface needs and identify data display designs for care coordination. We specifically sought to identify care coordinator goals in their workflow, activities they undertook to meet these goals, barriers to goal achievement, and design preferences for data displays and interaction.

Contextual inquiry sessions were conducted with each care coordinator and care coordination manager two months after the first focus group and before the second focus group. Prior to scheduling contextual inquiries, the lead author drafted a protocol document that was reviewed and finalized by four additional design team members. The document included five introductory questions and outlined the priorities and focus of the contextual inquiry. Individual one-and-a-half hour sessions were scheduled with all care coordinators (n=4). Two interviewers conducted each contextual inquiry session, with the lead author in-person as the lead interviewer on all four inquiries and three of the design team members rotating in the role of second interviewer (Table 1). Contextual inquiry sessions were video-and-audio recorded with consent of the interviewee. Recordings were made with a virtual meeting software (Zoom). A backup secondary recording was

captured with an audio capture device. The interviewee shared their screen, which was also recorded.

We began each contextual inquiry session by introducing the goal and requested informed consent. The contextual inquiry format was then outlined for each session: 15 minutes of opening questions, one hour of observation and as-needed interviewer interruption, followed by 15 minutes of wrap up. Opening questions acquainted the interviewers with the care coordinators' background and job responsibilities. During each observation and interruption period, interviewers adopted the role of an apprentice as the care coordinator showed their workflow for using sensor data to determine activity patterns. Care coordinators selected examples of client behavior deviations they had previously identified in the course of their work. Interviewers probed for more details and requested clarification as needed by interrupting the care coordinator as they explained and showed their work habits. In the final part of the inquiry, each interviewer and care coordinator shared particularly insightful moments or highlights from the inquiry.

Qualitative Data Analysis

We applied our goal of defining a set of information needs for the design and development of an interface and data dashboard for care coordinators to use for supporting clients with self-management of their health and well-being to data analysis.

We followed a modified variation of the framework method of qualitative content analysis for analyzing focus groups.⁴⁸ Our approach was inductive; our codebook developed from the data.⁴⁹ The process began with coders independently creating preliminary codes from a portion of the data, then coders met to review the preliminary codes, reconciled an initial set of codes, independently coded additional data, had another

reviewer assess for code drift, organized codes into categories, reconciled as a group, and created themes. Results were used to inform design requirements and directly applied in prototypes that were reviewed and validated by the care coordinators.

Specifically, coders were three of the five members of the design team who acted as interviewers during focus group sessions and reviewers included the other two members of the design team (Table 2). Four design team members familiarized themselves with the transcripts. Three independently coded at least 20% of the first focus group transcript before an initial coding reconciliation meeting. The lead author and one other coder independently coded the full transcript of the first focus group. The lead author completed a first pass code reconciliation, and all five design team members met for discussion to verify and reconcile codes. The lead author coded the second focus group transcript, added new codes as necessary, and organized codes into categories. Design team member 2 reviewed all codes and coded data, providing input and suggestions to refine the categories into themes.

Table 2. Design team roles in data analysis

| | |
|----------------------|--|
| Lead Author | Independently coded all transcripts, independently categorized focus group codes, participated in all coding reconciliation, organization and theme development. |
| Design team member 1 | Independently coded the focus group 1 and contextual inquiry 2 transcripts in full, assessed for code drift on contextual inquiry 2, participated in focus group reconciliation, and participated in contextual inquiry coding reconciliation. |
| Design team member 2 | Independently coded 20% of focus group 1, independently categorized focus group codes, and participated in focus group theme development. |
| Design team member 3 | Participated in focus group and contextual inquiry coding reconciliation. |
| Design team member 4 | Participated in focus group coding reconciliation. |

We took a similar inductive qualitative approach to analyze the contextual inquiry transcripts as our team completed with the focus groups. However, we determined that providing clarity specifically for prototype design needs required an adaptation to meet the aims for the contextual inquiries. This adaptation included coding for specific purposes: to identify goals and activities in care coordinator workflows, needed features, and observed barriers to goal completion. Additionally, we determined we did not need to re-cover the codes from the focus group as the same people participated in the first focus group and contextual inquiries. Thus, our codebook for the contextual inquiries remained separate from the codebook for the focus groups.

Each contextual inquiry session transcript was transcribed using Adobe Premiere Pro, exported as a CSV, reviewed by the lead author as primary interviewer, and modified for accuracy. Video recordings were reviewed when the action was unclear or more details were required to determine goals, activities, features, and barriers. Prior to coding, the team met to confirm the focus of the analysis and to create a spreadsheet template. The spreadsheet template kept the coding focused on the goals, desired features, and barriers. The lead author as primary coder completed first-pass coding on all contextual inquiries.

Then the lead author met with design team members for oversight and guidance on standardizing goals and barriers. With direction from the group, the lead author reviewed all coding and harmonized the descriptions as a set of standardized codes for goals and barriers to develop the codebook, which included descriptions and examples. A count of all codes was completed, and the team met to review the results. One code with a particularly high count required another review for subdivisions. Next, the lead author

provided the codebook and template with some examples to design team member 2.

Design team member 2 independently coded contextual inquiry 2. Results for both coders were combined in the coding template for side-by-side comparison. The lead author and design member 2 met to reconcile codes and verified agreement on the code definitions.

Results

Focus Group Theme 1: Purpose in dashboard and interface use

This theme encompasses general statements about the goals in the use of the dashboard and interface. Theme one includes codes:

1. Identify and understand normal patterns or behaviors
2. Identify, act on, and follow up on abnormal patterns or behaviors
3. Decision support to inform behavior or environmental changes for healthier living
4. Decision support for disease prevention
5. Better understand patterns of all older adults

Representative quotes include:

“We keep fairly consistent routines in our home spaces and changes and slow changes even potentially over time.” – Occupational Therapist, Second Focus Group

“So if they normally visit the kitchen each day, and then all of a sudden there’s no activity in the kitchen [...] for days on end we would probably give them a call, and just see what’s up, why they’re not going into the kitchen. Maybe they’re sick, or something.” – Occupational Therapist, First Focus Group

“How can we change their environment to help them achieve their health goals, their wellbeing and age in place if that’s their goal as well. And we look at

those more kind of like mezzo and macro level ways to intervene as well and to affect their ability even to manage their own health. So beyond just the individual behaviors that more macro environment is, is really important to us.” – Social Worker, Second Group

“I look for [...] signs of early illness detection. So, are they not moving as much as they would have? Are they falling where they previously had fallen? Are there changes in vital signs? However, vital signs changes are very late changes physiologically and are crude instruments. [...] You might see somebody flip into atrial fibrillation and you start to see irregularities and an elevation in their heart rate, which would then indicate that need to intervene immediately.” – Nurse 1, Second Focus Group

Focus Group Theme 2: Interface / technology needs

Within theme two, we collected considerations for the design process and creation of the web-based interface. This group included three sub-categories and codes within, as seen in Table 3.

Table 3. Codes and representative quotes within three categories for theme 2 of the information needs and design requirements stage

| Overall Requirements | |
|---|--|
| 1. Continue to involve users in the co-creation process | <i>“Some of the best stuff [...] truly does involve the people that are going to use it throughout the entire process.” – Occupational Therapist, Second Focus Group</i> |
| 2. Maximize usability (accessible and desirable to use) | |
| 3. Incorporate all data in one place | <i>“Right now they’re having to go multiple places and they’re having to draw those corollaries themselves that it’s problematic.” – Nurse 1, Second Focus Group</i> |
| 4. Expandable for additional data capture methods | |
| 5. Align with users’ preferred workflow | <i>“I’m doing two clients right now, and I’m exhausted, you know, after doing the two clients, just to see if this is their pattern. This makes sense, this doesn’t make sense” – Social Worker, First Focus Group</i> |
| 6. Available on all devices and platforms | |
| 7. Support alerts and prediction modelling | |

| | |
|---|--|
| <ol style="list-style-type: none"> 8. Easily interpreted visualizations 9. Capture attention with clearly delineated with colors, highlights, and call outs 10. Provide information for clinicians to help them read and understand visuals | <p><i>“It would help them quickly put together the rudimentary data needed for [a client] visit so they would know how to organize their time.” – Nurse 1, Second Focus Group</i></p> <p><i>“So anything that helps them really kind of match what’s events. You need to be clearly delineated so that it captures their attention. It’s not just, you know, different color or a different size or whatever it is.” – Nurse 1, Second Focus Group</i></p> <p><i>“I don’t know that, like maybe we need a little more training on how that works.” – Occupational Therapist, First Focus Group</i></p> |
| Functionality of data visuals | |
| <ol style="list-style-type: none"> 1. Integrated into single visuals with overlap, overlay or side-by-side views 2. See several days at a time in overlap 3. Hover or pop-up boxes to provide additional details 4. Visualize summary data (not just daily data) 5. Visualize normal/average data 6. Zoom in and out, defining timeframe of data 7. Input and see events alongside the sensor data 8. See alerts alongside sensor data 9. Make custom selections of data to be seen together 10. Filter clients | <p><i>“Integrate information into single displays or at least housed in a single system, the more information, almost the better and clinical decision making.” – Social Worker, Second Focus Group</i></p> <p><i>“I love the hover over or click on and you don’t necessarily jump out of whatever that visualization is you’re looking at, but like a little box or whatever, it pops up, you know?” – Occupational Therapist, Second Focus Group</i></p> <p><i>“We want to say, how does this week compare to their average over the last three or four weeks. So that’s like their norm that’s established.” – Occupational Therapist, First Focus Group</i></p> <p><i>“Compare in each individual room luminance and motion, and then have those different colors so we can see multiple variables at once.” – Nurse 2, First Focus Group</i></p> |
| Possible data display types | |
| <ol style="list-style-type: none"> 1. Run charts or line charts 2. Tree maps 3. Heat maps 4. Stacked area chart 5. Bubble race chart 6. Bar chart 7. Horizontal bar (looks like an DNA assay) 8. Pie and donut charts 9. Floorplans 10. Timelines | <p><i>“Trends and patterns over time is where you actually have those line charts, where you can put in a trend line and those kinds of things.” – Nurse 2, Second Focus Group</i></p> <p><i>“Bar chart that shows the length of time of motion, [...] like we can see how long that activity in the kitchen was going on.” – Nurse 2, First Focus Group</i></p> <p><i>“Like with Apple watch, it’s the circles. [...] Once you complete it, you know it’s a percentage based on what you’ve done.” – Social Worker, First Focus Group</i></p> |

It was important for the design team to understand focus group participants’ comfort with various data display types and their interpretation of charts so that the design of data displays could be designed with features familiar to the target users. To help the focus group participants articulate the types of diagrams they are familiar with,

we showed several samples, ranging from common charts – such as bar, pie, area, and line – to more uncommon charts – such as Sankey, tree map, mind map, radar, and wind rose charts. Participants described where they had seen various charts and what they determined to be their usefulness. The first focus group participants (primary users) tended to talk about pie, donut, floorplan, timeline, and bar charts. The second focus group participants (secondary users) had familiarity with line or run charts, tree maps, heat maps, area charts, and bubble race charts. Common to participants from both focus groups was an interest in displaying data across time and the ability to zoom in and out to see data over specified and custom time frames (i.e., hourly, daily, weekly, monthly, all time).

We also asked about their experience with data displays from other technologies and applications. Participants had experience with consumer wearable dashboards (e.g., FitBit,¹⁸ Garmin⁵⁰) and custom developed and touch-display dashboards as well (e.g., REDCap,⁵¹ Foresite,⁵² Casamba⁵³).

Focus Group Theme 3: Data collection expectations

The ASSETs care coordination interface and dashboard needs to support different types of data; understanding the sources, uses, and challenges around the data collected is imperative. The list includes data currently in use in this project as well as prospective data to be able to plan for expansion of the dashboard to include additional data sources and types.

There were two types of data sources identified: objective and subjective. Objective data sources included: wearable, motion sensor, depth sensor, bed sensor, luminance, and air temperature. Subjective data sources included self-reported data. From

objective sources, we can expect to potentially collect the following types of data: sleep activity, activity patterns (steps, miles), hard falls, pulse oximetry, EKG, location (within and outside the house), heart rate and video playback. Subjective data could include ratings like sleep, energy, and pain levels, or additional information gained from health records. Challenges with data reported by participants included: difficulty in assessing a single individual from environmental data, physical range of sensors, active measurement only (as opposed to passive), and perceptions of data quality.

Contextual Inquiry Results

Results of the goals analysis were grouped into three categories: 1. Surveillance and assessment, 2. Data probing, and 3. Documentation and communication (Table 4).

In addition to the goals, we coded tasks or activities that were not goals themselves. Most of the tasks identified during analysis of the contextual inquiries with care coordinators were in the data probing category and thus most of their time was spent in this area. A standardized workflow, including tasks identified from the inquiries, showed the general process of the care coordinators (Figure 4). As expected, we found that the care coordination workflow process is influenced by the tools available. With the existing tools, repetitious actions to adjust a view of data resulted in a high frequency of coded tasks and barriers. For example, recurring tasks included making selections of sensors, timeframes, and clients. We found that the inability to review data from multiple sources either side-by-side or overlaid was a consistent hinderance to assessment of behavior and required high cognitive load and reliance on personal notes by care coordinators to determine normal patterns of behavior and discover behavior deviation. For example, when reviewing motion sensor data, the care coordinator viewed a line

chart of binary on/off results, hovered over data points on the graph to find the general times activity was occurring, wrote down their observations and then reviewed additional data streams individually.

Table 4. Categories, goals and examples for coded transcripts of contextual inquiries

| Surveillance and assessment | |
|---|---|
| Goal | Examples |
| Verify/review configuration added to interface | actions taken to review sensors in a configuration; configuring a new home; confirming new configuration appears in the dashboard |
| Check for emerging client issues | reviewing list of homes and summaries of information provided; reviewing summary information of trends over time |
| Check client online status of home and sensors | reviewing status of sensors and system (offline/online); viewing sync date and time for wearable data; ability to force a sync |
| Assess sensor function and placement | user suspects that a sensor is not placed correctly from client activities divergent from data captured |
| Add, edit and review alerts | user reviewing heart rate spikes; user talking about documenting abnormal activity frequently |
| Data probing | |
| Goal | Examples |
| Learning/understanding a client's normal behavior | user explaining their process for determining a pattern of behavior by taking notes and reviewing/simplifying them; discussion with a client about normal habits such as sleeping or grooming |
| Compare data between sensors with same timeframe | comparing data from two locations; determining pattern of behavior from written notes of sensor firings on the same day |
| Compare data with normal behavior | comparing data to past behavior to determine normalcy |
| Review aggregate or summary information | reviewing a total number of minutes of activity in a room on a given day; reviewing summary wearable data |
| Identify client location status at a given time | inferring that a client is not home from high wearable data and no activity detected in environmental sensors; using door sensors to determine status |
| Add and review annotations for events | documenting observations that are concerning; documenting known upcoming events; reviewing documentation of observations |
| Review trends in behavior | reviewing the amount of sleep time to assess for seasonal affective disorder |
| Documentation and communication | |
| Goal | Examples |
| Document observations from data review | documenting a concern; user completes a process of evaluation and determines no further action is required but does not document |

| | |
|---|--|
| Assign and review assignments of client to coordinator(s) | assigning client to coordinator or coordinator to client; includes temporary assignment or reassignment |
| Client reviews their own data and sets personal goals | client reviewing their own data; user showing a client their data |
| Communicate issue with colleague | user talks to another user about a potential concern |
| Determine follow-up action, document and complete follow-up | making a note, reviewing notes, or interacting with clients to document and/or follow-up |
| Document and review safety and health concerns | Safe at home checklist, Inter RAI assessment, Quality of Life assessment, or others; follow-up with client |

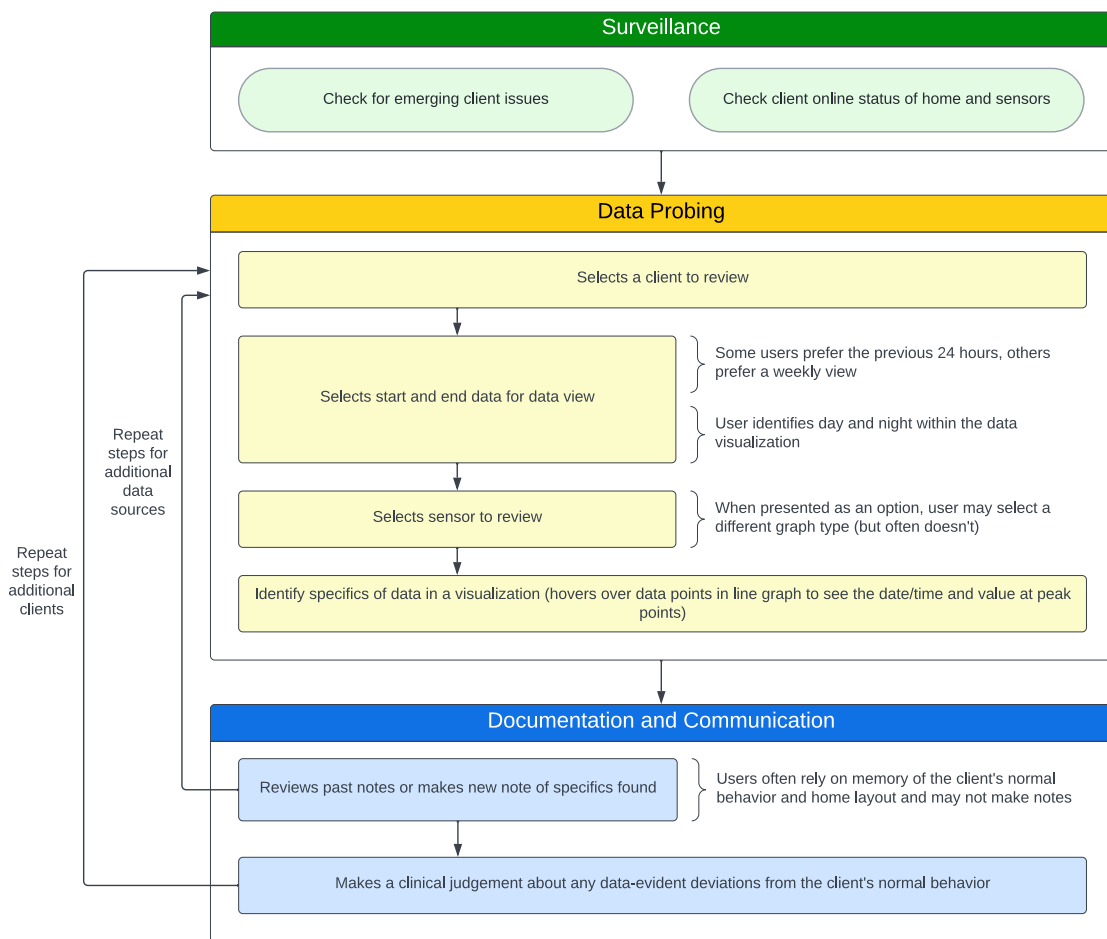


Figure 4. Standardized care coordinator workflow from contextual inquiries

We also standardized the barriers we discovered and used the list to make design decisions about the care coordinator dashboard and also for determining changes to the site management interface.

Discussion and Conclusion

As a result of this work, the design team was able to discover detailed care coordinator needs and clarify their typical workflow. Focus groups provided the basis and valuable details for information needs and design requirements. The opportunity to explore the priorities of the dashboard and expectations of ASSETs members was an essential step to the success of the interface and dashboard development. Additionally, the contextual inquiry process gave us considerable data for making design and layout decisions that would not have been possible without this process. We learned a lot about how care coordinators discern data, how important it is for the data to be in one place and viewable together to reduce cognitive load, and that our care coordinators are performing repetitive tasks that reduce the time they spend making decisions about what they observe in the data. Creating a new interface that addresses these concerns and is co-designed with care coordinators will open possibilities for additional ways to augment cognition. For example, the platform could assist with determining a pattern of behavior and provide a distinct visual cue for movement as opposed to periodic checkups by the care coordinator, so they can discern changes more quickly and begin to surveil more. While the system at this next stage will not be able to assist care coordinators in determining behaviors such as grooming or eating, the following steps of applying machine learning (ML) and artificial intelligence (AI) algorithms could support next level understanding of behaviors without undue burden for the clients and care coordinators. Once advanced

behavioral analysis is applied, care coordinators will still be able to examine the data behind the AI and ML results and provide professional insight that ultimately leads to better quality of life for their clients. The ASSETs team is committed to contributing to care coordinators' knowledge of their clients with technological advancements. As one of our focus group participants said, "*work smarter not harder. Whatever the computer can do for us.*" – Nurse 2, First Focus Group

Chapter 3: Prototyping an Integrated Sensor Data Interface for Remote Care Coordination

Introduction

As large quantities of data about human behaviors exponentially expand through the broad adoption and use of personal activity trackers and smart home systems, there are opportunities for new digital health services that augment human health using behavioral sensor data. However, new tools and methods for delivering concise, clear, and representative results are needed to aid health professionals in better decision making to support their clients and patients. Several projects indicate promise in leveraging sensor data from smart home systems through clinical decision support systems, specifically in the homes of older adults.⁵⁴⁻⁵⁸

Sensor-based Remote Health Coaching and Care Coordination

The Age-friendly Sustainable Smart and Equitable Technologies for Aging in Place (ASSETs for AIP) team at the University of Missouri began providing remote care coordination and health coaching in a Centers for Medicare and Medicaid demonstration project in 2022 (OSPA Contract #: 00076747). The ASSETs for AIP care coordination team supports older adult clients in meeting their health goals, improving quality of life, and aging in place. Remote care coordination and health coaching is provided by care coordinators with expertise in nursing, social work and occupational therapy facilitated by smart home sensors, wearable devices, and telehealth visits on tablet computers.

Clients enrolled in the ASSETs for AIP project receive a minimum of four Fibaro multi-sensors¹⁵ installed in their homes. These environmental sensors measure air

temperature, humidity, luminance, and motion with a passive infrared sensor. Clients are also provided a wearable activity tracker, either a Garmin¹⁷ or Fitbit¹⁸ watch, or Oura Ring.¹⁹ At a minimum, the wearable sensors captured steps and sleep data.

ASSETs for AIP care coordinators review client data to identify behavior and environmental concerns, make data-informed recommendations, and encourage clients to make positive changes. At the launch of this project, a design team developed a prototype interface for setting up and reviewing all homes within the project. This site management interface included rudimentary data visualizations for viewing environmental sensor data (Figure 5). In addition to this view of the environmental sensor data, care coordinators used separate manufacturer-provided data visualizations for reviewing wearable data. Care coordinators took meticulous notes about the wearable and smart home data, and then they made associations across the wearable and smart home data to learn client routines, distinguish deviations from routines, and used their expert judgement to determine possible health ramifications. This process was cognitively intensive and the systems for data review suboptimal. To reduce workload and increase client support capacity for the care coordination team, a new interactive interface and data dashboard for decision support was required.

User-Centered Design

One of the primary goals of the development of the ASSETs care coordination interface was to optimize the tool for the person interacting with the computer interface, an area that has been seen as a challenge.⁵⁹ One approach to overcome this challenge is user-centered design (UCD), which places the person using the interface at the forefront design process and accepts their needs as the driving force behind the design of the

system.⁶⁰ According to Norman, UCD requires at least three kinds of knowledge to create supportive interfaces: “*first, knowledge of design, of programming and of the technology; second, knowledge of people, of the principles of mental computation, of communication, and of interaction; and third, expert knowledge of the task that is to be accomplished.*”⁶⁰ Further, participatory design specifically includes users in all steps of the process which typically results in better user experiences with the end product.^{61–63} This project engaged care coordinators of the ASSETs for AIP project as co-designers of the a coordination dashboard interface. A key role of a co-designer is to act as a priority decision maker in the design process.^{64,65} The interface design process was facilitated and guided by a visual design team; members of the design team had expertise in informatics, data science, design science, and behavioral research.

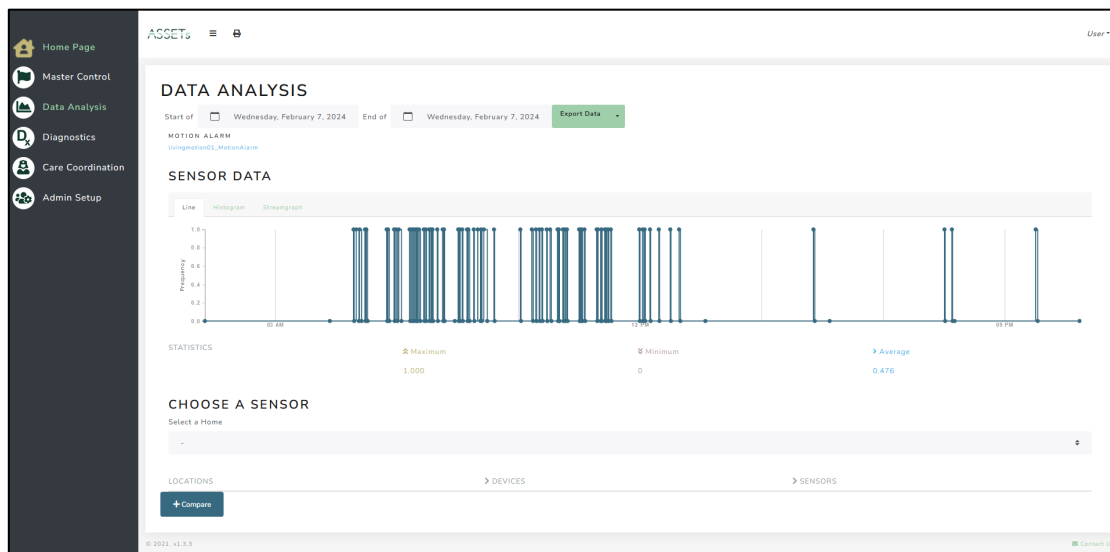


Figure 5. ASSETs site management interface data analysis page

The UCD process we applied in this project included: 1. Characterizing information needs, 2. Iteratively designing and assessing prototypes, and 3. Evaluating a high-fidelity interface and data dashboard. Figure 6 represents the design lifecycle for the

development of the two interfaces for use in the ASSETs project. The first step of characterizing information needs was completed using focus groups and contextual inquiries. The aim of this study was to iteratively design and evaluate low-fidelity prototypes with co-designers before proceeding to the development of a high-fidelity prototype for care coordination.

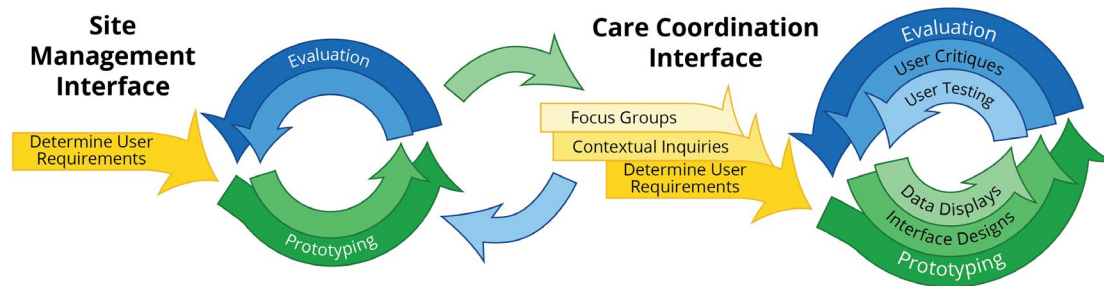


Figure 6. Design lifecycle of the ASSETs interfaces

Feedback and final decision-making from co-designers during low-fidelity prototype iterations was vital for maintaining focus on care coordination information needs and work.⁶⁶ Within-process critiques and feedback are crucial for making slight adjustments during multiple structured evaluation stages that could be more costly to change in later design iterations.² Therefore, multiple prototypes are created and evaluated cyclically using a rapid iterative design process. This process requires a small number of target users to evaluate, critique, or provide feedback on each prototype.^{2,67} However, one potential challenge is that target users may not have the language to provide valuable critiques to an expert designer. For example, they may identify that they dislike a layout, but not realize why – perhaps it lacks white space or fails to utilize chunking of information, two phrases that are common in design disciplines but are unfamiliar to them.

Two useful tools to close this gap in design language are the use of rubrics and A/B testing. Rubrics provide language that the evaluator can select with a meaningful description. For example, the person providing critique might choose from a list of statements: “needs a clear visual hierarchy,” explaining that the information needs to be displayed with layers of importance so that more important information is easier to identify by its prominence.⁶⁸ This helps the designer identify what needs to be changed. The use of rubrics to support non-design experts in giving valuable feedback have previously been successful in crowdsourcing design critique with non-designers.^{68,69} Another tool that can be applied is A/B testing, where two prototypes are evaluated and data collected from those two tests are compared so that a design team can identify the better design.⁷⁰ We used elements of both rubrics and A/B testing in our process of rapid iteration and evaluation with a small number of reviewers for each version. From the rubrics, we presented the reviewers questions with jargon-less language, as a tool to make the reviewers think about aspects of the design. We also gave reviewers more than one prototype at a time to compare them concurrently.

Additional context from reviewers and design team concordance were reached in critique meetings. With a focus on understanding how co-designers would use the interface, and how they reason through their use, discussions were centered on workflow and data interpretability. Disagreements or misunderstandings were resolved through education of design standards.

Importance of Pragmatic Data Displays

Additionally, since the care coordination interface contains interaction with data, the data displays (also referred to as data visualizations and data dashboard) require

specific and individual attention. Like the interface design, data displays lean on design principles to be effective, however separating these stages enabled the care coordinators to give focused attention to each stage. Data visualizations need to combine disparate information in a way that makes sense, provides meaning, and facilitates efficient perception.⁷¹⁻⁷³ Gestalt principles and pre-attentive processing from graphic design and information design provide valuable guidelines for developing data displays.^{1,4,74} Gestalt principles provide scaffolding for design thinking.⁶ Additionally, designing data visualizations that are familiar to users and make the most of intuitive human processes, including preattentive processing, supports a need to make the revelations efficient.^{5,73} We used design principles and preattentive processing in the design of the data dashboard.

Based on characterized information needs, data visualizations needed to represent short-term (daily or weekly) and long-term (monthly, quarterly, or yearly) trends based on integrated data. Short-term data refer to targeted review of a single day or week, where a coordinator would view multiple data streams (such as motion from all rooms in the home of one client) alongside a client's normal behavior. With short-term data, care coordinators were looking for recent aberrations in behavior, and determining if any algorithm-identified alerts were relevant. Some examples of what they were looking for include: accelerated heart rate during less activity, a decrease in general activity, or changes in time spent in rooms. Viewing long term trends, such as a slow decline in activity or increased time spent in one room, were identified as difficult with a daily or weekly view. Long-term trend data would be presented as a monthly, quarterly, or longer time period where all data are aggregated at a daily or weekly level. A trend view was

designed for a care coordinator to decipher shifts in behavior across time alongside crucial events, such as hospitalizations. Examples of what care coordinators may look for in the trends data included: total activity time in rooms, counts of visits to the bathroom or kitchen, gradual change in activity, heart rate averages over time, and increased or decreased sleep time.

With the initial rudimentary data visualizations from the site-level interface, care coordinators were limited to line, bar, and streamgraph charts of raw single-sensor views of data from the multi-sensors, including motion, temperature, and luminance (Figure 7).

