Check for updates

It Made Me Feel So Much More at Home Here: Patient Perspectives on Smart Home Technology Deployed at Scale in a Rehabilitation Hospital

Joshua Dawson
joshua.dawson@milsci.utah.edu
University of Utah
Salt Lake City, UT, USA

Thomas Kauffman
u1374928@utah.edu
University of Utah
Salt Lake City, UT, USA

Jason Wiese
wiese@cs.utah.edu
University of Utah
Salt Lake City, UT, USA

ABSTRACT

Smart patient rooms are arriving; however, their value has yet to be explored. We interviewed 20 patients in a rehabilitation hospital, which has patient rooms equipped with off-the-shelf smart home technologies, so the entertainment and environment are digitally controllable. This novel implementation supports varying control abilities through touchscreen, voice command, and accessibility controllers. The smart rooms and controls are potentially transformative for patients with reduced motor function, helping them regain lost independence and control of their surroundings. Through semi-structured interviews, we explore how smart home technology deployed in patient rooms: interacts with patients' needs, presents new challenges, and fits into the hospital context. We identify a range of considerations that inform how hospitals can integrate smart technology into their environment, including technology design considerations and adjustments to how hospital staff supports its use. These results take an important step toward understanding and improving the value of smart patient rooms.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; **Accessibility technologies**;

KEYWORDS

smart patient room, smart hospital, rehabilitation hospital

ACM Reference Format:
Joshua Dawson, Thomas Kauffman, and Jason Wiese. 2023. *It Made Me Feel So Much More at Home Here*: Patient Perspectives on Smart Home Technology Deployed at Scale in a Rehabilitation Hospital. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23), April 23–28, 2023, Hamburg, Germany*. ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3544548.3580757

1 INTRODUCTION

The smart patient room (SPR) — instrumented with a networked constellation of sensors, actuators, and interfaces — is arriving, driven by the vision that it can provide a positive patient experience [23–25, 50, 63]. However, the value of SPRs is not clear. The HCI literature has extensively explored smart home technology (SHT) located in typical home settings, but the findings on the value of the SHT are mixed [8, 53], and it is not clear if that value will translate well to a hospital context because the value that many people extract from SHT is entangled in the particularities of domestic life. On the other hand, a rehabilitation hospital (RH) presents some valuable opportunities for SHT. Most patients admitted to an RH have just experienced a severe life-changing injury, illness, or disorder — such as a spinal cord injury (SCI), traumatic brain injury (TBI), or stroke. After being first stabilized in an emergency room or intensive care unit (ICU) at an acute care facility, they are transferred to the rehabilitation hospital, where they will spend the next few weeks or months in recovery. When admitted, many SCI patients cannot move without assistance. They are confined to their bed or potentially a powered wheelchair and might require the aid of a mechanical ventilator. Their doctor will assess the possibility of gaining back any function they may have lost, but there is no guarantee. Many patients are understandably depressed by the realization that their life has drastically changed. Patients can feel as though they have lost all independence and autonomy because they must rely on a family member or the hospital staff for everything — even simple tasks like changing the TV channel or turning off the lights in the room [38, 55]. In this context, the value proposition of SPR is clear but untested — perhaps it can return some autonomy to these patients in a time of need.

In this work, we collaborated with the newly-constructed University of Utah Health Craig H. Neilsen Rehabilitation Hospital (NRH), where all 75 patient beds in the hospital are equipped with SHT. We conducted 20 semi-structured interviews with hospital patients — and six informal caregivers who were in the room when we conducted the patient interviews — to understand their experiences in these patient rooms. Through these interviews, we explore how the SHT employed in patient rooms affects the patients at the hospital. Based on a thorough review of related works detailed in section 2, we developed the following research questions (RQ):

RQ1) To what extent does SHT employed in patient rooms affect patients' wellbeing?
RQ2) What are patients' challenges with the smart technology installed in their room?
RQ3) How does the SPR fit in the context of a hospital setting?

Taking a Thematic Analysis approach, we report on 14 overarching themes we developed from these interviews, which we also develop into design considerations for other hospitals looking to

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivs International 4.0 License.

CHI '23, April 23–28, 2023, Hamburg, Germany
© 2023 Copyright held by the owner/author(s).
ACM ISBN 978-1-4503-9421-5/23/04.
https://doi.org/10.1145/3544548.3580757

adopt similar SHT in their facility. Our research makes two main contributions. First, this work reports on the benefits and potential issues of adding commercial off-the-shelf (COTS) SHT to patient rooms at scale in a hospital; to the authors' knowledge, this is the first work to do so. Second, based on the analysis, we provide a list of the most important design considerations for hospital designers wanting to adopt a similar technology solution. Additionally, this work can serve as one example of how smart spaces might exist and provide value outside traditional smart homes.

