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Smart Home Technologies for Monitoring Cancer Symptoms and Enhancing Palliative Care

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Abstract **-** Cancer rates are rising, and more people are living longer with chronic disease qualifying them for palliative care services. Health innovations are needed to support palliative teams. Smart homes show promise, but their use has not been explored in palliative care. This case series study with n=3 participants used historic sensor data to explore continuous digital behavior markers in older adults receiving cancer treatment and experiencing disease or treatment related symptoms. We show that smart homes can recognize digital behavior markers related to daily activities and suggest that limitations are addressable in future work.

Keywords**:** smart home, behaviour visualization, palliative care

1. Introduction

Increasing rates of cancer globally underscore the need for technologies to care for patients and their families. Over the past decade, guidelines began to recommend the integration of palliative care into standard oncology practice [1]. Palliative care services screen, assess, and intervene for worsening or uncontrolled symptoms. Uncontrolled symptoms and treatment toxicities often lead to unplanned hospitalizations and emergency department (ED) visits [2].

Meanwhile, smart home technology has matured and proliferated in research labs around the world [4]. Initially focused on monitoring indicators of cognitive change [5] and security of the environment [6], these technologies have expanded to helping individuals manage challenging chronic conditions [7]. However, examining the use of smart homes and analysis of ambient sensor readings has not yet been explored for palliative care.

We hypothesize that symptoms of cancer and treatment are manifested in a person's behavior and can be detected by ambient sensors placed in a person's home. In this paper, we explore the definition of smart home markers and graphs for three participants managing cancer treatment. Given smart home data, we compare these markers during periods of patient-reported difficulties with days reported as normal. The results provide evidence that smart homes offer a practical mechanism for monitoring the impact of disease on behavior and guiding nurses in designing proactive care for these individuals.

2. Methods

2.1. Participants

In this paper, we perform a case series study for n=3 participants (in this paper, named P1, P2, and P3). These participants were selected because 1) they participated in smart home studies and made ambient sensor data available for analysis and 2) they were undergoing treatment for cancer and reported symptoms related to disease and cancer treatment. Studies from which data were collected for this secondary analysis were reviewed and approved by the Institutional Review Board at Washington State University. All data were anonymized before performing these analyses.

All participants were age 65+. All participants lived independent in suburban or rural communities. P1 lived in a 1 bedroom, 1 bath home, P2 and P3 lived in 3-bed 2-bath homes. Cancer diagnoses included sarcoma with metastasis and prostate cancers at varying stages. In addition, P2 was diagnosed with atrial fibrillation, hypotension, and Wegener's (granulomatosis with polyangiitis) and P3 with Type 2 diabetes, obesity, and sleep apnea.

2.2. Smart Home Data Collection

Sensors were installed in each participant's home. These sensors passively and continuously collect data as residents perform their daily routines. First, passive infrared motion (PIR) sensors paired with ambient light sensors were mounted on ceilings in each area (2–5 sensors per room) to track movement and light levels. Second, magnetic units with door and temperature sensors were placed on exterior doors to monitor door usage and temperature fluctuations. These sensors reported time-stamped events when there was a change in state (i.e., start/stop motion, open/close door, above-threshold change in light or temperature level). P1 and P2 lived alone, while two residents were in the home of P3. We examine the data from each home using the same methods. As a result, the data for P3 reflects behavior of the participant and the participant's spouse.

We define digital markers to extract from ambient sensor readings and used to describe behavior. The markers are calculated for each day of data and describe behavior related to sleep, time out of the home, activity level, and behavior regularity. These behavior categories can be characterized by ambient sensors. Moreover, they directly impact cognitive, physiological, and psychological well-being, particularly for individuals managing chronic health conditions. The behavior markers are:

- *Sleep duration.* Nighttime sleep is detected between 9pm and 7am when motion sensor readings are ≥5 minutes apart in the bedroom. If there are >2 contiguous motion sensor readings outside the bedroom, the state is considered awake. If the awake state is surrounded by sleep, the awake state is a sleep interruption. We note the total time spent sleeping, time of day when they first fall asleep, and time of day when they wake up for the day.
- *Sleep restlessness.* We measure sleep restlessness as the number of movement sensor readings during sleep. Because movement readings are influenced by the number and density of motion sensors in the home, we normalize this value.
- *Sleep interruptions.* If the participant is awake during the nighttime sleep hours, but asleep before and after that time, the awake period is considered a sleep interruption. We record the number of such interruptions each day.
- *Bathroom use.* This marker indicates the amount of time, in seconds, that is spent in the bathroom in each day.
- *Time out of the house.* Time out of the home is an indicator of a person's mobility and social engagement. If the person's most recent state was awake, more than 20 minutes elapsed between motion sensor readings, and the most recent sensor readings are from an external door or door area, the person is considered out of the home until more than 2 sensor readings occur inside the home.
- *Walking speed.* To calculate walking speed, we examine time for transitions between bedroom and bathroom. This speed is averaged over all transitions between bedroom and bathroom that occur on a given day.
- *Activity level.* Activity level is estimated by the number of motion sensor readings that occur when the participant is home, divided by the time spent at home. This number is dependent on sensor density and so is normalized.

3. Results

Figure 1 shows a visualization of behavior markers collected for the three participants. Each chart shows a heatmap of the marker during a time the person was experiencing health difficulties (the left side of the chart) and during a series of days self-reported as "good" (the right side of the chart). Every marker has a different value range, but for each row darker blue reflects a lower value and dark red reflects a high value. The graph is accompanied by a summary of the changes in behavior values between time periods, shown in Table 1.

For P1, the left side of the graph reflects a series of days when they felt pain. This contrasts with the right side when they were feeling normal. This participant experienced dramatic changes between the two times. Most remarkable is the sleep restlessness that occurred while they were experiencing pain (a 240% difference occurred between the two periods). Also notable is the time spent out of the home. On Day 3, they left the home for a medical procedure (indicated by a green box). The rest of the first week, they rarely left home. When this day is removed from the analysis, time out of home increases by 34% during the non-pain period. For P2, the changes are more subtle. This person reported more sleep interruptions during the health challenge period, and this was detected by the smart home (a 12% decrease in the normal week). However, restlessness was inversely correlated with sleep interruptions. Additionally, activity level increased by a large amount for all participants from the health challenge period to the normal period. Analyzing P3 is more complex, because the data reflect activities of both residents in the home. During the health challenge, the participant reported more bathroom use. The data do reflect a small decrease in bathroom use transitioning between the health challenge and normal periods. Many other markers improved as well during the normal period, including more sleep time with less restlessness, faster walking speed, and more time spent out of the home.

Fig. 1: Heat map of behavior markers. The green lines separate a days when the participant reported difficulties related to disease (left) from a sequence when they felt good (right). Colors represent values ranging from low (dark blue) to neutral (gray) and high (red).

