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Assessing Older Adults' Perceptions of Sensor Data and Designing Visual Displays for Ambient Assisted Living Environments: An Exploratory Study

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Summary

Objectives—Our objectives were to: 1) characterize older adult participants' perceived usefulness of in-home sensor data and 2) develop novel visual displays for sensor data from Ambient Assisted Living environments that can become part of electronic health records.

Methods—Semi-structured interviews were conducted with community-dwelling older adult participants during three and six-month visits. We engaged participants in two design iterations by soliciting feedback about display types and visual displays of simulated data related to a fall scenario. Interview transcripts were analyzed to identify themes related to perceived usefulness of sensor data.

Results—Thematic analysis identified three themes: *perceived usefulness of sensor data for managing health*; *factors that affect perceived usefulness of sensor data* and; *perceived usefulness of visual displays*. Visual displays were cited as potentially useful for family members and health care providers. Three novel visual displays were created based on interview results, design guidelines derived from prior AAL research, and principles of graphic design theory.

Conclusions—Participants identified potential uses of personal activity data for monitoring health status and capturing early signs of illness. One area for future research is to determine how

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visual displays of AAL data might be utilized to connect family members and health care providers through shared understanding of activity levels versus a more simplified view of self-management. Connecting informal and formal caregiving networks may facilitate better communication between older adults, family members and health care providers for shared decision-making.

1. INTRODUCTION

Given global demographic shifts due to aging, there is a need for innovative ways to help greater numbers of older adults manage their health and maintain independence at home. In developed countries, Ambient Assisted Living (AAL) environments that detect a person's activity in the home may help meet this need. By allowing older adults to view their activity patterns over time and share these data with family members and health care providers, these environments may help identify functional changes that predict falls or behavioral changes that indicate risks for social isolation (1). Electronic health records can provide an infrastructure for these data that affords ease of access and a single point of maintenance if they incorporate visual displays for use by older adults, family caregivers and health care providers. However, one challenge of AAL environments is the deluge of data they produce that can overwhelm the abilities of older adults and families to understand and process it as information for decision-making (2).

Visual displays play a significant role in decision-making from both provider and patient perspectives (3, 4). Design of specific visual displays to accommodate the changes in cognitive and physical abilities that people experience as they grow older can help promote understanding of complex datasets. A broad literature exists on appropriate design of visual displays, ranging from theoretical frameworks of information visual designs (5, 6), to cognitive principles of information processing (7, 8). In addition, there are specific heuristics and design guidelines that target older adults as users of web pages and interfaces in computer systems (9, 10). However, there is limited literature about the design of visual displays of sensor data obtained from AAL environments specifically for use by older adults.

To promote adoption and sustainable use of AAL environments, technology must be easy to use and visual displays must present activity data as meaningful information to all stakeholders. This is particularly true with older adults, who may be disinclined to adopt health-related technology unless they perceive it as useful and easy to use. Participatory design can facilitate usable designs for older adults by 1) including older adults in the design process; 2) characterizing older adult needs and preferences 3) conducting multiple design iterations (10, 11). Thus, older adults' perceptions of sensor data from AAL environments are important to inform early designs of new systems and visual displays that accommodate their needs. Therefore, as part of a larger study that tested a theory-based mobility monitoring protocol using in-home sensor technology (12), we engaged older adults about their perceptions of sensor data and visual display preferences.

2. OBJECTIVES

The objectives of this exploratory study were to: 1) characterize older adult participants' perceived usefulness of in-home sensor data and 2) develop novel visual displays for sensor data from Ambient Assisted Living environments based on participant feedback from three- and six-month interviews.

3. METHODS

We enrolled community-dwelling older adults 65 years or older residing at an independent retirement community in Seattle, WA in a six-month study of in-home sensor technology. Each participant provided informed consent prior to enrollment. Inclusion criteria were: to be 65 years of age or older, a resident of the retirement community and fluent in English. Exclusion criteria were inability to provide written informed consent, known life expectancy of less than 6 months and unwillingness to have sensor technology installed in the residence. In-home sensor technology that consisted of motion sensors, a custom-built gateway, and a Web-based application for administration and data access was installed in each participant's home. Details of the sensor system and a full description of the parent study, including technical difficulties, are reported elsewhere (12). Members of the research team included clinicians, gerontologists and informaticians.