2 RELATED WORK

There is ample research exploring smart homes and technology deployed in a hospital context. However, no literature reports on how patients engage with SHT deployed broadly in patient rooms. Our research explores this gap. To better understand the intersection of these two research areas, we looked comprehensively at prior work on technologies that improve the patient experience, smart homes, and other HCI research in a hospital context.

2.1 The patient experience and how technology aims to improve it

Being hospitalized can be so disempowering, overwhelming, lonely, and boundary-violating [4, 5, 7, 20] that patients can be considered situationally impaired [44], in addition to being impaired by their injuries. The patient room becomes, in effect, a temporary home, especially for more extended stays [3, 37], which can be challenging for patients because they have limited control over the physical environment in the hospital [4, 35, 44, 61]. Research identifies a range of opportunities for technology to better support patients during stays: redesigning the nurse call system and improving interaction techniques with hospital technology [52], supporting video chat to combat loneliness [40, 52], and facilitating patient engagement in their care, mainly by providing information to patients about their condition, treatment, trajectory, care team, and other hospital details [33, 42, 43]. Ways for this information to be relayed to the patient involve several different means, including tablets [62], mobile tools [30, 35, 45], or even patient-centric information displays [64]. Beyond information sharing and presenting technologies, some patient room environment-specific interventions like sun-synced lighting [15] and natural soundscapes [29] have been shown to also improve patient experiences in the hospital. Our research expands on this previous work by implementing an SHT package that aims to provide patients with information, entertainment, and complete control of their environment, with accessibility as a priority.

With respect to accessibility and control, previous research identifies a need to better support patient agency in the hospital and changing needs during hospital stays as each patient's condition fluctuates [21, 22, 42]. The single-patient rooms in the NRH, where we conducted the research in this paper, enable many opportunities: improving interaction, fine-grain lighting and sound control, and supporting video chat. Self-determination theory predicts that the capabilities offered by the SPR can facilitate emotional well-being in these patients [48, 49], who otherwise would not be able to control these functions themselves. This led us to ask the following research question: **RQ1)** To what extent does SHT employed in patient rooms affect patients' well-being?

Conversely, HCI research exploring other kinds of technology deployed in a healthcare context has illustrated the many pitfalls that await deploying new technology in a hospital. Seemingly minor changes to nursing work practices and workflows lead to information loss, as seen with the introduction of electronic health records [31] and a computerized provider order entry systems [66]. Furthermore, hospital staff can abandon new technology in favor of old systems when they encounter usability barriers. Tang et al. provided an excellent example in a study where hospital team members showed hostility toward adopting a new mobile hands-free voice communication system due to usability problems [57]. Some literature also suggests that technology deployment in patient rooms might have negative outcomes. While past work shows that it is possible for patients to feel at-homeness in a technology-dense ICU patient room [4, 58], being in a technology-dense environment can be overwhelming and increase stress for visitors [54] and patients [4]. This potential negative experience from the technology employed in a hospital setting led us to ask: **RQ2)** What are patients' challenges with the smart technology installed in their room?

2.2 Studying smart home technology in a hospital context at scale

Modern commercially available SHT leverages two decades of research [27, 28, 34, 65] to offer a breadth of commercially-available sensors, actuators, digital plumbing [59], and interfaces that enable homeowners and renters alike to assemble their own smart homes. Smart home users have rich and diverse interactions with their smart homes. With these interactions, users express that SHT can provide them comfort, convenience, security, leisure, protection, productivity, and pleasure [27, 53]. Brause et al. expanded on this, showing that early adopters of smart speaker assistants use the technology beyond convenience and entertainment; they use it for companionship, health, and increased accessibility as well [8]. Even though all these previous studies were conducted in the context of a home, there is promise for a hospital application as well. Studies on "smart space" interactions outside of a personal residence are much less common for the obvious reason that most spaces people interact with outside of their own homes are public or shared in some way. Deploying and living with SHT in a shared household already comes with its own tangled combination of social issues, including surveillance and privacy [9, 12], differing preferences [19], and new social dynamics [53]. The different social environment of a public smart space — even the basic idea of shared thermostat control [60] — is an even more challenging social context to design for. The complex nature of SHT installed in the public environment of a hospital is one of the interesting dynamics we want to explore.

Regarding studying SHT in the hospital context, there are two major differences in our research compared to previous work. The first difference is the scale. Pervasive in vivo studies of novel technology are especially important in hospital settings [16, 51] and more broadly across ubiquitous computing [1, 10]; yet, they are rare because the complexity, cost, and safety concerns of deployment are prohibitive unless already planned by the hospital [16, 17, 26]. There have been some studies attempting an alternative approach, like prototyping a single room [37], but it comes with limitations [11], like the fact that that room may be considered a *special* room and thus may introduce confounds compared to being deployed across the hospital. The second difference is that we focused on SHTs installed in the patient rooms specifically for the patient to use. Previous studies of commercially available pervasive technology in hospitals generally do not focus on patient rooms, instead exploring, e.g., how employee workflows change to accommodate new technology, then settle into routines and develop necessary workarounds [18, 56, 57]. Although patient rooms can impact patient safety, quality of care, worker safety and efficiency, and organizational outcomes [47], studies of commercially available technology in these spaces were limited to lighting and sound environments [15, 29].