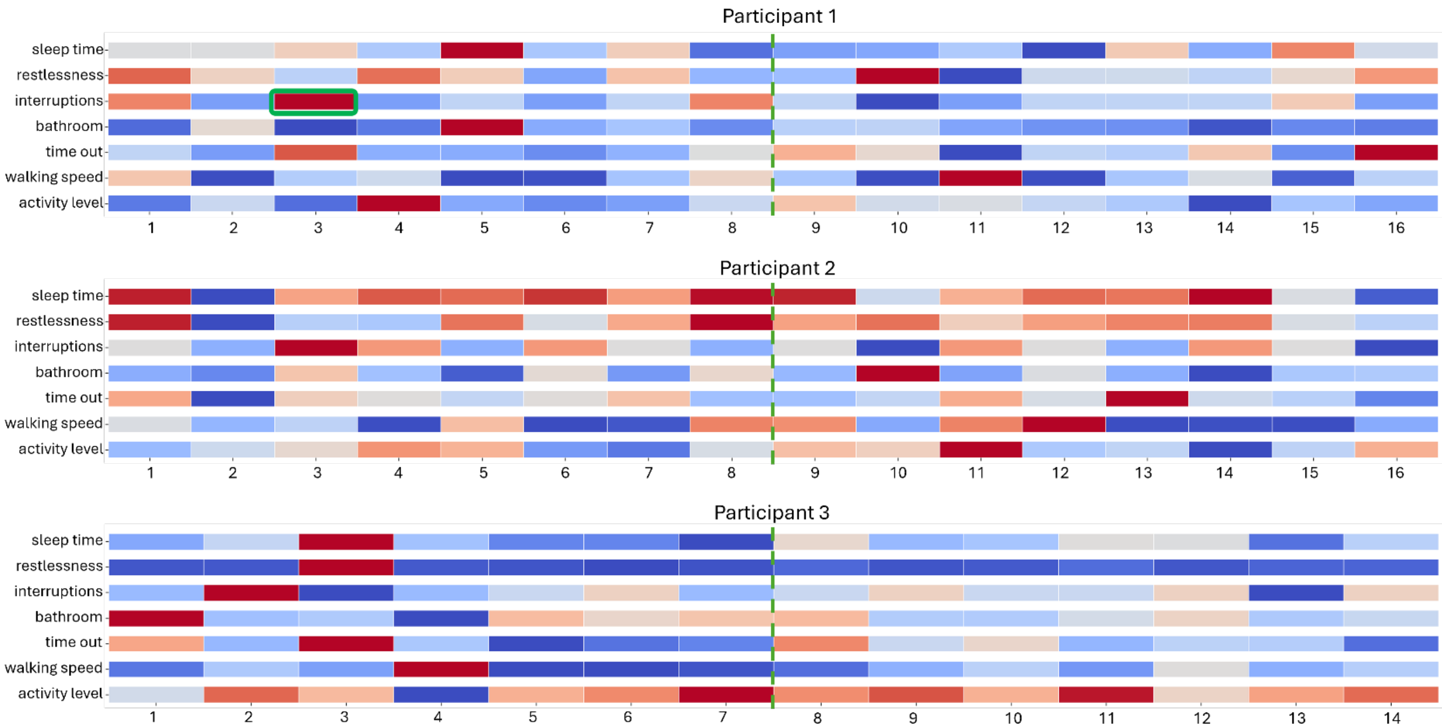

Table 1: Summary of marker changes from time period 1 (reflecting health challenges) to time period 2 (reflecting a normal baseline). A percentage increase is denoted by an up arrow ↑, a percentage decrease is indicated by a down arrow ↓.

Marker	**Participant 1 change**	**Participant 2 change**	**Participant 3 change**
Sleep time	5% ↓	5% ↓	11%↑
Restlessness	240% ↓	21% ↑	144% ↓
Interruptions	12% ↓	12% ↓	3% ↑
Bathroom	5% ↑	5% ↑	8% ↓
Time out	2% ↑	2% ↑	11%↑
Walking speed	11%↑	17%↑	14%↑
Activity level	21%↑	80%↑	137%↑

4. Discussion and Conclusion

When people feel unwell, they move and behave differently. Such changes can cue palliative nurses that clinically important health changes are occurring. For example, pain is known to cause poor sleep quality [8] as seen with P1 and prostate cancer exacerbations can lead male patients to experience difficulties with urinating, causing them to stay home and be less active, as seen with P2 and P3 [9]. Often patients with cancer experience acute worsening of symptoms that may be prevented or reduced by home- and distance-based interventions that accurately monitor health declines. Our findings show that smart homes using ambient sensing without cameras or microphones can observe these clinically relevant behavior changes.

In this study, we examined continuous behavior markers in a sample of patients with cancer, visualized these markers during periods of patient-reported difficulties and compared them with days reported as normal [10]. The analysis described here was limited by examining a small sample of participants and dates. Additionally, analysis of P3 reflected behavior for everyone in the home instead of focusing on the one person who was reporting health difficulties.

Future iterations of this work have the potential to assess behaviors associated with worsening of uncontrolled symptoms and toxicities of cancer treatment, potentially leading to reductions in unplanned hospitalizations and ED visits and associated health care costs. More research is needed to better understand smart home monitoring capabilities for palliative care and how this new "evidence" can be utilized in the evidence-based practice palliative care field.

Detection of behavior changes by skilled healthcare teams may ensure patients are triaged into necessary care based on emergent needs. Automating the recognition of these behavior changes affords opportunities for palliative patients and families to obtain more timely, precise, and informed.

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