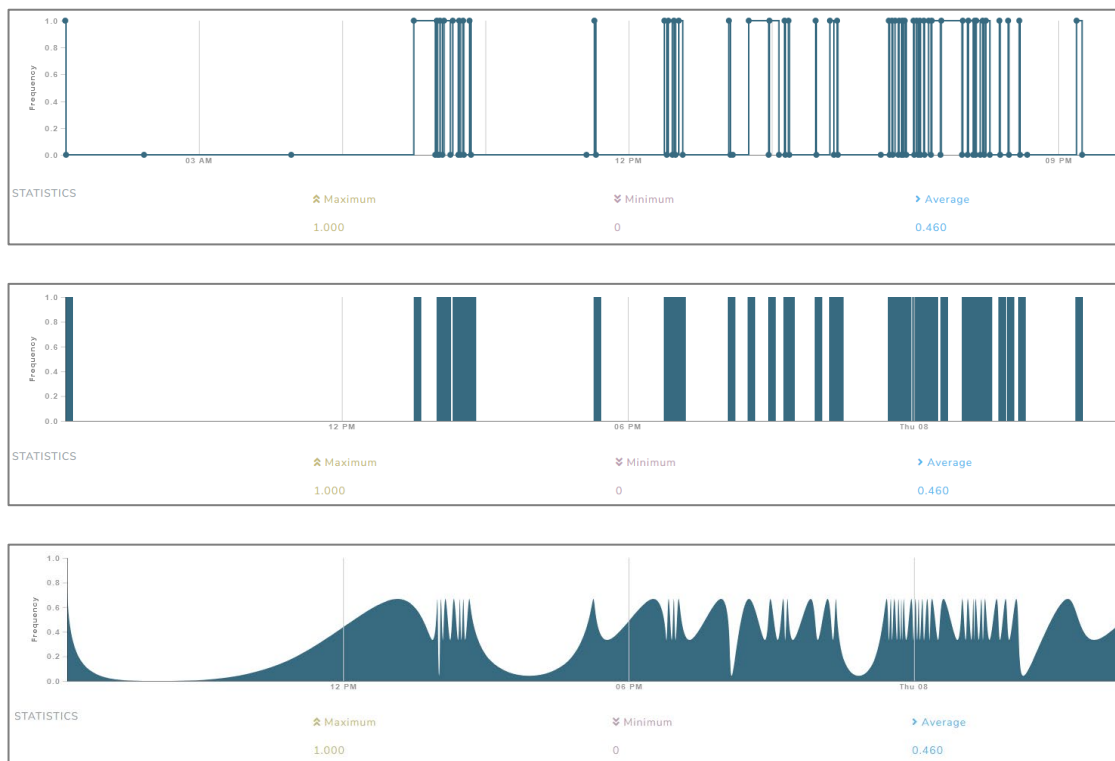


Figure 7. Management interface visuals of one client's 24-hours of data as a line,

The process of reviewing room-level raw binary motion data in this manner was unnecessarily time-consuming and frustrating. Additionally, care coordinators were using a separate proprietary Garmin dashboard⁵⁰ to review 24-hour views of heart rate and

activity. Care coordinators developed their own personal way of reviewing individual data streams to discern patterns of behavior at great cognitive expense. Reducing care coordinator cognitive load and time required to review data were top priorities for the new interface.

Methods

With information needs and design requirements in hand, design of an interface and data dashboard occurred in four stages that resulted in distinct products as outputs. Iterative versions were created and reviewed cyclically within each of the four stages and each stage ended with a final output. Outputs were: 1. Written conceptual model and scenarios of use; 2. Interface layout and interaction solutions; 3. Data visualizations and interaction; 4. High-fidelity web-based prototype. Care coordinators were co-designers throughout all stages, providing input and making final decisions about designs.

Stage 1: Scenario-Based Design

A scenario-based design (SBD) approach was used for the first stage of prototype development of the interface. SBD involves writing vignettes (scenarios) that use plain language to describe processes for accomplishing tasks within an interface.⁷⁵⁻⁷⁸ Scenarios were used as a tool to facilitate conversation between developers and designers, laying the groundwork for understanding how care coordinators will interact with the system.^{75,76,79,80} The SBD approach was used previously by the design team to create a prototype for the site management interface. At the start of this study, the care coordination team used the site management interface as their primary tool to review room sensor data.

The lead author drafted scenarios of use from the standardized goals and barriers captured previously. Scenarios are often written alongside personas^{78,81,82} that represent target users of a system. A persona describes a realistic user, often characterizing a synthesis of multiple real users, describing their level of expertise in specific fields, typical behavior, attitudes, environment, or other aspects relevant to the artifact being designed.⁸² For this project, the care coordinators were engaged as co-designers so personas were unnecessary. Therefore, we scripted scenarios from the standpoint of care coordinators' information needs and design requirements, and from their perspectives as experts in nursing, social work and occupational therapy. We expanded upon the scenarios to include a high-level summary of needs and a set of essential features to encapsulate goals and barriers that were not always captured or highlighted within the vignettes. The draft of the scenarios was shared with the care coordinators and their edits were incorporated. The design team met to discuss scenarios and determine definitions for consistent terms used. Once approved by co-designers, the scenarios were shared with the development team and guided the design of prototypes.

Stage 2: Interface layout and interaction solutions

Next, the lead author created interface functionality and design prototypes using Adobe XD, a program for designing web and application prototypes.⁸³ The functionality-focused prototypes intentionally did not include data visualizations.

The lead author sketched possible layouts and created two initial prototypes. The two prototypes had minimal interaction and included placeholder boxes (wireframes) for visual and textual information. Similar to A/B testing, we provided prototypes 1 and 2 for co-designers to test concurrently. We allowed our co-designers to view both designs so

they could determine features that they preferred to see in future designs. The goal with the initial two prototypes was for users to click through pages and see the basic layout properties. Like a rubric for design critiques, co-designers responded to a survey that directed them through a series of questions and tasks to guide their assessment. Survey instruments were created in REDCap (Research Electronic Data Capture), hosted by the University of Missouri (see Appendix 1 for the full REDCap survey).^{84,85} All co-designers – including all the primary users and other members of the research design team – were asked to complete the REDCap surveys. This method allowed evaluators to test the prototypes at their own pace and individually captured their thoughts.

Following review of individual evaluation results, the lead author led a critique meeting, which included all four ASSETs for AIP care coordinators and two other design team members. The objectives for the critique meeting included: 1) determine which prototype to iterate from, 2) clarify confusing or conflicting survey answers with co-designers, and 3) synthesize highest priority changes for the next prototype iteration. In guiding the meeting, the lead author set aside any personal biases about design preferences, explaining that the goal was to design the best possible tool for use and that co-designer feedback was critical to creating something useful to them. This critique meeting concluded the first iteration of stage two.

Three additional iterative prototypes were provided to co-designers. They were able to add comments through Adobe XD's review platform and critiqued prototypes in hour-long virtual meetings. Co-designers provided input on design choices, identified terminology and navigation that was unclear or unhelpful, and commented on their preferences. At the end of each critique meeting, input was synthesized into next steps

and decisions were made with support of all co-designers present. Once consensus on all primary navigation and layout needs were met by the interface design prototype, the design team agreed to conclude the iterative process for stage two.

Prior to sending the consensus functionality prototype to the web developer, the lead author wrote a document explaining design choices and interactivity of the design to provide clarity around what was not readily apparent in the prototype. The co-design team reviewed and edited this document prior to delivery to the development team.

Stage 3: Data visualizations and interaction

The iterative process of designing and evaluating data visualizations began prior to the requirements gathering phase and was concluded following stage 2 of prototype development. Multiple data visualization prototypes were created including daily and weekly views of data, views of “normal” or “average” activity data, long-term trends, and combinations of data streams (e.g., normal activity data shown side-by-side with a 24-hour window of activity data). Co-designers critiqued data displays in nine virtual meetings over a one-year timespan. Critiques included feedback about the general usability of information displays, observations about the clarity and readability of visuals, as well as comments on user preferences for design choices. Like the iterative functionality process, solutions synthesized during user critiques were incorporated in later iterations of data displays. The ASSETs for Access intervention research team provided feedback on data displays in the second focus group during requirements gathering. Late-stage data visualizations were shown to co-designers within the Adobe XD interface prototype to show interactivity. The iterative process of designing and evaluating data displays concluded when co-designers reached a consensus on preferred

visuals. Again, a document explaining design choices and interactivity of the data displays was created by the lead author, reviewed by the team, and provided to the developer.

Stage 4: High-fidelity web-based prototype

The web developer re-created the consensus prototype in a sandbox environment and provided previews to the co-design team and ASSETs for Access intervention research team prior to connecting it to real data for usability testing.

Results

Stage 1: Scenario-Based Design

The SBD document included a summary of needs, important features, and the scenarios of use. The summary of needs was described as:

Users need to be able: to surveil all clients; setup, receive and review alerts; and review diagnostics (observe a divergence, explore the data to make informed decisions on next steps for care delivery).

The top three important features included: 1.) view multiple sensor data in a single visual (for one home) with a mix of overlay and faceting, 2.) Turn on/off sensors in visual display, and 3.) Average sensor time on (time in each room), with the ability for users/coordinators to customize how this is figured (not all days are the same). Two example scenarios are below. For the full SBD document, see Appendix 2.

1. **Title:** Check for emerging client issues

Examples: client offline/online status, no activity detected, or other alert

Description: The care coordinator begins their day by surveilling offline/online status and other alerts of multiple clients. They choose to review “all clients,”

“my clients,” or select “custom” clients to review. If they choose custom clients, they are prompted to select clients to review. (Alternative or additional customization: filter alerts by type, such as: offline/online status, room activity deviation, vital signs, nighttime behavior deviation.) The interface displays a list of alerts with an option to expand and view more information / take action for each alert.

2. **Title:** Review an emerging client issue / alert

Example: last sync more than an hour ago

Description: Following the identification of an alert: last sync more than an hour ago, expansion of the alert shows the normal behavior: attempt to sync one hour ago, the deviation: last successful sync 12 hours ago. The coordinator is provided choices for identifying follow-up from the alert, including reviewed/not a concern (dismiss); errant data (dismiss); follow-up with client (snooze); persistent concern (snooze); share with a colleague for review (share/reassign); annotate with more information (dismiss). Alert automatically moved out of the main alerts screen, but still accessible from menu choices on the page.

Definitions

“Annotation” referred to information that a user would add to data points and would be accessible within the dashboard.

An “alert” was set by applying boundary conditions for the system to create instances.

An “alert instance” was a single trigger of the alert.

“Tags” were pre-defined actionable items a user can apply to an alert instance or an annotation.

“Notes” were open textbox fields where a user can add context to an alert instance.

Conceptual models

Two conceptual models helped explain this interface: an email inbox and alarm clocks. The alerts page of the interface showed a list of items, much like a person might find upon opening their inbox. Alerts were like an alarm clock where a user sets the parameters for the alarm (the time and reason for the alarm). Once the alarm was triggered and an instance created, the user had choices: to ignore it, to dismiss it, or to snooze it. The management of alerts and annotations was like our model of a personal email inbox and had some similar functionality (Figure 8).

| Conceptual Model | ~ | Interface Functionality |
|--|---|--|
| Email inbox: shows a list of emails | ~ | Alerts page: shows a list of items |
| Alarm clock: set parameter (time) to alert user | ~ | Setting alerts: set parameters to alert user of something that happened |
| Alarm goes off: user can choose to ignore it, dismiss it, or snooze it | ~ | Alert instance occurs: user can choose to ignore it, dismiss it, or snooze it |
| Managing emails: user can mark for follow-up and set due date | ~ | Managing alerts and annotations: user can mark for follow-up and set due date |
| Managing emails: user can forward an email to another person | ~ | Managing alerts and annotations: user can share with another user |
| Managing email views: user can temporarily sort email view and apply filters to view (like which sender or subject headings) | ~ | Managing alert and annotation views: user can temporarily sort and apply filters (like which homes to view) |
| Default email view: new emails appear bold until opened, however a user can set their view to only show unopened mail | ~ | Default alert view: only "new" alerts where user has taken no action to dismiss or mark the alert for follow-up |
| See opened or archived emails: filter option | ~ | Review prior alerts: filter option |
| Reviewing emails and sorting them into folders | ~ | Reviewing alerts and adding action tags |
| Adding a flag to an email for follow up and then sorting view to show only flagged items | ~ | Follow-up page: where alerts or annotations tagged for follow-up are sorted |
| Applying rules or filter logic to incoming emails to the inbox | ~ | Setting alerts: defining the logic or rule for when an alert is triggered |
| Sending yourself an email and marking as opened/read | ~ | Annotations: user-added information connected to a piece of data (all tags and options available in alerts are available in annotations) |

Figure 8. Similarities between the conceptual model and the interface functionality

Stage 2: Interface layout and interaction solutions

Prototypes 1 and 2 were designed to meet the needs outlined in the scenarios.

Both initial prototypes had the same primary navigation pages, which persisted through all designs:

1. An alerts page designed for reviewing all alert instances allowed the user to filter and sort alerts for multiple clients.
2. The data page was designed to prioritize a daily or weekly view of multiple streams of one client's data in a single visual. This view incorporated filtering and customization options, including specifying sensors to populate the data display. Additionally, a user could insert annotations about the data, view the home layout, view relevant alert instances, and see summary aggregates of the visible data.
3. The trends page allowed the user to see behavior over longer periods of time from daily or weekly aggregates and averages of data, alongside user-entered annotations. It also included filtering and display options for the data view.
4. An annotations page provided space for users to review the notations they have inserted into the system. They could filter, sort and search for past notes.
5. A follow-up page combined the instance alert views and annotations a user tagged for follow-up.
6. In the settings page, users could identify data and filters for default data visualizations. They could also hide clients from view and assign a custom set of clients for regular review.

The first prototype (Figure 9) featured primary site navigation in a left sidebar, a design layout similar to two interfaces familiar to care coordinators (the ASSETs site management interface and the Garmin Connect interface).⁸⁶ A header announced the name of the site and included login and help buttons. A secondary header included page-specific data filtering functions. Website content was chunked with information and features framed into cards, like evenly spaced windows within a larger window. This

design used floating lightbox overlays for adding information into the interface and delivering system messages.

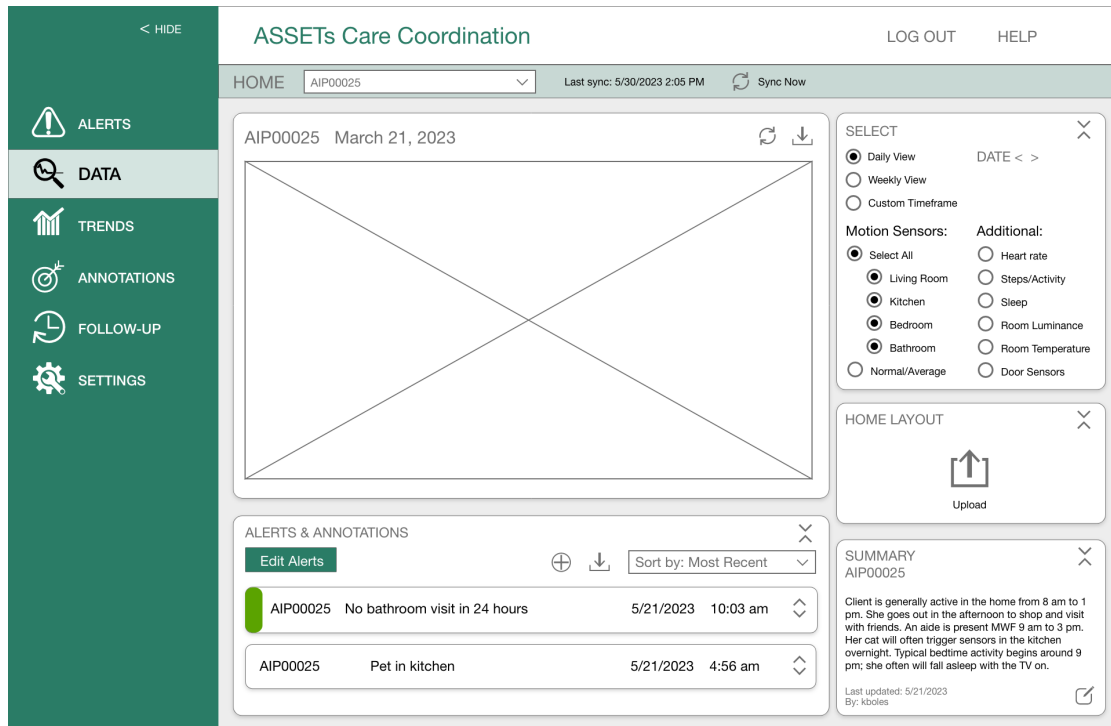


Figure 9. ASSETs Care Coordination prototype 1 data view

The second prototype (Figure 10), designed in tandem with prototype 1, had primary site navigation in a header.⁸⁷ Functions, filters, and adding information to the interface was completed through slide-in left and right sidebars that could be hidden to maximize space for content. A grid design enabled content chunking, like cards but without the space between. Both prototypes drew inspiration from project management web designs, where multiple filters, functions and chunks of information need to be accessible and hidden.^{88,89}

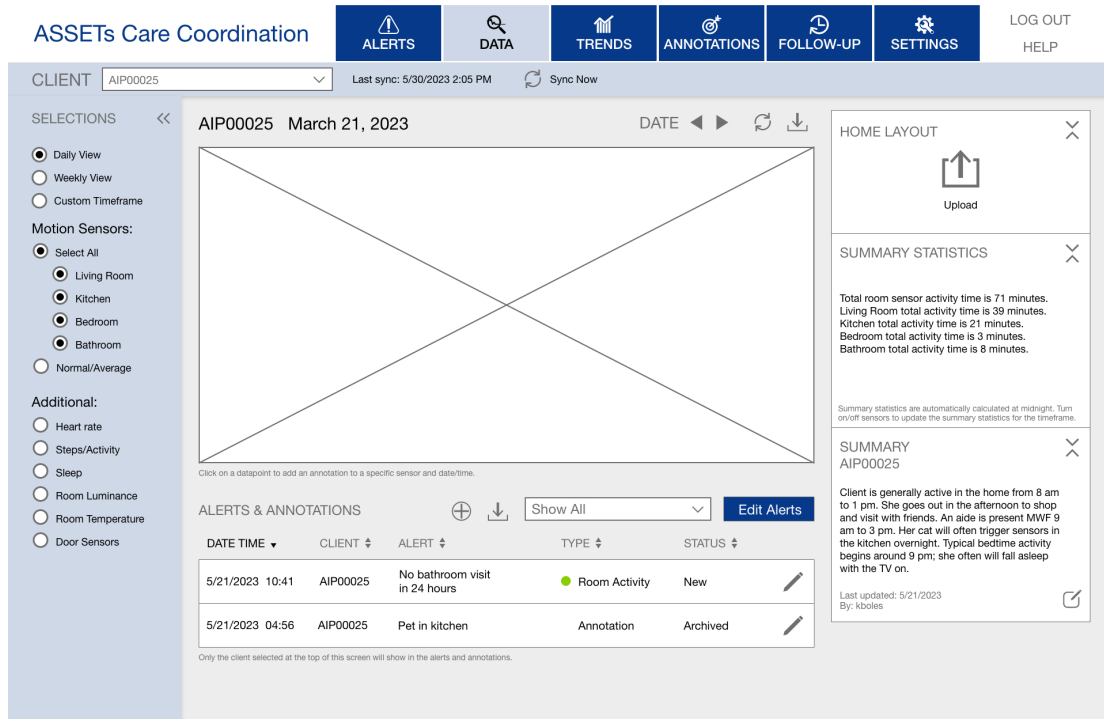


Figure 10. ASSETs Care Coordination prototype 2 data view

Three care coordinators and one design team member completed the REDCap surveys for the two designs. In addition, care coordinators asked questions and left comments in the Adobe XD web interface where they interacted with the prototypes. The comments were overall very positive for both prototypes. The care coordinators unanimously preferred prototype 1 to prototype 2, stating that it was more intuitive and familiar. The design reviewer and the lead author both preferred prototype 2. In the first critique meeting, co-designers decided the future iterations would use the main layout and design of prototype 1 as the basis.

Critique notes and collected comments were compiled into a spreadsheet with 154 rows, a sample of which is visible in Table 5. The resulting output of stage 2 (interface layout and interaction solutions) was an interactive Adobe XD prototype (Figure 11) and document of detailed explanations for the developer (Appendix 3).⁹⁰

Table 5. Sample spreadsheet of critique comments

| Prototype Version | Location or Page | Comment | Commenter |
|-------------------|------------------|---|----------------------|
| 1 | Alerts page | I love the ability to set up custom alerts! Love how the normal behavior and deviation show on alerts. I love that the action options are check boxes that let you check more than one option. I also love having the custom client selection option in the alerts tab. There are some clients who might have alerts going off every day if they're having internet issues or something, and it will be great to filter that out as needed. | Care coordinator 1 |
| 1 | Alerts page | I was a little confused on the View and Edit alerts page. I'm not sure what you do on that page. Can you change the logic/title/type? For the expanding the alert on a client, I like how you have the normal and deviation behavior and then the care coordinator can check what action was done. Wondering if you need an "other" in addition to "note"? Also how do you then archive the alert? | Design team member 1 |
| 1 | Data page | I love the idea of being able to see the home layout which allows for easier correlation/understanding of the data. Having a summary to remind us of the typical pattern/routine is very helpful. | Care coordinator 3 |
| 1 | Trends page | As far as totals, we might not want totals from all data to-date. For example, total kitchen visits to-date since enrollment isn't relevant, but average kitchen visits per day would be. I think I'd be more interested in running averages for each trend option. The time selections would still be relevant -- average daily kitchen visits from all Mondays, average kitchen visits per week, etc. | Care coordinator 1 |
| 1 | Trends page | That the system could find trends is the best thing about this page. The current system uses a lot of brain power and time to figure trends out. | Care coordinator 2 |
| 2 | Alerts page | customization is very helpful | Care coordinator 3 |
| 2 | Alerts page | I think the stronger color variance of the first prototype is more helpful. | Care coordinator 3 |
| 2 | Data page | I like the summary statistics feature on this prototype! | Care coordinator 1 |

| | | | |
|-----|--------------------|--|----------------------|
| 2 | Data page | I like how you had the layout of the selections on the left and bottom and then if you need to edit something, the right-hand panel pops up, which is consistent with the alerts page. It is easy to follow and like the color (next to room activity) to alert the user of something new. | Design team member 1 |
| 3 | Alerts page | I want to make sure that I gave it to you. But then I also want to make sure that neither one of us lose it [...] but I still feel like, if it's my client, I'd want to follow up. | Care coordinator 2 |
| 3 | Annotations page | I was thinking, [...] if there was a way to pin or unpin all of those pins on the side that can potentially scroll, because then you could get the visualization as well as annotations across the whole bottom. | Design team member 2 |
| 4.1 | Data page | I like that we can add an event to make our own instance of an alert being triggered, even though it's not like it was triggered. We're just putting that in ourselves. | Care coordinator 1 |
| 4.1 | Alerts page | When we're on the alerts page and it says add alert, we add rules for an alert, we're not adding an instance of an alert. So maybe clarifying between those two. | Care coordinator 1 |
| 4.1 | Alerts edit page | That's where I'm setting the value, or the protocol. And then view is where I'm going to see the results of my equation or whatever I put in there. But I'm confused about the other page. | Care coordinator 2 |
| 4.2 | Notifications pane | I really like that; think it could be really helpful, especially with the follow-ups just having that pop up as a new one that we have not seen yet | Care coordinator 3 |

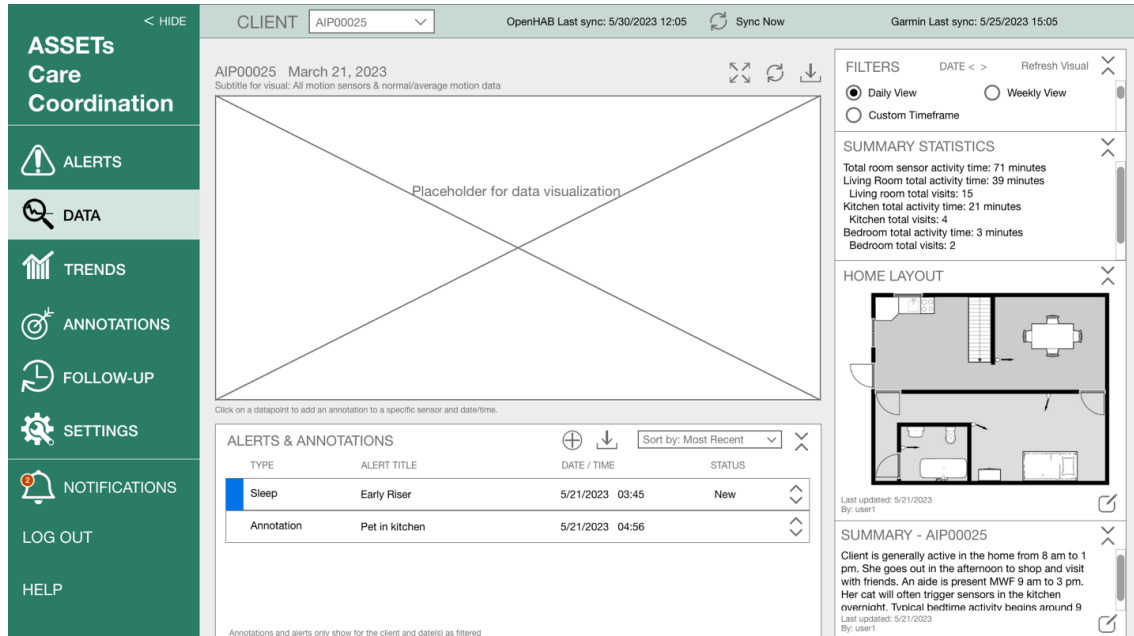


Figure 11. Data page of ASSETS Care Coordination final Adobe XD prototype

Stage 3: Data visualizations and interaction

Early prototypes of daily and weekly short-term data illustrated the raw motion data as horizontal bar charts with time in the x-axis and rooms in the y-axis (Figure 12). When motion was captured by the sensor, a black bar would appear on the chart to indicate the length of time there was motion. The resulting visual was often sparse, and users commented that it looked like a DNA assay; users had a hard time understanding what they were seeing and struggled to understand quantitatively how much time someone was active. As care coordinator 2 said, *“I don't particularly like this one, but what would simplify it for me would be the whole day snapshot of everything, the timeline at the bottom [...] I just get confused to try and figure out that was at 3 am. But the whole day snapshot is really helpful, you can see they are in the bedroom during normal sleeping hours. [...] I like the whole day snapshot it's just hard to read the timeline at the bottom.”*

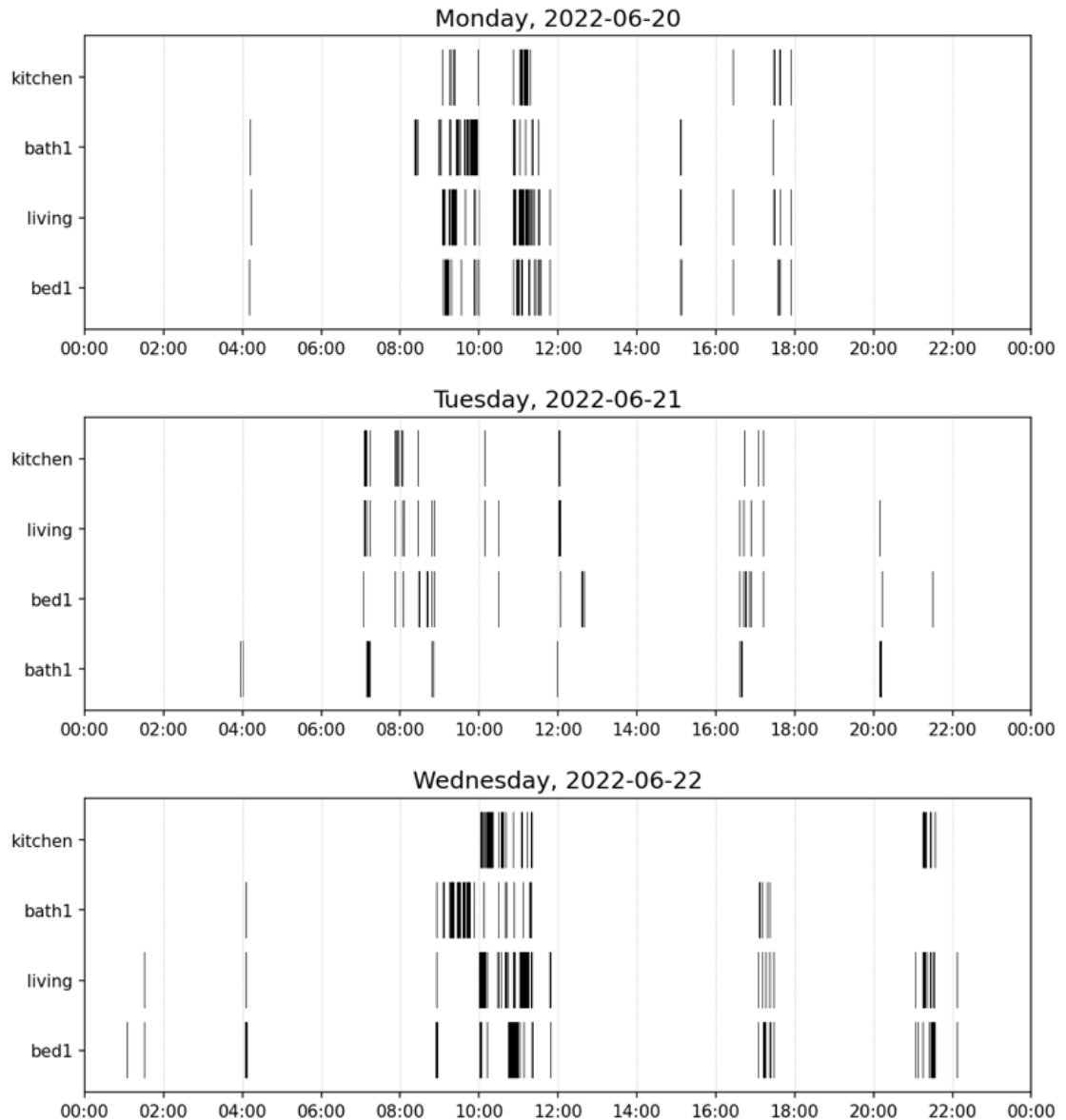


Figure 12. Early prototype of motion activity visualization using unaggregated sensor data in a horizontal bar chart

Additionally, users thought colors would help identify rooms and identifying day vs. night could be useful, as evidenced by design team member 3: *“And if I see certain movement that's happening around sunset, that's going to get me some additional information.”*

A similar strategy for visualizing room data with horizontal bar charts was used to view normal activity (Figure 13). This density view was also a challenge to interpret correctly. Care coordinator 2 indicated *“it was just hard to differentiate the shades.”* As a result, these horizontal bar charts of unaggregated data were determined to have limited usability for quick discernment.

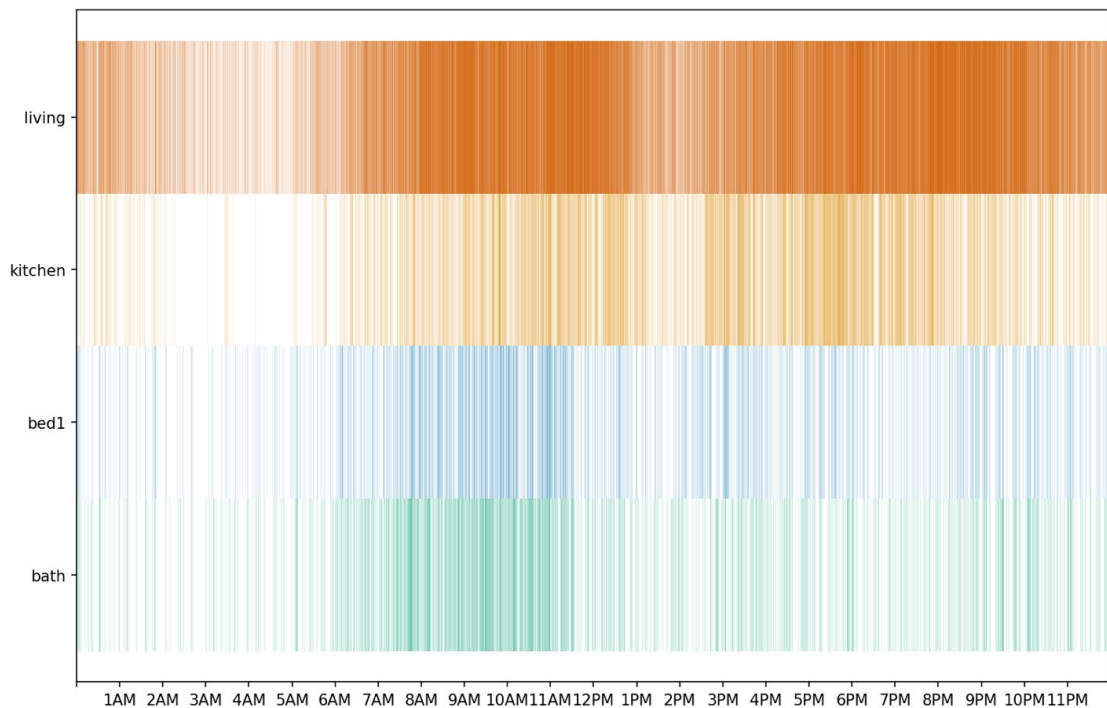


Figure 13. Density view of all captured daily data for one individual in a two-month timeframe as a horizontal bar chart

We took another approach to visualizing daily data with activity time aggregated in 15-minute increments as common bar charts and area charts. Users thought the aggregated visuals of data were much easier to read, as evidenced by care coordinator 1, *“the fact that I can easily see that there’s more activity in the living room than the other rooms [...] makes it easier to see.”* For the normal behavior view, we also shared a version that aggregated all time activity with a gaussian smoother on the bucketed data

since the 15-minute cutoffs create a hard stair-step view of the data that is somewhat arbitrary due to the cut points. The design team preferred the smoothed area chart visualization for viewing normal behavior patterns.