SPRs sit in a gap between these bodies of work: patients and their families are temporary inhabitants — so the smart home literature may not be relevant — while being in a hospital context complicates the deployment and usage of the SHT. This knowledge gap led us to ask: **RQ3)** How does the SPR fit in the context of a hospital setting?

3 METHOD

Doing research in a hospital setting and with the vulnerable population who may inhabit an RH requires a careful methodological approach. In this section, we give a detailed description of our methods with the goal of facilitating other researchers in adapting our approach to similarly challenging research areas. The subsections below highlight techniques we used to ensure the most comprehensive inclusion possible. The University of Utah Institutional Review Board (IRB) approved all the methods and procedures for this study.

Figure 1: A smart patient room in the NRH with a hospital-furnished iPad running the smart room app. Each patient room has lights, blinds, thermostat, television, and soundbar that can be controlled with the smart room app installed on a hospital-furnished iPad or on a personal device. In several rooms, the door can also be controlled.

3.1 Research environment

An RH primarily serves patients recovering from an injury, illness, disorder, or surgery with a diagnosis resulting in reduced motor or cognitive function. An RH is usually considered post-acute care, seeing patients after stabilization in another hospital; however, in some instances, patients are admitted directly from their homes. The NRH, where we conducted our research, is a newly-built facility designed with technology in mind throughout all phases of construction. Each patient room contains connected lights, blinds, thermostat, television, and soundbar, all controlled through an app on a hospital-furnished iPad or personal device. In several rooms, the door can also be controlled. This novel implementation supports variable control based on patients' levels of independent mobility — including capacitive touch, voice command, sip-and-puff (SNP) controller, or traditional wall switches and remote controls.

In an RH, patient stays are typically unplanned, and the duration varies by condition. For example, SCI patients stay an average of 60.8 days ($\sigma = \pm 38.7$) [13]. All patients have full days, with schedules set by a scheduler on the hospital staff to include three hours of daily therapy with occupational therapists (OT), physical therapists (PT), and speech therapists, in addition to traditional hospital activities: meals, nursing care, and examinations by physicians. Patients are often accompanied by a family member (caregiver), with some family members staying in the hospital overnight.

3.2 Recruitment

We used purposive and convenience sampling drawn from inpatients at the NRH; we asked informal caregivers to participate if they were in the room during the patient interview. All patients were in the rehabilitation stage of their recovery with a diagnosis that resulted in reduced motor function. We recruited participants through medical team referrals and chart reviews conducted by clinical research team members to ensure they met the inclusion criteria. For the inclusion criteria — as taken directly from the recruitment flyer — our participants were:

- At a minimum, seven years old.
- In the rehabilitation stage with a diagnosis that results in reduced motor function.
- Able to tolerate a 30-minute engagement for an interview.
- Must be able to communicate in English.
- Capable of consenting if over 18. Or if 7-17 years old, capable of assenting and parent permission.

Our collaborators who assisted with recruitment through chart review were all medical providers who had access to and reviewed charts as part of their professional duties. Medical providers, primarily OTs, helped us identify potential participants using the criteria outlined in the inclusion criteria. If a patient expressed interest, the OT provided them with a recruitment flyer and helped establish an appointment with the research team to participate in the study.

We regularly met with our collaborators to see if there were any participants they excluded from the patient chart review and the general reasons why. We did this to ensure we were not excluding patients unnecessarily. Some exclusions were obvious; for instance, we excluded some patients who had suffered a brain injury resulting in a cognitive level that would not allow them to consent. However, it was through these collaborator meetings that we identified some bias in our recruiting. The NRH services approximately 10% of Spanish-only or Spanish-preferred patients. We made an inclusion decision that participants "Must be able to communicate in English" because the research team is all English-speaking, and we were unable to retain a Spanish-speaking team member. We now know this study design decision may have unnecessarily excluded some otherwise qualified participants. For future smart hospital work, we will incorporate this population into the study through translated documents and the use of a translator for interview sessions.

3.3 Consent

Before data collection, the research team provided a written consent form to the participant and any informal caregiver present and reviewed it with them orally. However, since there is a potential for decreased motor function due to a spinal cord injury or disorder (SCI/D), we did not require a physical signature on the consent document. Instead, the interviewer read the consent paragraph aloud and asked the participant to acknowledge it. We recorded the interviewer reading the consent paragraph and the participants' acknowledgment as part of the interview. Our IRB approved this alternative procedure.

