Privacy vs. Awareness: Relieving the Tension between Older Adults and Adult Children When Sharing In-home Activity Data

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While aging adults frequently prefer to "age in place", their children can worry about their well-being, especially when they live at a distance. Many in-home systems are designed to monitor the real-time status of seniors at home and provide information to their adult children. However, we observed that the needs and concerns of both sides in the information sharing process are often not aligned. In this research, we examined the design of a system that mitigates the privacy needs of aging adults in light of the information desires of adult children. We apply an iterative process to design and evaluate a visualization of indoor location data and compare its benefits to displaying raw video from cameras. We elaborate on the tradeoffs surrounding privacy and awareness made by older adults and their children, and synthesize design criteria for designing a visualization system to manage these tensions and tradeoffs.

CCS Concepts: • **Human-centered computing** → **User studies**; **Ubiquitous and mobile computing design and evaluation methods**; **Visualization design and evaluation methods**.

Additional Key Words and Phrases: Health, Older adults, Smart Home, Indoor localization, Privacy, Surveillance

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1 INTRODUCTION

In 2020, 56 million people aged 65 and over lived in the United States, accounting for 16% of the total population [52]. Among them, the majority of older adults live in the community instead of nursing home or elder living facilities [51]. 90% percent of seniors express their willingness to stay in their own homes and community as they age [26].

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"Aging in place" is defined as "the ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income, or ability level."[29]. "Aging in place" has many advantages for the elderly. It enables social connection and emotional attachment within familiar communities [25], and provides a sense of security, familiarity and identity[68]. Because of these advantages, helping older adults who are aging in place has gradually become a crucial topic for researchers [66].

Although aging in place is beneficial and often desired by older adults, their adult children are often concerned about its practicality. In the U.S., 73% of older adults live independently or share a home with only one spouse or partner, away from their adult children [5]. As older adult's self-care and cognitive abilities gradually deteriorate, their children are often concerned about the well-being of their parents, especially when they are not able to provide help in a timely manner in the case of emergency. When helping seniors aging in place, it is important to involve their children in the process, not only to ensure the safety of older adults, but also to give their children peace of mind [48]. Since seniors spend significantly more time at home, the need for technological interventions to communicate with children who may live hundreds of miles away, so that the children can understand their parents' activity at home, is extremely urgent.

Although there are numerous systems and technologies available on the market for this purpose, only a few of them have taken into account the power dynamics between older adults and their children, particularly with respect to preserving the dignity of the elderly. For instance, indoor camera is one of the most commonly used home security systems, as indicated by the fact that 38% of Americans own a home security product and 18.2% of those report owning a video camera, doorbell, or both [1]. While the cameras fit the needs of adult children well, they are not always comforting for the elderly. Older adults usually don't want to be monitored by their children through indoor cameras, and sometimes feel uncomfortable with the constant sense of 'surveillance' around their own house. We have noticed that many seniors and their children have argued about the installation of indoor cameras or similar monitor systems, with one side stressing the importance of the product while the other stating that their privacy is being violated [2, 45]. Indoor localization data instead, is commonly captured data that better protect people's privacy during the process. However, how to effectively use this data to communicate useful information remains a major challenge. In this study, we explore the tension between older adults and their children surrounding sharing activity data, which we frame as "privacy vs awareness". We want to explore how to present older adults' activity data in a better way that can relieve this tension through the use of indoor location data.

In this study, we followed a user-centered design process and iterate our design along the way. The design of this research was progressively refined, largely informed by findings from earlier sessions. This process reflects in the paper layout as well: three separate data collection sessions are reported independently with their respective methods in each session [Figure. 1].

We now summarize the contributions of this paper. First, we elaborate the tradeoffs between privacy and awareness made by older adults and their children regarding sharing information about indoor activities. We summarize how these older adults and their children assess the privacy and importance of sharing information about activities divided into four categories: *crucial, private, casual, and customized*. We conclude that no visual information (such as videos) or any *private activities* should be shared explicitly with adult children in regard to protecting older adults' privacy. Second we synthesize key design insights for visualizing activity data. Third, we describe a visualization approach based on these insights and our iterative design process, and compare the acceptability of this design to sharing raw video data. Our visualization design, *iFloor*, has been shown to effectively address the tension between privacy and awareness, as confirmed by both parties involved. Our findings suggest that future designs should prioritize *movement* and *crucial* or *customized activities*, while highlighting significant areas and minimizing unnecessary

furniture based on the activities. It is also recommended to display ambient historical traces, reduce complexity, and enable a basic level of understanding to promote trust.

2 RELATED WORK

2.1 Monitoring Technologies to Support Older Adults to Age in Place

To support the independent living of older adults who want to age in place [26] and promote peace of mind for their adult children who live away from them [48, 56], there is growing interest in aged care monitoring technologies that are able to provide awareness of older adults' in-home activities [15, 18, 67]. Visual-information-based monitoring systems have been widely adopted to help adult children learn about their parents' activities of daily living at home, such as RGB monitor cameras [27, 50, 71], depth cameras [41, 71, 72], and thermal cameras [38]. However, due to the camera's limited field of view and the complex nature of older adults' in-home activity, the information and recognition results suggested by visual information are limited and not always reliable. For instance, based solely on visual information, it is hard to discriminate between unusual inactivity that results from a fall and normal inactivity that results from resting on a sofa. Compared to direct visual information, indoor location as another kind of data source demonstrates its potential to provide higher-level awareness of older adults' daily activities by adding spatial context to in-home activity recognition [32, 62]. Recently, technologies such as ultra-wideband (UWB) radio frequency, ultrasound, and FM have driven unprecedented advancements in indoor localization. These approaches made indoor localization an effective, with an improved accuracy from room-level to near-centimeter-level [37, 53], device-free [58], robust enough for commercial use [17, 37, 53], and flexible in its technology that could be combined with other information like the floor plan of older adults' home. Other than indoor location, motion is also something often detected by multiple ambient sensors such as motion sensor [19, 22, 35]. However, messy motion data from various sources makes it hard to detect or interpret complex activities. Wearable devices are also alternatives to other home monitoring technologies, however, wearables would be ineffective if the older adults forget or choose not to wear them, potentially because of discomfort. In our paper, we choose indoor location as our data source to stably visualize older adults' in-home activities in high fidelity.

2.2 Privacy Concerns in Aged Care Monitoring Technologies

While many monitoring technologies have been employed to precisely detect subjects' in-home behaviors, older adults have expressed various privacy concerns about these technologies [2, 30, 45, 54]. For example, previous studies have noticed the tension between privacy and independence that older adults value their autonomy and don't want others to know more than what is necessary to maintain independence [8, 47, 65]. Melenhorst et al. [46] found that potential privacy invasion might affect older adults' evaluation and adoption of smart home technologies. Other researchers found that the level of privacy concerns perceived by older adults varied according to the monitoring devices (the data input side)[12, 60, 65], as well as how much and in which way activity data was presented (the data output side) [13]. Therefore, many previous studies have tried to address older adults' privacy concerns either through the data input side or the output side. Most of the research has focused on how to choose and adjust monitoring technologies to control the type and the amount of data collected by devices as a means to preserve privacy. For instance, Zhang et al. [71] developed a privacy-preserving fall detection system using RGBD cameras by only capturing the foreground masks of the moving object. Several studies used a wireless, passive infrared sensor-based network system to only collect low-resolution activity dataset [6, 67, 69, 70]. For the data output side, prior work such as Digital Family Portrait [49] attempted to address

privacy concerns by mapping the quantitative collected data to three general, qualitative categories (health, relationship, and activity) formulated through interviews with adult children and their parents. DigiSwitch [14] is an information-sharing system that helps older adults maintain privacy by allowing them to have control over the transmission of information. Unlike previous work that only focused on either the input or output side, our work attempts to protect older adults' privacy through both sides by choosing only the indoor location as our data source to prevent any potential visual information disclosure.

2.3 The Tension Between Older Adults and Adult Children in Sharing Information

There is a growing number of studies that aimed at analyzing the tradeoffs or tension in sharing information using aged care monitoring systems. For instance, Townsend et al. [65] developed a tradeoff model to determine in which situation older adults are more willing to accept intrusive monitoring technologies and trade their privacy for autonomy. Similarly, Schomakers and Ziefle [59] also noticed the tension between privacy and security and concluded that privacy concerns would be outweighed if the life-saving security benefits of monitoring technologies are perceived. It is worth noting that previous work mainly focused on older adults perceived benefits and concerns about monitoring systems, but we believe sharing information through aged care monitoring technologies is a collaboration between older adults and their adult children, and therefore, such system should meet the needs of both sides: promoting awareness of older adults' daily life while preserving their privacy. In addition, while there are quite a few empirical studies that have developed aged care information sharing systems and were tested in real settings [20, 21, 36, 40, 61], these systems all presented the activity information from a quantitative view, which made it hard for adult children to be aware of their parents' wellbeing at a glance.