Semi-structured interviews to solicit feedback about specific uses and perceived usefulness of sensor data were conducted with participants at three and six-month visits. The same interview protocol was used during both visits, with the exception of questions about visual displays and two study exit questions. This was because the parent study called for comparison of participant attitudes related to privacy; data sharing; technology disclosure; data access and personal control of technology over time (12). During each interview session, we engaged participants in two total design iterations to create new visual displays. Design iterations involved two steps: soliciting and incorporating participant feedback in the design process. As part of the three-month protocol, participants were asked about their preferences for different visual display types. As part of the six-month interview protocol, a fall scenario was explained to each participant while he or she viewed bar chart displays of simulated activity data on a computer screen. Participants were asked to respond with observations and preferences regarding the bar chart displays to inform design. Interviews were recorded using a digital audio-recorder and transcribed verbatim by a member of the research team. All study protocols and instruments were approved by the Institutional Review Board of the University of Washington.

3.1. Thematic analysis

Three- and six-month interview transcripts were systematically analyzed by at least three coders to identify themes (13) related to perceived usefulness of AAL environments. Three coders independently coded a randomly selected transcript to create a code book. Disagreements about applications of codes were reconciled through in-person meetings. After coding several transcripts, codes were reviewed by the study principal investigators (PIs). The coding team independently coded and reconciled all subsequent transcripts. When the three-month interview transcripts had been coded, the study lead and the PIs met for a coding review to maintain fidelity to the coding process. Coded instances were grouped into themes according to similarity (for example: specific potential uses of activity data). The six-month interview transcripts were coded using the same code book.

3.2. Design Process

3.2.1. Fall scenario conceptualization—Our original intent was to present each participant with visualizations of his or her own activity data. However, technical difficulties precluded this approach. As an alternative, we conceptualized a fall scenario and created bar chart visual displays of simulated data for presentation at the six-month interview. We chose a fall scenario because falls are a major cause of morbidity and mortality in older adults (14, 15) and because it was relevant to the current study as two of our participants experienced falls between the three- and six-month interview visits (12).

The first author drafted a fall scenario informed by persona research (16, 17) and case examples from prior AAL environment research that visualized activity data from in-home sensors (18–21). The fall scenario was reviewed by the research team and revised based on their feedback. The final scenario was a short vignette that described a 93-year-old woman who experienced a fall, a visit to her health care provider, a short stay at her nephew's home and subsequent return to her residence. The time period covered by the scenario was about three-and-a-half weeks.

3.2.2. Initial design iteration—Participants were asked about their preferences for three different display types: time series plots that presented longitudinal activity data (bar charts); matrix displays that demonstrated activity data by room (room layouts); and status list displays that showed daily events inferred from activity data. The bar chart display type was by far the most popular among our participants. Bar charts are also the most common visual displays in the case examples of AAL environment research (18–21).

We created a bar chart display of simulated activity data of the fall scenario for use during the six-month interviews (Figure 1 – Display A). To guide design, we reviewed prior AAL research to identify guidelines for visual displays of in-home sensor data. One general guideline was to reduce the large amounts of sensor data to be visualized. A common strategy for data reduction was to aggregate activity data, for example, by displaying data by bedroom and non-bedroom activity levels (18) or by showing activity level categories by room (20). Other identified guidelines were to use date labels for displayed data and to maintain consistent backgrounds, labels and color format schemes to reduce cognitive load during interpretation of visual displays (16).

We generated simulated data for the fall scenario to represent motion sensor firings using a random number function for each hour of the day for rooms in the fall scenario residence. Simulated data were graphed for periods of aggregate activity level corresponding to *normal*, *change before fall*, and *return to normal* periods. These types of activity patterns are consistent with published case studies of AAL environment research. In accordance with the identified guidelines, simulated data were displayed as bedroom and non-bedroom activity levels in 4 six-hour intervals (12am to 6am; 6am to 12pm; 12pm to 6pm; 6pm to 12am). Categories for activity levels in rooms were defined as “None”, “Low”, “Medium” and

"High". "Low" indicated 0–15 minutes of activity per hour in a room, "Medium" indicated 15–30 minutes and "High" indicated 30 minutes or more. To assist with explanation of the scenario, three additional bar charts that showed close-ups (or "zoomed" views) of data for approximately one week were presented to participants (see Figure 1 – Display B for an example). All bar charts for the fall scenario were reviewed by the research team and revised based on their feedback.