In the consent document, we clarified that although the interview would last approximately 30 minutes, we could take breaks or conduct the interview in multiple sessions. This principle is crucial when interviewing patients who have suffered a traumatic injury. As highlighted by Kabir et al., individuals with SCI have a higher degree of difficulty with long speech tasks, and there may be an increased potential for fatigue [32]. We wanted to ensure we were sensitive and accommodating to this concern.

3.4 Semi-structured interviews

The primary means of data collection was 20 audio-recorded semi-structured interviews lasting between 6 and 51 minutes — with an average of just under 24 minutes. The shortest interview was only because the patient primarily gave short, concise answers to the questions but still provided valid data. The next shortest interview was just under 8 minutes with P8 because she did not use the iPad. Nevertheless, we adapted the interview questions to understand her particular barriers to use; we report the specifics in our findings (4.3.1). For the semi-structured interview script, we included questions about the following:

- Asking the patient to describe their injury or disorder and current abilities
- Their familiarity and comfort with technology in general and previous experience with SHT
- Their use of the smart features of their patient room; including how they control the room and any positive or negative interactions they have had with the technology
- The most important feature they use
- Any issues with the SHT or its application
- Anything else they wish they could control in their room
- Feelings of independence or autonomy and quality of life
- Others that might have used the SPR features (e.g., caregivers, visitors, or hospital staff) and their observed interactions with the technology
- Perceptions of privacy and security of the SPR technology

In all, we interviewed 20 patients and six informal caregivers. Our participants' ages ranged from 20-78, with an average of 54.5. This range and the average age are consistent and represent the demographics of patients in an RH. We provide the detailed demographics of our interview participants in Table 1. Because the average age is in the mid-50s — with 13 participants over the age of 60 — it is understandable that many have not had previous experience with SHT. This observation is consistent with prior research that although older adults were active users of digital technology, they did so with weariness, suspicion, and circumspection [6], which could affect their exposure to and adoption of SHT.

As part of the interview, we asked the patients to describe their injury or disorder regarding their remaining abilities and how they can control the SPR. In Table 2, we describe the patients' abilities in terms of if they have full use, limited use, or no use of their voice, hands, arms, and legs. We further categorized the patients into three main categories, whether they can use the iPad capacitive touch screen fully, partially, or with voice control only. Additionally, in Table 2, we highlight the medical provider's assessment of if there is a potential, through rehabilitation, to regain some lost function. This table helps provide context to quotes found in the findings section by providing a link from patient insights to their current abilities and rehabilitation potential.

3.5 Data collection, transcription, and analysis

We audio-recorded each interview with the consent of the participant. Immediately following the interview, we uploaded the recording to Otter.ai for initial automatic transcription. The noisy hospital environment caused errors in the auto-transcription; therefore, we listened to each recording and manually corrected it.

The research team uploaded the transcripts into Atlas.ti for open coding and analysis. We used inductive coding and reflexive thematic analysis to generate high-level themes from the data, similar to the approach outlined by Alhojailan [2]. A single researcher coded each interview. The first author and a research assistant met to discuss the initial codes after completing the coding of interviews 1 and 2. In this meeting, they collaboratively reviewed the codebook, discussing each code and identifying any to delete, reword, or merge. Both researchers used this base codebook — modifying or adding codes as necessary — to code the rest of the interviews. As the researchers coded, they could see each other's codes in the code manager, which eased the process of applying codes already in the codebook or creating a new unique code as necessary. If a researcher created a new code, we discussed it as a team, so both researchers shared an understanding of the evolving codebook.

Once the research team completed coding 15 interviews, the codes and associated quotations were exported to a Microsoft Excel file using the download feature of Atlas.ti's quotation manager. The quotations were then copied and pasted to stickies on a Miro board. The research team then conducted several interpretive sessions where they analyzed the quotations tagged with codes on the Miro board and grouped them into high-level themes.

After 15 interviews, we had exhausted our recruitment pool at the hospital and needed to wait for some patient turnover to happen. We decided to do the first round of analysis while we waited because we did not want to lose the freshness of the data. After discovering some preliminary findings from the first round of interviews, we decided a second round was warranted because we wanted to evaluate whether we had reached saturation. Once we interviewed five more patients, we were not identifying any new

Table 1: Interview Participants Details. Technology Level is their self-reported level of expertise with technology on a scale from one to five (one being little to no experience with technology, and five being an expert with technology). Participants ranged in age from 20-78, with an average age of 54.5. Most participants did not have much, if any, previous experience with SHT. The most common SHT was a Smart TV, with 11 of 26 participants owning or using one. Only one participant — a caregiver and friend of P15 — lived in a home with extensive smart home technology. The lowercase letter 'c' denotes a caregiver.