The team critiqued this smoothed view of the normal behavior patterns overlaid with a single day's view – shown three different ways in the same 15-minute increments: as assay-like bar chart, area chart, and histogram. The care coordinators preferred the histogram view of daily and weekly data, overlaid on the smoothed normal data. Figure 14 shows examples of the data displays determined to be best for rapid discernment of daily or weekly views of data.

We also created and reviewed area, line, and bar charts of other data streams alongside the motion data to round out a mosaic of information about a client's behavior in a short time frame. The data display types chosen for numeric views, such as room temperature and luminance, were line or area charts. Time-based binary information, such as sleep and door status (open/closed), were displayed as horizontal bars.

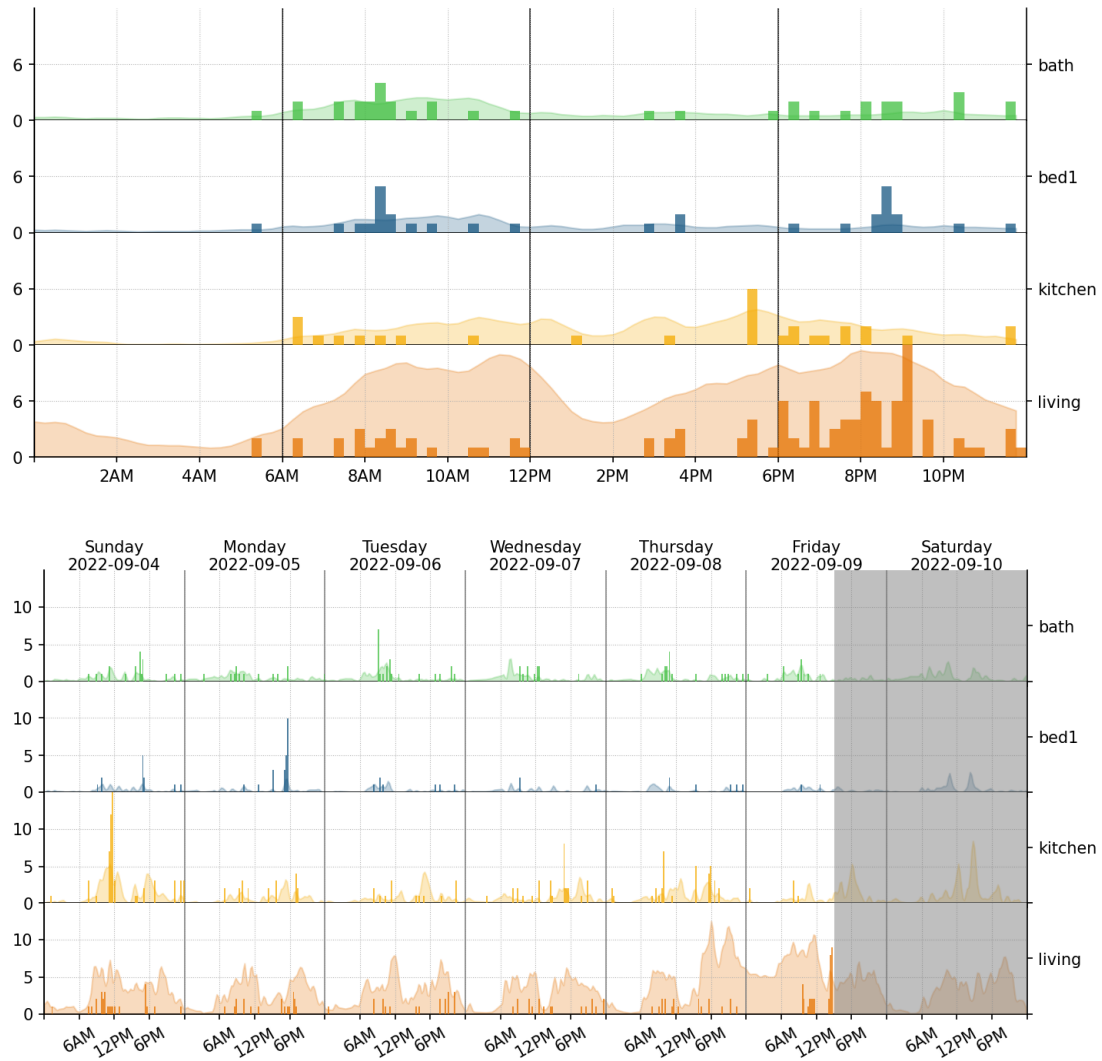


Figure 14. Day view and week view of average motion activity as underlay with single day or week activity overlaid

Long-term “trend” data visuals

Long-term trend data visuals that displayed data over months or longer were focused on reducing user cognitive load to decipher and assess for gradual changes in behavior. Like short-term visuals, the x-axis would present time aggregated to daily or weekly totals. Again, we plotted data in familiar ways: as bar charts, histograms, line graphs, and area charts. Figure 15 shows an aspirational view of trends, including data

from wearables that were not yet available in the interface. The co-designers were able to discern the data from these visuals, as represented by care coordinator 2: “so the colors are indicating which room and then, you know, time spent per minutes so obviously like the living room. He spent the most time in that room.”

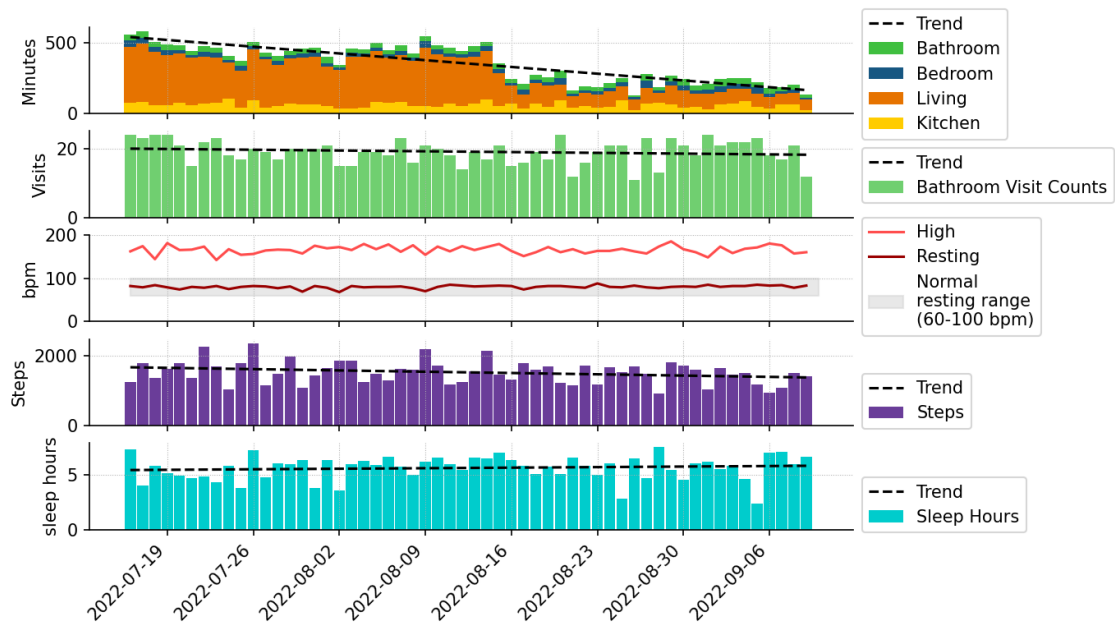


Figure 15. Aspirational trend view of multiple data streams with a daily unit of aggregation

The design team reviewed the various data displays made from the real ASSETS data; care coordinators generally preferred bar and histogram charts. In general, motion data as stacked histograms and separate bars for count information were determined to be of easiest discernment, as care coordinator 1 said, “I think a bar chart makes more sense to me than the area chart. I just understand what it means better.” Co-designers liked that bar charts made each bar distinct, as indicated by care coordinator 2: “To me, the white space differentiates. I know that it’s one block of time, the next block of time, the next block of time, I would probably have to do some guessing what day it was.” Discussion

between care coordinators helped them identify that the histogram view allowed them to see stacked bars in a way that is more akin to area charts, so that the user focuses on the time as a group rather than the individual units of summary, as indicated by care coordinator 1: *“I thought the no space in between them looks better, because I can see better like that. The living room was increased and then decreased rather than when there's spaces. It's harder to see that trend flowing.”*

We examined views that included rolling average and trend lines, and the team preferred the trend line views overlaid on bar and histograms, as captured by care coordinator 1: *“I think the trend line is much better,”* and care coordinator 3: *“I like the trend line.”*

Line charts were decidedly the best choice to represent heart rate, as it is an average value rather than a total or a count. Important to reviewing heart rate was being able to quickly assess whether the resting heart rate was within a normal resting range. Thus, we added an annotated grey box to indicate a normal range, as provided by our nursing professionals on the team.

Care coordinators were shown how they could apply filters to modify visuals to their needs. Visualization display types would remain consistent and not adaptable; aggregation levels would include both daily and weekly options.

One of the user concerns about long-term trends data was that they be able to identify dates and details, which was one of the reasons they liked the bar charts with space between them. We offered a solution of a pop-up for hover activity. When a user would hover over a location in the visual, a box would appear with all the summary data, even that which is not visible in the current view, so that they could assess all the relevant

information on that day/week. As represented by care coordinator 2, *“I mean that just would be so helpful. [To see] in the hospital or grandchildren visiting [...] that will make such a difference in what we’re seeing.”*

The design team also reviewed several color themes, cognizant that colors needed to be distinct and consistent across all visuals, as well as flexible enough to accommodate additional rooms where the color representation would hold across room types. For example, with blue as the main color for bedrooms, multiple bedrooms would be shown as separate shades of the bedroom blue color.

Once data visualization decisions were finalized, a document describing the consensus visuals was given to the developer for implementation (Appendix 4).

Discussion

Limitations

Scenarios intentionally do not cover every use case and provide general concepts without specificity of a step-by-step task list. Therefore, they can be interpreted by a developer or designer many ways. Similarly, while it is important to avoid jargon in written scenarios, we found that defining terminology is important in the process of writing scenarios. Discovered in the scenario stage, the care coordinators had difficulty understanding the use cases for applying tags to annotations. We utilized conceptual models to support understanding and help clarify design uses, by describing similarities to existing technology or common experiences.

The layout design of the prototype is based on the existing user workflows developed over time by three care coordinators of the site management interface. As a

result, we can expect that workflows will change, and future iterations of the interface will likely need to accommodate further adjusted workflows and new challenges.

When it comes to data display decisions, the histogram view and smoothed area chart are less detailed views of the data than the horizontal bar view – one cannot discern the exact time point the sensor identifies motion. However, much like the tradeoff that is pervasive in information design between information and time,⁶⁰ our users found the more familiar views of data to be more useful in their rapid discernment than a view of the details.

The lead author is a trained graphic designer and data analyst. The role of lead designer and leader of critique meetings inserted opportunities for researcher biases to limit the results of this work. The paradoxical situation may have resulted in co-designers holding back negative feedback for fear of hurting the lead designer's feelings, though the lead author repeated that this work belongs to the whole team, and the goal of making the best possible design could only be accomplished with open and earnest critique.

Next steps

The final prototype for this stage is designed to satisfy the needs of care coordinators right now to view data and apply their clinical expertise. Additional data will eventually need to be included in the interface. We also aim for future iterations of the interface to continue to reduce the cognitive load of users through alert management, behavior recognition, and additional contributions from future studies of sensor-based care coordination. The possibilities go beyond what we can envision now.

On the near horizon, we anticipate the application of machine learning and other automated analyses applied to the data to recognize several behavioral concerns. In our

requirements gathering sessions and prototype critique meetings, we identified several areas to focus on, including personal care behaviors like grooming and preparing meals, medication adherence, and rating social health based on an individual's radius of travel.

The system will have much room for improvement in alerts management as well. Much like an email inbox can get flooded with spam, we anticipate the possibility that the alerts notifications could become overwhelming for care coordinators. A concern about false alarms and oversensitivity may initially be rectified by care coordinators making manual adjustments to their alerts, however, a future version of the system could adjust alerts automatically or make a recommendation for the care coordinator to make specific changes to their alerts based on machine learning algorithms.⁶⁴

Conclusion

The new data displays and user-optimized interface will support the care coordinators' workflow and need for rapid discernment. Care coordinators will spend less time trying to align what they see in the data and reducing cognitive load spent on understanding the data; they will have more time and brainpower for providing their clinical expertise to changes in behavior with this new interface. Next, we will report on usability testing of the high-fidelity prototype developed from this process.

Chapter 4: Usability Testing a Dashboard for Sensor-Based Remote Health Coaching and Strengths-based Care Coordination

Introduction

The process of aging is often accompanied by the management of co-occurring conditions, a plethora of instructions for self-managing health, and potential for increased isolation, in addition to expected physical and mental changes. After leaving a nursing home or elder care facility, an aging adult may lose access to a health care professional or team of professionals focused on their quality of life. At the same time, behavioral activity has been identified as one of the most crucial and most changeable aspects of improving one's quality of life.^{21,91} The incorporation of a health professional to provide a broad understanding of lifestyle and disease management in the context of aging shows promise in improving quality of life.⁹²⁻⁹⁵ These health professionals may act as health coach,⁹³ supportive coordinator of self-managed care,⁹⁶ or interventionist when appropriate, to provide direct support to the aging individual and indirect support to the individual's care team.

A team of health professionals and researchers at the University of Missouri are providing sensor-based care coordination and health coaching to adults aging in their homes as part of a Centers for Medicare and Medicaid Services demonstration project (OSPA Contract #: 00076747). The Age-friendly Sustainable Smart and Equitable Technologies for Aging in Place (ASSETs for AIP) intervention team, including an occupational therapist, social worker and nurse, monitor client activity data and assess for potential clinical concerns. They meet with clients regularly to assess quality of life, discuss health concerns, and set healthy lifestyle goals. They share tools for reaching

goals and self-monitoring a client's health to improve quality of life through the aging process.

The ASSETs for AIP intervention team monitors client data captured by environmental and wearable sensor devices. Environmental sensors include infrared motion capture, luminance, and temperature via a minimum of four Fibaro multi-sensors placed throughout each client's home.¹⁵ Each client also has either a Fitbit,¹⁸ Garmin,¹⁷ or Oura Ring¹⁹ wearable device. Environmental data are collected via Raspberry Pi¹⁶ and transmitted to the ASSETs database through a WiFi hotspot and wearable data are captured through proprietary software on a tablet and transmitted to the respective company's database, shared via API to the ASSETs database. Figure 16 shows the setup for ASSETs for AIP.

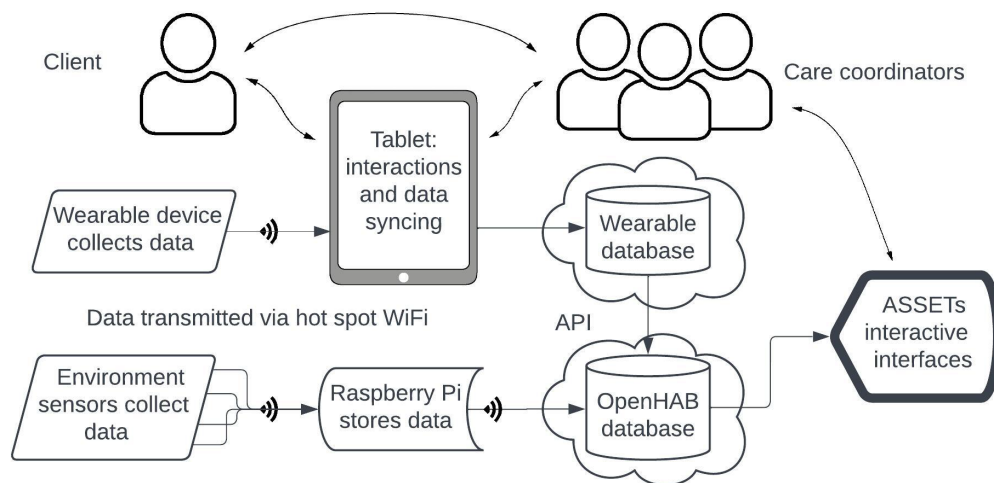


Figure 16. ASSETs for AIP system setup for each client

Care coordinators use the data to identify deviations in normal behavior and changes in trends to detect potential health concerns. The team was closely involved in the user-centered design of a new interface for reviewing sensor data. While iterative review of

prototypes occurred throughout the design process, no formal usability testing and evaluation of a high-fidelity prototype had yet taken place.

In this paper, the research team presents the results of usability testing the ASSETs for AIP web-based interface and data dashboard for care coordination (Figure 17). In addition to informing changes needed to the existing interface, the results of this work highlight a combined approach to usability testing for other developers and designers to consider.

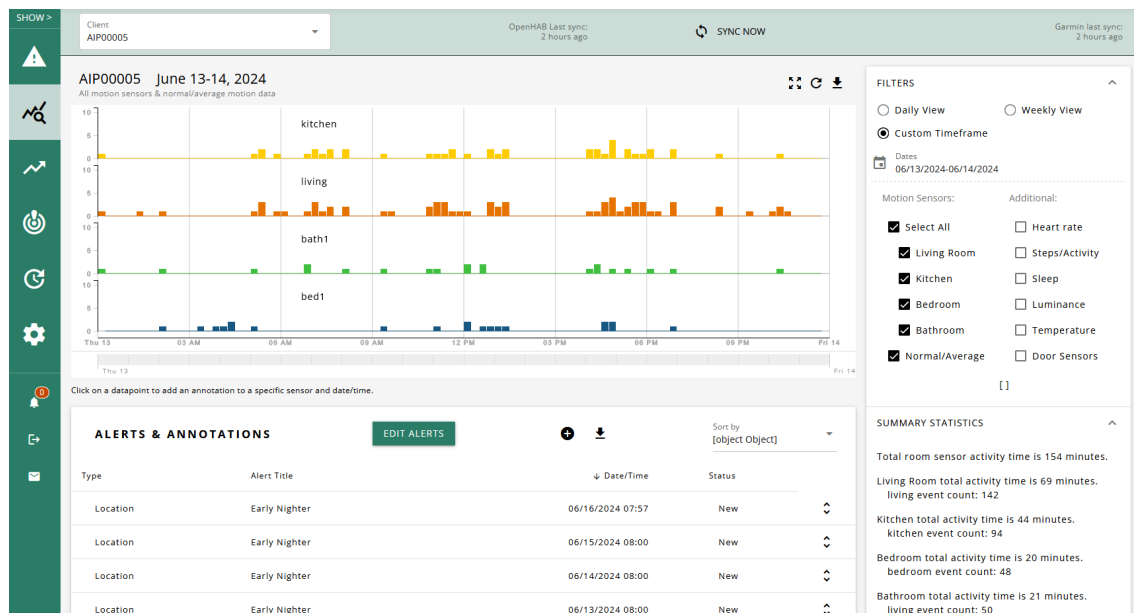


Figure 17. ASSETs for AIP Care Coordination interface and data dashboard

Importance of Usability Testing

Usability testing and evaluation is a critical step to determining the usability and functionality of novel data dashboards and interface prototypes. The user-centered design approach encourages assessment at many stages in a design process.^{2,60,66} When multiple assessments are completed, only a small number of evaluators are required.² There are many established methods for assessing interfaces; they may take a quantitative,

qualitative or mixed methods approach.^{21,62,97} Common methods for evaluation include interview, survey, heuristic evaluation, system use log data analysis, standardized questionnaire, cognitive walk-through, and think-aloud.⁶² Goals of evaluation often include evaluating the usability of the interface, evaluating the usefulness of the interface, understanding the user's perspective about the interface, understanding a user's behavior, or measuring the functionality of the interface. Evaluation methods should correlate with the goals of the evaluation. For example, analyzing system use log data would be more appropriate than a user questionnaire or focus group for determining how long it takes a user to complete a task. This evaluation project incorporates well known and frequently used methods for testing an interface: heuristic evaluation, standardized questionnaire, and usability testing sessions that include cognitive walkthrough with think-aloud and interview.

Traditionally, usability testing sessions are conducted in person. However, the research team, design team, users, and prospective users for this project conduct most of their work through virtual meeting software. There is precedent for conducting virtual evaluations, as some research groups had to adapt to virtual environments during the COVID-19 pandemic.⁹⁸⁻¹⁰⁰ Though other studies indicated participants may be less committed during remote studies, this issue may be circumvented if users are already accustomed to a virtual work environment.^{98,101} A benefit to conducting evaluations virtually includes the ability to share and record a participant's screen.

Ideally usability tests are conducted by an external entity not involved in the design and development of an interface. Due to the need for rapid development and

limited budget for interface development on this project, we opted to completed usability tests when we could with the resources available.

Heuristic Evaluation

Heuristic evaluation, originally developed by Nielsen, assesses an interface for usability problems with a small number of evaluators focused on finding usability problems through self-guided exploration of an interface.^{2,102-105} Heuristic evaluations are completed individually, often by usability researchers; they may optionally include a combination of users familiar with the interface and evaluators who are new to an interface.¹⁰⁶ Three-to-five evaluators can capture most of the usability issues by inspecting the interface alone; their results are aggregated together to capture as many issues as possible, not necessarily all catching the same issues.^{2,82,107} A short form heuristic evaluation was used previously by members of the design research group to assess early stage mobile applications for use within clinical settings.¹⁰⁶ This short form heuristic evaluation does not include error management, help and documentation, and privacy. At this stage of prototyping on this project, these features are not yet developed and not a focus of evaluation at this stage. The same usability heuristics for a mobile app apply to a web-based interface and are therefore appropriate to use in this study without adjustment.

Cognitive Walkthrough

Cognitive walkthrough is most often used for assessing the learnability of a product, or ability to walk up and use it without a manual. The method enables an evaluator or group of evaluators to assume the role of user assigned with prescribed tasks to complete.¹⁰⁸ Cognitive walkthrough testing is often completed by designers or

developers focused on catching usability problems, but it has also been adapted to be more user-centered.¹⁰⁹

Think-aloud

The think-aloud method is another frequently used tool for usability testing. In this method, evaluators are instructed to narrate their actions as they perform an assigned task; they are prompted by moderators who limit their interactions to reminders for a participant to keep talking.^{110,111} A modified version of the think-aloud allows the moderator(s) of the usability tests to have more interaction with evaluators, putting the user at ease, answering participant questions as they complete tasks, and requesting feedback following the think-aloud.¹¹¹

Interview

Interviews are considered an indirect method of evaluating interfaces, useful for clarifying user's opinions. Researchers have long considered indirect methods for evaluating interfaces as secondary to observing actual behavior and have found the results of interviews are more useful if the actual behavior immediately precedes the interview.²

System Usability Scale (SUS)

The SUS is a fully developed standardized tool implemented as a Likert-style 10-item questionnaire and is often used as a quantitative metric of usability.¹¹²⁻¹¹⁴ It is a highly cited and recognized tool for administering to participants. While the questionnaire itself is simple, the scoring is complex and requires conversion to be interpretable.^{115,116}

Methods

This study to evaluate the ASSETs for AIP care coordination prototype used the following methods for evaluation: heuristic evaluation, SUS survey, cognitive walkthrough with think-aloud and interview. The Institutional Review Board (IRB) at the University of Missouri approved this research as an exempt minimal risk project (#2101502).

Participant groups were as follows:

1. Experienced interface evaluators (n=4) completed heuristic evaluation and SUS (Group 1).
2. Health professionals with experience providing remote monitoring of sensor-based activities of daily living (n=7) were in two sub-groups:
 - a. Group 2 included usability testers who have no knowledge of the project or data, and they have never seen the interface (n=4). Group 2 completed a cognitive walkthrough with think-aloud and interview, and SUS.
 - b. Group 3 included usability testers who were part of the design team and are daily users of the interface (n=3). Group 3 completed a think-aloud with interview, and SUS.

Heuristic Evaluations

The short form heuristic evaluation survey data were collected using REDCap (Research Electronic Data Capture) hosted at the University of Missouri.^{84,85} The survey includes 30 Likert-style questions and 30 open text comment fields within eight heuristic categories: 1.) visibility of system status, 2.) match between system and the real world, 3.) user control and freedom, 4.) consistency and standards, 5.) recognition and

memorability, 6.) flexibility and efficiency, 7.) minimalist design, ergonomics and learnability, and 8.) structure of information.¹⁰⁶

Four participants were recruited to complete heuristic evaluations, including two completely new evaluators and two evaluators who were on the design team during the requirements stage of the project, but not the prototyping stage. Prior to completing the evaluation, study participants and the lead author had a 20-minute meeting to introduce the purpose of the interface, provide a guided tour of the interface, support participants in accessing the interface, and answer questions.

Usability Testing Sessions with Cognitive Walkthrough, Think-aloud, and Interview

The lead author reviewed the typical user workflow identified through contextual inquiries in the categorizing information needs stage of interface development, which included three buckets of activity: surveillance, data probing, and documentation and communication, as presented in a previous chapter. The prototype was reviewed in relation to these three activities and scenarios written for each of the activities based on currently functioning features in the prototype. An introduction, opening questions, overview of the interface, and follow-up interview questions were added to complete a protocol for usability testing sessions (Appendix 5).

Prior to recruiting and scheduling sessions with participants, the lead author and senior author completed a pilot test of the protocol with a participant who had no knowledge of the project or data, and was included with the Group 2 testers for analysis. Following the pilot, minor adjustments were made to focus the protocol on the most important aspects of the testing session and streamline the interview.

Ninety-minute usability testing sessions were conducted individually with domain-expert users, following the protocol. Usability testing sessions were conducted virtually with the support of virtual meeting software (Zoom), provided by the University of Missouri.

Two participant groups were recruited, an unfamiliar group (Group 2) and a familiar group (Group 3). We recruited Group 2 participants from a separate, but similar research project. Group 2 participants were provided access to the interface, an introduction and short guided tour of the interface, and three scenarios to complete. Participants shared their screen and were asked to think aloud as they navigated the interface. In the first scenario, Group 2 participants were instructed to do a routine check to determine if there are any client issues, such as sensors offline or behavioral concerns. Our expectation was that the participants would spend time reviewing alerts to surveil all the clients as a group. In the second scenario, participants were asked to review the data and information for a single client in a 24-hour period to determine if there are any clinical concerns. We expected participants to explore the data visualization and make an assessment based on their clinical expertise and what they saw in the data. In the final and third scenario, participants were instructed to make a note for follow-up with a client about a possible deviation from normal behavior. Participants should open an alert and add a note to the alert, marking for follow-up. These three scenarios were based off workflow knowledge gained in contextual inquiries with care coordinators. Participants were asked to think aloud as they completed tasks.

We recruited the Group 3 participants from the existing users of the ASSETs for AIP care coordination team, who were already daily users of the interface and were co-

designers on the project. For Group 3, we used a shortened version of the protocol, where we eliminated the introduction to the interface and replaced the scenarios with a request that care coordinators walk us through their process when working in the interface. Participants shared their screen as they navigated the interface and provided verbal commentary on their thoughts as they demonstrated their workflow.

System Usability Scale (SUS) survey

Brooke's ten-item System Usability Scale (SUS) was created as a REDCap survey.¹¹³ All participants from all groups were asked to complete the SUS survey following their evaluation assignment.

Data Analysis

Data analysis of evaluation results had multiple goals: 1. Identify design and usability issues, 2. Observe participant behavior and identify preferences, 3. Assess learnability of the interface, 4. Identify future needs and prioritize updates.

SUS survey analysis followed the recommended scoring calculation and used the acceptability ranges for assessment.^{112,115,116} Heuristic evaluation scores from Group 1 were displayed as a stacked bar for all four evaluators. Write-in answers for heuristics were reviewed for specific issues and suggested updates. Usability tests for Groups 2 and 3 were auto transcribed by the virtual meeting system (Zoom). The lead author examined transcripts line-by-line and verified with the video recording when activities were unclear to complete first pass summaries.^{48,49} The lead author also completed second-pass coding to streamline language, and sorted results into inductive categories. Codes were further refined in a third-pass review and reorganization was completed to align with the goals of the project.

The senior author reviewed the analysis process, verified the fidelity of results, and completed a content validity check of the codes in a meeting with the lead author. In addition, we used member checking, the process of assessing the credibility of the results with subjects of the qualitative research, to ensure authenticity of the results among usability testers.¹¹⁷⁻¹¹⁹ We provided a summary of findings to Groups 2 and 3, who completed usability tests with the lead author, and requested corrections if the results did not match with their experience. Additionally, results from the qualitative analysis for both heuristic and usability tests were combined into a task list for the developer, which was also reviewed and edited by the care coordinator co-designers (Group 3). The task list included prioritization derived from the analysis, including participant-provided severity ratings. Feedback from participants were incorporated and adjustments made to reflect care coordinator information needs.

Results

Participants

Group 1 heuristic evaluators (n=4) included researchers from the Precision Smart Technologies for Rapid Translation (Precision START) lab. All four were PhD-trained professionals in health and behavioral research. All evaluators had experience testing mobile apps using the short form heuristic.

The Group 2 participants (n=4) included the pilot usability tester, a PhD-trained nurse informatician with five years' experience, two occupational therapists and a nurse with a collective experience of 84 years (two with 35 years' and one with 24 years' experience). Except for the pilot tester, the Group 2 participants had 1-2 years' experience on a similar project as care coordinators reviewing sensor-based data from home

environmental sensors to detect falls, changes in sleep, and other activity in aging adults. Group 2 participants had not seen the ASSETs for AIP interface prior to the study.

Group 3 participants (n=3) were comprised of care coordinators on the ASSETs for AIP project, including a social worker, occupational therapist, and nurse with a collective experience of 57 years (30, 4, and 23 years' experience). Group 3 participants each had 1-2 years' experience on the project including about six months with the dashboard and interface prototype that was tested in this study.

The SUS survey was completed by 10 of the participants (Group 1 n=3, Group 2 n=4, Group 3 n=3).

Heuristic Evaluation Results

Heuristic evaluation ratings are displayed in Figure 18. Results from the heuristic evaluation indicate that a header or title for each page (1) and show the sidebar navigation names as default (7) were the two major problems. The two results that most evaluators considered a problem were: typographically distinguishing labels and fields (12), and accessibility of help and instructions (23).