3.2.3. Final design iteration—Based on participant responses to the fall scenario bar charts during the six-month interviews and principles of graphic design theory proposed by Tufte (22, 23), the final output of the design process was three new bar chart designs using simulated data from the fall scenario. The final iteration built on the information gleaned from review of the AAL case examples and three-month interview data in the initial design iteration. The three novel visual displays are presented in the Results section (see Figure 2) along with participant feedback and design process results.

4. RESULTS

We enrolled 8 community-dwelling older adults between the ages of 79–86. All eight participants participated in the three-month interviews. One participant died before the six-month interviews. Thus, only seven participants were interviewed about perceived usefulness of sensor data and visual displays at the end of the six-month study.

4.1. Perceived usefulness of AAL environments

Three themes were identified through thematic analysis of three- and six-month interviews. Following accepted practices for reporting qualitative research, these themes are described below with illustrative quotes.

4.1.1. Theme 1: perceived usefulness of sensor data for managing health— Participants identified specific potential uses of personal activity data for monitoring health status and capturing early signs of illness. For instance, one participant suggested that changes in bathroom activity might be used to detect the onset of diabetes: "*It could be signaling diabetes coming on or something of that nature… you don't recognize the frequency with which you're doing that but it's starting to show up here*" (P4). Another participant cited the potential usefulness of personal activity data when describing those who suffer from depression: "*They go to bed pull their sheet over their head and put on a hat to boot under the influence of depression and then an antidepressant they are suddenly out of bed again and reasonably active and so forth so I see a pattern shift*" (P8). Other ideas discussed by participants about potential health applications for personal activity data included monitoring sleep interruptions due to sleep apnea, changes in bathroom activity due to administration of diuretics, changes in eating behavior and detection of social isolation.

4.1.2. Theme 2: factors that affect perceived usefulness of sensor data— Participants discussed factors that influenced the degree to which sensor data were perceived as useful or not useful. As mentioned above, participants' desires to understand personal activity patterns were related to perceived usefulness of sensor data. One participant commented: "*It would be interesting if I wanted to find out if I am a patterned person* *because I don't know*" (P3). Similarly, participants mentioned that changes in health status could affect perceived usefulness. When talking about sleep, one participant noted: "*That's something that I think creeps up on people. They don't realize they aren't sleeping like they ought to be*" (P4). Living situation was cited as a factor that influenced perceived usefulness. For instance, participants thought that monitoring through sensor data could be more useful to those who were living alone: "*We're* [in] *a little different of a situation than a person living by themselves because we've got each other. We monitor each other*" (P2), and contrasted how the characteristics of a stand-alone residence, versus those of a community, might influence the usefulness of sensor and data: "*I can see where in a private home it would it would be of more use to your loved ones.*" (P7). Participants also voiced concerns about the availability of contextual information necessary to make sense of sensor data. Several brought up the point that the system would need external information to detect patterns and wondered how this would be possible. An example of an external information source is scheduling information that could enable alerts based on whether a person was away from home or motionless and in need of assistance. One participant in particular was against extra personal effort to notify the system that might interrupt his day. Other identified factors that affected perceived usefulness were age, the time when health monitoring begins, perceived interest level of others in accessing data and accessibility of data to others.

4.1.3. Theme 3: perceived usefulness of visual displays—Visual displays were cited as potentially useful for use by caregivers of older adults who might be experiencing cognitive decline: *"If they're not fully cognizant of things or don't remember things very well it could be useful for a second party to be looking at that to keep tabs what's going on"* (P6). Visual displays were also cited as potentially useful for use by older adults and health care providers to consult about activity levels: *"I would think it would be useful especially if someone - a lot of the time older people don't want to admit to being inactive - and you know you would be more, to be sure this is what is happening"* (P5). Another participant noted the visual displays could be useful for his adult children to maintain awareness of his health status, as demonstrated by the following three quotes: *"I know that one of my kids if they were saw that would probably say what's going on at night? You're not sleeping well? What's happening?"* later followed by: *"Now we got a fall, and so the next time we see something going on at night my kids are going to say wait a second, we're repeating here, now we got to be more serious about our inquiries"* with the final observation: *"It's just that kind of thing that would trigger I believe a little more depth in the questions"* (P4). Interestingly, those participants who perceived a lack of usefulness of sensor data for themselves were still open to discussion of the usefulness of visual displays of data.