Mynatt et al. [48] noticed these two gaps and introduced the "Digital Family Portrait" which was designed for the collaborative information-sharing process and could provide a qualitative sense of the daily activities of older adults. While Mynatt et al.'s work [48] focused on daily glances, casual visual inspection, and lower-level awareness, they also pointed out that in the future, a second step might be conveying pertinent details about an individual with higher data granularity, which could be seen as the basis of our work. In our research, we recognized the importance of releasing the tension between privacy and awareness. This work is an attempt to build on Mynatt et al.'s work [48] and focused on using indoor location data to display more detailed and personalized information about older adults to open the opportunity for providing higher-level awareness, such as emergency tracking and safety, while mitigating privacy concerns of older adults.

3 RESEARCH QUESTIONS

With a focus on enabling peace of mind to both the elderly and their children, we ask two pertinent questions in this work:

(1) What are the tradeoffs surrounding privacy and awareness made by older adults and their children who live apart from each other?
(2) What are the design insights of visualizing older adults' in-home activities using indoor location data that can relieve the tension of privacy vs. awareness between older adults and their children?

4 METHOD

We took a mix-method approach in this study and followed a user-centered research process. We conducted both qualitative and quantitative data analysis, and continually iterated our design throughout the whole process. As mentioned in Section 1, the design of user research was largely

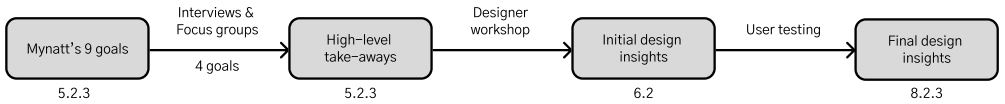

Fig. 1. The structure of the iterative user research process in this study, and how final design insights were built on findings from previous sessions. The numbers on the bottom are the corresponding section numbers in this paper.

informed by findings from earlier sessions. For better presentation clarity, in this paper, we report the three separate data collection sessions independently with their respective methods in each session, while the current section only aims to provide a high-level overview of the study structure. Briefly, the design process and the corresponding sections are depicted in Figure 1.

4.1 Interviews and Focus Group

First, we organized focus group sessions and separate interviews with both older adults and their adult children to learn about their needs and concerns during the activity data-sharing process, and combined the result with previous research to summarize a list of high-level take-aways. A more detailed description to examine the procedures of the interviews and focus group sessions can be referred to in Section 5.1.1.

4.2 Designer Workshop

We held an online design workshop to distill the high-level take-aways generated from earlier sessions into detailed design insights. We then designed and selected a visualization, *iFloor*, as its embodiment to further evaluate those insights. A more detailed description to examine the procedures of the designer workshop can be referred to in Section 6.1.

4.3 User Testing

In order to examine if those design insights were able to guide us in balancing the tradeoffs surrounding privacy and awareness, we compared its embodiment *iFloor* with two extremes: raw video (easy-to-understand but privacy-invasive) and an abstract art based on *Travelogue* [42](privacy-protected but hard-to-interpret) through user testings with both seniors and their children. A more detailed description to examine the procedures of user testing can be referred to in Section 8.1.

4.4 Ethical Considerations

This research has been approved by the Institutional Review Board (IRB) at our institution. Since this study focuses on the tradeoffs surrounding awareness and privacy between older adults and their children which could potentially lead to conflicts, we have paid extra attention to the methodology and language used in our user research. Both interviews and the final user testing were conducted separately with older adults and their children. In the focus group session, we provided participants with paper and a pen to jot down their thoughts in case they felt uncomfortable speaking up during the session. In order to protect the identity of the participants, a random alphanumeric pseudonym was assigned to participants which would be the only link for the data collected in the study.

5 NEEDS AND CONCERNS: INITIAL USER RESEARCH

To get guidance on what type of information should be displayed to relieve the tension, both children's needs and parents' concerns were considered. In previous research, Mynatt et al. [48]

described five aspects that need to be considered in the context of sharing information between older adults and their children: *health*, *environment*, *relationships*, *activity* and *events*. Using indoor location as our data source, we only focused on the *activity* category in this research, and elaborated on this basis.

To summarize, in this section, we will discuss older adults' and their children's needs and concerns regarding sharing elderly's *daily activities*. We conducted interviews and focus group sessions with both parties to gather their qualitative input regarding their overall needs and concerns, and designed a rating scale to provide deeper insights into both parties' different perspectives toward various types of activities.

5.1 Method

5.1.1 Interviews and Focus Group Sessions.

To explore the first research question — to learn about the tradeoffs surrounding privacy and awareness made by older adults and their children in the activity data-sharing process — we conducted two focus group sessions and 10 individual interviews. We chose these two methods (focus groups and interviews) in order to combine the strengths of both methods to understand their needs and concerns not only from a broad spectrum but also in detail [9, 63].

The two focus group sessions followed the same procedure and were conducted with different participants. Both sessions were held in person with older adults and their children present at the same place. Each focus group session consisted of 3 parts. In the beginning, the participants were asked to share their thoughts on sharing activity information with their children or knowing their parents' activity information, and were asked what their current strategies to share information were. In the second part, we concentrated on the use of indoor location data for information sharing. Each participant shared his/her views on indoor location data and how to present the data and in which granularity. Each session ended with a Likert rating scale survey to gain deeper insights into both sides' attitudes towards different types of indoor activities, which will be further elaborated in Section 5.1.2. Other than discussing during the sessions, we also provided paper and pens throughout the whole session to enable every participant to contribute their different needs and concerns, and to catch their thoughts even if the participants do not feel uncomfortable sharing those insights in public or in front of their families [55]. The duration of each focus group session was about 60 minutes. One researcher took notes of the whole session due to the community's restriction on video/audio recording.

The individual interviews followed a similar structure as the focus group but focused on more detailed and personal experiences in activity information sharing. For example, the moderators encouraged the participants to recall the conflicts or disagreements between them and their parents/children during the current information-sharing process. Each interview lasted about 60 minutes and was audio-recorded and transcribed.

5.1.1.1 Recruitment.

We recruited the participants for the focus groups and individual interviews by posting an advertisement in the newsletter of a local community for older adults through email, text messages, and fliers. As an inclusion/exclusion criteria, we ensured that the older adults live away from their children or primary caregivers. All the older adults recruited were capable of self-care. The participants for the interviews did not overlap with the focus groups, because the structure and information goals for the two methods are very similar but just with different focuses and granularity.

We eventually invited 17 participants (F1-F17) to join the in-person focus groups. To facilitate effective discussion, we conducted two focus groups [39] splitting the participants evenly as was practically possible given everyone's schedules (7 participants were present for the first focus group,

Participant IDs of older adults	Participant IDs of adult children	Relationship
P1p	P1c	Mother and daughter
P2p1, P2p2	P2c1, P2c2	Parents and daughters
P3p	P3c	Aunt and niece
P4p	P4c	Father and daughter

Table 1. Relationship of participants in the interviews and user testing sessions.

and 10 in the second group). Even given the limited sample size, we remained conscious of the need for a diverse user base. In the 2 focus group sessions, 52.9% of the participants were white, 17.6% are black, 11.8% were Asian and 17.7% did not specify their race; 47.1% of them identified as male, 47.1% of them identified as female and 5.8% participants did not disclose their gender identity. Participants were not required to specify their exact relationships with other participants (children, step-children, nieces or nephews etc.) in the sessions, however, they were required to describe if they were older adults (52.9%) or caregivers (47.1%).

For virtual individual interviews, we had five older adults and five adult children participate. The average age for the older adults was 77 and the average age for adult children was 47. 60% of the participants were white, 40% were black; 20% of them identified as male, 80% of them identified as female. During the interviews, participants did specify their relationships with the other participants that were related to them, however, each interviews were conducted separately (see Table 1). All the 10 participants interviewed with us decided to join the later user testing session, which we will specify in Section 8.1.2.1.

5.1.1.2 Data collection and analysis.

As a result of the focus groups and interviews, we collected a large amount of qualitative data consisting of participants' thoughts written on paper during focus groups, notes of the whole focus group sessions, and audio transcripts obtained from individual interviews, which were then analyzed by qualitative coding [10]. We decided to apply an iterative semi-open coding procedure [28] as the form of thematic analysis, i.e. inductive as well as deductive approach. While we had already defined specific research questions or interests (e.g. tradeoffs, current sharing strategies, attitudes toward the usage of indoor location data, etc.), we also noticed that some other themes and categories (e.g. movement, daily activities, etc.) emerged during our inductive analysis. Two researchers were in charge of the coding work. First, we coded the transcript of the same focus group session separately. After that, we compared each other's codes, discussed and identified any mismatch, and reached an agreement. Then, we continued coding the rest of the texts.

5.1.2 Rating scale.

In the previous sections, we approached *activity* more holistically. However, it is obvious that there are many types of *activities* in the daily life of the elderly, and there are significant differences in the attitudes of the elderly and children pertaining to different *activities*. Therefore, in order to further explore what kind of information should and should not be provided to adult children, we decided to delve into the different daily activities through a rating scale.