Figure 18. Stacked bar graph of heuristic evaluation results

Usability Testing Session Results

Results of the usability testing data analysis were categorized by the goals of the analysis (Table 6). In the learnability category, testers from Groups 2 and 3 indicated the interface had a learning curve, as represented by Group 2 tester 3: *“I think I would get the hang of it if I did use it a little bit more. Just right out of the gate, it's a little hard to make my brain think like this.”* Some aspects of learnability were only captured by either the Group 2 or 3 participants. Group 2 testers indicated some of the elements were not intuitive, that they could not read the axis labels of the data display, and they needed definitions for some terms. Group 3 testers continue to rely on memory for interpretation, and they expressed confusion about the accuracy of some of the information, as noted by Group 3 tester 2: *“And I have noticed that this last sync in here is not always entirely accurate.”*

Most codes for user behaviors and preferences were captured between both Groups 2 and 3. Participants were able to achieve the goals of identifying activities and normal behavior, making clinical assessments, and following up with clients. Notably only Group 3 testers discussed diagnosing a potential problem, typically related to sensors offline and often solved by a review in the site management interface. Only the Group 3 testers could tell us that they have changed their behaviors, specifically by reducing paper documentation, because of the new interface. And Group 3 testers do not document findings within the interface, only Group 2 testers were instructed to document findings in the protocol and demonstrated how to do this. Both Groups 2 and 3 expressed gratitude for the data filters, including zoom, expand, and refresh features. Representative quotes include:

“You can get that at-a-glance picture of what's going on for this individual, whether that be across a 24-hour time period, or a longer time period. And I think because most humans are pretty visual in how they tend to process information. That's it's just a nice at-a-glance view.” – Group 2 tester 1

“I can see this person's active here from 8 a.m. to noon between the kitchen, living room and bath. They're in and out of all the rooms, though, unless there's more than one person there.” – Group 2 tester 4

“I've moved to [...] check marks [in my paper notes] to make sure that I've checked everyone, and there's no issue. Now, if there is an issue, I am still documenting.”
– Group 3 tester 1

Both usability tester Groups 2 and 3 identified issues, though the issues themselves varied. For example, within the code for non-functioning elements, we learned about non-functioning buttons through Group 2 testers and inaccurate placeholder text from Group 3 testers. Both usability tester groups found the alerts to be the most confusing and cognitively intensive part of the interface, with the Group 3 testers ignoring the alerts completely. Only Group 3 testers could help us understand the challenges with disparate data locations and proprietary wearable interfaces, due to their familiarity and knowledge on the project. Representative quotes include:

“It was kind of glitching a bunch where oftentimes, when I would start to do custom [timeframe], it would kind of close this part out, and I'd have to refresh.” – Group 3 tester 3

“It's not very clear, like when they're going to bed, or what all's going on.” –
Group 3 tester 2

“Is that a cat jumping in their bed? I think that that data alone, I guess, isn't enough information. It's from as a clinician, it would be me talking to the patient and them going through what does your day look like?” – Group 2 tester 4

“I am starting to get mixed up between who's on Garmin and who's on Fitbit. Because we have had a number of clients who their watch broke, or something happened.” – Group 3 tester 2

Both Group 2 and 3 testers indicated future needs for support resources, additional data, and additional views for trends, normal activity, and ability to discern time spent in rooms. A support resource was frequently requested, be it an FAQ or help page, or a video tour of the interface. Participants needed definitions, explanation about how the sensors work and what can be observed from the sensor data, and how to read the data visualization in this resource. As Group 2 tester 4 said, *“I would want to know more about what it is that I'm looking at like, why am I seeing no data in these? Does that mean they're not in the room?”* Groups 2 and 3 also expressed a need for additional data, as stated by Group 3 tester 2, *“we would expect at least luminance and temperature to work”* and Group 2 tester 3, *“integrating Garmin into it. That's one of the things [we need].”* Groups 2 and 3 participants also indicated a need to be able to discern time spent in rooms, views of normal activity, and an additional trend view, all among future planned features. As expressed by Group 3 tester 2, *“probably trends would be important to me to see,”* and Group 2 tester 2, *“I think it's beneficial to look at the trends.”* In the interview, Group 3 testers prioritized their top needs, including incorporating additional data and building the trend view.

Table 6. Usability testing results, categorized by goals of the analysis, with indicators for which usability tester groups codes were present

| Categories | Codes of interest | Group 2 | Group 3 |
|--------------------------------|--------------------------------------|----------------|----------------|
| Learnability | Challenging learning curve | ✓ | ✓ |
| | Elements not intuitive | ✓ | |
| | Reliance on memory | | ✓ |
| | Definitions | ✓ | |
| | Understanding visual and/or sensors | ✓ | ✓ |
| | Accuracy of features/data | | ✓ |
| | Readability concern | ✓ | |
| User Behaviors and Preferences | Identify activities | ✓ | ✓ |
| | Identify normal behavior | ✓ | ✓ |
| | Diagnose a potential problem | | ✓ |
| | Make clinical assessment | ✓ | ✓ |
| | Document findings | ✓ | |
| | Follow-up with client | ✓ | ✓ |
| | Data filters (zoom, expand, refresh) | ✓ | ✓ |
| | Reduced paper documentation | | ✓ |
| Design and Usability Issues | Non-functioning buttons/features | ✓ | ✓ |
| | Filters not working | ✓ | ✓ |
| | System feedback missing | ✓ | ✓ |
| | Error requiring browser refresh | ✓ | ✓ |
| | Clinical assessment challenges | ✓ | ✓ |
| | Disparate data locations | | ✓ |
| | Alert fatigue | ✓ | ✓ |
| | Proprietary wearable interfaces | | ✓ |
| | Alerts | ✓ | ✓ |
| | Summary statistics | | ✓ |
| Future needs | Support resource | ✓ | ✓ |
| | Additional data | ✓ | ✓ |
| | Trend view | ✓ | ✓ |
| | Normal activity view | ✓ | ✓ |
| | Time spent in a room | ✓ | ✓ |

We requested member checks from all participants on a summary of this analysis. All four Group 2 testers approved and had no edits. Two of the three Group 3 testers approved, indicating it aligns well with their experience. The developer task list was also sent to Group 3 testers for review. Two of the Group 3 testers provided minor edits, including adjusting priorities and providing additional information so the developer could replicate an issue to fix and the third said, *“the task list looks great and I agree with the prioritization of the items!”* The final task list can be seen in Appendix 6.

SUS Results

The SUS mean score for the interface was 72.5 from all evaluators, a “good” or high marginal acceptable score. Group 3 testers scored the interface more harshly than the average of all scores, and included independent scores of 52.5, 67.5, and 70. Independent SUS scores from Group 2 were 62.5, 65, 80, and 90. SUS scores from Group 1 were 62.5, 82.5, and 92.5.

Discussion

By including multiple methods of evaluation and varied small testing groups, we were able to identify a broad range of usability fixes needed, see what is working well, understand the learnability of the system, and detect the most pressing fixes needed. The value in this mixed method approach is in the depth of the results. As seen in Figure 19, the combination of methods helped us meet our goals.

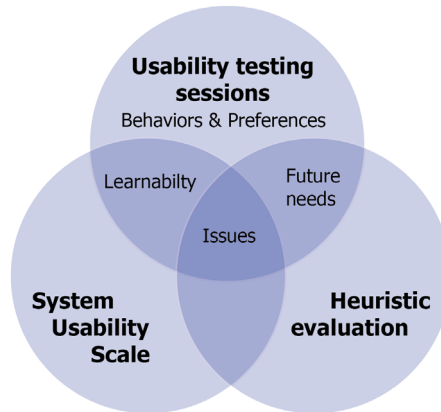


Figure 19. Venn diagram of evaluation methods and results

Design and Usability Issues

All methods revealed some design and usability issues to be fixed. Issues related to adherence to design standards were primarily discovered through heuristic evaluation, issues of whole-system complexity were indicated in SUS scores, and nuanced issues of usability from a domain expert perspective were discovered in usability testing sessions. Visible features that were not functioning at the time of testing was a particularly pressing issue including buttons that did not work, placeholder text that provided incorrect or confusing information, and pages that held no actionable features. Combining the analysis between heuristic evaluations and usability testing sessions, we saw that the lack of page header was a design issue of concern, however in the testing sessions, participants signaled that they would get used to the sidebar navigation as their page indicator, liking that they could show or hide the navigation titles. Similarly, heuristic evaluators and usability testers identified some icons in the navigation bar were unclear and indicated that the order of pages on the navigation bar should be reconsidered. Finally, system feedback is a critical feature of any interface.¹ In this interface, there were a few instances where a participant was confused due to a lack of system feedback, where

an indication that the site had updated based on a participant's actions was needed. Along with the removal of the most confusing part of the interface – the alerts – removal of non-functioning features or placeholders and adding system feedback are among the higher priority tasks on the developer task list.

User Behavior and Preferences

We were able to see user behaviors and preferences through usability testing sessions. We found that participants liked the data visualization and the features that helped them filter and view the data of interest in the visualization. A few participants remarked that they really appreciated the colors on the visual and that the refresh, expand, custom timeframe selection, and zoom features were particularly helpful. Group 3 participants indicated that they are better able to quickly gauge if there is a concerning behavioral issue than from their previous workflow and have significantly reduced the amount of paper documentation in their workflow. Operationally, this supports the team's need to expand the client to coordinator ratio.

Learnability

We discovered that some participants felt they could learn the system on their own and be confident using the system without more technical support, while others couldn't. We discovered that only Group 2 testers could tell us that definitions were needed and that some elements were not intuitive. Group 2 and 3 testers shared some learnability concerns, particularly regarding the alerts. Neither Group 2 or 3 were able to learn what to do with alerts and saw it as too challenging to be worth the time to learn. Group 2 testers who are accustomed to a different system thought the data visualization showing only activity in the bedroom during nighttime was more challenging to interpret than the

bed sensor data they are accustomed to viewing. To them, thinking about the data as only showing activity, not location of the client at any given time, was a mental shift from their normal review of client data. Also, Group 2 testers were reviewing the data without the inside knowledge that Group 3 testers have, subject to their own memory of each client's home layout and normal behaviors. Regardless, both usability testing Groups 2 and 3 demonstrated they could interpret the data visualization to identify where clients were most active and identify their normal behavior. The most important insight regarding learnability was the need for support resources.

Future Needs

Heuristic evaluators and usability testing sessions helped us identify future needs, and a review of the overlap between them shows that help instructions are a critical future need. We can also infer from the details of the SUS that instructional support materials are needed, but from the usability testing sessions, we were able to see what should be included in those help tools. From the interview portion of the sessions, we know that participants want more than helper text, and many methods for delivering this information were discussed. Identifying what format(s) would make those support tools most useful is an area where more work is needed. For example, we had one Group 2 tester who said they needed support, but they were unlikely to go to a help page as they prefer to poke around and figure it out on their own. Another indicated they would watch a video and take notes that they could refer to. And yet another said a readme file they could have printed out in front of them like a manual would be acceptable. Only one participant read the existing help text out loud in their think-aloud.

Other future needs were aligned with planned features. From the testing sessions, both Group 2 and 3 testers thought a trend view would be very beneficial to determine changes in behavior. Additionally, they thought additional data would be crucial to understanding behavior. Group 3 testers rated the addition of wearable data as high priority for future changes. And both Groups 2 and 3 talked about wanting to see time spent in room, not just activity, to assess whether clinical concerns exist. While this last priority does not currently appear in the developer task list, it is among next steps for the research team to consider within a planned study to identify transitions between rooms based on the motion sensor data.

Limitations

Individually, each method has limitations. The conclusions that can be drawn from the SUS alone are very limited. We felt the SUS was best captured longitudinally and sets a baseline for acceptability. Following the roll out of updates, we could capture SUS values again and hope to see improvements. The Group 1 evaluators were not asked to think-aloud while they reviewed the interface, thus we are limited to their ratings and comments in the survey. Nielsen suggests heuristic evaluations could be completed alone with screen recordings, or with an observer, to provide more information than a survey questionnaire alone.¹⁰⁷ Within the usability testing sessions, we found Group 3 had no problem talking as they navigated, but they talked about what they saw, not what they were doing. The pilot tester from Group 2 talked about what they were seeing and doing, however, the other three Group 2 testers really struggled to talk about what they were seeing, doing, and trying to get the interface to do. There is already evidence that thinking aloud is very unnatural and hard for participants to do.¹¹¹

The lead author was also the lead designer for the interface and has formal training in both graphic design and data analysis. As a result, some researcher bias may have affected the results of usability tests. Participants were blinded to the identity of the lead designer of the interfaces to avoid influencing participant responses, with regard to negative or positive comments. Additionally, as moderator, the lead author engaged in bracketing – intentional efforts to set aside assumptions and personal beliefs about design – and did not share opinions on design choices. In usability sessions, she prompted participants to explain what they were seeing, what they could determine from data visualizations, and asked how they came to conclusions prior to providing any education about reading a graph or navigating the interface.

Next Steps

Additional work is needed to create support resources, such as a help or FAQ page, interactive site overview, or video of an example workflow. Once created, we would need to test the resources. This work could be done with A/B testing to see which method(s) of delivery would be best received by care coordinators. Usability testing would provide insight on the success of these resources.

Work needs to be done to improve the alerts and make them valuable to care coordinators. Future iterations of alerts must include a direct method for care coordinators to see the data that contributed to the alert, logic for understanding why the alert was triggered, and a persistent ability to mark the alert as important for follow-up and easily access it later. Similarly, a study to assess room transitions and thereby identify a client's location at any given time, should commence.

In the future, as the features expand, an assessment of on-site web analytics that measures user behavior within the interface could help guide future iterative adjustments. For example, clarifying how much time a user spends in one part of the interface can reveal work processes and bottlenecks to efficiency. As our goal is to help care coordinators spend more energy making decisions from surveillance and augmented intelligence findings, we would hope to see time spent on pages where surveillance is possible. We would also hope to see an increase in annotations, where care coordinators add contextual information to reduce memory load and separate documentation. Shifts in workflow and how time is spent would support efforts to continually improve the interface where it will have the best effect.

Conclusion

In this study, we evaluated a data dashboard interface using direct methods of evaluation (e.g., heuristic evaluation, cognitive walkthrough, and think-aloud) and indirect evaluation (e.g., SUS and interviews). We assessed the interface with both prescriptive tasks (e.g., cognitive walk-through and think-aloud) and self-guided exploration (e.g., heuristic evaluation). The conglomeration of usability testing results revealed some important changes to be made, especially the removal of non-functioning features and placeholder elements, possibilities for streamlining the design of future features, and guides the developer's and the research team's next steps. In the meantime, the interface has helped care coordinators streamline their review of client data and serves to support their efforts to improve quality of life for adults aging in place.

Chapter 5: Conclusion

A focus on user-centered design and the incorporation of principles of design were introduced in chapter one of this dissertation. The three primary objectives for designing interfaces were outlined as: 1.) characterize information needs, 2.) iteratively design and assess prototypes, and 3.) evaluate high-fidelity prototype.

Characterizing information needs for a care coordinator dashboard was the focus of chapter two. Contextual inquiries and focus groups provided valuable insights about user workflow, what care coordinators need in a new interface, and allowed us to observe their use of the site management interface to determine what design changes to make in future iterations of that interface.

The iterative design and prototyping process for the care coordinator interface was described in chapter three. This process was split into stages: conceptualizing the care coordinator interface with written descriptions of scenarios, design and prototyping of the functional layout for the interface, and the design and prototyping of the data displays. Primary feedback came in critique meetings, comments on prototypes, and surveys. Care coordinator co-designers made the final decisions on designs prior to sending to the developer to create a high-fidelity prototype.

Chapter four focused on the evaluation and usability testing of the high-fidelity prototype. Several methods were employed with multiple usability testing groups to gain a broad scope of the effectiveness and usability of the interface. Results indicated that the implementation for existing workflow was mostly successful, but more work needs to be done to better accommodate computer augmented tools for rapid evaluation. Additionally, the creation of a developer task list makes this step an actionable one.

The goal in this project was not to design a perfect and complete tool, it was to create prototype designs that support a vision of incorporating sensors and clinical expertise into the everyday management and self-care of older adults. This project intentionally does not end here, rather the final prototype serves as a launchpad for continued adaptation.

Future work

A project to identify room transitions so that care coordinators can identify the location of a client in their home has already begun. This project would support a user-identified need to better understand time spent in rooms and assessment of healthy behavior. Additionally, work is underway to perform causal discovery analysis to understand behavior from passive sensors and provide more information to care coordinators in their support of clients. We hope this work replaces the alerts that troubled so many in our usability tests. Further usability testing will be required as additional changes are made to the system.

Contribution to informatics

The interactive displays of data and information are essential to understanding data rapidly. As our participants exclaimed while we were characterizing information needs, they needed information integrated into single displays, they have limited time for deciphering what is in the data, and they need the tools to support them in understanding client routines and behavior change. One cannot simply make a visualization of data and assume it works for the care coordinators' needs. If that were the case, early prototype visuals that appeared like DNA assays would be in the interface due to the ability to pinpoint exact times of activity. However, aggregate visualizations that traded precision

for rapid understanding of activity prevailed, as they met the needs of care coordinators more appropriately. Through this research, our understanding of the interpretability of a mosaic of personal sensor-based data by health professionals has expanded. Additionally, the interface itself is a tool that opens opportunities for exploring a new way of providing behavioral intervention and care support to individuals at the crossroads of augmented decision-making and clinical expertise.

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Appendix 1

REDCap Prototype Evaluation Survey for Prototypes 1 and 2

Since functionality is very limited, there are only a few things you can do on each screen. The sidebar navigation (except for the hide) should work to allow you to navigate between screens. To review the layout, please look around on each screen though not everything is functioning.

Prototype tasks:

Alerts:

1. Starting on the Alerts main page, review the layout and perceived functionality of the page. Non-functioning elements: actual filtering by clients choices, filtering by new alerts vs. archived alerts, open window for most of the alerts, log out and help.
2. On the Alerts main page, you want to filter by your clients. How would you do this?
3. The My Client filter is currently a non-functioning element, but a lightbox appears to give you more information about what to do next. Since you cannot actually filter in the prototype, dismiss the lightbox.
4. On the Alerts main page, you realize you are not seeing an alert you expected, so you want to add an alert, assess how you would do that.
5. On the View and Edit Alerts subpage, review the layout and perceived functionality of the page. All dropdown menus should function, but you cannot make selections. Checkboxes can be turned on and off, though it will not actually change the alert on the prototype. Close the page.
6. Back on the Alerts main page, you are interested in the Early riser alert and wish to expand the window so you can make edits to the alert.
7. In the expanded alert window, the functionality will not change anything in the prototype, but you can turn checkboxes on and off, and you can close the expanded window or review more information about the alert. How would you review more information?

Data:

8. On the Data main page, explore what's available. Dropdown menus are viewable, but there is limited functionality other than the tasks:
9. On the Data main page, you decide you want to be able to see the home layout. How would you do that?

10. On the Data page, you notice an alert for no bathroom visit in 24 hours. You want to mark that to follow-up in a meeting with the client. How would you do that?
Note: functionality does not change anything.
11. On the Data page, you want to add an annotation. How would you do that? Assess your choices within the annotation add popup window but note functionality does not actually work.
12. Now that you have assessed the daily or weekly data for this individual, you want to view their long-term trends and assess whether the alert for no bathroom visits is ongoing. What do you do?

Trends:

13. On the Trends page, explore what's available. Dropdown menus are viewable, but there is no other true functionality.
14. You are now ready to view the data you have input (annotations). How would you get there?

Annotations:

15. On the Annotations page, explore what's available. Dropdown menus are viewable, but there is no other true functionality.
16. You are now ready to view both alerts and annotations you have snoozed for follow-up. How would you get there?

Follow-Up:

17. On the Follow-up page, explore what's available. Dropdown menus are viewable, but there is no other true functionality.

Settings:

18. Explore the Settings page. There is no true functionality here.

Appendix 2

Scenario-Based Design of the ASSETs Care Coordinator Interface

Summary of needs:

Users need to be able: to surveil all clients; setup, receive and review alerts; and review diagnostics (observe a divergence, explore the data to make informed decisions on next steps for care delivery).

Important features:

- View multiple sensor data in a single visual (for one home) with a mix of overlay and faceting
- Turn on/off sensors in visual display
- Average sensor time on (time in each room), with the ability for users/coordinators to customize how this is figured (not all days are the same)
- Summary information (daily amount of time active in each room, active minutes, sleep minutes, bedtime and rise time, average heart rate, comparison to an average)
- Standard timeframes (daily, weekly) with option to change the start date, and custom timeframe selection
- Refresh button (this should be automatic, but user should also be able to force update the information display following timeframe change and/or sensors on/off)
- Zoom in and out on a timepoint
- Add data annotations (documentation provided by a user that includes a title and description, automatically generated and added to the visual is the user who added/edited the annotation and the datetime of addition/edit) to a datapoint and a client
- Quickly search and find annotations for easy access to review the data visualization for the annotation timepoint
- View layout of home (uploaded file)
- Summary of normal behavior (this could be something the coordinator writes based on current knowledge, computer generated, or some combination such as responses to a few questions: normal wake up time, normal bedtime, normal sleep interruptions, days expect regular visitors, times regularly out of the home, pets, normal sleep location, etc)
- Set and receive alerts personalized to each client
- Take action on alerts: easily access data that triggered alert for diagnostic review, mark the alert as reviewed, tag for follow-up, share the view and a note with another coordinator (mental model: reminders/alerts on your phone which choices like dismiss and snooze, but with more detailed options)

- Alphabetized organization of clients and standard organization of sensors (most used to least used: 1. Motion, 2. Luminance, 3. Temperature)
- Limit clicks and scrolling to get to information rapidly
- Display “last sync” with main visual display
- Individual coordinator customizations: time format, default view of overview graphic (daily, weekly)

Scenarios of use:

1. Check for emerging client issues (surveillance)
Such as: client offline/online status, no activity detected, or other alert
 - a. The care coordinator begins their day by surveilling offline/online status and other alerts of multiple clients. They choose to review “all clients,” “my clients,” or select “custom” clients to review. If they choose custom clients, they are prompted to select clients to review. (Alternative or additional customization: filter alerts by type, such as: offline/online status, room activity deviation, vital signs, nighttime behavior deviation.) The interface displays a list of alerts with an option to expand and view more information / take action for each alert.
2. Review an emerging client issue / alert: last sync more than an hour ago
 - a. Following the identification of an alert: last sync more than an hour ago, expansion of the alert shows the normal behavior: attempt to sync one hour ago, the deviation: last successful sync 12 hours ago. The coordinator is provided choices for identifying follow-up from the alert, choices including: reviewed/not a concern (dismiss); errant data (dismiss); follow-up with client (snooze); persistent concern (snooze); share with a colleague for review (share/reassign); annotate with more information (dismiss). Alert automatically moved out of the main alerts screen, but still accessible from menu choices on the page.
3. Review an emerging client issue / alert: early riser/sleep behavior deviation
 - a. Following the identification of an alert for sleep behavior deviation, expansion of the alert shows the normal behavior: wake 8-10 am, the behavior deviation: wake 6:45 am. Coordinator is provided the option to review the data. Additionally, the coordinator identifies follow-up from the alert, choices including: reviewed/not a concern (archive); errant data (archive); follow-up with client (snooze); persistent concern (archive/snooze); share with a colleague for review (share/reassign); annotate with more information (example: client has UTI and is using the bathroom more frequently) (archive). Alert automatically moved out of the main alerts screen, but still accessible from menu choices on the page, and still accessible within the data visualization for the timeframe.
4. Define behavior alert specific to a client
Examples: more than or less than a number of bathroom visits, wake before or after time, total daily volume of activity in a room, continuous elevated heart rate, etc

- a. In a conversation with a client, coordinator identifies routine as: client wakes between 7 and 8 am, has an aide from 9 am to 3 pm Monday, Wednesday and Friday, often leaves the house for long periods on Sunday, begins bedtime routine around 9 pm, watches TV in bed until falling asleep. Coordinator wants to be alerted if client wakes earlier than 7 or later than 9. They click on “add alert” and are prompted to include: client, day(s): all, title for alert, normal behavior description, selection sensor(s): kitchen motion, before: 7 am, and chooses the type of alert: sleep deviation (which is assigned a color). Coordinator saves the alert. It is now editable from a list of all alerts and is applied to all future data.
5. Review an individual client’s data overview/dashboard summary
 - a. Coordinator seeks to review one client’s data. They proceed to a summary page (the main dashboard for an individual client) and selects the client to review. A primary visual shows the most recent 24-hour day of data (yesterday), showing all motion sensors in the home together, but distinguishable. Included is the activity data from the wearable device. The coordinator sees the option to switch to week view or choose a custom timeframe. They also are presented with options to add an overlay of heart rate, sleep, temperature, and/or luminance. They can choose to turn off rooms, which removes the motion sensor, temperature and luminance for that room. Coordinator notices a data point of interest, hovers over it and zooms in for more detail. To the side or below, they have the option of showing a home layout drawing, normal behavior patterns, trends, any alerts for the day, a written summary of notes, and any annotations specific to timepoints viewed in the primary visual. They can also resize windows to adjust their view.
 6. Add a summary and other pertinent information to view along with data overview
 - a. On the summary page, with a client selected, coordinator clicks to view the summary for the client. Finding it empty, they are given the option to add or edit summary. Coordinator clicks this option and provides a written summary of routine behaviors collected in a conversation with the client. They click save. The summary window indicates a date for the latest update and who provided it.
 7. Add a home layout to view along with data overview
 - a. On the summary page, with the client selected, coordinator clicks to view the home layout. Finding it empty, they are given the option to upload an image file. They browse for the file, upload it and crop or rotate, then save. The home layout window now shows the visual, gives an option to replace or edit, indicates a date for the latest update and who provided it.
 8. Review alerts from daily summary view (diagnostic review)
 - a. On the summary view, coordinator chooses to show the alerts for the time period selected, alongside the main visual. They review the alerts and can easily see which have been dismissed or snoozed and which still need

review. They click on an alert needing review, add a tag to revisit in quarterly review, and snooze the alert.

9. Add an annotation to a data timepoint

- a. When reviewing a client's summary, coordinator has zoomed in on the display to find an explainable deviation: a middle-of-the-night motion on in the kitchen tripped by the client's pet. Coordinator clicks on the datapoint and adds an annotation. They are given a list of previous annotation titles to choose from or make a new one. List is sorted by most often used tags to least often. They select the "pet" title, is given the option to select "confirmed," "follow-up," or "suspected," and saves. Annotation shows on the view with an icon that can be expanded to see the details (including the user and datetime the annotation was added) and is visible in any view that includes that data point (including daily, weekly and custom views). Coordinator can also review all annotations and data inputs for each client on a separate page.

10. Search annotations and snoozed alerts

- a. Preparing for a quarterly check-in with a client, the coordinator goes to the follow-up page to search annotations and alerts by client and is able to review the annotations or alerts from the results list. An overlay window shows the data display connected to the alert/annotation. Coordinator reviews the events with client and marks the alert/annotation with "confirmed." Alert/annotation now shows an update datetime and user who updated.

11. Add event

Examples: hospital visit, vacation or extended period outside the home

- a. Client emails coordinator about a hospitalization event. Coordinator navigates to the start date of event in the summary page, selects "add event," and notates start and end datetime of event and brief summary of the event. Event now appears on the daily summary page for each day of the event and is searchable for later review. Update date and user are also included with the summary.

12. Review trends in behavior

Example: wake up or bedtime changes, amount of activity over time, time spent outside the home, etc

- a. Coordinator notices a recent increase in alerts about a behavior change, such as early or late wake times. They begin to wonder if this is a trend and lifestyle adjustment. On the summary page, they observe that general activity has been on the rise during the day and wonder if this could be a factor. To observe the trends together, they consult the trends page of the interface, where they can see some behavior patterns over longer periods of time. During discussion with the client, they review the client's goals and whether the trends in behavior are related to these goals.

13. Communicate/consult with a colleague about an emerging client issue/ health concern
 - a. Coordinator notices abnormally high heart rate over an extended period of time and determines a need to consult with a nurse coordinator on the team. They annotate the time in the dashboard and click “share” and includes another user to review the note and same view of the data. The other user receives the notification by email with a preview of information (the annotation title and who it came from) and on the interface, marks the annotation as “follow-up with client” and discusses the concern with the team to determine next steps.
14. Adjust default settings
 - a. Coordinator navigates to their settings to customize their view of the interface. They find the option here to assign clients to “my clients” for quicker review. They change the option for military time to AM/PM local standard time. They change their default view to a week view rather than daily view, or any date range view choose which sensors they want to see on the default view, and set which sort/filter they prefer for alerts and annotations. They click save and this refreshes their default settings across the interface.

Appendix 3

Design and Functionality of the ASSETs Care Coordination Interface

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Summary

The ASSETs care coordination interface was designed as a collaboration between the Precision START visualization subgroup and primary users (occupational therapists, nurses and social workers) as part of the lead designer's PhD research. Following a multipronged approach to gathering user requirements, the current low-fidelity prototype is the result of multiple design iterations and consecutive reviews to orient and direct the design choices. The interactivity is a little buggy and the transitions between button toggling and action completion should be ignored – they are not intentional. While we anticipate future design changes and functionality adjustments will occur, our goal was to create the primary visual and functional parameters for the development of a high-fidelity prototype for user testing. The current prototype does not yet include data visualizations, though the design team has made progress in creating early data visualization prototypes and the resulting output of that work is forthcoming. We would like the interface to scale for varying browser sizes, though the design is sized 1920x1080. Currently users would only be interacting with the interface on a desktop monitor or tablet. Future considerations could be made for use on a phone or other mobile device, but the design does not address that at this time. A prototype with limited functionality can be viewed here: <https://xd.adobe.com/view/1d34f0b6-ec84-44cb-951a-59ca81e6fef2-4867/>

Fonts

The current prototype uses Helvetica Neue font family, ranging in size from 14 to 40 and varying weights including regular, italic, medium and bold. Primary navigation buttons are sized 26 in Helvetica Neue Medium. Most titles are sized 24 in Helvetica Neue Medium. Much of the main text is either 16 or 18 point Helvetica Neue Regular. Helper or information text is sized 14 Helvetica Neue Regular. If Helvetica is not accessible or appropriate, Open Sans or some other sans-serif web font with varying weights would be preferred.

Colors

An important consideration for the design team included maximizing colors and shades for users who may have low vision or colorblindness. Most of the text is in either white (#FFFFFF), black (#000000), or grey (#707070), depending on the background for maximum contrast. The background for the interface is a very light grey (#EDED). Grey text indicates a user cannot do anything with the text. The sidebar is green (#2A7C66) and the header bar is a lighter version of the green (#CCDDD8) with a grey

outline (#707070). A light blue (#69B1F8) is used for a button icon for information. Additional colors (navy, red, orange, lime green, blue, and lilac) are used as indicators for alerts – more on that later in the document. Other colors will likely be added for data visualizations.

Figure 1: Colors

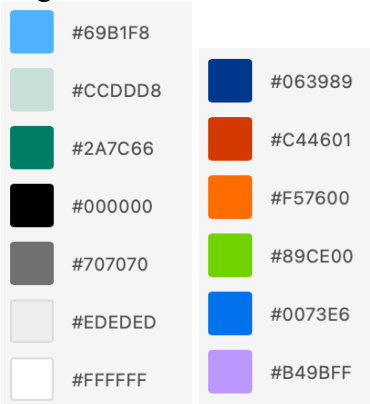
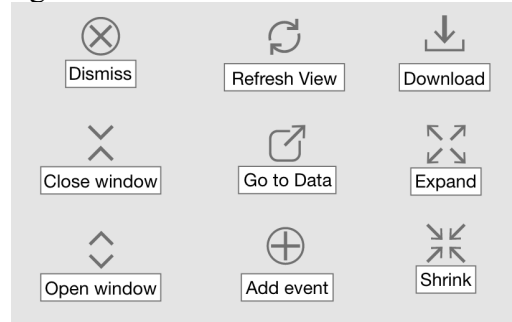


Figure 2: Icon buttons with hover labels



Icons

We used icons that were similar to icons we found on other interfaces to reduce clutter in many instances. Since they don't have text as part of the button and clicking them makes a change on the page, they do not need a toggle state. However, a hover state with labels that indicate what the button does is preferred for increased usability. This helper text needs to be high contrast and be within a box so that the background doesn't interfere with readability. This is a functional need, not a design need. Figure 2 shows the icons that are standalone as well as their hover text and what that would look like.

Primary Navigation

Primary navigation is in a fixed position lefthand sidebar (Figure 3). This sidebar includes the title of the interface (not a button) as well as buttons to main pages: Alerts, Data, Trends, Annotations, Follow-up, and Settings. Below the main pages are buttons for Notifications (which activates an overlay box similar to notifications you might see on Facebook or other sites that list user-specific items that need attention), Logout (another overlay box that will ask if the user is sure they want to logout), and Help (as yet to be determined place for information on using the interface and interacting with the data). There is no “home” page currently. Functionally, the main pages are uniquely useful at stages of a user’s work process. Each page will be discussed in detail later in this document. Across the site, the primary navigation should be able to shrink to allow for more screen real estate and expand if the user needs additional help remembering what the icons mean. When it is in the expanded view (Figure 3), a “hide” button is visible at the top, and when in the reduced view (Figure 4), a “show” button is visible at the top. These buttons do not have a hover or toggle state. Throughout this document, because we did not create the reduced view as a functional element in the interface, all visuals will only show the expanded sidebar. However, reducing the size of the sidebar would make it more possible to see everything in more crowded pages.

As a user hovers over a button on the sidebar navigation, a hover state appears half-way between the default and toggle states with a black icon and 50% opacity white square over the green. The toggle state changes the white text to black and increases the opacity of the white box to 80% (alternately, this could be another lighter version of the green, but it needs to have at least a 15% shade difference for low-vision users). When a user has clicked to navigate to that page, the button appears in the toggle position. In the corresponding visuals, the Alerts button is in the toggle state, the Data button is in the hover state, and all other buttons are in the default state.