4.2. Three novel visual displays

Three novel displays resulted from the final design iteration (see Figure 2). We identified several areas for improvement of visual displays from participant responses. Based on participant comments about the amount of information in the initial bar charts, we observed a need for ways to reduce clutter and facilitate ease of use. Due to the amount of time it took to give verbal explanations of the fall scenario bar charts during interviews, we identified a continued need to reduce complexity. This need was explicitly recognized by one study participant. In addition, the use of colors for the narrow bars in the bar chart created visual confusion for at least one participant. Another participant noted the need to display data in a way that more closely matched how people think about time in everyday contexts: *"When you divide people's world up into four six hour segments I don't think it is quite the same thing as looking at day and night and yet we don't go by day and night because none of us sleeps for 12 hours we combine 3 of those bars and compare it against the 4"* (P8).

In addition to incorporating participant feedback, we employed selected principles from graphic design theory in design of the new visual displays. For separation and layering, we widened vertical gridlines to indicate night and day periods, using shading to keep all gridlines in the background and bring the prominent information – the sensor data – forward(22). To avoid competing with data, we reduced the weight and darkness of lines in grids (23). To avoid activation of white space and reduce unintentional visual activity, we eliminated boxes that surround text (22, 23). Further review of the AAL case examples identified an additional guideline: the use of black and white to emphasize contrast (21). Figure 2 shows three novel visual display designs based on interview results, design guidelines derived from review of prior AAL environment research, and principles of graphic design theory as outlined above.

We applied these guidelines where appropriate according to context. For instance, Figure 2 - Displays B and C demonstrate data reduction by representing data for only one area of the residence and one time of the day, respectively. For Figure 2 - Display A, a design trade-off was made that involved introducing greater visual activity by using a dotted line, that competed with the solid line connecting markers for other room sensor markers rather than leaving blank space between markers for bedroom sensors, to distinctly separate bedroom sensor data trends from other room sensor data trends (22). For Figure 2 - Displays B and C, to emphasize magnitude and direction in the time series we used markers of different, yet consistent, sizes to visually indicate activity levels categories ("Low", "Medium" and "High") along the Y axis (23). To reduce visual activity (22), we used solid lines for trends, as in Figure 2 – Displays A and B, or eliminated lines completely, as in Figure 2 - Display C.

5. CONCLUSIONS

In this exploratory study, we aimed to characterize older adult participants' perceived usefulness of sensor data from AAL environments. Toward this end, we identified three themes related to perceived usefulness of sensor data and visual displays of these data. In addition, we created three novel visual display types for data from AAL environments for future evaluation with older adults and other stakeholders.

Personal access to Ambient Assisted Living (AAL) environments data in electronic health records (EHRs) has been posited as a way to help promote health-related decision-making for older adults. For example, shared activity data available through an EHR could allow for monitoring changes in activity patterns that could indicate the onset of cognitive or functional decline. Participants of this study acknowledged and supported these types of uses of activity data. Our participants also identified many circumstances and influencing factors where data and visual displays might be useful for this purpose. A prevailing theme from participants in this study concerned the potential for AAL environment data and visual displays to alert family members and health care providers to the health status of older adults.

Previous research has shown that health care providers prefer holistic views of data to ascertain an overall understanding of patient health status followed by more granular views of data to determine how different factors interact (4). However, when engaged in encounters with patients, simpler views that communicate summaries of health are preferred as a starting point for conversations that can be directed by older adult patients (4). Both health care providers and older adults acknowledge that family members have distinct information needs that vary by family (24). In particular, health care providers have observed that family members might be more concerned with knowing if their older adult relatives were “OK” and older adults acknowledged that some family members may not be interested in this type of information at all (24).