Previous studies have summarized and listed everyday activities, and we benefit from those lists. In a recent study, McNaney et al. asked older adults to conduct 5 categories of tasks in their mock-up study: Meal preparation, Cleaning, Sleep-related activity, Washing up, and Resting [43]. Elaborating on this, we listed 11 activities: eat, cook, get a drink (Meal preparation), clean up the house, do laundry (Cleaning), sleep (Sleep-related activity), relieve, take a shower, brush teeth (Washing up), watch tv, read books (Resting). We also added 3 other activities that were considered crucial for

older adults based on previous studies: take medication [34], get stuck in a loop (dementia-related activity repetition) [3, 4] and fall/slip [7].

Finally, we generated a list of 14 daily activities/status: *sleep, brush teeth, cook, eat, relieve/go to the toilet, read books, watch TV, get a drink, take a shower, do the laundry, take medication, clean up the house, get stuck in a loop, fall/slip*, and designed a rating scale to evaluate older adults' and children's perspectives on the importance and privacy level of different activities.

After generating the list of 14 activities, we collected the data from a rating scale from 27 participants (10 from interviews and 17 from focus group sessions). For older adults, we let them rate the privacy level of those activities (*Q: Please rate the privacy level of sharing the following activities: 2 Very private, don't want others to know; 1 Somewhat private, probably okay to share; 0 Not private, comfortable to share*). For the adult children, we let them rate the importance level of knowing these activities (*Q: Please rate the importance of knowing the following activities (of your parents): 2 Very important, want to know about; 1 Somewhat important, beneficial to know but not necessary; 0 Not important, don't need to know*). When explaining these questions, we specifically emphasized the information sharing context creating a conduit between older adults and their adult children (instead of strangers or doctors). At this stage, since we do not want to dictate the format of the presentation, we asked the participants to see this as an alarm-like notification that someone is aware that some specific activity is occurring. We collected the privacy and importance values of the 14 activities from 27 participants, and calculated the deviation of two values as a parameter *score=importance-privacy* (results are depicted in Figure 2). Since *importance* and *privacy* were evaluated on the same scale (0-2), we used their deviation (*score*) to indicate whether the information should be shown. The higher the *score*, the more necessary and desirable the information about the activity is to be displayed. Based on the results, we further categorized the 14 daily activities into four types, which we would describe later in the 5.2 Results section.

5.2 Results

In this section, we have provided a summary of the qualitative findings from the interviews and focus groups. Additionally, we have categorized 14 daily activities into four categories based on the results of the rating scales. To recap our findings, in order to safeguard the privacy of older adults, it is crucial to refrain from sharing any visual information, such as video data, or any direct information relating to private activities. To provide useful information to adult children, we should focus on delivering two categories of information: *movement* and *daily activities*. Moreover, within the various activities, we should focus on presenting the *crucial activities* to balance the tradeoffs. Finally, building upon prior research, we have developed a list of key takeaways that we will continue to refine in later sections.

5.2.1 Qualitative Quotes.

Movement and daily activities

We expanded the types of information that needs to be communicated from *activities* to *movement* and *daily activities*. *Movements* includes real-time location/movement as well as short-term historical moving traces. Knowing this information would enable the adult children to be informed about their parents' well-being. P1c mentioned that she would be concerned if her parent stayed in a room for a period of time without any movements. *"If so, I would be worried about if she slipped or fell in the bathroom when she took a shower. I will call her."* said P1c. *Movement* information also provides a low-level understanding of what's going on during the day [48]. One of the children F4 told us that it would be good to know where their parent were and if they were moving around that area, not necessarily the details about what they were doing. One participant (F10) expressed that they would like to see if their parents had gotten up from bed and if they were active or not throughout the day,

which could be easily inferred through their movement. *Daily activities* represent more purposeful and specific information that children want to receive. These activities are often time-sensitive and need to be completed on a regular basis. P1c would like to learn if her mom actually ate the food that she cooked. *"My mom sometimes gets distracted and never eats the meals after she cooked."* Many participants were also worried about medication adherence, such as have their parents taken their AM/PM medications on time. For different families, there are both overlaps and variances in the specific activities children want to know. In the later section, we will discuss in-depth how different daily activities should be presented in terms of privacy and awareness.

Only showing necessary information and avoiding any video data

As expected, we noticed that many older adults were not fully receptive to indoor cameras. In the focus group session, one of the homes had indoor cameras installed at the senior's home. The adult child told us that their parent eventually agreed to have cameras installed in their home, however, they continued to turn the system off manually. Some seniors said that they were okay with indoor cameras, however, their original statement was very interesting, especially considering the power dynamics between older adults and their children. *"If I reach a stage where I need to be watched, I'm okay with that."* said F6. As we can imagine, the elderly and their children do not always agree completely on whether or not they have reached such a 'stage'. For the aforementioned family who already had a camera in their home, the child said they had always wanted to install additional cameras near the stairs for their parent, however, their parent did not feel it was necessary, so the plan was put on hold. Based on our interviews, we found that adult children typically initiate discussions and negotiations, but older adults ultimately make the final decisions. To preserve the dignity of older adults, it is crucial to avoid giving the impression that they are under surveillance when addressing the needs of adult children. In the interview, P1p mentioned that she could not accept having a camera at home showing her face and body. P1p told us that *"If I have a camera at home, I would need to be dressed up all times. I don't want my daughter to see me naked."* On the contrary, seniors are far less reluctant to install systems that can detect indoor locations compared to cameras (mentioned by P2p1, P2p2). Almost all seniors thought there was nothing wrong with sharing their indoor location or related activities with their children. To summarize, in order to protect older adults' privacy, we should only present necessary information and avoid showing additional data such as visual information.

5.2.2 Quantitative results from Rating Scales.

***Different types of daily activities:* crucial, private, casual, and customized**

In previous sections, we've learned that adult children care a lot about their parents' daily activities, while older adults don't always feel comfortable sharing all the information. At the same time, various activities tend to have different impacts. In this section, we would like to dig deeper and discuss how adult children perceive the importance, as well as how older adults perceive the privacy of various daily activities differently.

The first type we named it as ***crucial activities***. *Crucial activities* have high scores, which represent higher values of importance level and relatively low values of privacy level. In the 14 activities, *eat, take medications, get stuck* and *fall/slip* have the scores higher than 1, and are considered under this category. We also noticed that since the older adults were aware of the importance of these information, they were usually willing to share. *Crucial activities* are the information that we should clearly deliver to the adult children in our visualization with no doubt.

The second category is ***private activities***. For these activities, the older adults had expressed strong willing that they would not like others to learn about this information. We noticed that most of the *private activities* happened in the bathroom. The privacy level of *relieving themselves* (1.36)

Fig. 2. The average values of privacy (red), importance level (green) and final scores (yellow; score=importance-privacy) of 14 daily activities. The background colors and the labels on the top represent the activity categories (from left to right: red - private activities; green - crucial activities; grey - casual activities; and blue - customized activities).

and *taking a shower* (0.86) are higher than other activities (average 0.37). We did see a possible tension in this category. *Taking a shower* which has the highest privacy levels also has a high importance level (1.18). Although some of the adult children did express their willingness to know the activities of *going to the toilet* and *taking a shower*, the reason of that was mainly because many dangerous activities happened in the bathroom. P3c rated both two activities as *very important* (value=2). However, she told us in the interview that she did not care what exactly her mom was doing in the bathroom. She worried about her mom slipping on the wet floor, which often happened in the bathroom while she was doing these two activities. As a result, for those *private activities* that have a low importance level, we shouldn't display related information. And for other *private activities* that are somewhat important to learn for the children, such as those activities happened in the bathroom area, we should restrict the details of information revealed to the children to balance this tension.

The 3rd category is ***casual activity***. For these activities, adult children did not feel the need of knowing this information due to its low importance level. The older adults, at the same time, were usually okay to share this information because of the same reason. Since our design priority is to deliver only useful information, we should avoid presenting these data. *Watching tv* (privacy 0.29; importance 0.36) and *reading a book* (privacy 0.14; importance 0.6) have the 2 lowest levels of importance among the 14 activities and relatively low privacy levels, which makes them 2 classic *casual activities*.

The last category is ***customized activity***, which could not be clearly classified into any of the above three categories. The privacy and importance level of such activities vary for different families, thus we don't have a clear statistical pattern from the data collected from our 27 participants. In our

study, *customized activities* are: *sleeping, brushing teeth, cooking, getting a drink, doing laundry,* and *cleaning up the house.* These activities usually have a mid-level final score, and for some households, they have a relatively high importance level while for others they have a high privacy score. For these activities, the visualization needs to be customized to balance the tension between privacy and awareness.

To summarize, in order to categorize the 14 activities, our first step was to examine both the score (importance-privacy) and the value of privacy. For activities with a score/privacy above the established threshold, we classified them as *crucial/private activities.* Conversely, if the privacy, importance, and score were all relatively low (falling between 0 and the threshold), we categorized these activities as *casual.* Any remaining activities fell into the category of *customized activities.*

The appropriate threshold for participant groups can vary depending on the particular study. Since the size of the data was limited, we visually examined the data and used interview quotes to establish the thresholds for this research. For *crucial activity*, we set the threshold at 1, for *private activity* at 0.8, and for *casual activity* at 0.6. This means that any activities with a score above 1 will be classified as *crucial*, those with a privacy score above 0.8 will be considered *private*, and those with all importance, privacy, and score values between 0 and 0.6 will be designated as *casual activities.* Any remaining activities will be classified as *customized activities.*

We also observed that while the first three categories were distinct from one another, the *customized activities* could be more challenging to classify, especially those such as *taking a shower*, *sleeping*, and *having a drink*. In addition to comparing the results with the interview data, we used the standard deviation of the results from each participant to determine the appropriate category. For instance, although *getting a drink* has a relatively high privacy score, its standard deviation was 0.93, which was the highest among all activities. Thus, we concluded that participants had varying perspectives on this activity and classified it as a *customized activity.* If we had access to more data and participants, a more structured clustering formula could have been applied to the dataset.