Figure 3: Primary navigation sidebar expanded

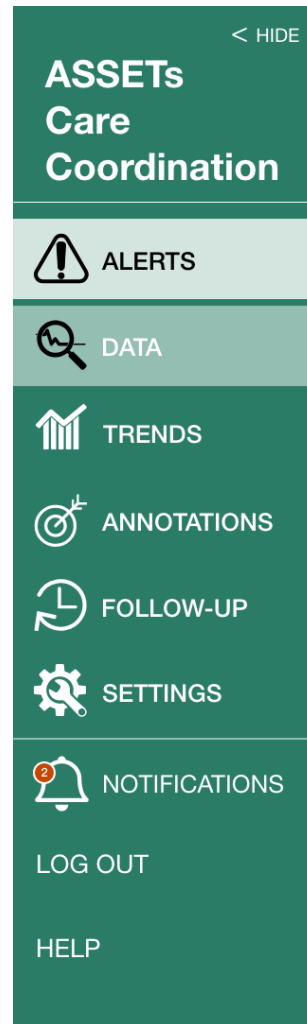


Figure 4: Sidebar reduced



For the notifications button, the red circle with a number inside should only appear if there are notifications, with the number indicating how many notifications are awaiting the user.

Alerts Pages

When a user is viewing any of the alerts pages, the Alerts button on the sidebar navigation should be in the toggle mode so that the user is clear where they are in the interface (see Figure 5). There are two alerts pages. Both have a header bar that indicates which alerts page the user is currently viewing. “View Alerts” should be the primary/default view.

Figure 5: View Alerts page

| TYPE | ALERT TITLE | DATE / TIME | CLIENT | STATUS |
|-------------------------|-------------------------------|-----------------|----------|--------|
| Sync (System generated) | Last sync 12 days ago | 5/21/2023 12:05 | AIP00001 | New |
| Sync (System generated) | Last sync 2 hours ago | 5/21/2023 10:05 | AIP00005 | New |
| Sleep | Early riser | 5/21/2023 03:45 | AIP00025 | New |
| Room Activity | No bathroom visit in 24 hours | 5/18/2023 13:41 | AIP00015 | New |
| Wearable Activity | No steps | 5/17/2023 08:01 | AIP00013 | New |
| Heart Rate | Continuous heart rate spike | 5/01/2023 12:06 | AIP00005 | New |

Alerts Header Bar

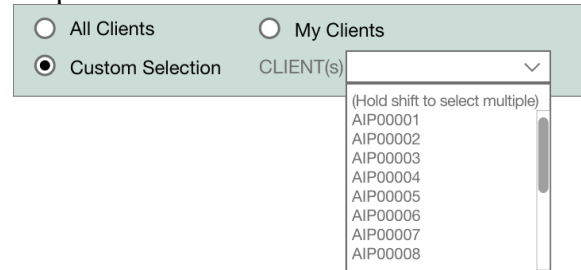
For both alerts pages, the header bar should always have client choices, sort and filter choices. If “View Alerts” is the currently active page, checkboxes for “New Alerts” and “Prior Alerts” are visible (see header in Figure 5). If “Edit Alerts” is the page currently active, the checkboxes are replaced by an option to “Add Alert (Rule)” (Figure 6). The header bar remains in a fixed position for any scrolling. The header bar should be reactive to browser resizing and not result in a left-right scroll. Options should only decrease in size to a minimum of 12-14 point font and stack if they do not fit.

Figure 6: Edit Alerts header

The Client selection choices only allow the user to select one of the three: All Clients (which shows all clients that the user has in their settings to view – more on that in the settings section of this document), My Clients (which will show the clients a user has set as their clients in Settings), and Custom Selection which shows a client(s) dropdown (Figure 7). A user can select multiple clients by holding the shift key and selections made here automatically change the radio buttons so that “Custom Selection” is filled in and the other two are not.

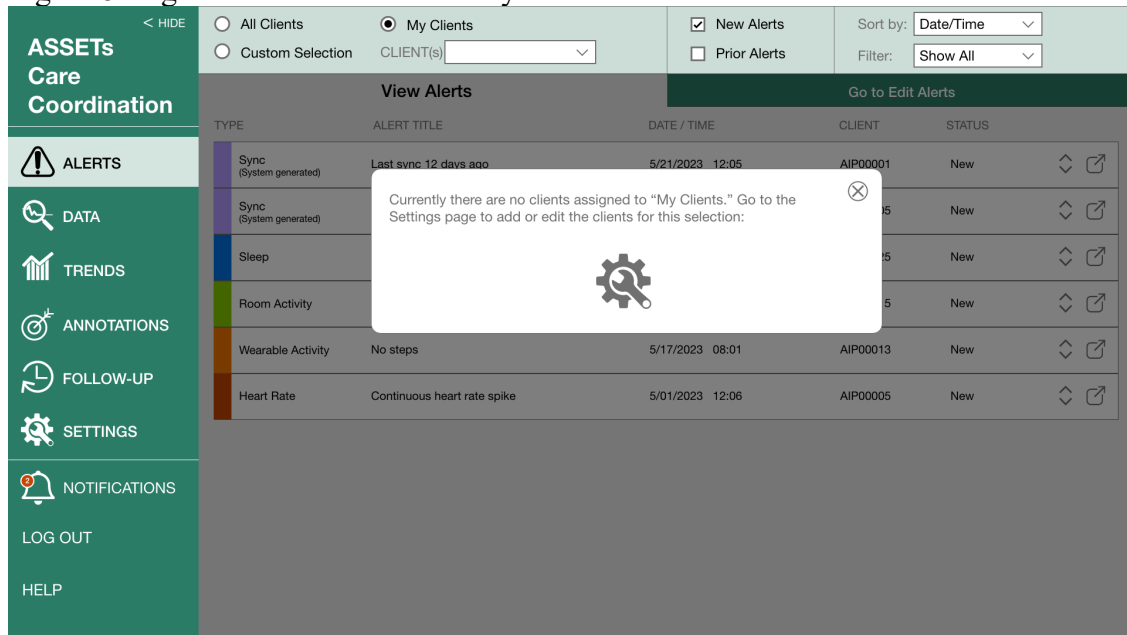
This dropdown should have a scroll and all clients should show in alphanumeric order. As a user makes choices, the page results should update automatically and indicate the choice was made (radio button changes from empty, to filled as indicated in the visual). If there are no

Figure 7: Custom Selection CLIENT(s) dropdown



clients assigned to “My Clients” in settings, a lightbox notification with one-click access to Settings appears with a darkened background (Figure 8). Users can dismiss the lightbox notification by clicking on the x in the corner. If they hover over the x, helper

Figure 8: Lightbox notification for “My Clients”



text will identify the button as “dismiss”. Alternately, they can click on the settings icon to go to the settings page.

The sort by function default is date/time, but provides the user options to sort by type, client, alert title, or status (Figure 9). The filter dropdown default is show all (Figure 10), but also shows the types of alerts and the colors assigned. Options include Sleep (#0073E6), Room Activity (#89CE00), Heart Rate (#C44601), Wearable Activity

(#F57600), Door Sensor (#063989), and Sync (#B49BFF). Changes to either of these filters are immediately applied to the list view of all the alert instances or alert rules (based on which page they are applied). All selections should persist as a user changes which page they are viewing, until they make a different selection on either of the alerts pages.

Figure 9: Sort by dropdown

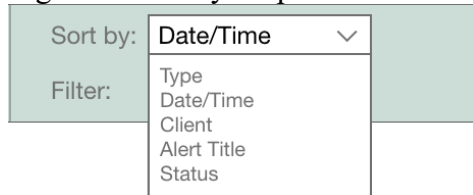
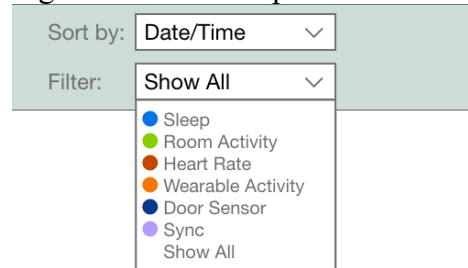


Figure 10: Filter dropdown



The user also has the option to choose to view “New Alerts” and/or “Prior Alerts” on the “View Alerts” page, where they are viewing instances of alerts (when the alert was triggered by the system based on rules in the alerts). By default this is set to “New” to reduce clutter in the view. However, we have given them the option to also view “Prior Alerts,” or instances of alerts where an action has already been taken and saved by the user. A conceptual model to apply here is the idea of managing a personal email inbox. As new emails (alert instances) come in, the user has a view of only the unread emails. Once they’ve read the email, they automatically are removed from their main inbox view and put into an archive. Similar to an email inbox, a user often has sort and filter options, as we have here.

On the “Edit Alerts” page, the New and Prior Alerts checkboxes are replaced by a button to “Add Alert (Rule)”. This button has a hover state that matches the primary navigation buttons and a toggle state (more on what this looks like below).

Immediately below the light green header bar are the buttons that allow the user to switch back and forth between the two alerts pages. When viewing a page, the toggle of the button should not react to hover and should appear like it is a title to the page. The opposing button should be green with white text, like the sidebar navigation, with additional text that helps the user know that clicking will “Go to Edit Alerts” or “Go to View Alerts”. The hover state should match the hover state on the primary navigation buttons. However, the title should not have the “Go to” text; it should also appear larger and bolder than the default and hover button states.


View Alerts

The view alerts page is for the user to review instances where alert rules were triggered. We anticipate a limit of about 25 alerts viewable on the page and a top to bottom scroll on the right hand side that will only scroll the alert instance cards (similar to Clockify) and an option to go to the next page to view the next 25 alerts. We would not retroactively

create alert instances for new alert rules that are created. Alerts are meant for day-to-day or at least weekly review by care coordinators.

At the top of the view alerts page (Figure 5), are subheadings for the types of data attached to each alert instance. Below the fixed headers (fixed meaning they do not scroll), are cards for each alert instance. Each card displays the type of alert (assigned when the alert is created), an indicator if it is system generated as opposed to user generated, an alert title, the date/time the alert rule was triggered, the client, the status, and two additional buttons for “open window” (with helper text on hover state that indicates what the button does as shown in Figure 11), and “go to data” (also with helper text on hover state).

Figure 11: Alert instance with header on “View Alerts”, user is hovering over the open window button

| TYPE | ALERT TITLE | DATE / TIME | CLIENT | STATUS | |
|----------------------------|-----------------------|-----------------|----------|--------|---|
| Sync (System generated) | Last sync 12 days ago | 5/21/2023 12:05 | AIP00001 | New |  Open window |

If a user clicks on “open window,” the card expands in size and all cards below shift down to make room. The user now sees the description that was written when the user created the alert rules. They also see checkbox choices to take action(s). They can select as many actions as they want. Selecting actions “Follow-up” and/or “Share” will result in the alert instance added to their “Follow-up” view. Follow-up selection will also give the user the option to select a date for follow-up. Share selection will also require the user to choose a user from a dropdown menu. The date selection here will result in a notification appearing for this user on that date. The share selection will result in an immediate notification appearing for the user chosen in the dropdown menu. Selecting any of the other actions only (Not a concern, Data error, Persistent concern, Concern assessed, and/or Note) will not include the alert in their Follow-up view. The user must click “Save & Close” to apply the action(s) to the instance, which will also change the status to “Prior” and remove it from the view if “Prior Alerts” is not selected in the header (Figure 12).

Figure 12: View Alerts with one alert instance opened, the follow-up action item checked so the user can select a date, and the share action item checked so that user dropdown appears

The screenshot displays the 'View Alerts' interface. On the left is a navigation sidebar with options: ALERTS, DATA, TRENDS, ANNOTATIONS, FOLLOW-UP, SETTINGS, NOTIFICATIONS, LOG OUT, and HELP. The main area is titled 'View Alerts' and includes filters for 'All Clients' (selected), 'My Clients', and 'Custom Selection'. It also has checkboxes for 'New Alerts' (checked) and 'Prior Alerts', and dropdowns for 'Sort by: Date/Time' and 'Filter: Show All'. A 'Go to Edit Alerts' button is visible. Below the filters is a table of alerts:

| TYPE | ALERT TITLE | DATE / TIME | CLIENT | STATUS |
|-------------------------|-------------------------------|-----------------|----------|--------|
| Sync (System generated) | Last sync 12 days ago | 5/21/2023 12:05 | AIP00001 | New |
| Sync (System generated) | Last sync 2 hours ago | 5/21/2023 10:05 | AIP00005 | New |
| Sleep | Early riser | 5/21/2023 03:45 | AIP00025 | New |
| Room Activity | No bathroom visit in 24 hours | 5/18/2023 13:41 | AIP00015 | New |
| Wearable Activity | No steps | 5/17/2023 08:01 | AIP00013 | New |
| Heart Rate | Continuous heart rate spike | 5/01/2023 12:06 | AIP00005 | New |

The 'Early riser' alert is expanded, showing a description: 'Typically wakes up between 6-10 am. Alert is for any motion in the bedroom between midnight and 6 am.' The 'ACTION(s)' section includes:

- Not a concern
- Data error
- Persistent concern
- Concern assessed
- Follow-up (with DATE dropdown)
- Share (with USER dropdown)
- Note (with text input field)

 A 'Save & Close' button is present in the top right of the details window.

Other options available to the user within the open alert instance window include the ability to “close window” (the button has replaced the open button next to the “go to data” button, and again should include helper text on hover) without saving actions. The user also might notice the light blue circle with an “i” inside and a note next to it. The user can hide the note by clicking on the light blue icon. They can also make an adjustment in their settings to hide all info notes/helper text once they are used to the interface and no longer need them.

Importantly, from any of these alert cards, the user can go to the data page using the top right button on each card. When the data page opens from one of these cards, the data page should open with the filters applied to view the data connected to the alert. For example, if the user clicks on go to data for this sleep alert instance, on the “Data” page, the data would load for client AIP00025 on the date 5/21/23 and sensor data from the alert rule would be shown (so, if the alert came from motion activity in the bedroom, that sensor data would be selected in the filters). More information on the data page is later in the document, but it’s important to note here that we want the selections to carry over to the page so the user is not relying on their memory to maintain what they need to be looking for and find the alert again.

Edit Alerts

The “Edit Alerts” sub-page of the Alerts section (Figure 13) is the only place the user can add or edit alert rules customized for individual clients. Since the alerts need to be customizable based on client, the user will find all the same client selection options and other sort/filter options in the header, as discussed earlier.

Figure 13: Edit Alerts default view

Since the default view shows all of the alerts expanded, we give users the option to close all cards or close them one-by-one using the same button used in other card views. Scrolling will only occur top to bottom, with the sidebar and header (including the Edit Alerts title and Go to View Alerts button) fixed.

Within the cards, since we were not clear on the best way the development of rules should be determined, we included a note about that in green and italics (this is not meant to be part of the interface and is acting as a placeholder). We do know the user will need to be able to identify the type of alert, give the alert a title that is relevant to them, and add a more detailed description, so we included those in the design. Additionally, we anticipate the user needing the ability to choose the day(s) of the week, timeframe of the day for the rule, and which sensors are included in the rule. The user can also make the rule active or not active. It may be determined that users can only adapt/customize some existing rules or fully create their own. Users must click on “Edit” to make any changes to the alert – client and type become dropdowns, title and description become open text

boxes where the user can type – and then save once they have made changes (Figure 14).

Figure 14: Editing an Alert

To add a new alert (rule), the user must click on the “Add Alert (Rule)” button in the header. This button has a default, hover, and toggle state that match the primary navigation. When it is activated (Figure 15), a lightbox appears and the main page is darkened, much like the lightbox for “My clients”. The same options appear as in the edit alert view, except the dropdown defaults for client and type should be empty, as should the text input boxes for title and description. Again, the user has the choice to dismiss without saving or save the alert rule once they have made their edits. User-input descriptions should appear in italics for clarity that they are user-input.

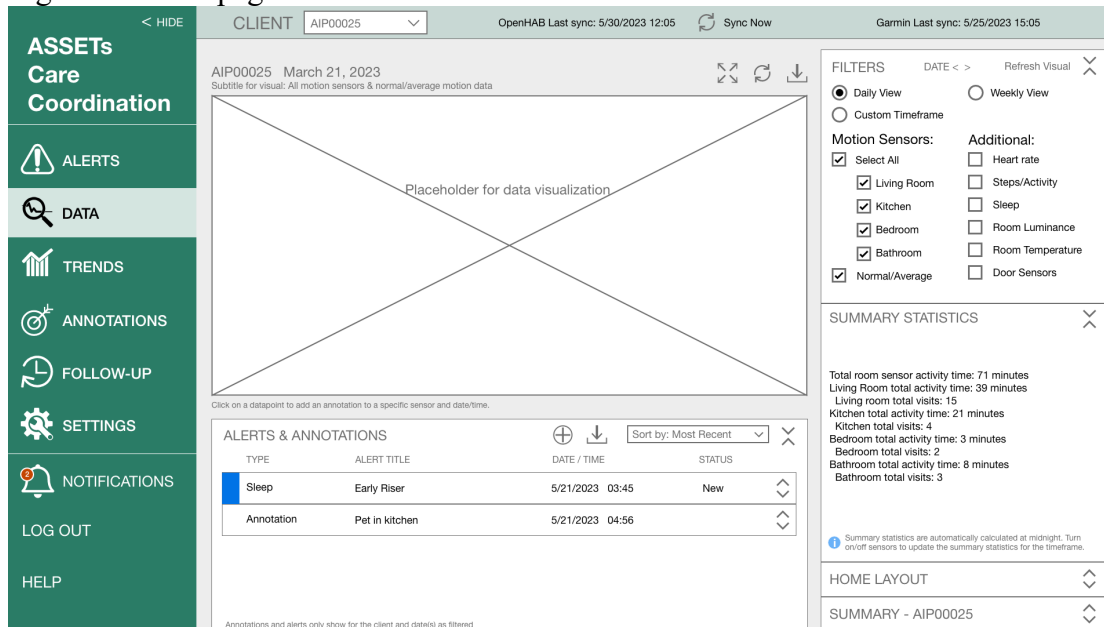
Figure 15: Add Alert (Rule) lightbox

Data Page

The data page (Figure 16) is for a close view (daily or weekly) of an individual’s behavior and activity. It is most like the data analysis page of the current ASSETs site management interface and replaces the tool for the coordinators’ current work process of reviewing client data on a near daily schedule. It includes the primary navigation, a header, the data visualization pane, and cards/windows for tools. Overarching goals for

this page include minimizing clicks to change the visualization, providing summary statistics based on selections made in the filters, a list of all alerts and annotations for the date(s) within the view, and two places for additional user-added content: home layout and summary.

Figure 16: Data page default view



The full view is fixed, due to a goal to always keep the data visualization within the frame of view. The cards/windows for Alerts & Annotations, Filters, Summary Statistics, Home Layout, and Summary allow for the user to close or open. If all cards are open, this results in scroll bars appearing within the cards.

The header is where the user can select or change which client they are reviewing from a dropdown of all clients in alphanumeric order (the only clients that would not appear in this list would be any client the user has set to “hide” in settings). Additionally, the header shows when the last sync for openHAB and a button to “sync now,” and a last sync for the wearable device (when applicable). The label for this device should indicate whether it’s a Garmin or Fitbit.

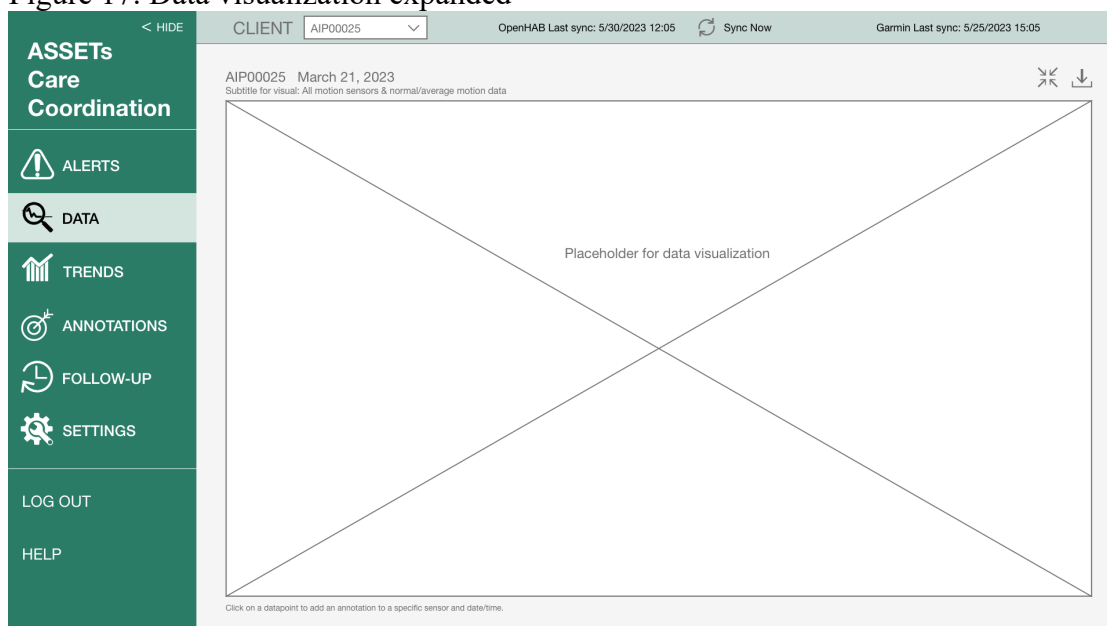
Since a coordinator typically reviews one client’s data at a time, the interface should persist in keeping a client selected as the coordinator navigates between the Data and Trends pages and should persist from the Alerts page. For example, if a user comes to this page by the “go to data” button on one of the alerts, the data page would load and the header would already have the client selected based on the alert. The filters would ideally already be selected for viewing data pertaining to the alert, including sensors and the date, with checks in the checkboxes next to each sensor; the title and subtitle above the visual would tell the user what client, date (or date range) and sensors that are selected; and the data visualization would load based on filters. When the user is ready to review data in terms of longer-term trends, and they click on the Trends page in the primary

navigation, the client selection would remain. The system would ideally hang on to this selection even if a user goes to another page to do something else.

Data visualization

The design team is currently working on designing visualizations for this pane. Functionally, the visualization title and subtitle should be reactive and automatically change based on what is being displayed (based on filters). At the top right corner are buttons to expand the visual (Figure 17), refresh the visual and download the visual. The download should also include the title and subtitle, as well as axis labels and legend, if applicable. The expanded view includes buttons for shrinking the view or downloading the visual, and retains the ability to add an annotation to a specific sensor and date/time.

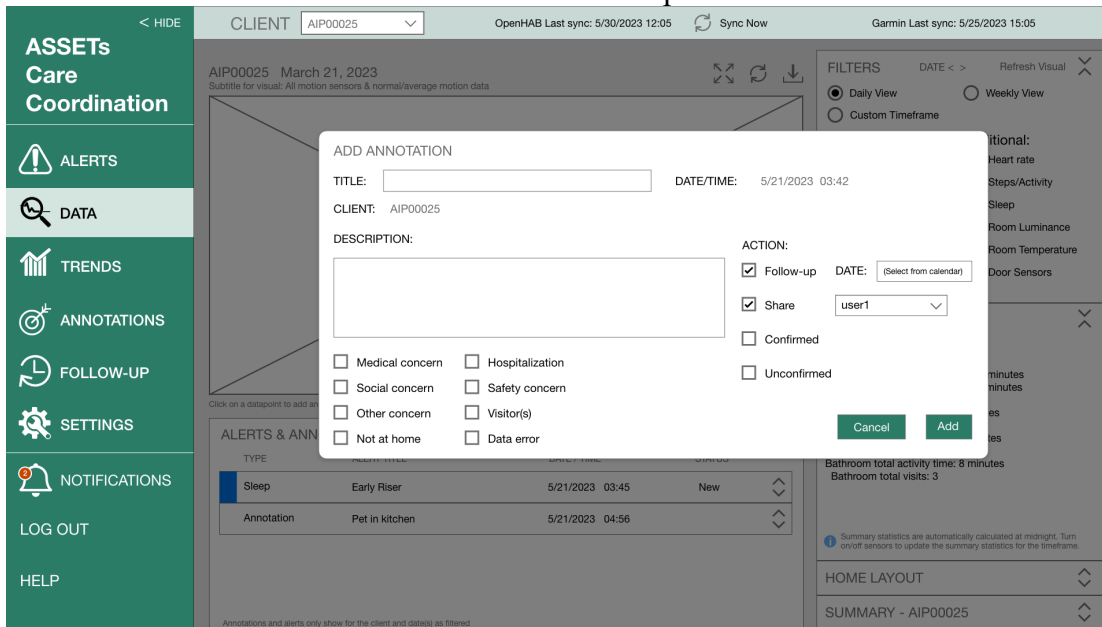
Figure 17: Data visualization expanded



Below the visualization is a note that the user can click on a datapoint to add an annotation to a specific sensor and date/time. Once a user clicks within the data visualization, on the closest datapoint, a lightbox window appears (Figure 18) with the background for the user to add a title, description (optional), assign action(s): Follow-up, Share, Confirmed, or Unconfirmed. Additional checkbox choices include: Medical concern, Social concern, Other concern, Not at home, Hospitalization, Safety concern, Visitor(s), and Data error. These are envisioned like tags in a database. Saving them in addition to the open fields makes it easier to remove data points from evaluation, sort them, search them, or use them as features in machine learning. A user can select multiple checkboxes or none. Notice: since this is an annotation applied to a specific data point of a sensor at a specific date and time, the user is unable to change the date/time. A similar “Add Event” is an option for the user, from the Alerts & Annotations card and also accessible within the Annotations page. If the darkened box behind the lightbox would be more appropriate covering the entire background, including the header, that would be fine. If a standard lightbox view also includes a dismiss button in the top right, that would

also be fine.

Figure 18: Add annotation lightbox with action “Follow-up” checked and toggle state includes space to add the date a user needs a reminder for follow up, and action “Share” checked with toggle state of a user dropdown to add a shortcut to this view for another user to their Notifications and Follow-up areas.



Alerts & Annotations card

Just below the data visualization is an alerts and annotations card (Figure 19). The contents within this card are filtered by only the timeframe and client set in the filters (not filtered by the sensors viewed).

Figure 19: Alerts & Annotations card with alert opened



At the top of the card, users can see the card title, a button to add an event, a download button, a sort/filter dropdown, and the ability to hide the card (which would expand the data visualization). The add event button will result in a lightbox (Figure 20) that appears over the whole background like the add annotation lightbox. The download button would result in a CSV of the alerts and annotations information. The default for the dropdown is

“Sort by: Most Recent” but includes options for: Show All, Filter: annotations only, Filter: alerts only, Filter: Follow-up, Filter: Prior Alert, Filter: New Alert, Sort by: Most Recent, and Sort by: Oldest (Figure 21).

Like on the alerts page, listed instances of alerts and annotations can be expanded and edited, as seen in Figure 19.

When the list gets too long to show all on the same screen, a scrollbar appears on the right side of the card, but ideally only scrolls the list (so that the headers stay at the top).

Filters card

The top card on the far right is where a user adjusts what is seen on the visual and filtered in the summary statistics and alerts/annotations cards (Figure 21). Like the other cards, it can be closed, which would expand the space within the cards below it. At the top, a user can click on “Date” and choose a date from the calendar for the start (if week is the view) or the 24 hour day, the user has an easy ability to go to the next or previous date, and a button to refresh the visual. Users can set their default view to daily or weekly, and then change to the opposite when they need to. A custom timeframe is also an option, where they would choose the start and end dates. The sensor choices need to show only the sensors available to the client’s home and includes data from the wearable device. For example, if a user has an additional room, that would show up here, or if a user does not have door sensors, the checkboxes would appear for what is available and not visible if there isn’t a sensor. The user can set their default sensors viewed here in their Settings page. The labels should be clear and simplified. Only the motion, luminance and temperature sensors are needed from the multi-sensors. When a user selects “Room Luminance” and/or “Room Temperature” the results would show from only the motion sensors selected, so if a user doesn’t have any rooms selected under motion sensors, all the rooms would - by default - be added for luminance and/or temperature. If only some of the rooms are checked under motion sensors along (for example, only living room) with luminance and/or temperature, only the luminance and/or temperature sensors from selected room(s) (the living room in this example) would be visible. This card should be open by default, but the user can close it if needed.

Figure 20: Add Event lightbox (no background shown)

ADD EVENT

TITLE:

DATE:

CLIENT:

DESCRIPTION:

Medical concern Hospitalization

Social concern Safety concern

Other concern Visitor(s)

Not at home Data error

ACTION:

Follow-up

Share

Confirmed

Unconfirmed

Figure 21: Filters card

FILTERS DATE < > Refresh Visual ✕

Daily View Weekly View

Custom Timeframe

Motion Sensors: Additional:

Select All Heart rate

Living Room Steps/Activity

Kitchen Sleep

Bedroom Room Luminance

Bathroom Room Temperature

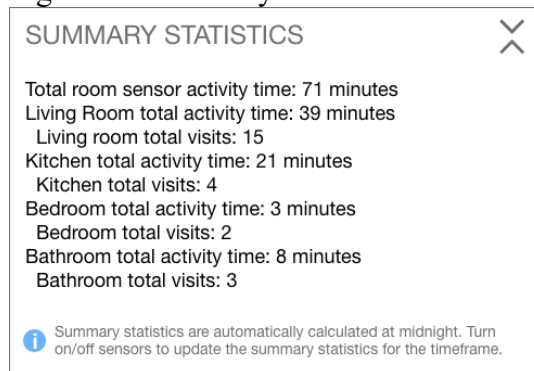
Normal/Average Door Sensors

When other cards on the right side are open, particularly the home layout card and summary card, this card should shrink significantly and have a scrollbar on the right side that keeps the top grey text information always visible.

Summary Statistics card

Summary statistics are needed to provide additional information that the visual cannot (Figure 22). Presumably, the summaries would be calculated by the system at midnight. Though a user could select to filter on the current day, summary statistics would be unavailable until the next day. Which summary statistics are shown would be based on the filters selected. Summaries would be based on the timeframe selected as well. Users need to be able to view total activity time from the motion sensors, a count of visits to each room, as well as data from the wearable device: max heart rate and average resting heart rate, total steps, total sleep time. If the system or a sensor is offline, the timeframe or amount of time offline would be helpful here too. The only action a user can take here is to close the card and to turn off the helper text. This card should be open by default and shrink with a scroll bar as needed, particularly if the summary and/or home layout cards are opened.

Figure 22: Summary Statistics card



Home Layout card

The home layout card is closed by default. It holds only a single visual that a user uploads. The first time a user opens this card, they will see a button to upload a visual (Figure 23). When a user clicks on upload, a lightbox appears (Figure 24) with the ability to browse their computer for a file (jpeg, png, tiff, or pdf). Once the user selects upload, the visual appears in a window with two tools to crop and rotate. Once the file is adjusted, the user can save the visual into the card. Opening the home layout card with a visual uploaded will show only one additional button at the bottom where they can edit. This would enable them to crop, rotate or even upload a new version. The system should also identify when the visual was last updated and by whom.