Future research related to perceived usefulness must further identify goals, needs and preferences regarding use of AAL data for these three stakeholder groups to realize the benefits of home-based technology innovations. Potential benefits for older adults include the ability to monitor their own health at home and connect to their informal and formal caregiver networks to support independent living. For family members, potential benefits include greater peace of mind and the ability to participate in older adult relatives’ support networks at a distance. For health care providers, potential benefits include delivering better services across the continuum of care and earlier preventive interventions that support their patients to remain independent.

Visual displays play a large part in technology interactions. We aimed to create visual displays that maintained simplicity by removing clutter that contributes to visual fatigue. Tufte notes that time series plots are the most commonly used charts and are often used for large, variable data sets (23). Our participants’ preferences for time series plots supported this idea and may be due to prior experience with this type of chart. Because new designs can appear odd to viewers, we balanced the need for novel visual displays of AAL environments data against the likely chart familiarity of the intended audience. It is important to note that generalized design advice is most useful when employed flexibly. Specifically, the design of individual visual displays may require context-specific techniques not required for all displays. This was true in design efforts for the three novel visual displays in our use of specific elements to separate trends or emphasize magnitude and direction. Future work should determine where design advice can be applied to create new visual displays, such as those in Figure 2, that show tailored time frames, from granular level display of daily activity patterns to aggregate snapshots of trends over a year. Furthermore, future system implementations could allow the annotation of trends with the occurrence of adverse events or other health-related information to maximize the utility of the graphs to support decision making.

Simulation is a process that recreates or imitates the behavior or characteristics of the real world (25, 26). The use of simulated data in health informatics research is common practice.

For example, simulated data have been proposed as a means to facilitate the development and validation of activity monitoring systems for older adults at home(27), have been used to compare different techniques for obtaining patient counts from a clinical data warehouse (28) and have been used to gauge provider preferences for different visualization types (4). This study relied on simulated data to model a fall scenario based on research team expertise and case studies of activity data from prior research (18–21). Much of this prior research reports the use of bar chart graphs for visualization of sensor data (18–21). For transparency, we report the methods by which we generated the simulated data.

This study employed convenience sampling within a single setting, rendering a homogenous participant sample with regard to race, middle-old and oldest old age bands, socioeconomic status and community of residence. We conducted two interviews with each participant over the six-month study period, nearly doubling the amount of collected data. In homogeneous samples, Kuzel recommends a sample size of six to eight interview participants (29). To provide evidence-based recommendations for sample size in qualitative studies, Guest et al analyzed sixty semi-structured interviews of a relatively homogenous sample, finding that 94% of all high-frequency codes were identified within the first six interviews and 97% within the first 12 interviews (30). Therefore, based on study scope, and evidence-based recommendations from the qualitative methods literature, the sample size for this study is sufficient to meet the study aims. However, sample size and homogeneity are also limitations. Thus, findings may not generalize to other populations.

One area for future research is to determine how visual displays of AAL data might be utilized to connect family members and health care providers through shared understanding of activity patterns. Connecting informal and formal caregiving networks may facilitate better communication between older adults, family members and health care providers for shared decision-making. In addition, applications and visual displays of AAL environments data in EHRs may be useful to facilitate behavioral modification for health promotion in older adults. With regard to design of visual displays, future work should also include a broader range of sources to inform guidelines for design. Other efforts should integrate external sources of information, such as scheduling data from calendars, to facilitate system awareness about occupancy. New interaction methods, such as voice control via acoustic user interfaces (31), may improve usability of external information sources and increase the usefulness of AAL environments through technology integration. For instance, improved system awareness about occupancy would improve the reliability of alerts to family members and health care providers. One novel contribution of this study is that it complements a recent Delphi study that engaged different types of stakeholders across a range of ages to identify requirements for AAL technology but did not specifically focus on older adults over the age of 75 (32). In addition, this study engaged older adults early in the design process for AAL technology. Bardram identified the need to move away from technical proof-of-concept studies where a small number of research colleagues validate system functions and move toward clinical proof-of-concept studies where members of a target audience use a system in the field (33). Early engagement during design efforts may facilitate successful clinical proof-of-concept studies if AAL technologies support the needs and preferences of older adults and other stakeholders who will interact with these systems.