The previous results show the tradeoffs surrounding privacy and awareness of different activities. Categorizing 14 daily activities as *crucial, private, casual and customized* can help us decide what information is necessary to display in our visualizing system.

5.2.3 ***Summary: high-level take-aways.***

As discussed in Section 2, many researchers have explored how information about indoor activities should be presented to seniors, however, few studies specifically focused on sharing information between older adults and their children. Among them, the Digital Portrait is a well-established work in this field [48]. As a result, in this study, we chose the design criteria described by Mynatt et al. in their study to serve as the basis for our in-depth study.

In the Digital Portrait field study, Mynatt et al. described five initial goals and four subsequent goals of sharing activity data between older adults and their children [48]:

(1) The design should convey relevant information about a person's daily life to support low-level awareness of that person's well-being.
(2) The design should depict trends over time for the different categories of information represented.
(3) The visualization should provide a qualitative view respecting privacy concerns.
(4) The visualization should be aesthetically pleasing, a typical home decoration.
(5) The visualizations should be emotionally appropriate, conveying "negative" information (e.g. a bad day) in an appropriate manner.
(6) Reduce the display's complexity.
(7) Create a stratified design allowing a typical day's display to be as simple as possible, and adding interface layers for less common display needs.

(8) Develop designs that are appropriate for male and female senior adults. (Many of our icons seemed particularly feminine).
(9) Focus on elderly parent to adult child communication.

In our research context, the following four goals (1,2,3,6) combined with our previous findings were used in the design process. These goals are specific about what information should be presented and how it should be presented between the elderly and their children. While we followed all the above goals throughout our study, we only chose 4 goals as our main focus since we want to further refine them (No. 1-3, 6). For the other criteria, they are either not relevant to our main focus on privacy and awareness (NO. 4,5,7,8), or too general to improve upon (NO.9).

After selecting four goals from Mynatt et al.'s study [48] to start, we refined those goals and combined them with our findings. Here we present our **take-aways** at this stage:

(1) The design should convey relevant information about a person's daily life to support low-level awareness of that person's well-being.
  (a) *Movement* and *daily activities* (*crucial* and *customized*)
(2) The design should depict trends over time or the different categories of information represented.
(3) The visualization should provide a qualitative view respecting privacy concerns.
  (a) Information of *crucial* and *customized activities* should be provided in a qualitative view.
  (b) Information of *private* and *casual activities* should not be displayed.
  (c) No visual information should be captured and delivered.
(4) Reduce the display's complexity.

6 BRAINSTORMING: DESIGNER WORKSHOP

Now we have a list of high-level takeaways generated from previous user research sessions. Starting from there, we wanted to explore how these takeaways could be transferred to concrete design ideas. In order to achieve this, we organized a designer workshop to brainstorm different design ideas and seek inspiration.

6.1 Method

6.1.1 Recruitment.

In order to synthesize more detailed design primitives, we organized an online designer workshop with 5 designers to collect creative ideas regarding the visualization design (see Table. 2). We sent out flier emails to the design department in a university through newsletters and to professional designers through personal connections. When recruiting designers, we valued their ability to understand user needs more than the ability to create visual design since we are aimed at generating insights and inspiration instead of getting a fully polished visualization from the workshop. The final prototype will still be made by researchers who specialize in visualization design. Most of our participants have some experience in user experience research and design with an average self-rating of 3.8 (0-5: no experience-professional). Some of them are also familiar with visualization design (average of 2.2). Designers were less familiar with smart home system (average of 1.4) and the populations of older adults (average of 1.2).

6.1.2 Workshop procedure.

Firstly, the researchers presented the key goals and takeaways to the designers. We described 2 personas [31, 57], one for the older adults and one for adult children [Fig. 3]. The personas were created based on the target-population-related codes and themes generated in our thematic analysis to best represent the typical profiles of the populations. To quickly familiarize the recruited designers with the older adults and their adult children in the context of activity data sharing,

Participant IDs of designers	User experience research and design	Visualization design	Smart home system	Older adults	Visualization ID
D1	5	3	0	3	Va, Vb
D2	5	2	3	1	Vc
D3	3	2	2	1	Vd
D4	5	3	1	1	Ve
D5	1	1	1	0	Vf

Table 2. Participants in the designer workshop, their expertise in different domains (0-5: no experience-professional), and the corresponding visualization number each participant created.

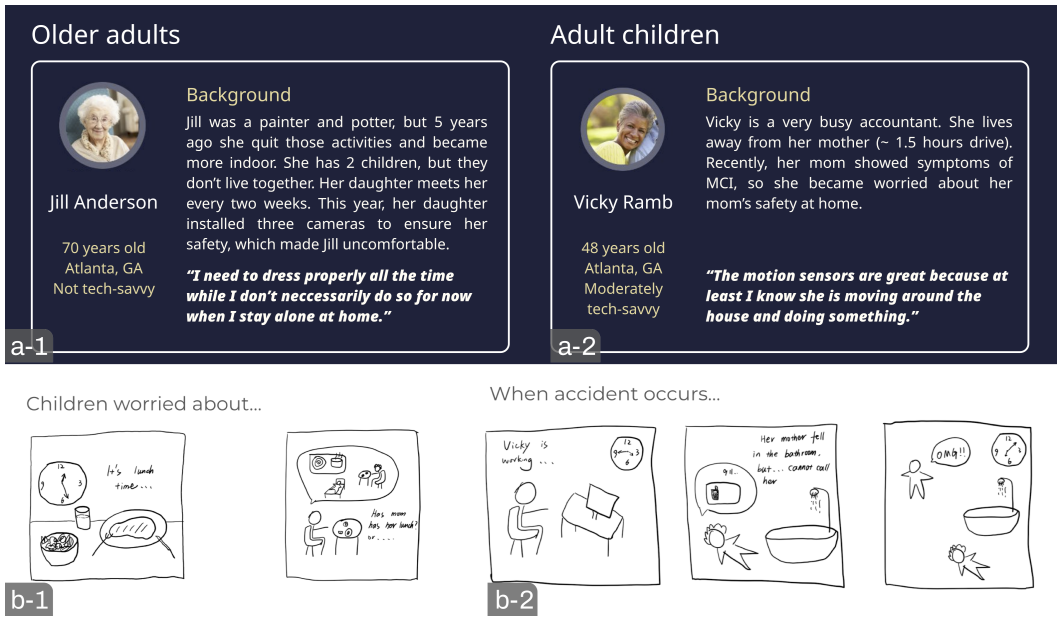

Fig. 3. a-1: the persona of the older adult; a-2: the persona of the adult child (persona images have been restyled for clarity in the paper. The exact images used during the artist's workshop will be submitted as additional/supplemental material.); b-1: storyboard - at lunch-time the child made a phone call to check on her mom, but since her mom already had eaten her meal she got annoyed by the constant pestering by her daughter; b-2: storyboard - the senior fell but the child was not notified in a timely manner. For detailed descriptions please check supplementary materials.

the personas captured both parties' demographics, in-home activities/activities of interest, quotes, background information about their relationships with each other and past experience in data sharing, goals and needs of data sharing, and concerns about data sharing. Inspired by Zhang et al. [73], we also presented 2 storyboards that clearly described the contexts and scenarios when the seniors and children often experience when they don't live together [Fig. 3]. The storyboards further elaborated the idea of awareness, in which the adult children at a distance could be aware of something that had or had not happened without the need to call or visit. Tradeoffs around

privacy and awareness described in the previous sections were shared with the designers during the workshop as well. We pointed out the two categories of information - *movement and daily activities* - to be shared, the tradeoffs around privacy and awareness of different daily activities, and the idea of only presenting necessary information without any visual information to avoid violating privacy. We also defined the design restriction which was only using the indoor localization data as the input source. The purpose of this session was to get the designers familiar with the populations and the context, and enable them to build on our previous findings.

After that, each designer was asked to take 1 hour to design a digital prototype of the visualization with a short paragraph describing the design details. We did not set restrictions on the fidelity or format of the prototype, however, all of our designers found the time was enough for them to create a mid-high fidelity prototype in a digital format. We collected 6 prototypes (Va-Vf) from 5 designers (one designer produced two prototypes) shown in Fig. 4. All the participants then came back to the workshop, presented, discussed and criticized each of the designs.