Figure 23: Home Layout card

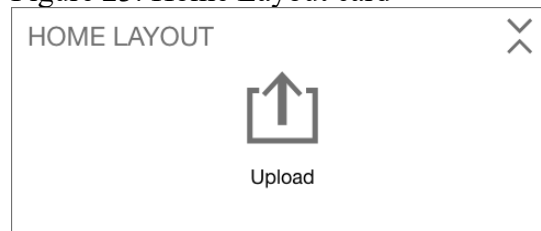
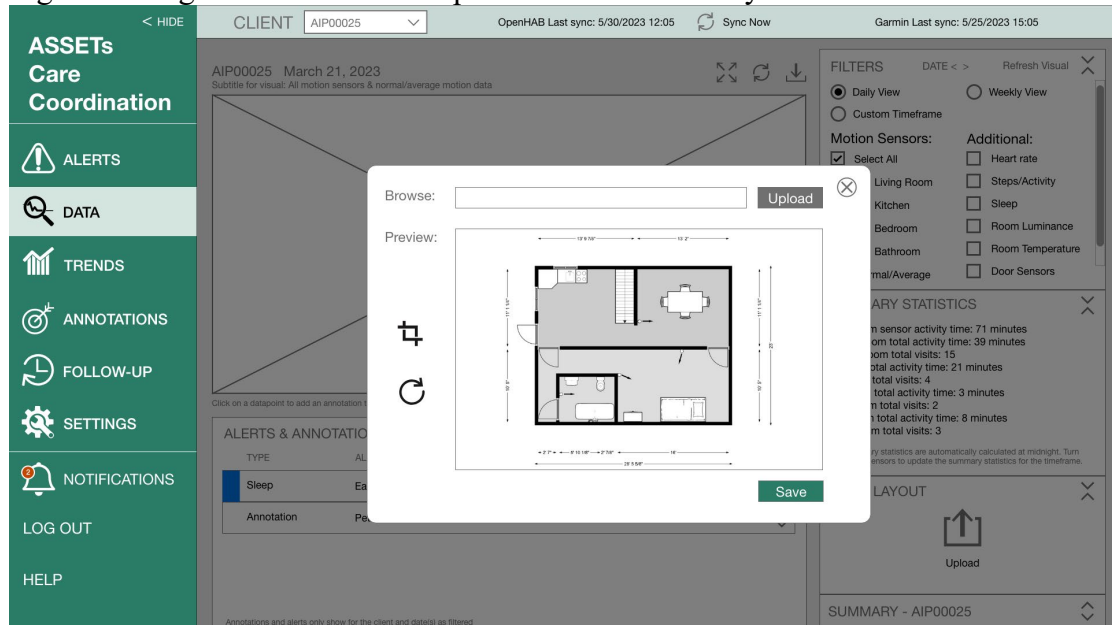


Figure 24: Lightbox for a user to upload and edit home layout visual.



Summary card (user-input summary)

The final card on the data page is the summary card (Figure 25). Upon opening the card, the user is presented with the ability to add a summary if none exists in a lightbox (Figure 26). Once the user saves, the card is updated and includes when it was last updated and by whom. Figure 27 shows all cards open.

Figure 25: Summary card

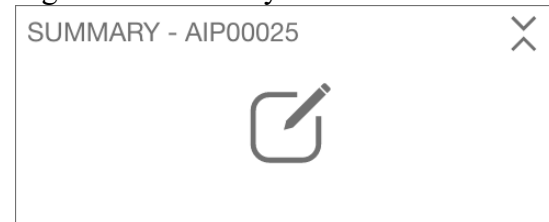


Figure 26: Summary add/edit lightbox

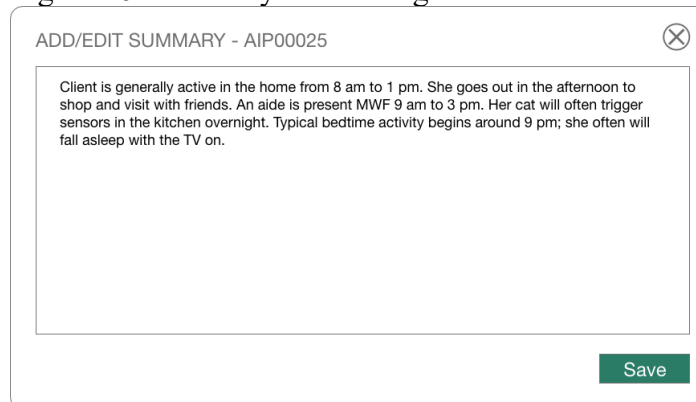
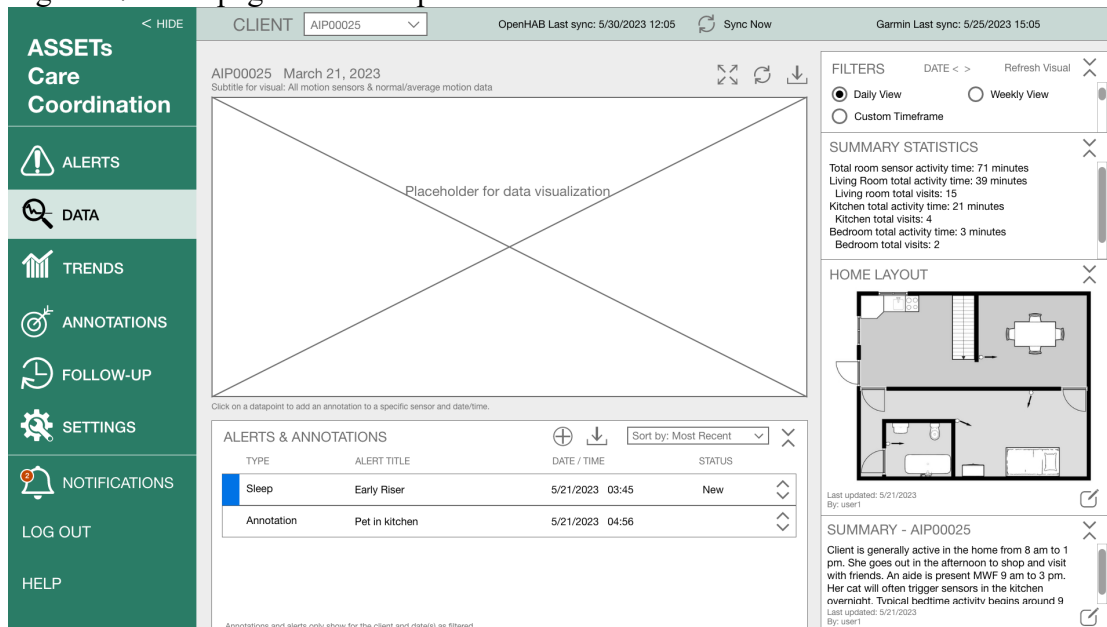


Figure 27: Data page all cards open



Trends Page

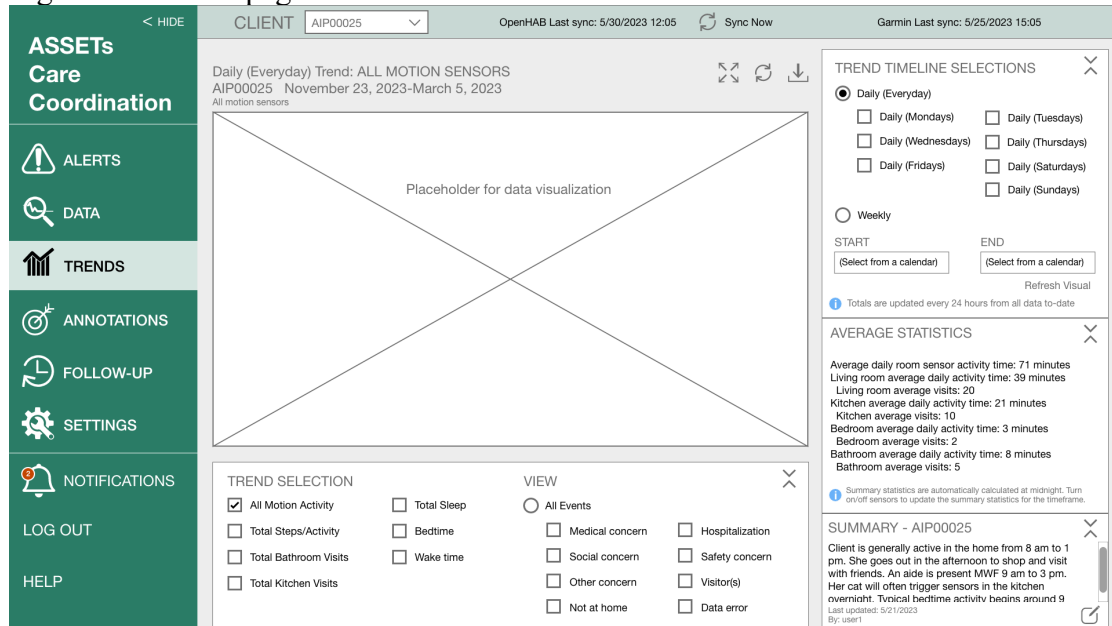
The trends page is designed to allow the user to review the summary data (to assess behavior change) over longer periods of time (Figure 28). The header is the same as on the data page and the choices in that header should persist as a user navigates the interface. Like the data page, scroll bars should not appear for the whole frame either right or bottom. Scrolls should only appear within the cards. The visualization space itself is also similar to the data page, with no option to add annotations or events. The title and subtitle should update to reflect filters. There are options to expand, refresh and download the visual.

The filters for the visual are split between two cards. The trend selection card sits below the visualization and provides the user with choices of data streams to include. Adding events would not change the summary statistics but would provide more insight for the care coordinator to assess the pattern of behavior. The timeline selections card sits in the top right. Timeline selections need some customization, allowing the user to identify which days are included in the trend visualization and average statistics, as well as a time frame in which to use to assess trends. The customization is likely to be more necessary for the average statistics. The usefulness of this is based on the understanding that many of the clients have different habits on different days. For example, a client may have an aide present on Monday, Wednesday, Friday. Another client may commonly have a visitor with them on the weekends or is perhaps away most weekends. Since these are totals calculated daily, only full 24-hour cycles should be included.

Average statistics would show a mean value based on the data streams and timeline selected, not all time nor all data. We can see at the bottom right a summary card. This is

the same information in the summary card on the Data page. All the cards can be closed to make more room.

Figure 28: Trends page



Annotations Page

An annotations page is most similar to the alerts page, with some differences (Figure 29). Like the alerts page, we anticipate a limit of about 25 annotations viewable on the page and a top to bottom scroll on the right hand side that will only scroll the annotation instance cards (similar to clockify) and an option to go to the next page to view the next 25 annotations.

Figure 29: Annotations page

The screenshot displays the 'Annotations' page within the 'ASSETS Care Coordination' interface. The header bar features client selection options (All Clients, My Clients, Custom Selection), a search bar, a 'Sort by' dropdown set to 'Newest first', and a 'Filter' dropdown set to 'Show All'. The left sidebar lists navigation options: ASSETS Care Coordination, ALERTS, DATA, TRENDS, ANNOTATIONS (highlighted), FOLLOW-UP, SETTINGS, NOTIFICATIONS, LOG OUT, and HELP. The main content area shows three annotation cards for client AIP00025. Each card includes a title, client ID, date, description, and a list of action items with checkboxes. The first card, 'Pet in kitchen' (5/21/2023 04:56), has actions: Follow-up, Share, Confirmed, and Unconfirmed. The second card, 'Visitors in the home' (5/06/2023), has actions: Follow-up, Share, Confirmed, and Unconfirmed. The third card, 'Pet in kitchen' (5/02/2023 02:13), has the action: Follow-up. Each card also includes an 'Edit' button.

The header bar includes the same client choices as the Alerts page. The header bar includes a search bar for word and phrase searching all the annotations for the client(s) selected. A sort by dropdown would give the user choices for sorting by client, newest first, or oldest first. A filter dropdown gives the user choices to filter by all of the tags and action items (medical concern, hospitalization, other concern, visitor(s), social concern, safety concern, not at home, data error, follow-up, share, confirmed, unconfirmed, and show all). On the far right of the header, the “Add Event” and “Download” buttons are available. The add event button displays the lightbox for the add event feature (Figure 30). The download button allows the user to download a csv of all the annotations listed based on the filters.

Below the header are choices to expand or close all cards. The default view shows all cards expanded (as shown in Figure 29). Figure 31 shows all cards closed.

When a user clicks the “Edit” button in an annotation card, the fields that are editable become altered and the edit button is replaced with the save button (Figure 32).

Figure 30: Add event lightbox

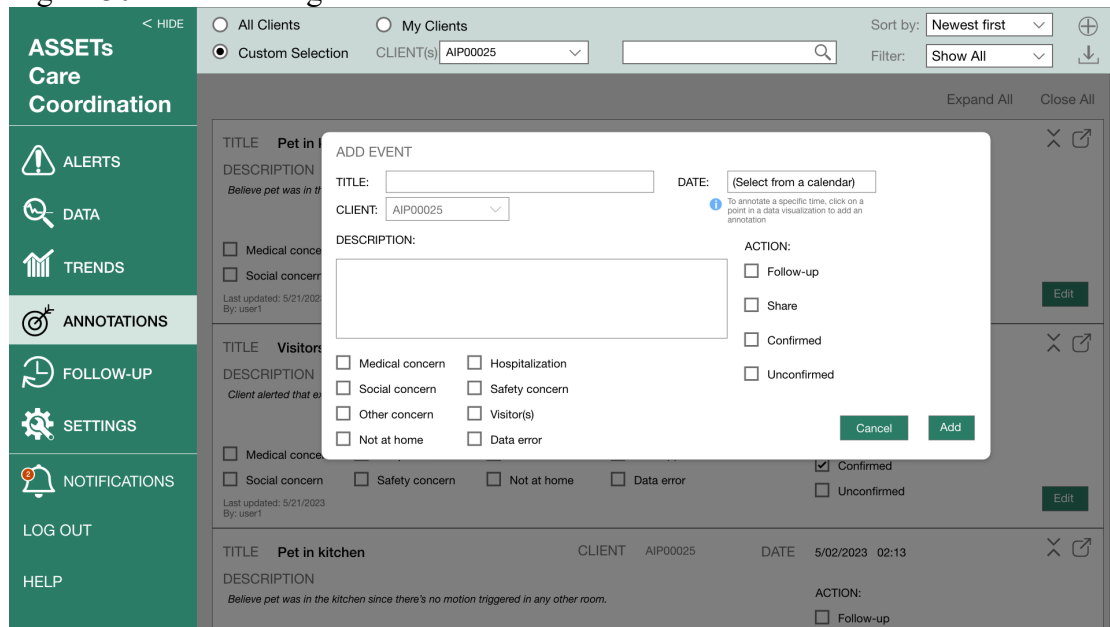


Figure 31: Annotations all closed

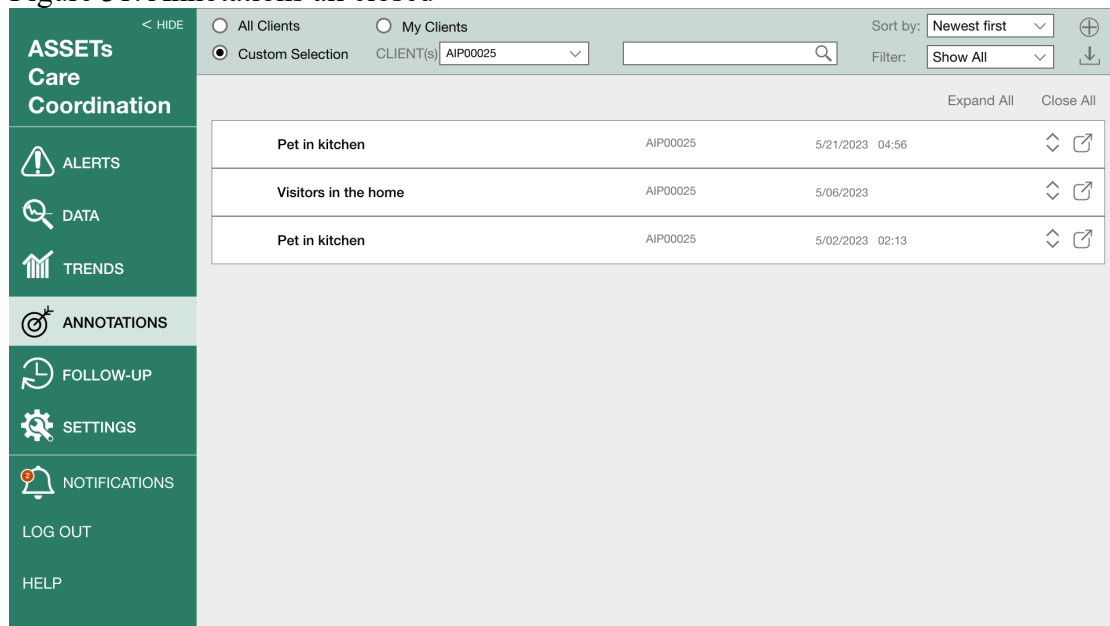


Figure 32: Editing an annotation on the annotations page

The screenshot shows the 'Annotations' page for client AIP00025. The interface includes a sidebar with navigation options like Alerts, Data, Trends, Annotations, Follow-up, Settings, Notifications, Log Out, and Help. The main content area displays a list of annotations. The top annotation, titled 'Pet in kitchen', is currently being edited. Its description is 'Believe pet was in the kitchen since there's no motion triggered in any other room.' The 'ACTION' section for this annotation has 'Unconfirmed' checked. The middle annotation, titled 'Visitors in the home', is also being edited. Its description is 'Client alerted that extra visitors staying the weekend.' The 'ACTION' section for this annotation has 'Confirmed' checked. The bottom annotation is another 'Pet in kitchen' entry with the same description as the top one. The interface includes filters for 'All Clients', 'My Clients', and 'Custom Selection', and a search bar. The sort order is set to 'Newest first' and the filter is set to 'Show All'.

Follow-up Page

The follow-up page could be thought of as a filtered version of alerts and annotations together (Figure 33). Only alert instances and annotations marked either follow up or share appear in on this page. Annotations and alerts that were shared with the user should also appear on this page.

Figure 33: Follow-Up page viewed with default sort and filter and sustained client choice

The screenshot shows the 'Follow-Up' page for client AIP00025. The interface is similar to the Annotations page but filtered to show only follow-up and share actions. The top entry is 'Pet in kitchen' with a description 'Believe pet was in the kitchen since there's no motion triggered in any other room.' The 'ACTION' section for this entry has 'Follow-up' and 'Share' checked, and the 'DATE' is 8/01/2023. The middle entry is 'Room Activity' with a description 'Alert is for no bathroom events in 24 hours.' The 'ACTION(s)' section for this entry has 'Follow-up' and 'Share' checked, and the 'DATE' is 8/01/2023. The bottom entry is 'Wearable Activity' with a description 'No steps in 3 days'. The 'ACTION(s)' section for this entry is currently empty. The interface includes filters for 'All Clients', 'My Clients', and 'Custom Selection', and a search bar. The sort order is set to 'Newest first' and the filter is set to 'Show All'.

Similar to other pages, the header bar filters should be sustained as a user navigates the interface (for example, if the user was previously on the annotations page, whatever adjustments they made to client filters would remain in effect). The search bar would search all the follow-up annotations and alert instances. Sort options include: client, newest first (default), oldest first, and follow-up date/time (follow-up date/time would sort by oldest first so that any past dates would appear at the top followed by the ones that are most relevant to the user’s workflow on this page). Filter choices include: show all (default), annotations only, alerts only, shared with me, and shared with another. On the far right of the header, the “Add Event” and “Download” buttons are available. The download button allows the user to download a csv of all the annotations listed based on the filters.

Above the individual cards of alerts and annotations are choices to expand all or close all. The default view shows all cards expanded. Figure 34 shows all cards closed (annotation helper text – title, client and date – disappear from view and realign with the alert instances).

Figure 34: Follow-up all cards closed

| | | Expand All | | Close All | |
|-------------------|-------------------------------|------------|-----------|-----------|---|
| Pet in kitchen | AIP00025 | 5/21/2023 | 04:56 | ⌵ | 🔗 |
| Room Activity | No bathroom visit in 24 hours | AIP00025 | 5/18/2023 | 14:25 | ⌵ |
| Wearable Activity | No steps in 3 days | AIP00025 | 5/17/2023 | 08:01 | ⌵ |

Settings Page

The settings page (Figure 35) is where users go to change their password (the only button in the header bar), choose their view for time (military or local time), choose their default views of the data visuals: daily vs. weekly, weekly start of Sunday or Monday, and default sensors viewed on the data page (where available for client selected).

Additionally, they can turn off/on the view of the helper text defaulted on. In the lower card, they can adjust their client selections. For each client, a user can assign to “My clients” by clicking on the checkbox (and remove it by clicking here again). For each client, a user can choose to hide or show the client in all dropdown client filters and all

clients selections. Hiding them here would also make it so that the alerts would not come through until a user would unhide the client home. Finally, the user can see all the users that have added each client to their clients.

Figure 35: Settings page

| MY CLIENTS | SHOW/HIDE | USERS SELF-ASSIGNED TO MY CLIENTS |
|------------|-------------------------------------|-----------------------------------|
| AIP00001 | <input checked="" type="checkbox"/> | user1 |
| AIP00002 | <input type="checkbox"/> | user2, user3 |
| AIP00003 | <input type="checkbox"/> | user2 |
| AIP00004 | <input type="checkbox"/> | user3 |
| AIP00005 | <input checked="" type="checkbox"/> | user1 |
| AIP00006 | <input type="checkbox"/> | user2, user4 |
| AIP00007 | <input type="checkbox"/> | |
| AIP00008 | <input type="checkbox"/> | user2 |
| AIP00009 | <input type="checkbox"/> | |
| AIP00010 | <input type="checkbox"/> | |
| AIP00011 | <input type="checkbox"/> | |
| AIP00012 | <input type="checkbox"/> | |
| AIP00013 | <input checked="" type="checkbox"/> | user1 |

Notifications lightbox

The Notifications button on the primary navigation sidebar results in a view of items that need attention for one of a couple of reasons: a follow-up item date on an annotation or alert the user marked for follow-up has either passed or is in 3 days, or another user has shared an annotation or alert instance with them. Notifications should only include upcoming days of instances the user created or that were shared with the user.

Clicking on the notification will take the user to the data page with the view of relevant data. A user can also dismiss the notification by clicking the x inside a circle. So that the notifications are easier to see over the rest of the page behind, changing the main page button to hover and overlaying a 35% transparent black box over the page helps to show the notifications (Figure 36).

As a user dismisses notifications, the number within the red circle should update. As new notifications appear in the list, the number within the red circle should also update.

Figure 36: Notifications

The screenshot shows the 'Notifications' section of the 'ASSETS Care Coordination' dashboard. The left sidebar contains navigation options: ASSETS Care Coordination, ALERTS, DATA, TRENDS, ANNOTATIONS, FOLLOW-UP, SETTINGS, NOTIFICATIONS, LOG OUT, and HELP. The main content area displays a table of alerts with columns for DATE / TIME, CLIENT, and STATUS. A 'Go to Edit Alerts' button is visible above the table. Two alerts are highlighted with callouts: 'Due soon: Follow-Up on AIP00020' and 'Shared: Alert on AIP00005'.

| DATE / TIME | CLIENT | STATUS |
|-----------------|----------|--------|
| 5/21/2023 12:05 | AIP00001 | New |
| 5/21/2023 10:05 | AIP00005 | New |
| 5/21/2023 03:45 | AIP00025 | New |
| 5/18/2023 13:41 | AIP00015 | New |
| 5/17/2023 08:01 | AIP00013 | New |
| 5/01/2023 12:06 | AIP00005 | New |

Log out

Clicking this should produce a lightbox asking if the user is sure they want to log out with choices: cancel or confirm logout.

Help Page

Currently this is a placeholder with content not designed yet. The idea here would be to create a how to use the dashboard “tour”, Q&A, etc.

Appendix 4

Design and Functionality of the ASSETs Care Coordination Data Visualizations

Author and Lead Designer: Katrina Boles

Co-Designers: Suzette Bacon, Elizabeth Conrow, Ashley Roberts, Elizabeth Heaton, Blaine Reeder, Knoo Lee, Lisa Young

Summary

The ASSETs care coordination interface and data visualizations were designed as a collaboration between the Precision START visualization subgroup and primary users (occupational therapists, nurses and social workers) as part of the lead designer's PhD research. Like the interface prototype, the data visualizations went through multiple iterations and choices were made deliberately.

Fonts

Fonts should remain the same across the interface with either Helvetica Neue, Open Sans or some other sans-serif web font. Minimum text size should be 10 for the axes tick labels. And the font size should increase if a user increases their browser percentage view.






















Colors

An important consideration for the design team included maximizing colors and shades for users who may have low vision or colorblindness.

The main color for bathrooms is green and begins with #40BF40. The main color for bedrooms is blue and the first blue is #175782. Living room color is orange (#E67300). Kitchen is yellow (#FFCC00). Any additional room sensor would use a lighter or darker version of the main color, with at least 15% shade difference and to enable easier to see them, alternating darker and brighter versions so that the contrast is easier to distinguish.

Sleep is teal (#00CCCC); steps are purple (#6A3D99). Wake time line are a dark gray (#262626) and bedtime a lighter gray (#737373). Heart rate has a high color bright red (#FF4D4D) and average color (#990000). An overlay for the resting range is a light gray (#E8E8E8).

Figure 1: Colors

| | | |
|---|--------------------|------------------------------------|
|  | Bathroom 1 | #40BF40 |
|  | Bathroom 2 | #B3E6B3 |
|  | Bathroom 3 | #2D862D |
|  | Bathroom 4 | #79D279 |
|  | Bedroom 1 | #175782 |
|  | Bedroom 2 | #51A7E1 |
|  | Bedroom 3 | #2283C4 |
|  | Bedroom 4 | #92C8EC |
|  | Bedroom 5 | #D3E9F8 |
|  | Living room 1 | #E67300 |
|  | Living room 2 | #FFBF80 |
|  | Living room 3 | #FF9933 |
|  | Kitchen 1 | #FFCC00 |
|  | Kitchen 2 | #E2B700 |
|  | Sleep | #00CCCC |
|  | Wake time | #262626 |
|  | Bedtime | #737373 |
|  | Steps | #6A3D99 |
|  | High heart rate | #FF4D4D |
|  | Average heart rate | #990000 |
|  | Resting range | #E8E8E8 or #D3D3D3 at 50% alpha |

Data Page

When the data page first loads from an alert, it should show the data relevant to that alert. If a user navigates to the data page without an alert, the view should be the default, based on their choices in their Settings page. The same colors and elements should be used for the daily and weekly views. Please notice the title, subtitle, and summary statistics change as selections change, as indicated in the interface functionality document already shared. And the user needs to be able to zoom into and take a closer look at areas of data. They also need to be able to clearly identify everything, so if it's not available as a label, or in a legend (as in, it takes up too much space), it needs to be accessible with a little information icon.

The motion data for the single day (24-hour period, as seen in Figure 2) or week (7 days that either starts on Monday or Sunday, per the user's choice in the settings page, as seen in Figure 3) are histogram bar graphs of total minutes in 15-minute increments and are presented with 100% opacity/alpha. The users prefer space between the bars to be able to more clearly see the 15 minute increments; while this space is not visible in the weekly view, when a user zooms in those spaces should become more visible. If motion activity crossed the 15-minute mark, it was split between the two bars at that 15-minute point so the maximum y-axis scale is 15. When all the rooms are viewed together, users preferred they be viewed next to one another and the scales all match. When no data are available, as seen in the weekly view of Figure 3, a half-opacity gray box where either the sensors weren't on, or the time period has not happened yet. Instead of a legend, we have an information button to explain the data view (Figure 4).

Figure 2: Data page with visual of all motion sensors in a daily (24-hour) view

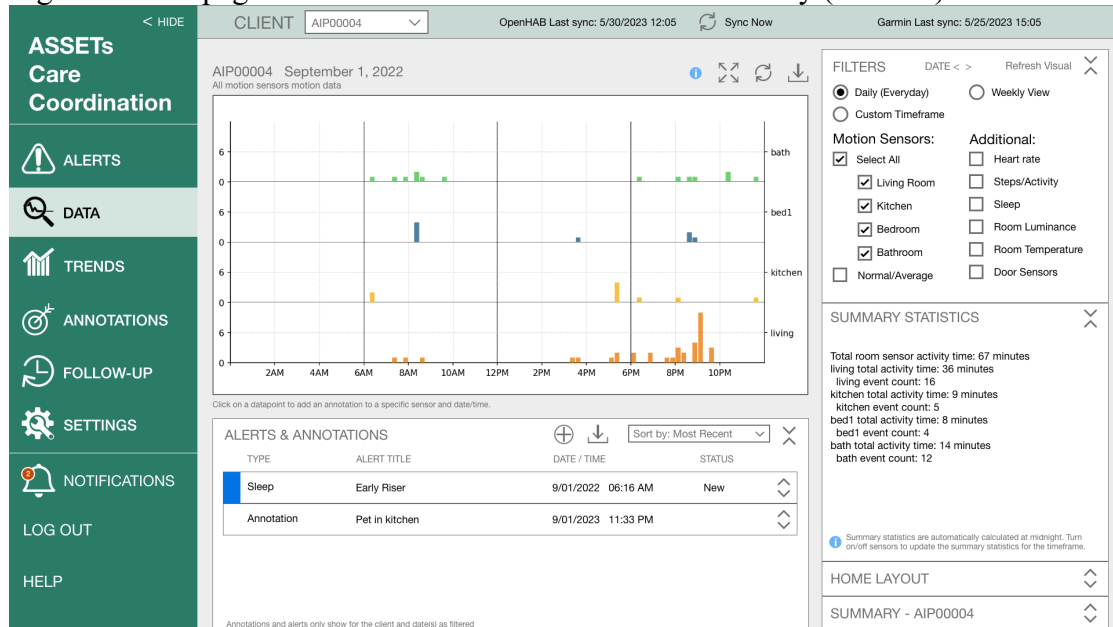


Figure 3: Data page with visual of all motion sensors in a weekly view

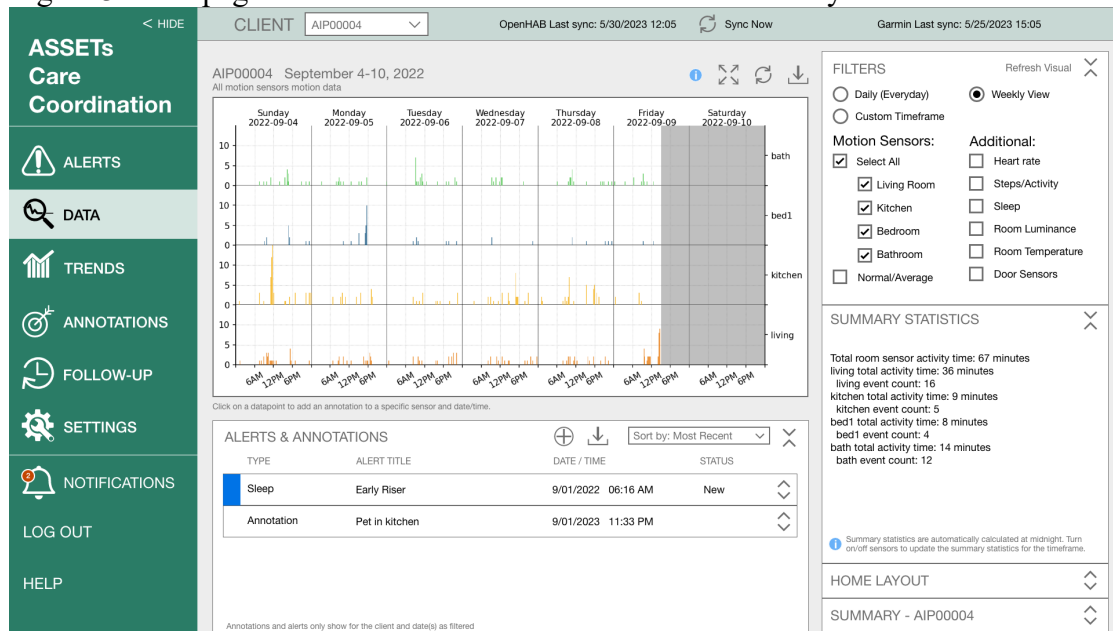
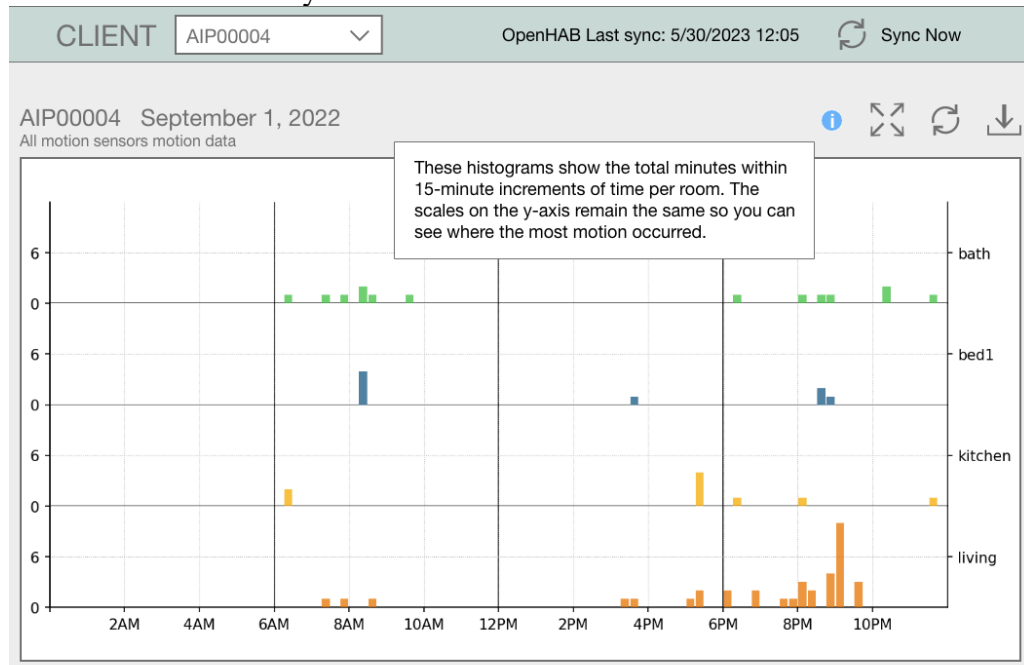


Figure 4: Partial data page with visual of all motion sensors in a daily (24-hour) view and information overlay



To create the normal/average, all time total time within the 15-minute increments across all time was aggregated together (kept within the 15-minute increments), divided by the number of days used to calculate the total and then smoothed with a gaussian filter. Again, the scale when viewing multiple rooms is the same and based on the maximum value of the room with the highest value in the maximum 15-minute bin (Figures 5 and 6). It is not meant to be exact numbers, but a smoothed area curve with 75% opacity. Like the popup for the histograms, the blue “i” above the visual will show an informational text box explaining the smoothed normal/average view (Figure 7).