In conclusion, this study identified three themes of perceived usefulness of AAL data for older adults and demonstrated the need for novel visualizations of these types of data. Future work will include greater characterization of the health information needs of older adults, their family members and health care providers to reflect all stakeholder requirements for visual displays and electronic health records that integrate monitoring data from Ambient Assisted Living Environments. In addition, studies that explore how visual displays are perceived and used on different types of screens, such as mobile devices, and for different types of data, such as door sensors or radio-frequency identification (RFID) tags, should be conducted.

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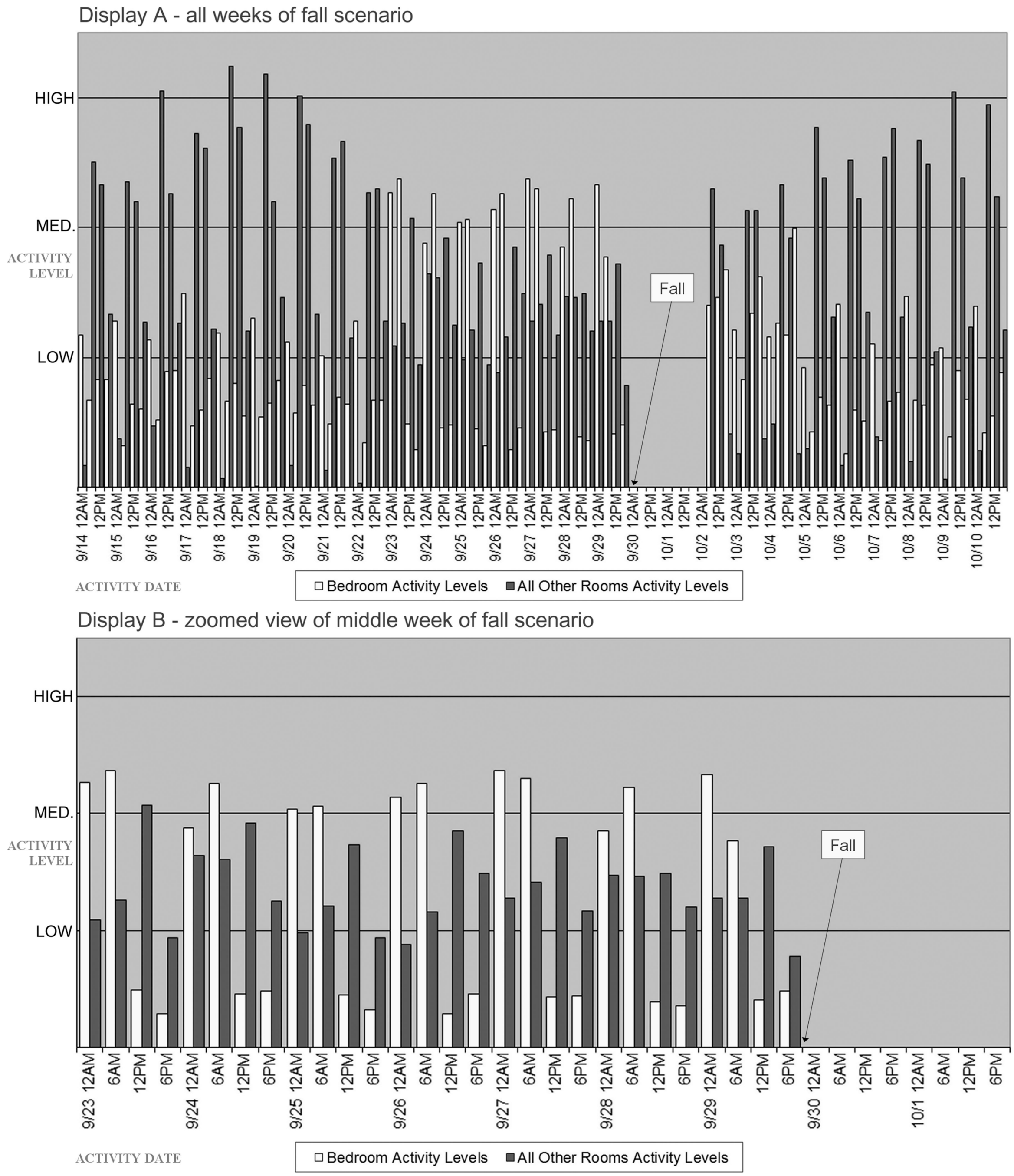

Figure 1.