ID	Age	Gender	Education Level	Technology Level	Previous Experience with Smart Technology
P1	37	M	Some College	3.5	TV, Alexa, Refrigerator
P2	55	M	Master's	4	None
P3	48	M	Some College	3.5	None
P4	70	F	Bachelor's	3	None
P4c	70	M	Master's	3	None
P5	55	M	PhD	3	None
P6	74	M	Master's	3	None
P7	78	F	Some Graduate	3.5	None
P8	75	F	Master's	0	None
P9	67	F	Bachelor's	3.5	None
P10	62	M	Master's	5	TV
P11	36	F	Master's	5	TV
P12	69	M	Some College	5	TV
P13	68	M	Bachelor's	Did not say	Did not say
P13c	66	M	Bachelor's	Did not say	Did not say
P14	57	F	Trade School	1	Alexa
P14c	58	M	Some College	3.5	Alexa
P15	21	M	Some High School	5	TV
P15c	24	M	Some College	5	Alexa, Google Assistant, Lights, TV, Speakers, Thermostat, Locks, Doorbell, Cameras, Smoke Alarms, Motion Sensors
P16	21	M	High School	5	TV, Alexa
P16c	43	F	High School	3	TV, Alexa
P17	20	M	High School	3	TV
P18	67	M	Some College	2.5	None
P18c	68	F	Master's	2	None
P19	34	F	Some High School	3	TV
P20	74	M	Bachelor's	2	TV

codes or themes from the data and could confidently say that we had reached saturation for this study.

Across all 20 interviews, we identified 747 quotes, created 132 codes, and developed 16 high-level themes that formed our results. For this paper, we excluded two themes — relating to patients' feelings on their transition to home — because we felt the transition from an SPR to their home is beyond the scope of this study and to manage paper length. The remaining 14 themes have been organized into subsections in the findings section of this paper based on how they provide insight into a particular research question.

3.6 Methodological reflection

Conducting this research was particularly methodologically challenging, both because this was an in-the-wild study being conducted in a dynamic hospital environment and because of the physical and mental state of our participants. After conducting the first few interviews, we had a good idea that the SPR technology was useful for patients. Early on, we made a study design decision that we would notify technical support and the app development team as we identified rectifiable problems so they could fix them right away. We felt an ethical responsibility that the benefit to patients was more important than trying to keep the system the same throughout the study. Thus, rather than completing the entire study with the same version of the technology, we conducted the interviews in parallel with continued refinement of the SPR app and technology. The development team pushed out some bug fixes based on feedback during earlier interviews, so those same issues were not present in later interviews. The same goes for feature updates. The best example is that the development team pushed out an update between the P14 and P15 interviews, allowing patients to use the SPR app on their personal devices in addition to the hospital-furnished iPad. As a result, personal device usage appeared in our later interviews. To manage this ever-changing research environment, we put equal weight on the codes in our thematic analysis process, regardless of how many participants expressed something within that code.

The second challenge with conducting research in an RH comes from patients' comfort and abilities. As described in work by Kabir et al. and Mack et al., working with participants who have limited abilities for accessibility research can be very challenging and requires additional preparation and the agility to adjust methods on

Table 2: Interview Patient Abilities. This table describes the patients' abilities in terms of full use, limited use, or no use of their voice, hands, arms, and legs. The last column is a medical provider's assessment of their rehabilitation potential to regain the limited or no use function. Additionally, the table is broken down into three categories based on the patient's ability to control the SPR app: iPad touch screen fully, partial ability to use the iPad touch screen, and voice control or SNP only.

ID	Voice	Hands	Arms	Legs	Rehab?
Patients can use the iPad touch screen fully.					
P9	Full use	Full use	Full use	Full use	Yes
P8, P17	Full use	Full use	Full use	Limited	No
P7	Full use	Full use	Full use	No use	Yes
P1, P10-12, P20	Full use	Full use	Full use	No use	No
Patients can partially use the iPad touch screen.					
P4	Full use	Limited	Full use	Limited	Yes
P3, P6	Full use	Limited	Full use	No use	Yes
P5, P15	Full use	Limited	Full use	No use	No
P14	Full use	Limited	Limited	No use	Yes
Patients are voice control or SNP only.					
P2	Full use	No use	Limited	No use	No
P18, P19	Full use	No use	No use	No use	No
P13, P16	Limited	No use	No use	No use	No

the fly [32, 39]. We adopted strategies outlined in their work to be more inclusive in our recruitment, consent, and study process, so we did not exclude potential participants due to their limited abilities. We specifically wanted to include high-level c-spine SCI patients — like P2, P13, P16, P18, and P19 — who are more likely to exhibit respiratory complications, fatigue, and difficulty sustaining voice or maintaining vocal intensity. Their interactions are critical to study since they stand to gain the most significant increase in autonomy through the SPR.