Figure 5: Data page with visual of average/normal on all motion sensors in a daily (24-hour) view

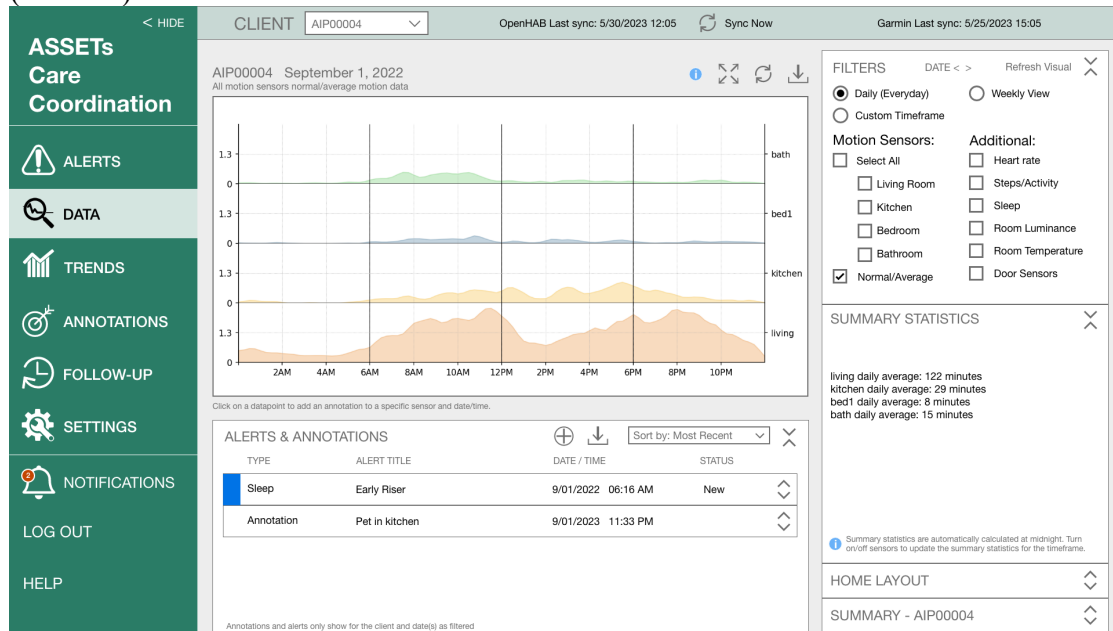


Figure 6: Data page with visual of average/normal on all motion sensors in a weekly view

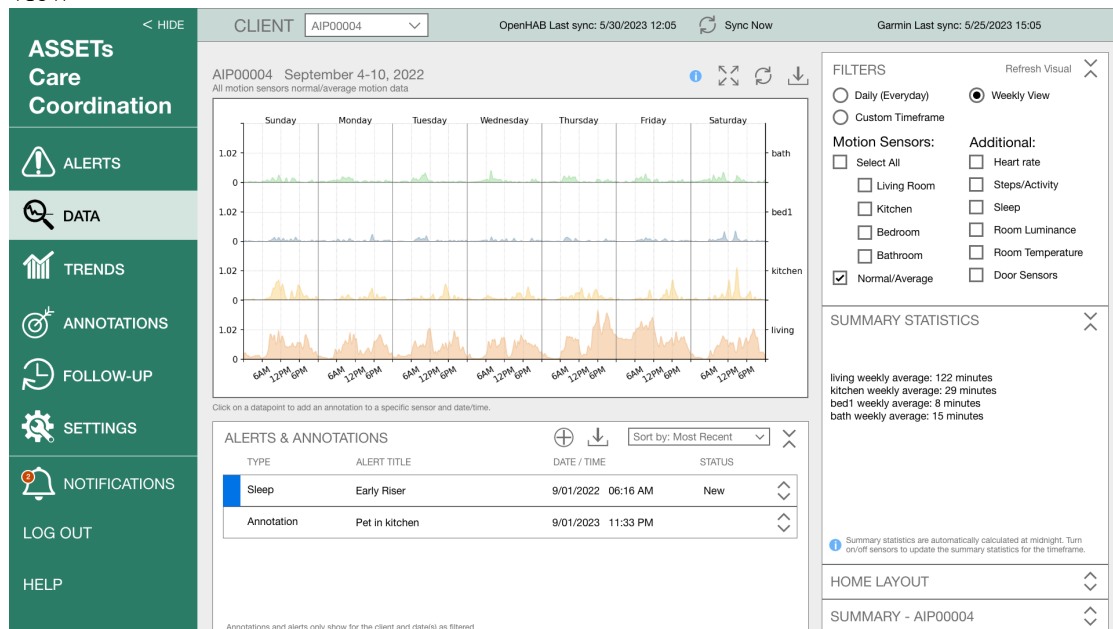
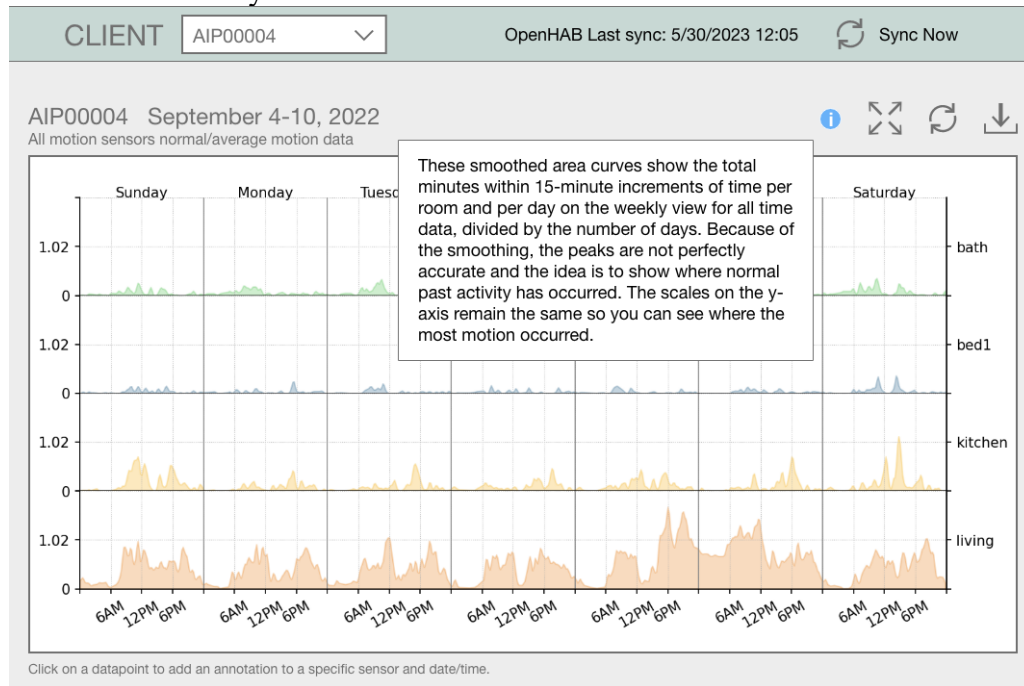


Figure 7: Partial data page with visual of all motion sensors in a weekly view and information overlay



When combined with a selected period-of-time in the foreground (Figures 8 and 9), the y-axis scales between the histogram and smoothed curve do not need to match, as the goal is to see where normal activity occurred in the past, with accuracy focus on the current timeframe rather than the past. Because this view combines the selected period and the past, the blue “i” above the visual will show an informational text box explaining both the histogram and the smoothed normal/average view with a visual example, like a legend (Figure 10).

Figure 8: Data page with visual of all motion sensors and average/normal in a daily (24-hour) view

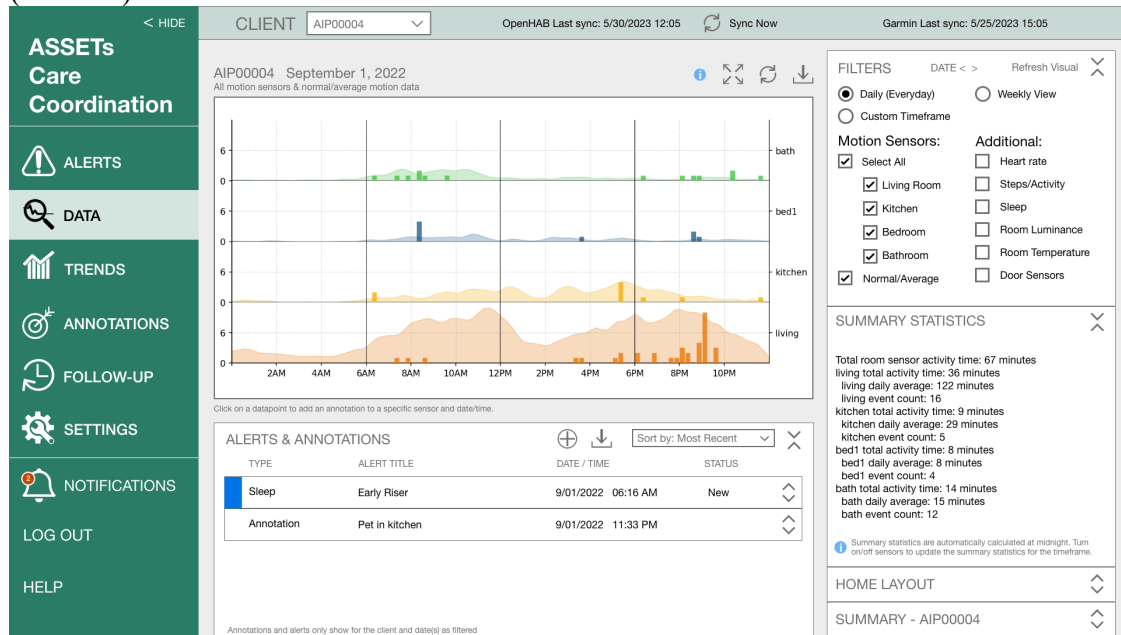


Figure 9: Data page with visual of all motion sensors and average/normal in a weekly view

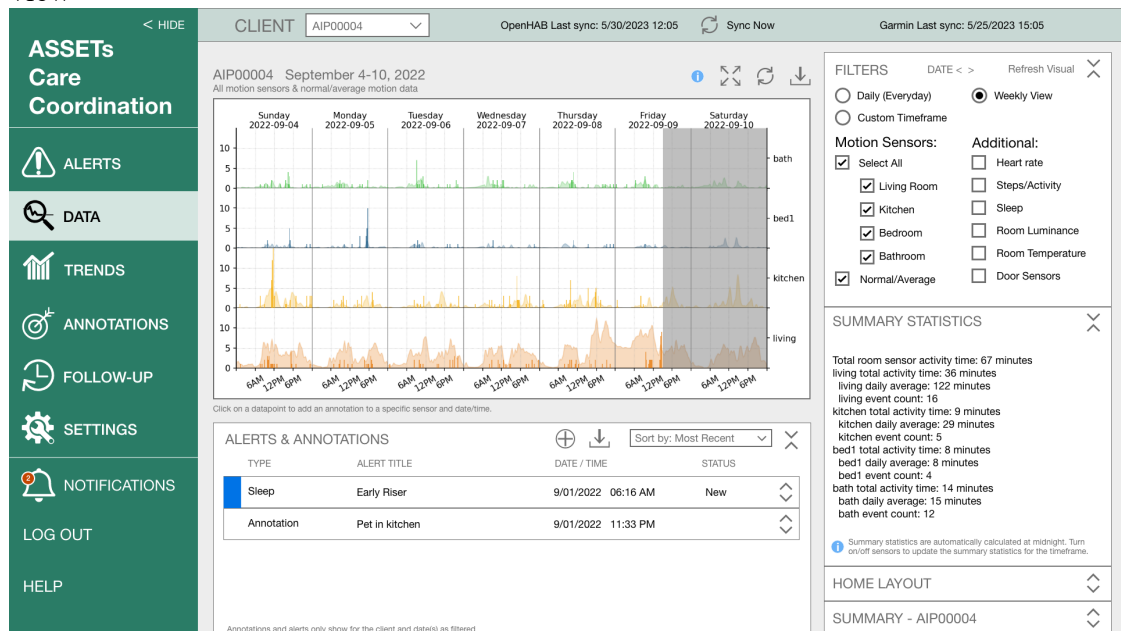
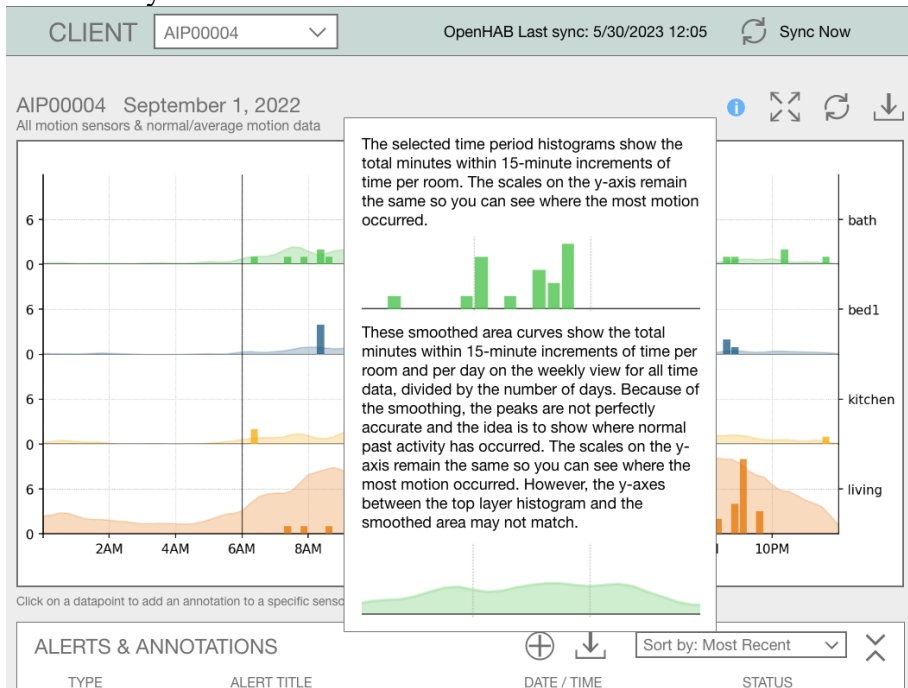


Figure 10: Partial data page with visual of all motion sensors and average/normal with info overlay



A 24-hour daily view that includes sleep will show a horizontal bar graph that shows the bedtime (or midnight if prior to midnight) to wake time (Figure 11). Additionally, if the bedtime for the next day if it is before midnight another bar will show the bedtime until midnight. Currently these views show sleep from the wearable device, but sleep from the motion sensors could also be used if no wearable sleep data are available. A weekly view will show all the bedtime to wake times for each day in the time frame (Figure 12). There is no normal/average view for sleep.

Assuming we can get access to step data with an epoch less than 24-hours, we would want to show that as a histogram bar graph (like the trends view). And if we have access to more detailed heart rate data from wearables, that data would show as lines with a “normal” range (like the trends view).

Figure 11: Data page with visual of all motion sensors, average/normal, and sleep in a daily (24-hour) view

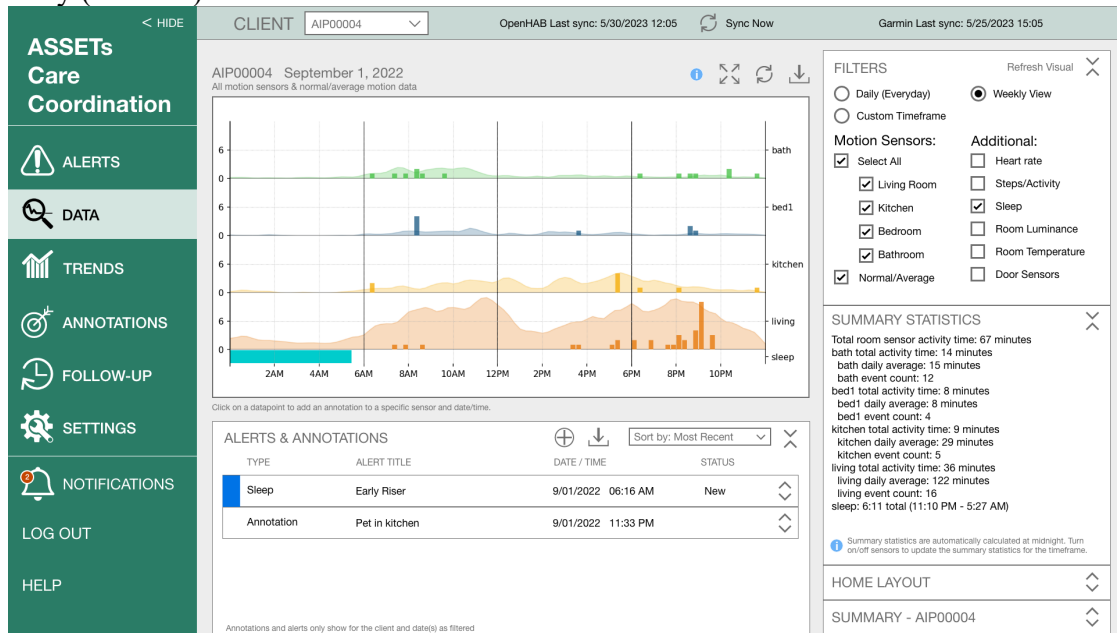
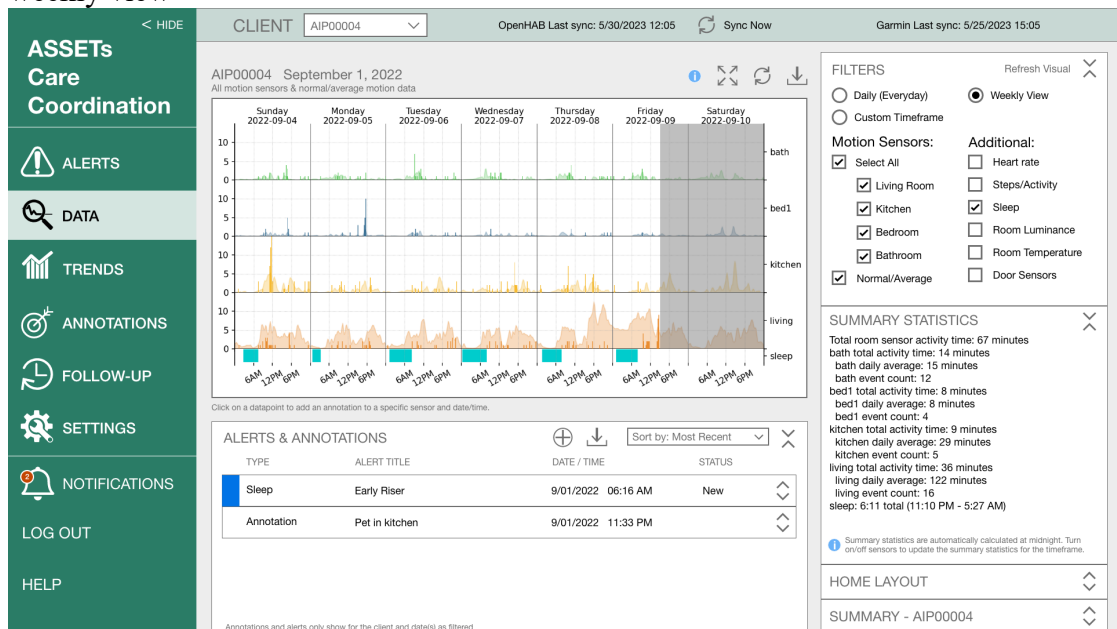


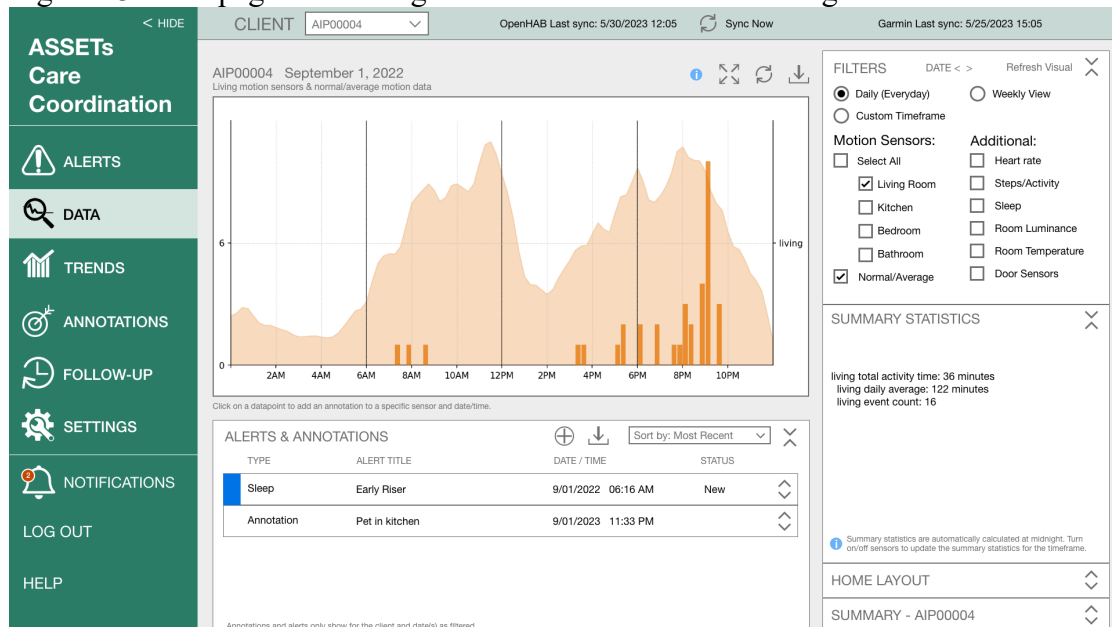
Figure 12: Data page with visual of all motion sensors, average/normal, and sleep in a weekly view



Adding luminance and temperature

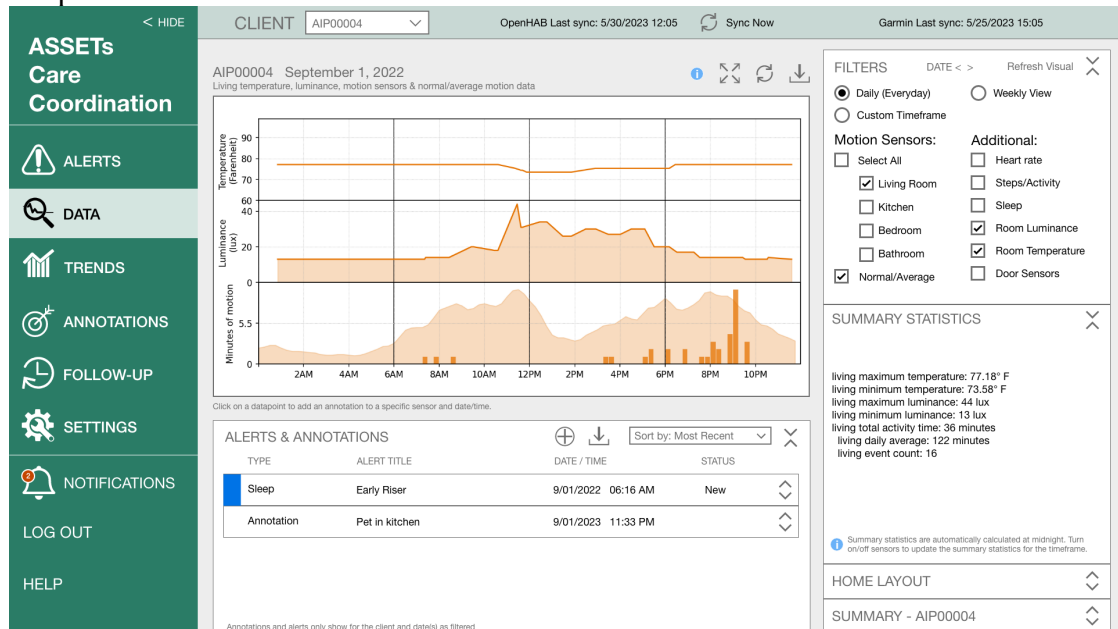
Users indicate that they would only look at luminance or temperature if there is an indicated need (so it would not be a regularly-used view). Thus, we focused on this view from one room at a time. A user may choose to only view one room anyway (Figure 13). Note: normal/average by itself would always show all motion sensors.

Figure 13: Data page with living room motion sensor and average/normal view



The luminance is shown as a line with area shading below and temperature as a line only (Figure 14). The team determined the luminance should be 0 to the luminance maximum (if needed, include a little room at the top to see the scale), and the temperature should show minimum minus 5 and maximum plus 5 degrees. The motion data should remain at the bottom. We chose to put the one with the highest maximum in the top plot, but it could be either. This could be viewed in weekly view or daily view and a user could choose to show just one, but for brevity we show both here.

Figure 14: Data page with living room motion sensor, average/normal view, temperature and luminance



Trends Page

On the trends page, the starting image should tell the user what to do rather than show a default (Figure 15). We added a button in the trend selection pane for “overlays”. We want the user to be able to turn on or off trend lines and normal areas in their views of the data. For daily trends, aggregates are in 24-hour periods and the x-axis is daily. For weekly trends, aggregates are in the 7-day periods (where the week either starts with Sunday or Monday depending on the user’s settings selection) and the x-axis show the week start date. For the motion data in each room, the data are stacked bars with no space between the bars (Figures 16, 17, and 18). All other bars (steps, room visits, and sleep) have space between them (Figure 19). Heart rate appears as lines (maximum and average), as does bedtime and wake time (Figures 20, 21, 22 and 23). The weekly trends for sleep show the average bedtime, wake time and total sleep between the averages (calculated by changing the wake and bed times to numeric values, averaged and then converted back to time, see Figures 22 and 23). The user has the choice to view the annotations over the trend visuals (Figure 24). Additionally, it is important for the user to be able to hover over any time point and get all the aggregate information available (Figure 25).