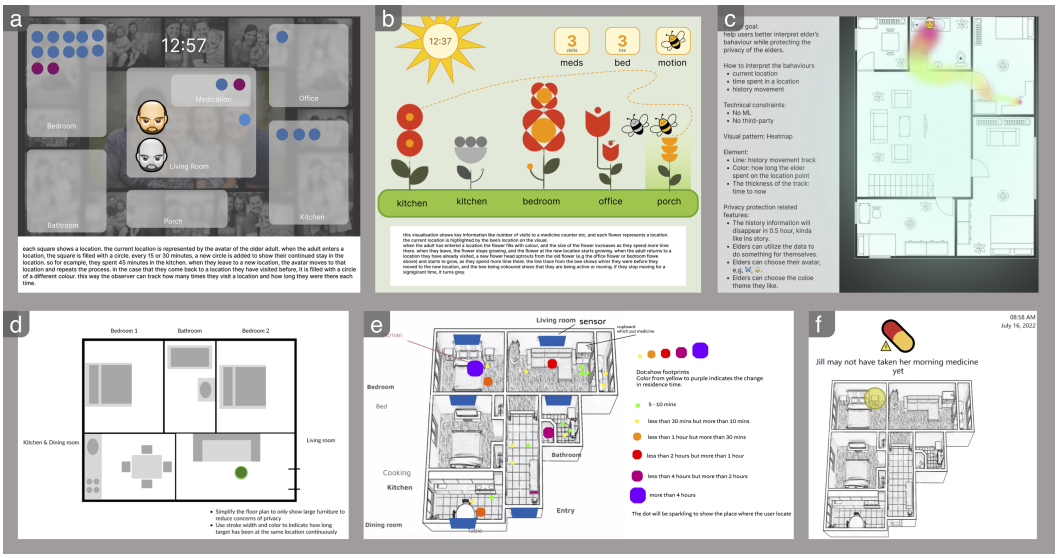

Fig. 4. Six different visualizations (Va-Vf) generated by designers during the workshop

6.2 Results

From all the designs, the idea of using the floor plan as the background was dominant (5/6). There were some creative design primitives around this idea. Instead of showing the furniture, the designer of Va drew several important areas (e.g. medication area) in the rooms to highlight important information and avoid showing unnecessary information. *"Based on previous research findings, it doesn't seem that their kids need to know the exact coordinate of the older adults, but more of are they doing these specific things, or are they safe. So I thought abstracting it a little and taking out the details like the floor plan might make them a little more comfortable."* (D1) Similarly, the designer of Vd decided to only draw the vague shapes of the furniture and blurred out the not important ones, assuming that furniture might play an important role in interpreting activities from the visualization. On top of the background, many designers had decided to outline important information using different visuals. These visuals have been carefully selected based on earlier user research with the children, and typically include information about *crucial activities*, movement,

safety, and other important factors. In Vb and Vf, text boxes were created to display the user's status, emergency, medication routines and bedtime. Designers also played with the visual of the avatar. The color of the avatar would change from colorful to gray or from green to red to indicate if the person was inactive in Visualization a and d. To display the historical data, designers provided various solutions. D1 and D4 tried to show the length of time someone spent in certain areas. In Va, the total number of dots in the squares represented the length of time someone spent in that area, while in Ve, it was the size of the dots conveying similar information. Other than the length of time, Vb and Vc tried to visualize the historical locations and traces using lines, tracks and heat-map-like color changes. However, in later discussions, other designers questioned the complexity of these designs. *"There are too many elements in Vc. Size, color, thickness... I don't know if older adults could understand these."* by D1. The possible growth of the messiness of historical traces over time was also pointed out. Designers agreed that the historical data should not lay over other important information, and the current designs might need to be adjusted to be simpler and clearer.

From previous research and our user research sessions, we described four key goals with elaboration in earlier sections. Based on this, we combined the creative ideas proposed by the designers to synthesize **six detailed design insights** specifically for indoor location visualization that we carried into our design:

(1) The design should convey relevant information about a person's daily life to support low-level awareness of that person's well-being.
  (a) *Movement* and *daily activities* (*crucial* and *customized*).
    (i) Particular areas should be created inside one room to highlight important activities (e.g. medication area).
    (ii) Avatar should have different stages to represent the person's real-time safety status.
    (iii) Important status/accidents/activities should be highlighted.
(2) The design should depict trends over time or the different categories of information represented.
  (a) Use visual ques (e.g. color, size) to represent the time someone spends in certain areas.
(3) The visualization should provide a qualitative view respecting privacy concerns.
  (a) Information of *crucial* and *customized activities* should be provided in a qualitative view.
    (i) Provide activity panels for *crucial* and *customized activities*.
  (b) Information of *private* and *casual activities* should not be displayed.
    (i) Only include necessary furniture and make them vague.
  (c) No visual information should be captured and delivered.
(4) Reduce the display's complexity.
  (a) History data is important, but make it ambient.

7 IFLOOR: DESIGN OF THE VISUALIZATION

After synthesizing all the findings and ideas from the previous sessions, we wanted to embody those insights and further test them. In order to do so, the researchers designed *iFloor*, a visualization artifact as our final design to be used in later user testing sessions [Fig. 5].

The visualization consists of 2 parts: the floor plan area and the panel area on the top. There are 3 elements in the panel: time, status and activities. In the floor plan area, different rooms are labeled, only necessary furniture are drawn, and important areas are especially highlighted using dot lines. The star in the middle represents the real-time location of the older adult. The color of the star shows the active status of the person which also aligns with the status box in the panel. When the person is moving, the status of he/she would be 'active', the emoji would be smiling, and the color would be green; when the person is staying in an area for a relatively long time (5

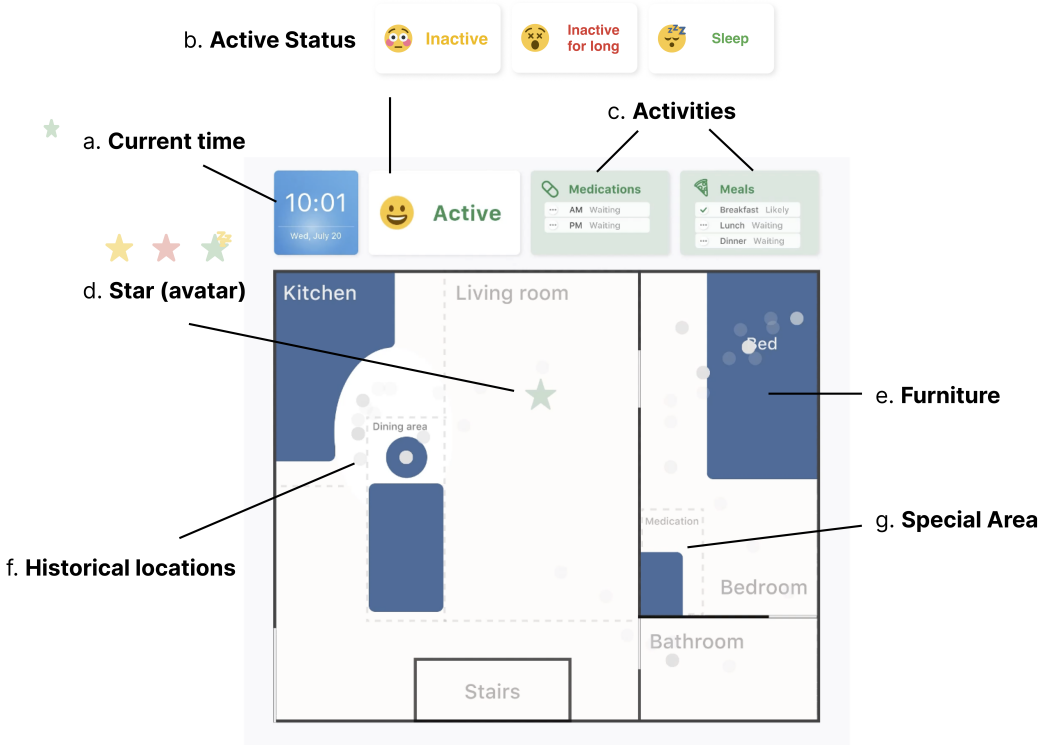

Fig. 5. Different elements in the final visualization.

minutes in this version), the status would be 'inactive', the emoji would change accordingly, and the color of the avatar would be yellow; when the person remains in active in a dangerous area (e.g. close to the stairs), the status would change to 'inactive in dangerous area', the emoji would be in a dangerous area, and the color of the avatar would turn to red. The grey dots all over the floor plan background show the history locations of the person. Every 30 seconds, a 50% gradient grey dot would be drawn at the current location of the person. The darker the dots are, the more movements have happened in certain areas earlier that day. In crucial areas, we also keep track of the historical location data to infer the completion of *crucial activities*. For example, if the person has not been to the medication area before 1pm, he/she might has missed his/her morning medications, and the results will change accordingly on the activity panel (AM med: not likely). In the visualization, we only draw furniture that are related to *crucial* or *customized activities* and left other areas blank (e.g. living room - *casual activities*; bathroom - *private activities*). The status of 2 *crucial activities* and *movement* information are specifically listed in the panels. In summary, all the design decisions we made were synthesized from the designer workshop with the intention of either limiting or expanding the ability to interpret related activities. For instance, we made unnecessary furniture vague, assuming that adult children will not be able to interpret certain *private activities* without the presence of those furnitures, in order to safeguard the privacy of the elderly. Moreover, we added a summary panel at the top of the visualization, assuming that it could help adult children quickly obtain important information. In the later user testing, we plan to use *iFloor* to evaluate these assumptions and design decisions.