One example to highlight our attempt to maximize inclusion is our consent form. In the study description of the consent form, we made sure to include that breaks could be taken as necessary during the interview and that the interview itself could be broken into multiple sessions as needed. This verbiage helped to ease patient anxiety and encourage their participation. P13 and P16 both used mechanical ventilators. Initially, our collaborators were going to exclude them as potential participants because of their respiratory difficulties; however, after we discussed the flexibility to modify the interview as necessary, we included them. During P16's interview, approximately 25 minutes in, he was experiencing pain, so he asked us if we could take a break so he could call his nurse for pain medication. He might not have felt comfortable interrupting the interview if we did not cover this during the consent process.

4 FINDINGS

We present 14 themes we developed from our collected data, organized in this section under the research question they address. Table 3 maps subsection numbers to the corresponding theme. For brevity, the subsection titles used in the paper are shortened versions of the full themes found in the table.

4.1 Smart home technology in patient rooms has a positive effect on patient wellbeing

Our initial hypothesis, based on the literature from section 2.1, was that SHT in the patient rooms would contribute to a positive experience for the patient; however, patient responses were even more positive than we expected. Patients were excited to talk about how controlling their environment led to feelings of independence and autonomy. They also spoke about the significant quality of life improvement and how having control made the room feel more at home. Additionally, we discovered that their remaining abilities dictate the preferred method for controlling the room and what they view as the most important feature. They even provided us with additional technology ideas for the room. We developed five themes that help to answer RQ1, described in the subsections below.

4.1.1 *Independence, autonomy, and control.*

Participants, who have recently had an injury or disorder causing new motor impairment, confirmed the finding from prior work that they struggle with their lost independence, autonomy, and control over their surroundings. Three patients elaborated on their initial feelings of hopelessness post-injury; however, having the SPR gave them the ability to control some aspects of their environment, which yielded positive feelings of independence and autonomy.

> **P19:** *Because it's not fun when you're in a position where you're completely paralyzed. And all you have is your voice. That's not, that's not fun. But then, when you have a sense of control over something, so yeah, it does make me feel better. Like I still have, I still have control. A lot of times when you are in a hospital, you feel like you don't have control over anything.*

Table 3: To help navigate the richness of the findings, this table lists the themes derived from our thematic analysis, including what section contains more detail on that theme. The bold titles are the primary finding based on the related themes.

4.1	**Smart home technology in patient rooms has a positive effect on patient wellbeing.**
Section	Theme
4.1.1	The smart home technology provided feelings of independence, autonomy, and control.
4.1.2	The smart home technology in the patient rooms creates a positive overall experience through improved quality of life and feelings of at-homeness.
4.1.3	Patients had different ideas for the most important feature, based on which features they used and their abilities to control those items if the technology was not there.
4.1.4	Patient abilities dictate the preferred method for controlling the technology, which can change with rehabilitation progress. The controls need to support all abilities.
4.1.5	The smart room technology excited patients; therefore, they brainstormed additional technology they would want for controlling and sensing the physical space.
4.2	**Technical support, training, and software/hardware issues are new challenges.**
4.2.1	Once people rely on the iPad, losing access is a serious problem.
4.2.2	The technology primarily works, but bugs and undesired behavior still appear and are especially bad in a hospital setting.
4.2.3	The onboarding process does not fully meet patient needs or provide consistent support for self-learning or re-training.
4.2.4	Patients have broad expectations for technology that go beyond *how to use the app*.
4.3	**The hospital context presents unique problems for smart home technology.**
4.3.1	The hospital is still a hospital, not private or permanent like a home, limiting patients' feelings of ownership over their room and its technology.
4.3.2	Patients questioned technology aspects of the room beyond the smart room technology.
4.3.3	The commercial products that comprise the smart room are not specifically designed for this purpose, which creates visible seams to the user.
4.3.4	Some visitors and hospital staff also use the smart room technology.
4.3.5	A hospital is a trusted place, so privacy and security were often a low priority for patients; however, a few patients still expressed some concerns.

> **P11:** *Especially in my condition. I can't walk by myself. I can't get off the bed by myself. But having that iPad, I mean, the iPad next to me, so I can control some things, makes me feel a little powerful.*

These patients communicated a complex combination of grappling with a major life transition and a sense of loss related to their changed physical ability, but also how the control afforded by the SPR might help to prevent those feelings from taking over.

4.1.2 Quality of life and feelings of at-homeness.

Patients felt that their SPRs provided a homey environment and were glad that the hospital had this infrastructure.

> **P3:** *Its great independence with being able to do this, it's great. It made me feel so much more at home here. With all the things that we're controlling in the room. It is a great feeling of independence and pushing forward. Another step towards something you can do when you're in this condition.*

Part of the SHT is a smart TV, Apple TV, and soundbar, which can all be controlled by touch or voice commands within the SPR app. Being able to easily control this entertainment package contributes to patients' positive feelings toward their hospital room.