Figure 15: Trend page with no selections

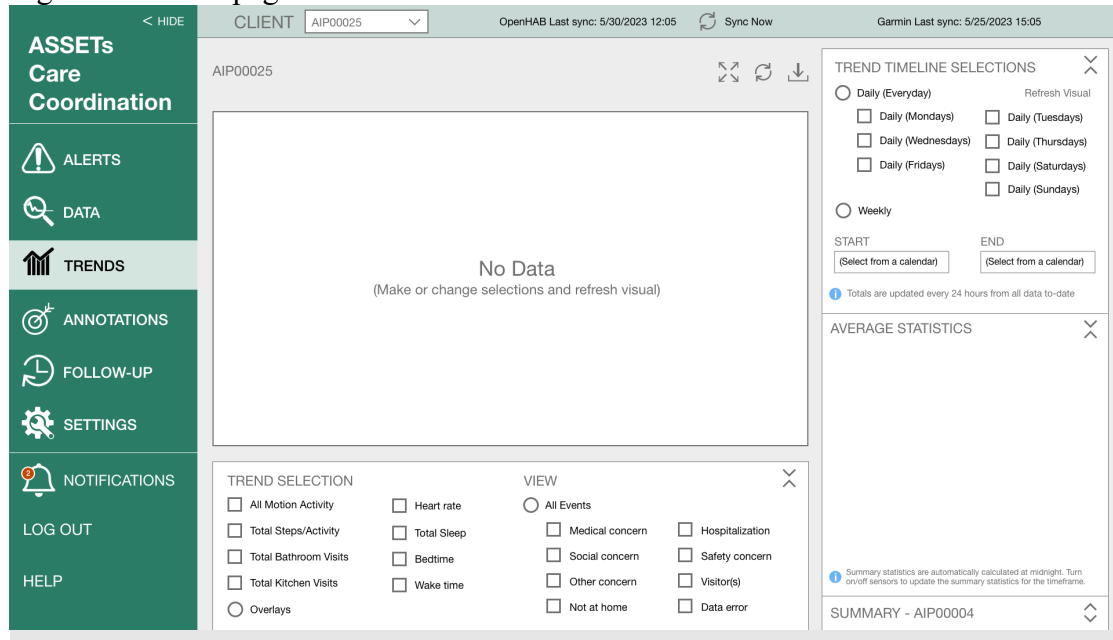


Figure 16: Trend page with location minutes with daily as selected timeframe

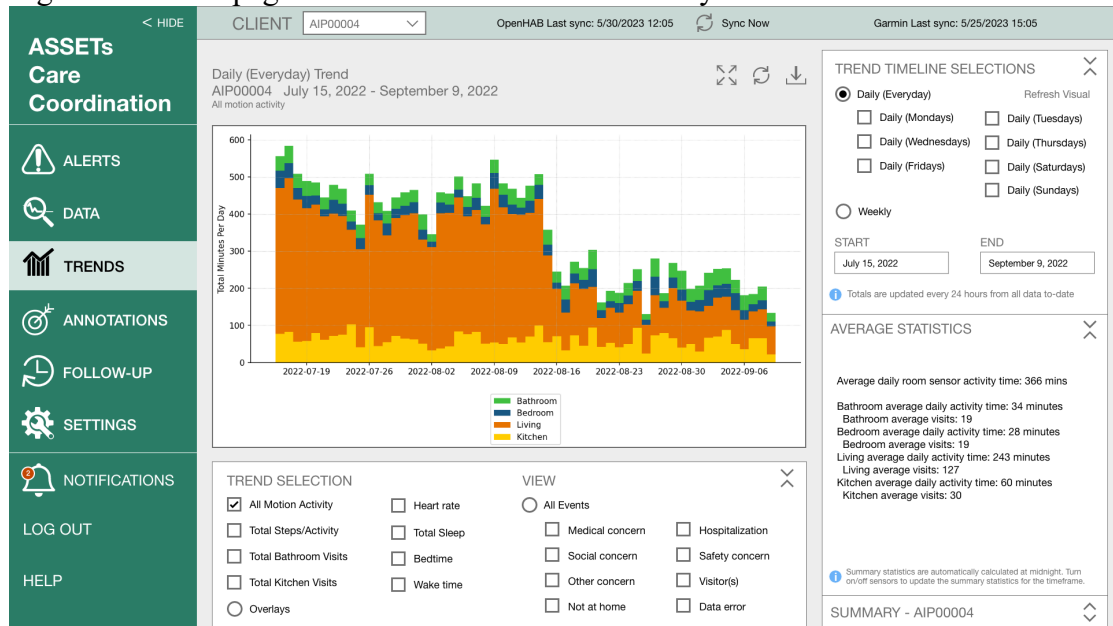


Figure 17: Trend page with location minutes daily and trend line

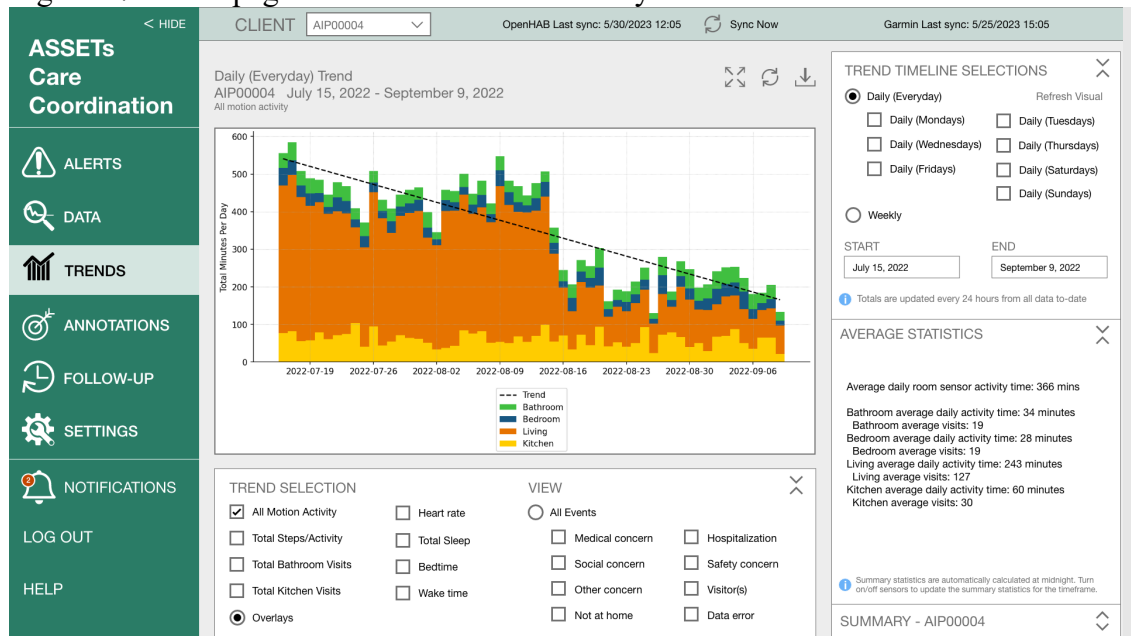


Figure 18: Trend page with location minutes weekly and trend line

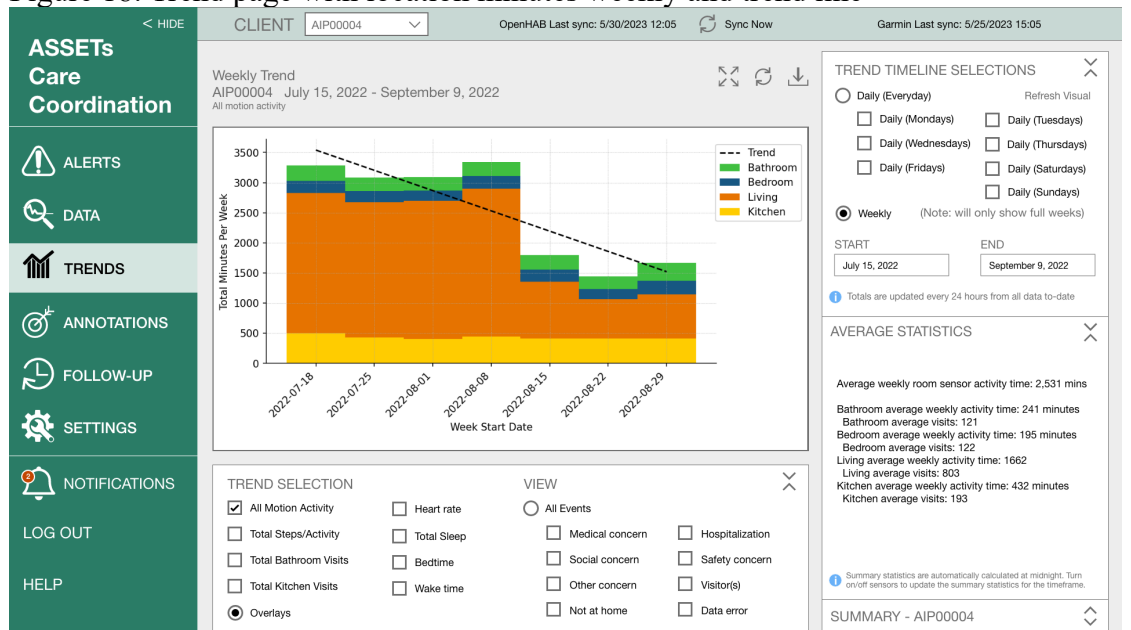


Figure 19: Trend page with location minutes, steps, and hours of sleep weekly

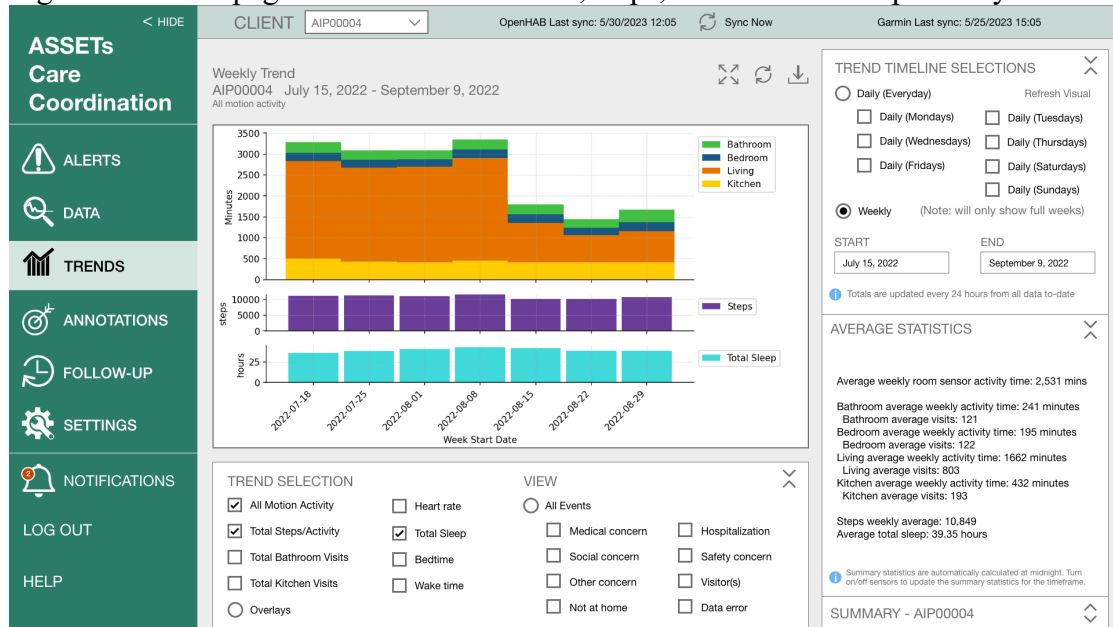


Figure 20: Trend page with location minutes, steps, and hours of sleep weekly

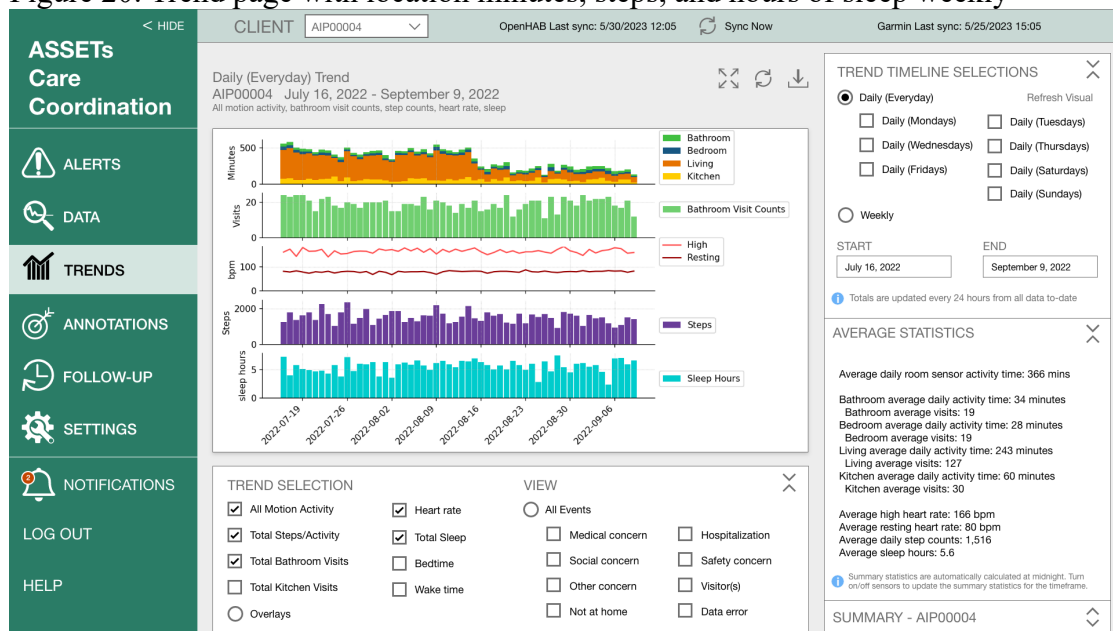


Figure 21: Trend page with heart rate (daily) and overlays

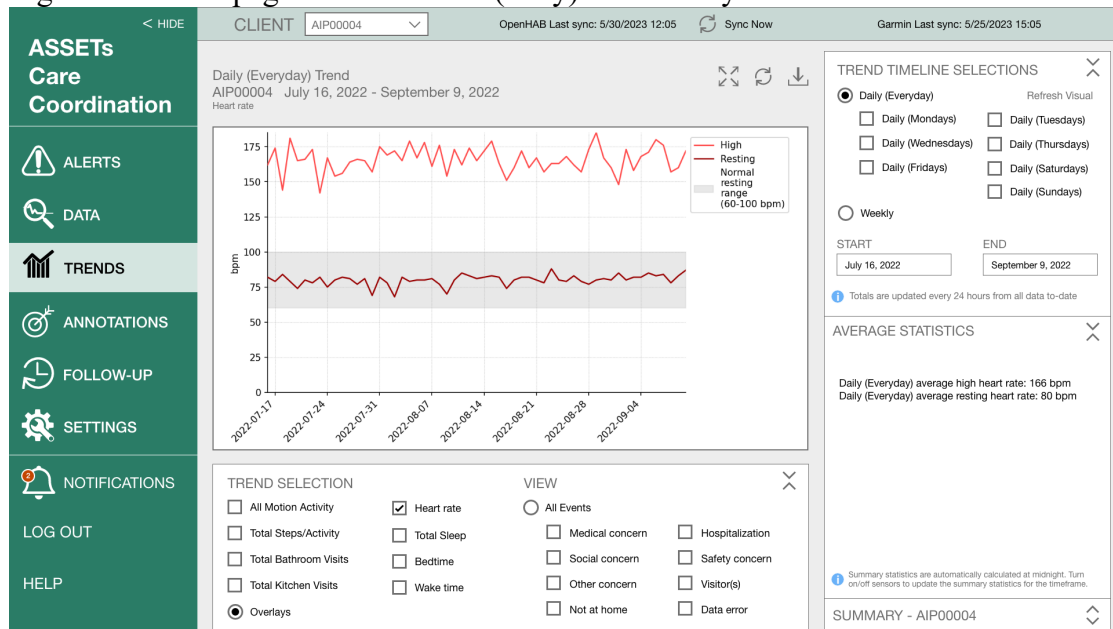


Figure 22: Trend page with motion, steps, wake time, bedtime and average sleep (weekly)

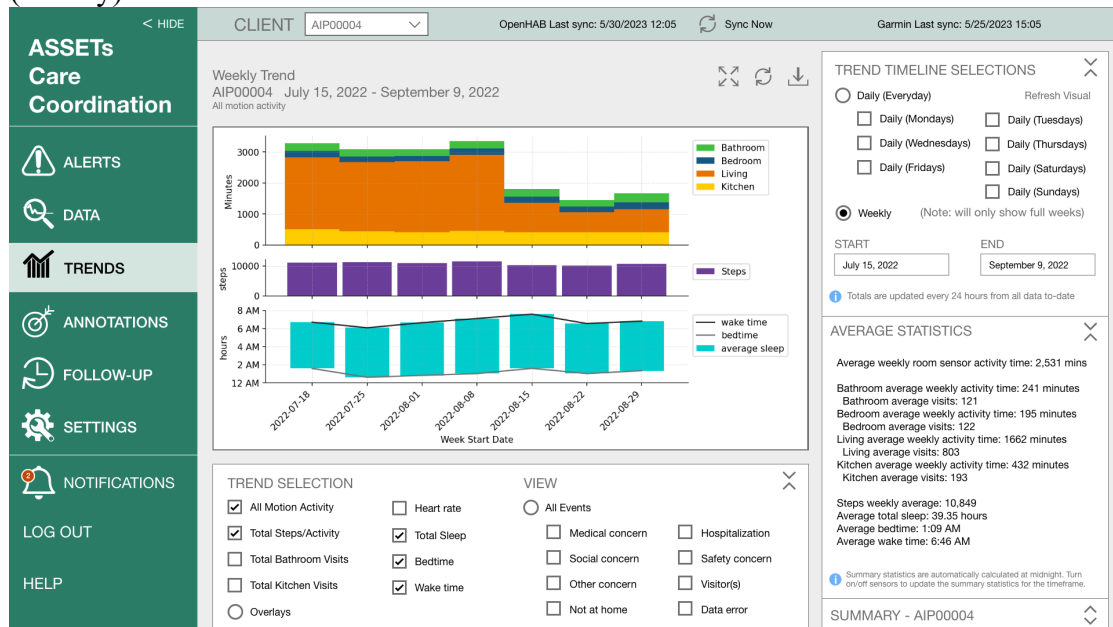


Figure 23: Trend page with wake time, bedtime and average sleep (weekly)

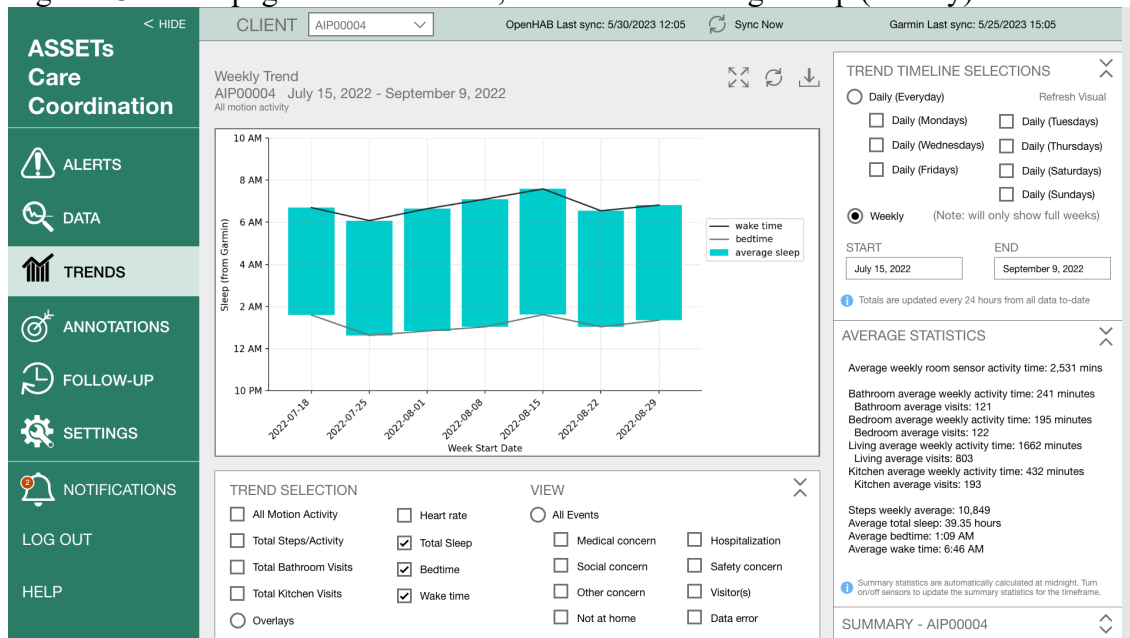


Figure 24: Trend page with motion, steps and all events (daily)

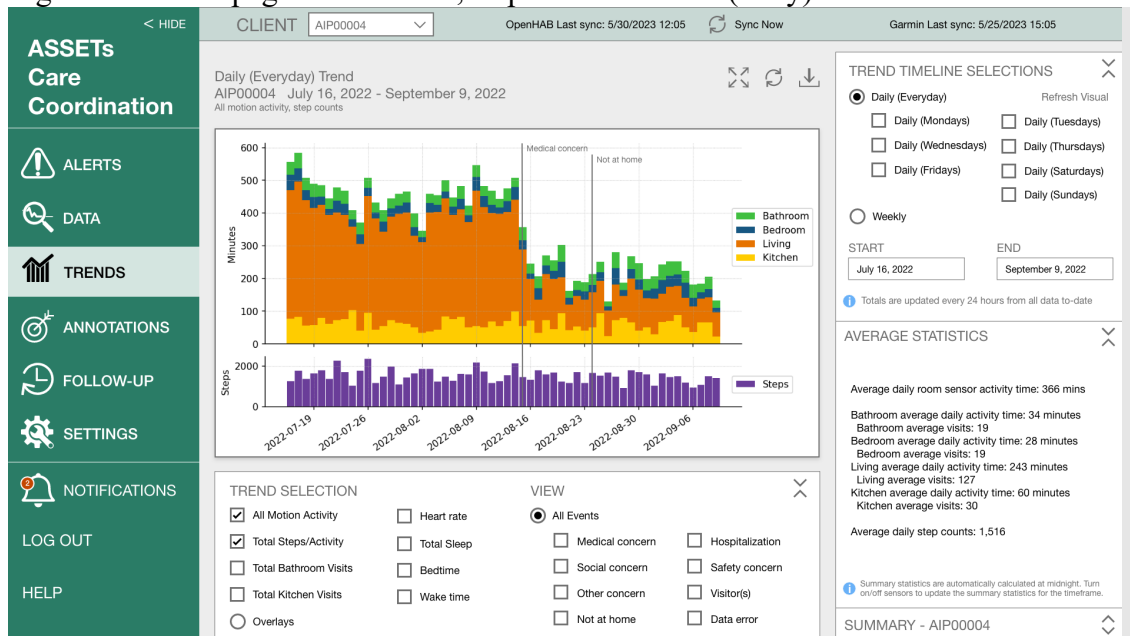
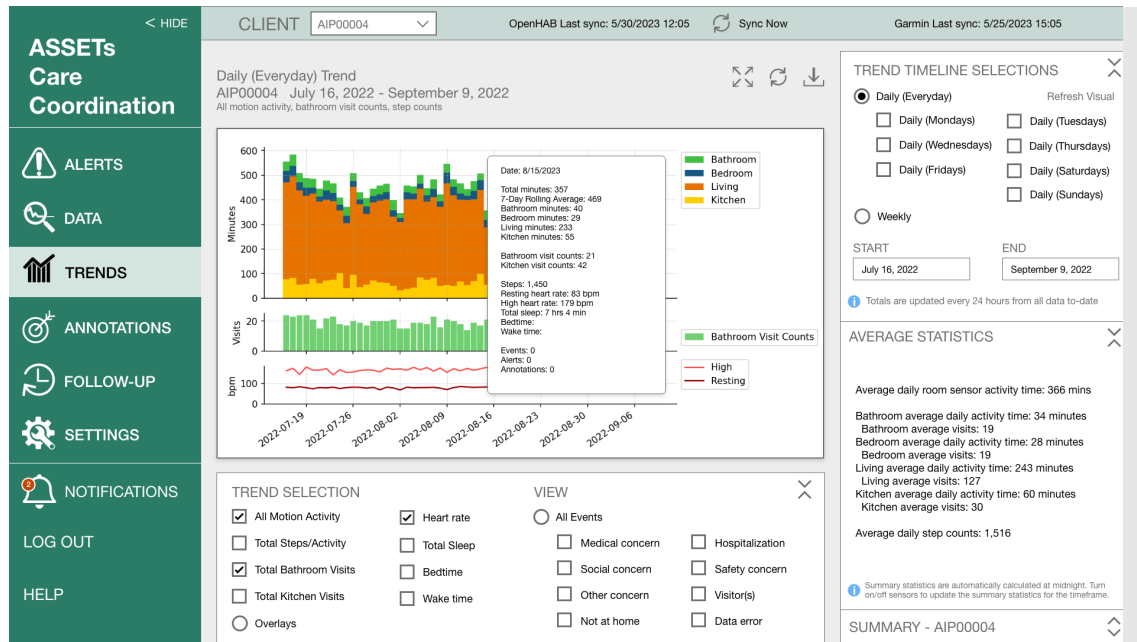


Figure 25: Trend page with motion, bathroom visits, heart rate (daily) and hover information for one date



Appendix 5

Protocol for cognitive walk-through with think-aloud of the ASSETs Care Coordinator Interface and Dashboard

Introductions:

Hello, my name is Katrina Boles. I'm a doctoral candidate in the MU Institute for Data Science and Informatics, joined by [insert name], faculty in the Sinclair School of Nursing and the ASSETs research group. [Give time to introduce.] If at any point you have questions, feel free to have me pause.

Thank you for agreeing to meet with us. We are meeting today as part of a study to evaluate and receive feedback on the design and functionality of the ASSETs Care Coordinator interface and data dashboard for sensor-based health coaching.

In this zoom session, we will ask you a few brief questions about your background and then we will ask you to:

1. explore the interface,
2. step through a series of scenarios and think aloud about your process,
3. provide your thoughts and feedback about the interface, including design and functionality recommendations,
4. and complete the 10-item SUS usability survey.

Our goal is to evaluate the interface; you will not be tested on your ability to complete tasks in the interface. We will ask your permission to record the think aloud session, including your screen as you navigate the interface. Recordings will not be shared outside the small research group approved by the IRB, and resulting data analysis will be de-identified. Your feedback is important to us and will remain confidential.

Participation is voluntary and there is no cost to participate. We do not know if participation in the study will result in direct benefits to you. Participation is not incentivized. You can end your participation at any time and if you choose to discontinue participation, any information collected will be discarded.

Do you have any questions before we begin?

[If they have not already completed the consent, ask them to complete it now]

User questions

1. What is your field of expertise/practice in health care?
2. How long have you been a health professional?
3. What is your current role?
4. Please tell us a little bit about your current responsibilities?
5. What information systems do you use in the course of your work?

About the ASSETs Care Coordinator Interface

Today we'll be evaluating the ASSETs care coordinator interface and data dashboard. The interface was designed for social workers, occupational therapists, and nurses in their roles supporting adults who were previously discharged from nursing homes and are aging in their homes, often in rural communities. Each client has at least four passive infrared motion sensors in their homes to unobtrusively capture activity in the bedroom, bathroom, living room and kitchen. Additionally, they wear an activity tracker, either a Garmin watch, FitBit watch, or Oura Ring. ASSETs care coordinators engage with clients on a quarterly basis at minimum, and they provide health coaching so that clients can self-manage their health and set goals for improved quality of life. The ASSETs team review client sensor data about three times per week, looking for changes in lifestyle, behavior, or indicators of disease onset. The interface was designed for surveilling the data and reviewing alerts, performing data probing to explore data to understand a client's normal behavior and find deviations in routines, and finally,

documentation and communication or follow-up about observations. While this is all real data, it is de-identified so you will not know anything about the clients other than what you see in their sensor data.

The interface is a prototype and is still in development. You will see that some prototype features are not enabled. We want to learn from you how we can make it more useful in a health coaching/mentoring workflow. We intend to make changes and we ask that you be as honest with us as possible so that we can make it better. It is designed based on an existing user workflow that we also expect to change and adjust based on the tools available.

[For unfamiliar group, share screen with care coordinator interface. Click on pages where functionality exists.]

[Guide user in opening the interface, logging in, and allow user to explore the application.]

Let us know when you are ready to proceed and we will have you explore the dashboard with some scenarios and have you “think aloud” about what you are doing and why.

Cognitive Walk-Through/Think Aloud

[Familiar group]

Could you begin by showing me what your typical workflow is when reviewing a client’s data using a client you are familiar with?

Now, could you navigate to a client instance where you saw something of interest and made some assessment using your expertise? As you navigate, explain what you are doing and what happened?

Now, you have decided to make a note for follow-up with the client or a colleague about the data you saw for client ### on date XXX. Could you determine how to make a note and next steps to take? Please think aloud as you document and communicate.

Follow-up Questions

[Familiar group]

1. How does the dashboard match your expectations?
2. Did the design features that were most important to you make it into this version?
3. What parts do you find useful?
4. What parts do you not find useful?
5. What changes would you most like to see?
6. What should we not change?
7. How can we improve the experience of working with this dashboard?
8. Do you have any other thoughts about the interface or this project?
9. Do you have any questions for me? Or is there anything you were hoping to discuss that we did not?

Cognitive Walk-Through/Think Aloud

[Unfamiliar group]

To begin, you are conducting a routine check to determine if there are any client issues, like sensors offline or behavioral concerns that you may need to address. Your clients for this are ###, ###, and ###. Please think aloud as you use the prototype.

Next, you noticed that you need more information about client ### on date XXX to assess a potential issue. Could you review data for client ### on date XXX? Please think aloud as you navigate and probe the data. [ideally we would have the easy access to change dates]

1. What questions do you have as a result of this activity?
2. Are you able to determine when and where they are most active?
3. Can you see if their activity is normal for them?

For your next activity, you want to determine if there are any gradual or long term changes in behavior for client ###. Please think aloud as you navigate and probe trends in the data. [can only do this if trends page is working]

Now, you have decided to make a note for follow-up with the client or a colleague about the data you saw for client ### on date XXX. Could you determine how to make a note and next steps to take? Please think aloud as you document and communicate.

Follow-up Questions

[Unfamiliar group]

What are your general impressions of the ASSETs care coordinator interface?
(What did you think about the look of it? What did you think about how you used it?)

What challenges did you observe in completing these tasks?

What design or functionality elements did you find most useful?

Are there other features that you would like to see?

How can we improve the experience of working with this dashboard?

Do you have any other thoughts about the interface or this project?

Do you have any questions for me? Or is there anything you were hoping to discuss that we did not?

Complete SUS

Thank you for participating in this think aloud. You can stop sharing your screen now. But before you go, we have one final task for you. In the chat, you should see a link to the system usability scale in survey format. This is a standard metric often used for measuring the usability of an app or web interface. Please complete it while remain online, you don't need to share your screen. If you have any questions, feel free to ask.

Let me know when you've completed it. Again, please be honest in your response. Please read the questions closely as they are opposite framed with the same scale. Understanding that there were planned features, just review the functional pieces.

Thank you again for participating!

Appendix 6

ASSETs Care Coordinator Interface Task List

| Description | Category | Priority | Comments |
|---|-----------------|-----------------|---|
| Add wearable data | Add feature | Very High | Incorporating steps and heart rate data from wearables is important for whole-person perspective; users currently have to log into a separate interface to see this data. |
| Build Trends page | New build | High | Trends page is not yet functioning, non-functioning visible features is confusing for users. Remove until it is functioning so that users know when it is working. Build it out so that users have access to longer-term information. |
| Remove Alerts page | Remove | High | Alerts are not providing enough useable information and require too much brainpower to understand. Users are overwhelmed and have determined it needs more work. |
| Remove Alerts panel from Data page | Remove | High | Alerts are not providing enough useable information and require too much brainpower to understand. Users are overwhelmed and have determined it needs more work to be useful. |
| Remove non-functioning features on the Data page: home layout card, summary card, text about clicking on data to add annotation, add event button, edit alerts button, and Garmin last sync | Remove | High | Non functioning features (placeholders) were confusing to users. They made it so that users were not sure what was working and accurate (last sync) and what was not. |
| Remove "edit alerts" page | Remove | High | The "edit alerts" button takes the user to a page that does not work with no way back. Remove the button and the page. |
| Remove Annotations page | Remove | High | Annotations page is not yet functioning, non-functioning visible features is confusing for users. |
| Remove Follow-up page | Remove | High | Follow-up page is not yet functioning, non-functioning visible features is confusing for users. |

| Description | Category | Priority | Comments |
|---|-----------------|----------|--|
| Build a help page | New build | High | Support resources need to include how to read the data visual, explain the data and what a user can understand from it, present a possible workflow, and explain quirks like how to select one day from the custom timeframe or how to use the brushing tool to zoom in/out. |
| Add luminance and temperature data | Add feature | High | Multisensors also have luminance and temperature measures that users currently have to return to a previous dashboard to view. |
| Fix the client visibility filter | Fix | Moderate | Users can turn on/off the visibility of clients in their settings, which should change what they see in the dropdown choices, but it currently is not functioning. |
| Fix the filter pane malfunction | Fix | Moderate | The Filters card disappears on the Data page when a user attempts to choose a custom timeframe within an already selected custom timeframe, and the only solution is to refresh the page in the browser. |
| Add system feedback when "sync now" button is pressed | System feedback | Moderate | Users were unsure if they can trust the last sync information. One way to help would be to give them system feedback when a sync has been set to occur and instructions for seeing updated data. |
| Add system feedback when system is applying filters and pulling data to show visual (e.g., a loading bar) | System feedback | Moderate | A loading bar is needed so the user knows not to hit the visual refresh button. Hitting the button multiple times results in data loading into the visual multiple times and displaying incorrectly. |
| Increase the size and contrast of axis labels of data visualization | Update existing | Moderate | Users had a hard time reading the axis information (dates and time in particular) because they are not black and too small. |
| Add system feedback when settings are saved on the settings page | System feedback | Low | A user doesn't know that their settings were saved after clicking "Save" on the settings page. Add a lightbox or text overlay to inform the user that the settings have been saved. |

| Description | Category | Priority | Comments |
|--|-----------------|----------|---|
| Add day/week forward/back buttons | Add feature | Low | Participants used the custom timeframe more than day or weekly view so that they could go back in time, but two buttons for forward and back would save time in helping them cycle through data. |
| Change the default view for sidebar navigation to show expanded with titles | Update existing | Low | New users don't know what the pages are. If we set the default view to show the sidebar navigation for new users and then have a user's preference maintained when they close the navigation panel, that would be best. |
| Update the subtitle on the data visualization to match filters and better describe the graph | Update existing | Low | The subtitle on the data visualization on the Data page is intended to provide system feedback to the user that their filters were applied and provide information to someone just looking at the visual. |
| Add navigational aids for menu items | Update existing | Low | Users were unclear what they would find in each of the sidebar menu buttons. |
| Preserve settings or setup user configuration to persist across devices | Update existing | Low | With the settings cookie-based, users have to re-select their user settings if they open the interface on a different browser or computer. |
| Update summary statistics | Update existing | Low | The data appear incorrect, it is unclear that the timeframe filters are actually being applied to the statistics; users are currently not using. |
| Brushing bar expand with expanded view | Update existing | Low | When a user expands the data visualization, the brushing bar at the bottom does not expand with it, so the bar does not align with the x-axis, and users cannot adjust the zoom with accuracy. |

VITA

Katrina graduated cum laude with a Bachelor of Fine Arts in Visual Communication and a Bachelor of Arts in Studio Art from Truman State University in 2004. She got her start as a stagehand on the wardrobe (costume) crews for Summer Repertory Theatre and the University Concert Series, which she continued to do part time for many years while working full time as a motion graphic artist and live event director in video production at the University of Missouri (MU). Her communications background led to management and art direction roles in video, photography, and graphic design at MU. Additionally, she was the first presentation manager for the critically and internationally acclaimed True/False Film Festival.

During her time in strategic communications departments, she discovered a growing interest in understanding the data behind what makes people take interest in a particular design, story, or other communication artifact. In her communication roles at MU and examining data for the True/False Film Festival, she began creating rudimentary data visualizations to glean more information about strategies of effective communications and understanding people's motivations. It turned out she really liked data. This led to an interest in merging creative and analytic skills to make data and results of analysis understandable to non-specialists. In 2018, she began her graduate career in the MU Data Science and Analytics (DSA) master's program, where she was the student representative for the DSA program at the Graduate Professional Council and was a founding member of the Student Assessment Advisory Board.

At the culmination of the master's program, she began pursuing a PhD in health informatics from the MU Institute for Data Science and Informatics. Katrina is currently

the data analyst for ECHO Autism Communities, where she supports the organization's mission of "building global communities where people see possibilities in all abilities" through data reports and research support. Following this PhD journey, she looks forward to spending more time with her family and taking on new and returning artistic endeavors. Maybe someday data will appear in her paintings or fiber arts, or maybe the arts will become more prominent in her data representations.