Fig. 6. The 3 presentations showed in the user testing session. Abstract art Travalogue (left): geometric patterns were drawn and overlaid on the background according to the real-time location [42]; iFloor (middle): different elements were shown as described in section 7; Video (right): raw videos were captured by an indoor camera installed at the corner of the room.

8 USER TESTING

In previous sessions, we described several takeaways about designing visualizations to balance the tradeoffs surrounding privacy of older adults and awareness of adult children. We then elaborated several design insights based on previous findings through a brainstorming workshop, and finalized a prototype *iFloor* that embodied those insights. Moving forwards, we would like to use *iFloor* as an artifact to validate and further explore those design insights.

Instead of creating a 'perfect' or 'state-of-the-art' indoor activities visualizing system, *iFloor* served as a tradeoff that researchers designed to ease the tension between older adults and their children in the data-sharing process. As a result, to validate our design insights, we wanted to find two extremes of the tradeoffs to test if those insights' embodiment (*iFloor*) stands in between. At one end of the tradeoff spectrum–very informative but less privacy preserving–we selected the raw video from the camera as the example [Fig. 6 right]. The raw video from the camera was considered a very informative but possibly privacy-invasive presentation, proved by past research[2, 45]. For the other end of the tradeoff spectrum–highly privacy preserving but less informative–we picked the abstract art generated from the indoor location created by Li et al.in their work *Travelogue - Blooming* [42][Fig. 6]. In *Travelogue*, geometric patterns are drawn and overlaid on the background according to the real-time location. Li et al. have shown their visualization to be both abstract and privacy-preserving with 12 participants (general populations). Therefore, we chose it as the other end of our tradeoff spectrum. *iFloor*, which is both privacy-preserving and informative, was our final design that stands in between.

To summarize, we chose to compare three different visualizations: the raw video from the camera, and two visualizations generated from the indoor location: *iFloor* and the abstract art *Travelogue* [Fig. 6] [42]. These three visualizations are expected to be seen as being located at three different positions in the tradeoff spectrum. By comparing the three different visuals, we are able to learn more about the tradeoffs around privacy and awareness regarding the specific visual elements.

8.1 Method

8.1.1 Data collection process.

The data that needed to be collected in the session is raw video from the camera and real-time locations in time series. In order to mimic the real-world situation, we conducted a day-in-fast-forward testing in a mock-up room [44]. The room was arranged as a mock studio apartment with a kitchen, dining area, bedroom, living room and bathroom. One researcher performed daily activities following a similar timeline in real-life (e.g. getting up in the morning, having lunch

around noon)[Table. 3]. The whole mock-up testing lasted 28 minutes with an additional 20 minutes of static videos depicting sleep. The total 48 minutes of collected data mimicked a day with a 30x speed-up. The video was captured through a camera, and location data was captured manually to generate the visualizations.

8.1.2 User Study design.

We wanted our participants to watch the actual video/visualization of the activity, learn their feedback, and see if there's any difference between various (categories of) activities and the three presentations. As a result, we designed a user testing that contained 13 tasks to test it out [Table. 5].

The first 12 tasks covered four activities (*relieving, eating, falling, sleeping*) in three forms of presentation (raw video, visualization, and art). In each task, we showed a 15 seconds short video/*iFloor*/abstract art of the researcher (assumed name *Jasmine*) performing a certain task. After that, the participant answered 3 questions regarding the content of the video/viz/art. For both the older adults and the adult children, the first 2 questions were the same: 1) What is Jasmine doing right now? 2) Do you understand this video/visualization? (*value=2: Yes, I can understand what's going on and interpret the activity; value=1: Yes, I can understand something is going on, but I cannot interpret what activity it is; value=0: No, I don't understand and it looks confusing to me.*). For the 3rd question, older adults rated if they were comfortable sharing this video/viz/art with their children (*value=2: comfortable; value=1: somewhat comfortable; value=0: not comfortable.*), and the adult children rated if they thought similar video/viz/art of their parents would be helpful (*value=2: useful; value=1: somewhat useful; value=0: not useful*). Due to the limited resources of participants (10 subjects including both older adults and children), we decided to conduct a within-subject experiment [16]. Since the 12 tasks were in three different forms and were not exactly equal in terms of difficulty (e.g. video is expected to be the easier), we should not simply use a random order in this study because of the carryover effects [64]. To assure proper counterbalancing, the researchers conducted a pilot study within the research group, and selected the order of 12 tasks with respect to the different interpretability of 3 visualizations (see Table. 4) [11, 24]. Task 0 *read a book* as a sample task for the researchers to explain different visualizations. Videos were placed in the later part of the user testing to avoid participants using this information to infer the answer to other questions [64]. None of the adjacent tasks were set to be the same activities [11, 24]. Extra options for different activities were provided as distractor items (see Table. 5 Q1) [33]. After finalizing the order of the 12 tasks, all participants conducted the experiment in the same order. We also asked participants at the end of the experiment whether they could infer the answers to the other questions from the earlier visualizations, and we received negative answers from all participants. As a result, we believe that this plan was reasonable under the current circumstances. For Task 13, researchers described one scenario when the adult children wanted to check if the older adults had taken the morning medication or not, and reached out to get the visual at that moment. After seeing a screenshot of the video/viz/art of that time, the adult children were asked to judge the status of Jasmine from the video/viz/art, and the older adults were asked to rate if they felt comfortable sharing these graphs. All of the participants were asked to complete the aforementioned 13 tasks which covered three forms of visualizations. They could answer the questions verbally or/and fill out a digital survey. After all 13 tasks, we discussed the three types of presentations with both sides and let them rate their general performance.

8.1.2.1 Recruitment.

For the user testing session, we reached out to the same participants in the focus group sessions and interviews. All participants in the interviews continued to conduct the user testing with us (10 participants, including five older adults and five children) [Table. 1]. Unfortunately, we did not get much response from participants in the in-person focus group sessions due to various reasons

Time of the day	Task content	Time of the day	Task content
0:00-8:00	Sleep	16:00	Watch TV
8:00	Get up	16:30	Go outside
8:30	Brush the teeth	18:00	Wash hands
9:00	Cook breakfast	18:05	Wander around the room
9:30	Eat breakfast	18:20	Relieve
10:00	Read a book	18:30	Go upstairs and slip
10:30	Relieve	19:00	Rest on the sofa
10:35	Watch TV	19:30	Get some water
11:00	Get some water	19:45	Watch TV
11:05	Watch TV	20:15	Take a shower
11:45	Cook lunch	20:45	Do the laundry
12:00	Get stuck on cooking	21:00	Watch TV
13:00	Eat lunch	21:30	Finish the laundry
13:30	Relieve	21:45	Take medication
13:45	Clean up the kitchen	22:00	Go to bed
14:00	Clean up the house	22:00-24:00	Sleep

Table 3. Different activities in the day-in-fast-forward testing to mock up a typical day.

(no digital contacts, etc.). Consequently, the participants who took part in the interviews and user testing were the same and did not overlap with those who participated in the focus group session. All 10 participants completed all the tasks (3 visualizations, 13 tasks for each visualization).

8.2 Results

We would like to examine if adult children were able to get enough information from the visuals and if older adults were feeling comfortable sharing those visualizations. We analyze the data with respect to our core tradeoffs: *Awareness* and *Privacy*. *Awareness* is exemplified by the correct inference of activity by the adult children. *Privacy* is exemplified by the level of comfort the older adults feel in sharing an activity's visualization.

- *Correctness*: Results of Q1. If the participant chose the correct activity, the correctness would be 100%; otherwise, the correctness would be 0% (including when choosing *'I'm not sure.'*). This result directly described if the participants had successfully comprehended the visualization.
- *Comfort level*: Results of Q3/4. This is the most direct indicator of participants' subjective perceptions of privacy of different visualizations.

8.2.1 Awareness.

For the adult children, raw video from the camera (Q1 correctness 100%; Q2 average 2/2; Q6 average 2/2) was clearly the easiest to understand; the visualization was easy to digest (Q1 correctness 80%, Q2 average 1.75/2, Q6 average 2/2); and abstract art was almost impossible to interpret (Q1 correctness 25%, 0% when excluding the task of sleep; Q2 average 0.75/2; Q6 average 0.4/2) [Fig. 7] [Table. 6]. The only situation when the children were able to interpret some data from the art is

Task number	Activity names	Presentation
0	Read a book	Art, Visualization, Video
1	Fall	Art
2	Relieve	Visualization
3	Eat	Art
4	Relieve	Art
5	Sleep	Art
6	Eat	Visualization
7	Fall	Video
8	Sleep	Visualization
9	Eat	Video
10	Fall	Visualization
11	Relieve	Video
12	Sleep	Video
13	Take medication	Art, Visualization, Video

Table 4. Order of tasks in the user testing.

when Jasmine was sleeping, where only one geometric pattern was generated since there was no other history of movement. Aligned with the correctness of the tasks, they also expressed that the video and visualization were much more useful than the art (Q3: video 1.95/2; viz 1.6/2; art 0.35/2). *"The visualization is definitely easier than the art but still left something hard to tell. (P4p)"* .