Bar chart display of simulated sensor data for the conceptualized fall scenario

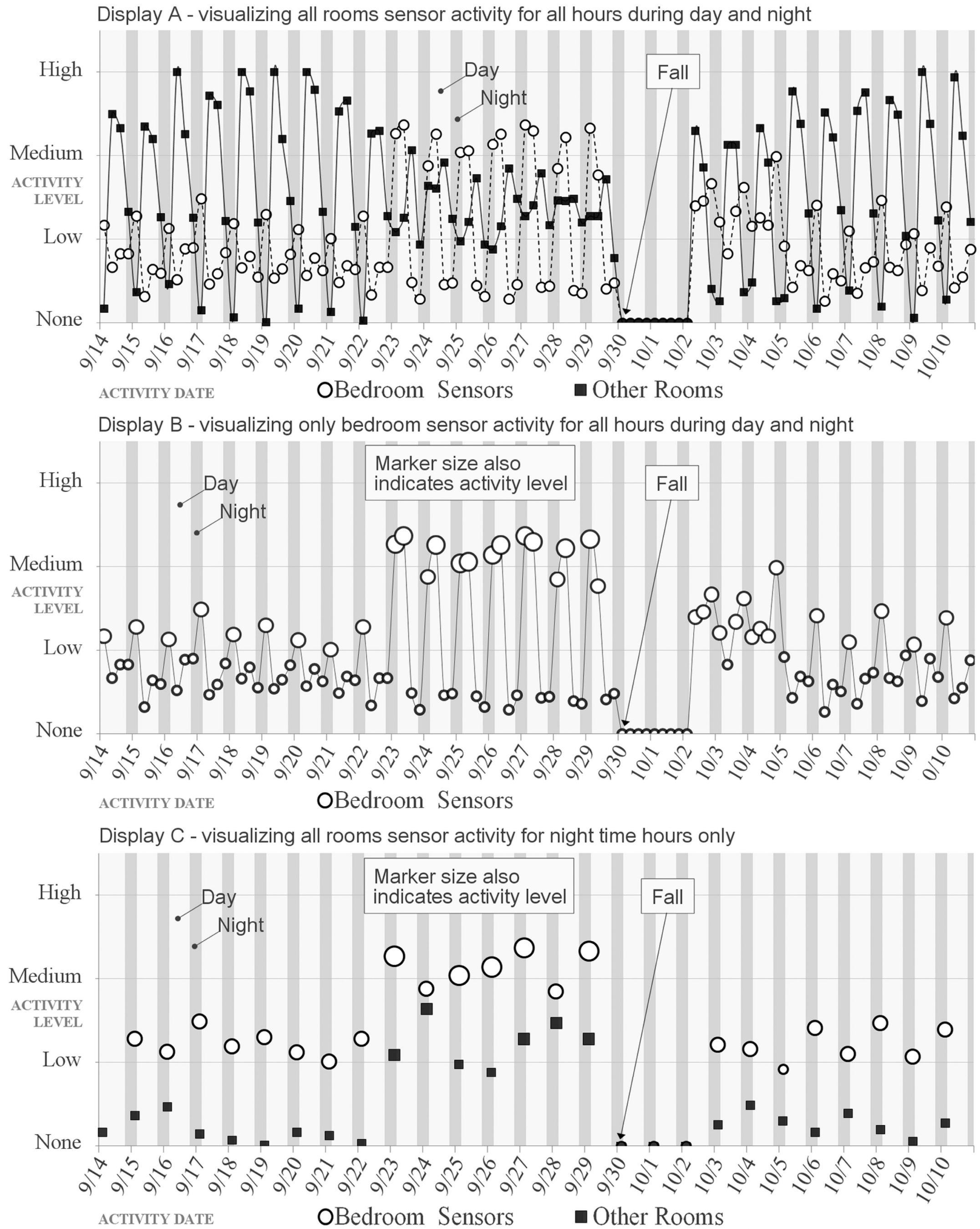

Figure 2.

Three novel visual displays for sensor data