> **P6:** *There's a lot of hours, just sitting here doing nothing. Yeah. So the better the entertainment, and television, and all that stuff is, the better your overall experience.*

> **P17:** *You don't have to just sit here and think about your injury because it's hard to think about stuff like that. You can just have a TV and where it's easy to control. So you can just like, I don't know, just get your mind off of things. It's nice.*

While many hospitals offer entertainment options, the SPR is more accessible. This means that patients with motor disabilities can use the entertainment and accessibility features of the SPR to take their minds off the stressful circumstances of their condition.

4.1.3 The most important smart room feature differs by ability.

We anticipated that there might be a consensus among patients for the most important feature, but one did not emerge; six said blinds, another six said thermostats, two said lights, and one said voice control. Five patients would not identify a single feature stating that multiple or all of the smart features were the most important. Instead, participant responses were tied to performing a function they felt they could not accomplish easily without assistance.

> **P17:** *The thermostat is super cool. It's just nice to be able to do it in the bed. You know, I don't have to get up. It's really hard; it takes a long time for me to get up.*

Participants picked the most important features based on what they could control without the SHT. For example, P15 had no leg function but limited arm movement and hand dexterity, so recognized he could still use physical switches for the lights.

> **P15:** *And the most like useful, probably that is just like common, is probably the blinds because that's the only thing I've done that I might not be able to do on my own. Like the lights I could do if I wanted to take the time to do it, you know like go all the way around the room, so definitely the blinds.*

He perceived that the only way he could control the blinds was through the SPR app; thus they were the most important feature.

4.1.4 Abilities dictate the preferred method of control.

Such a wide range of injuries or disorders cause reduced motor function at many levels; the SPR needs to accommodate all of these patients. Patients highlighted issues with the current implementation and some even developed methods for making the technology more accessible for their needs.

> **Interviewer:** *Okay, so I noticed you're using the app on your phone. That's just your personal phone, right? That you use it on?*
> **P15:** *I don't like the iPad because it's too big for me to like, hold.*

Although P15 had full use of his arms, his limited hand and finger strength meant the hospital iPad was too big for him to hold. Luckily, he installed the SPR app on his phone — which he specifically bought sized for his abilities — and controlled the SPR from his device.

P2 also had limited dexterity in his hands and fingers. Despite this limitation, he demonstrated how the capacitive iPad touch screen enabled him to use the SHT. He was grateful, considering he could not use the traditional physical hospital buttons.

> **P2:** *I use a little bit of touchpad where I can, if I can touch it with my knuckle. [. . .] To move 40 channels, I can kind of scroll a little bit with my knuckle and try to get me close to the channel I want. And then, you know, voice command up or down to get me to the exact channel I want. But I just don't have the dexterity to hit the buttons exactly. I usually hit the wrong button and go someplace I don't want to go.*

For P2 to control what he wanted in the room, he learned to use voice commands in combination with his knuckle. P6 also found a solution that allowed him to control the SPR app using the touch screen despite his limited hand function and finger dexterity.

> **P6:** *I have arm mobility. And the system that my daughter and I developed, she stuck that stylus in this piece of foam. [. . .] Most people, maybe they don't need them; but I can't operate this thing without something like that.*

Simply pressing an iPad stylus into a stress ball was an accessible solution for P6; this solution could have helped P2 and others.

4.1.5 Ideas for additional technology.

Patients also proposed ideas for additional technology for controlling or sensing in their rooms. Eight patients noted they could only control the bed by the physical switches located in an awkward spot by their head, and that impaired arm or hand mobility limited access to them. They wanted bed control incorporated into the app.

> **P2:** *It [the smart room app] doesn't control the bed at all, I'd like to be able to let my bed up and down. Which is really all I would do with it is just lift the bed up and down. But it doesn't control a bed in the slightest. So that would be kind of nice to lay myself down and pick myself up a little bit more if I wanted to.*

Other participants proposed adding additional smart features to the SPR including doors, fridges, faucets, and even a wireless smart pulse oximeter, and their enthusiasm was notable.

4.2 Technical support, training, software, and hardware issues are new challenges

For SPRs, the new technology brings new challenges. The introduction of SHT brings reliability concerns [14]. Networked technologies do not have the same reliability as traditional controls, such as physical light switches. Beyond technical issues, there are problems with inadvertently placing the iPad out of reach of the patient. Additionally, SPRs require staff support for the SHT — training patients to use the technology. We developed four themes relating to SPR challenges, technical support, and onboarding.