For different activities, the complexity to interpret useful information from the visuals was different for adult children [Table. 6]. Participants achieved the best scores when inferring sleep activity due to its simplicity. *"The only art I could understand was the one that had one area. It was simple, with no movement, so Jasmine was sleeping. (P2c2)"*. During the interview, we noticed that the adult children were able to synthesize different elements in the visualization to infer useful information. Location information combined with the floor plan and furniture is the main basis for presumption. *"The star (Jasmine) was on the bed, not moving, I think she was sleeping. (P1c)"* The crucial areas drawn on top of the floor plan were also helpful for quickly identifying important activities (P2c1). The active status box was able to convey the information when dangerous events happened. 4 of the 5 adult children successfully identified that Jasmine had fallen after seeing the visualization. The adult child who had not interpreted this information (P1c) suggested that the signs in the visualization could be more evident and not salient. She said: *" I wish the star could flash when any accident happens instead of just turning to steady red."* The activity panel also served its original intentions, however, it was less effective than we had thought. Only 2 of 5 children were able to realize that Jasmine had not taken her morning medication from the visualization in task 13, and one of the 2 children actually interpreted this information from the absence of historical gray dots in the medication areas instead of the medication panel. From the interviews, we realized that it might be caused by the limited time of introducing the example and watching the real-time visualization. Moreover, since the entire visualization is based on location information, participants also preferred to make judgments from location information. This leads to a discussion of the trust of the activity panel, which we will discuss in a later section. Two of our participants mentioned that they had used the timestamp on the panel to infer certain activities, one to identify sleeping (P2c1), and one to distinguish between relieving and taking a shower from the length of time spent

Older Adults		Adult Children	
Task 1-12			
Q1: What is Jasmine doing right now?			
Take medication	Relieve	Take a shower	Fall
Sleep	Eat	Brush teeth	Watch TV
Have a drink	Read a book	Cook	I'm not sure
Q2: Do you understand this video/visualization?			
Yes, I can understand what's going on and interpret the activity (value=2) Yes, I can understand something is going on, but I cannot interpret what activity it is. (value=1) No, I don't understand and it looks confusing to me. (value=0)			
Q3: If you are Jasmine, will you feel comfortable sharing this video/visualization to your children?		Q3: Think about Jasmine as the member, do you think it's useful to get this video/visualization?	
Not comfortable (value=0) Somewhat comfortable (value=1) Comfortable (value=2)		Not useful (value=0) Somewhat useful (value=1) Useful (value=2)	
Task 13			
Q4: At 13:39, your children want to check if you have taken your morning medication or not...This is what they see. Do you feel comfortable sharing this visualization with them?		Q4: At 13:39, you want to check if the member has taken his/her morning medication or not...This is what you see. Do you think he/she had taken the med?	
Not comfortable (value=0) Somewhat comfortable (value=1) Comfortable (value=2)		Not likely Likely I'm not sure.	
Final evaluation for art/viz/video (0 Disagree 1 Neither agree nor disagree 2 Agree)			
Q6: Overall, this visualization is easy to digest		Q6: Overall, this visualization is easy to digest	
Q7: This visualization makes me think my privacy has been protected		Q7: This visualization easily conveys information in different situations	

Table 5. The questions in the rating scales where older adults and the children will be answering in the user testing sessions.

in the bathroom (P2p2). We also realized visualization was considered to be less effective when conveying information in different situations (Q7 for children: video 2/2, viz 1.4/2). P2c1 wrote this in the digital survey: *It (viz) might not apply to some situations: 1. some temporary furniture (ladder*

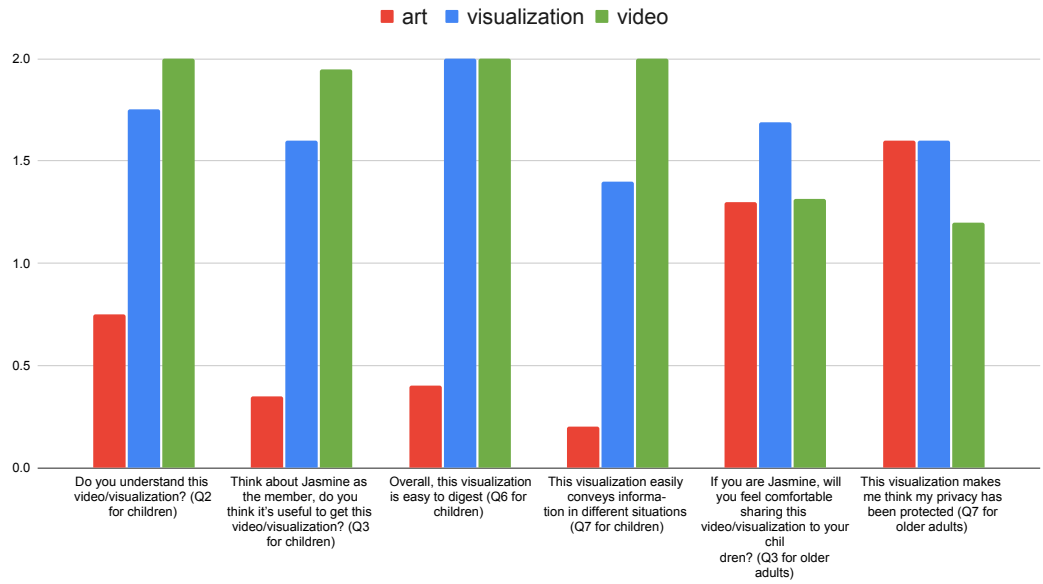

Fig. 7. Quantitative results collected from the rating scales. The 4 questions on the left are related to *awareness*, and the 2 questions on the right are related to *privacy*

Activity names	All	Raw video	Visualization	Art
Relieve	53.3%	100%	60%	0%
Fall	60%	100%	80%	0%
Eat	53.3%	100%	60%	0%
Sleep	93.3%	100%	100%	80%

Table 6. Task1-12 correctness of different activities for raw video, visualization and art for adult children.

is more dangerous than stairs) 2. The system cannot detect some accidents like when the kitchen is on fire.

8.2.2 Privacy.

For older adults, raw video from the camera was the most privacy-invasive presentation (Q3 1.3125; Q7 1.2), and the visualization was the most privacy-preserving presentation and received the highest scores in both privacy-related questions (Q3 1.6875; Q7 1.6). The abstract art, different from what we expected, had a high score in the final evaluation (Q7 1.6) and the lowest score in the questions that were provided right after seeing the graphs (Q3 1.3). We discovered that the correctness of inferring the activities from the art was only 11% for the older adults, and they also rated only 0.2/2 in Q6, both lower than their children. From the interviews, we realized that most of the older adults felt the art was okay and not privacy invasive because they could not understand it at all. But at the same time, since the kind of information presented remains unknown to them, some seniors

Activity names	All	Raw video	Visualization	Art
Relieve	0.78	0	1	1.33
Fall	1.58	2	1.75	1
Eat	1.73	2	2	1.2
Sleep	1.72	1.5	2	1.67

Table 7. Task1-12 average comfortable level of different activities for all, raw video, visualization and art for older adults. (Not comfortable: value=0; Somewhat comfortable: value=1; Comfortable: value=2)

questioned their own judgment and doubted that perhaps some additional information had been conveyed to their children without their knowledge. For example, *"Jasmine was going to the toilet? I don't understand it at all. Do my kids understand this?"* was asked by P2p2 who rated 4 activities with an average score of 1 in Q3s.

The comfortable-to-share levels for different activities vary [Table. 7]. Similar to what we had found in the previous session, the *private activities* (relieve) had the lowest score (Q3 0.78); the *crucial activities* (eat, fall) and *customized activities* (sleep) had a relatively high acceptance score (Q3 fall 1.58; eat 1.73; sleep 1.72). It is worth noting that the participants' comfort levels of sharing the relieving activity for visualization(1) and art(1.33) are higher than that of video(0). It can be inferred that the choice of capturing in-room information rather than video has mitigated the seniors' concerns about privacy. At the same time, the correctness of successfully inferring the relieving activities for the adult children was lower for visualization (60%) than the video (100%). Through the interviews we learned that the elderly were willing to share such visualization with their children, however, they had concerns when sharing the video.

8.2.3 ***Summary.***

Overall, our results show that the tussle between privacy and awareness can be mitigated through the right choice of visualization design. In our evaluation, *iFloor* provided a good balance between the privacy and awareness goals (see Figure 7), and yet it has limitations. Video provided more information to the observers than the *iFloor* visualization. However, *iFloor* proved to be a substantially better choice than abstract art. From a privacy preservation angle, *iFloor* is a top choice. We believe our conclusions are representative of real-world at-home situations, which have also informed the activities we choose. [Table. 6, 7].

In section 6.2, we summarized the design insights that we distilled from the previous sessions. Through user testing, criteria number 1-a-i, 1-a-ii, 1-a-iii, 2-a, 3-a-i, 4-a proved to be useful (being used as a reference by at least 1 participant when interpreting the visualization). 3-b-i and 3-a are considered feasible and efficient in protecting seniors' privacy. However, there are still elements that could be improved. From the results of Q7 [Fig. 7] and the feedback from the participant (P2c1), we realized that *iFloor* is less universal than raw video when adapting to different situations happening at home. We learned that location-related information is more useful to the participants because it is aligned with the raw data resource and is considered trustworthy. An important insight comes from how the older adults associated trustworthiness with visualizations that they could understand. We found it surprising that older adults did not prefer abstract art because they could not tell if there was some hidden meaning that their children could get from the abstract art that they did not understand. The activity panel in *iFloor* proved to be a steeper learning curve for older adults than we anticipated. While the design motivation behind 1-a-iii appears to be valid, the notification should be more evident and dynamic instead of a static change in visuals (P1c).

Combined with the previous list in section 6.2, below are the **final design insights:**

(1) The design should convey relevant information about a person's daily life to support low-level awareness of that person's well-being.
  (a) *Movement* and *daily activities* (*crucial* and *customized*)
    (i) Particular areas should be created inside one room to highlight important activities (e.g. medication area).
    (ii) Avatar should have different visual effects to represent the person's real-time safety status.
    (iii) Important status/accidents/activities should be highlighted with evident and dynamic changes.
(2) The design should depict trends over time or the different categories of information represented.
  (a) Use visual cues (e.g. color, size) to represent the time someone spends in certain areas.
(3) The visualization should provide a qualitative view respecting privacy concerns.
  (a) Information of *crucial* and *customized activities* should be provided in a qualitative view.
    (i) Provide activity panels for *crucial* and *customized activities*
  (b) Information of *private* and *casual activities* should not be displayed.
    (i) Only include necessary furniture and make them vague.
  (c) No camera-based information should be captured and delivered.
(4) Reduce the display's complexity.
  (a) History data is important, but make it ambient.
  (b) The learning curve of the qualitative view should be considered during the design process, especially for tech-unsavvy users.
(5) Design for trust.
  (a) Display more information that is aligned with the original data resources to promote trust.
  (b) Provide enough information and explanation to make sure the user has a basic understanding of the graphics.
  (c) Keep in mind that a certain level of trust is the basis for users to share information without worrying about privacy issues.

9 DISCUSSION

In the above study, we explored how visualization of indoor locations should be designed to convey information to children while protecting the privacy of the elderly. For many families, the root cause of tension is a disagreement between the two parties regarding the level of autonomy of the elderly. For different activities, the child's urgency to be informed is also different from the elder's privacy concerns about sharing that information, and this can cause conflict in some cases. For some *customized activities* and *private activities*, particular attention should be paid to the system design to present the relevant information.

Through this study, we further demonstrate that even for the same activities and information, different presentation methods can lead to different tensions between older adults and their children. Direct camera feeds are often considered worrisome (P1p). Videos from in-home cameras were the easiest to interpret, while the most privacy-invasive. Abstract art was the most confusing and incomprehensible artifact, and surprisingly was not seen as the most privacy-preserving one. *iFloor*, instead, did a great job in balancing the 2 needs and concerns.

We considered privacy and awareness as two equal tradeoffs, however, they have different priorities and order of precedence, especially when it comes to the power dynamics between the two parties. All of the participants in this study had mild cognitive impairment while still retaining a

significant degree of autonomy, and they typically retained the authority to make the final decision regarding the installation of monitoring systems. Nevertheless, as some of the participants noted, this power dynamic could shift along with the progression of the disease, leading to more profound tensions. To preserve the dignity of the elderly, designers may start with the children's needs and then blur out the information that will make the elderly feel uncomfortable. In other words, no information should be shown to children if it is not needed or cannot be interpreted, even if it does not violate privacy. In our initial design discussions, we took for granted the use of detailed floor plans as a backdrop, but in subsequent discussions with other designers, we realized that much of the furniture was actually not necessary to be displayed at all. When we get huge location data, it is very important to show the information selectively.

In addition, privacy and awareness are not simply binary correspondences in the design process, but have a more complex relationship. We thought that the most abstract and incomprehensible art would be the most privacy-preserving visualization, but this is not the case. The less tech-savvy elderly are often even more confused when their children are unable to understand the information in the visualization. And when seniors are unable to understand the visualization at all, their judgment about the extent to which privacy is compromised in it changes. Some seniors began to speculate whether their children were getting more information than they were, and thus became reluctant to share information that they had difficulty understanding and judging (P2p2). In other words, when the elderly cannot understand the information being shared, they cannot accurately judge whether it violates their privacy. Therefore, the information sharing process is not just a combination of quantitative data points, but more of a process of communication and reaching consensus.

The level of trust and involvement of children in the source of data is also a very interesting topic. We have found that when children understand the algorithms and logic of our visualizations, they judge for themselves whether the data is trustworthy. When P2c1 learned that our judgments about daily activities in the panel were only based on location information, she was more likely to look for relevant historical location information in the graph and determine whether her mother was taking her medication or not, by herself, rather than using the data we summarized. Considered from another perspective, indoor location information also provides much room for flexible inference.

Although we only focused on one-way communication in this research, mutual needs of communication certainly exists in reality. Mynatt et al. also mentioned the importance of the emotional connections between the two parties when sharing this information [48]. For children, knowing the movements of their aging parents is often more purposeful, such as learning about their safety, while for the elderly, knowing their children's daily activities is more emotionally directed, or even just "keeping up with old habits" (F3). Therefore, the design concept should be changed accordingly in this context. Since we decided to focus on discussing the sharing of parents' daily activities with children in this project, our starting point was more practical. However, considering more non-purposeful emotional needs is definitely an important direction for future work, and one that might be even more challenging to evaluate.

In this study, we decided to focus on visualizing only one type of data, indoor location. However, in real life, information from different sources can often be used in combination. In the questionnaire, we found that visualization scored low in Q7 (1.4). P2c1 told us that her mom did not have a fixed location for taking medication, so a smart pillbox might be more accurate than drawing a medication area. P2p1 confirmed it in our interview: "It would actually be so hard to determine if I have taken medication or not, because I can do anything in the bathroom or the dining room." In future studies, we should utilize indoor locations, motions as well as sensors that can detect specific activities to achieve the best results.

10 LIMITATIONS

Since our focus is to evaluate different design criteria through the final visualization approach rather than developing a system, we decided to have the researcher test in a mock up room to draw a sample of visualization videos suitable for user testing. In real life, the behavioral patterns of the elderly and the researcher are different, and the hardware sensing data is subject to error and will not be as 'pristine' as the data collected in the lab. Therefore, we can see that based on this study, long-term deployments and studies will be very meaningful.

As outlined in section 5.2.1, the majority of seniors who participated in our study expressed no objection to sharing their indoor location or related activities with their children. Nevertheless, we acknowledge that there may be some older adults who fall outside this category and prefer not to have sensors tracking their whereabouts throughout their home. To honor their preferences, alternative technologies must be explored to strike a balance in this tradeoff.

In this study, we conducted separate interviews and user testing with older adults and their children to ensure that the feedback was not influenced by other parties. However, we also recognize that the negotiation process for an agreement between the two parties was a critical issue to investigate. While it was beyond the scope of this research, future studies could design additional activities to reveal and study the negotiation process, including the tensions that arise when conflicts occur, while also taking ethical considerations into account.

Regarding our participants, female (80%) outnumber other gender identities in the interviews unintentionally. We might get a more inclusive result if we have more male participants joining the research. However, because female life-expectancy is indeed higher than male life-expectancy in the US [23], therefore a gender skew will likely remain even with a very large sample size. We should also be cautious when generalizing our results to other older adults or populations due to the sample size. As a result, we provided our results as design insights that aim to *inspire* other researchers when designing similar system rather than building a framework or synthesizing guidelines. The limitations of our study's small sample size were also apparent in our ability to accurately categorize activities, as discussed in section 5.2.2. As a result, we recommend that future research follow our methods but adjust the thresholds for specific populations. Moving forward, we plan to acquire more data and participants to develop a more comprehensive clustering formula.

Despite the focus group sessions consisting of an entirely different participant group, the same individuals participated in both the interviews and user testing, which may limit the generalizability of the testing results. To avoid over-generalizing our findings, we have chosen to present the results as design insights rather than broad descriptions such as design guidelines as described earlier. This approach emphasizes the inspirational nature of the study rather than drawing definitive conclusions. To ensure more comprehensive user research and testing, future studies should aim to involve a broader range of participants.

11 CONCLUSION

In this research, we elaborate on the key tensions of privacy and awareness between older adults and their children. We summarize how these older adults and their children perceive the privacy and importance of sharing information about movement and four types of daily activities: *crucial, private, casual and customized.* Through an iterative process, we synthesize the key design insights for visualizing activity information, and design a visualization approach based on these insights. We then evaluate the approach through comparing the acceptability of this design with raw video data and an abstract art *Travalogue* [41].We posit that *iFloor* is able to provide enough information while protecting seniors' privacy at the same time. We have also discussed the various ways participants

interpret the visualization, and how different factors (e.g. trust of the system, raw data resources) may influence their perspectives of privacy and awareness.

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