4.2.1 Losing iPad access is a serious problem.

Maintaining access to the iPad was a critical issue. All but one patient (P8) we interviewed relied on the iPad to control their room's SHT. P8 preferred not to use the iPad and instead used the physical remote or nurse call to control her environment. Patients described several scenarios where they had lost physical access to the iPad, usually because the hospital staff inadvertently placed the iPad out of their reach when helping transition the patient into or out of bed. If it stays out of reach when they return to their bed, the patient has lost the ability to control the room.

> **P20:** *They're pretty good about making sure I have access to it. It's been out of reach a couple of times, and the next time they come around or something. I don't bother them to come and get it, I don't make them make a special trip. But I'll ask them to bring it over to me when they're in here. And they can leave it close by.*
> **Interviewer:** *If it's not in reach does that kind of affect your mood at all? As far as not being able to control aspects of the room?*
> **P20:** *Well, sure. Then I've lost my power.*

The iPad and room infrastructure also suffer from common technological problems. It can become inoperative from an operating system or software malfunction or simply a dead battery.

> **P16:** *Last Saturday, our nurse had to check the bed plugins and all that. Well, she ended up unplugging something and plugged something else into that wall over there, into that bottom one [. . .] and it blew all the outlets. And it blew, and it took out the iPad, right. [. . .] So we were out the iPad from Saturday to Monday. Because there wasn't anybody here to reset the iPad.*

Patients who have become accustomed to controlling their space can lose that ability until staff fixes the issue.

4.2.2 The technology primarily works, but bugs and undesired behaviors still appear.

Every patient we interviewed praised having the ability to control their environment. Without the SHT, many would have relied on a caregiver or staff to do it for them. Nevertheless, any technology has the potential for bugs and undesired behavior. Participants provided valuable feedback on issues they identified while using the SHT. Four participants found a UI issue with the thermostat controls on the SPR app.

> **P15:** *The app works fine. The only problem with it is the temperature. [. . .] It was really frustrating that I couldn't get it to work at all with the air.*

The thermostat control bug is a minor annoyance but highlights that bugs exist. More alarming is when the undesired behavior undermines their ability to control the room; for example, the early voice control system needed much improvement. P2 solely used voice control due to his limited abilities; he described to us some of the issues he encountered using voice control:

> **P2:** *It doesn't necessarily register my commands like, sometimes I say channel up. And it thinks I said "Chandler." I don't know why it thinks I said "Chandler." And, it does nothing when it thinks I said "Chandler."*
> **P2:** *There is a function on it that's frustrating to me: If I want to go to a certain channel, like channel 46, and I'm on channel 29, I have to go channel up, channel up, channel up, channel up. It won't go directly to channel 46 for me, for whatever reason. And it takes the command, like it writes the command on the screen. So it takes it, I can clearly see that it's taking the command, but it doesn't do anything it just sits there.*

Here P2's only way to control his room is through a voice control plagued with bugs. These issues with voice control made controlling the room extremely burdensome. Worse is when the technology does not meet the user's expectations, like when P2 realized the UI does not allow him to tune directly to a TV channel. Despite these challenges, the frustration was never so much that he stopped using it — the benefits to his independence, autonomy, and well-being outweighed the frustration. The voice control has since been upgraded, and our later interviews confirmed that the voice control system was much improved.

4.2.3 Onboarding process.

During the interviews, participants described that they learned how to use the SPR through an onboarding process. The onboarding process is generally good; patients could use the room in part because onboarding worked. However, we learned that:

- The timing of the onboarding is not always consistent.
- Caregivers do not always get the same training as patients.
- The information delivered is not always the same.
- Retention of the information by the patient is limited.

These observations demonstrate how the hospital staff can directly impact the patient's comfort level with the technology in the room based on how they initially onboard and train the patient. For example, it is possible that P8 — who was highly reluctant to use the hospital iPad — did not understand the importance and capabilities of the iPad because she was not properly introduced to it and trained on it when she entered her room.

> **Interviewer:** *So, did anyone ever show you what's on the iPad though? Or?*
> **P8:** *No*
> **Interviewer:** *No? Okay.*
> **P8:** *Nobody showed me what was on this thing either [pointing to the hard-wired remote].*

It appears that P8 was not properly onboarded to the SPR, or perhaps she was simply uninterested when the hospital staff wanted to introduce it; she was extremely hesitant to use any of the SPR features. Even when patients were introduced to the SPR features, they sometimes forgot how to control certain features and needed to be retrained or needed support because of a malfunction.

> **P4:** *Well, we have a problem because my iPad didn't work. And um, they said that tech person couldn't look at it until Monday. And then the tech person looked at it, and then I guess they got it going. [. . .] And I couldn't hook my phone up to the hospital WiFi, because you need the iPad to do that and it wasn't working. So, I just finally got WiFi yesterday afternoon. So, I've been having to use the old-school remote.*

Furthermore, when hospital IT fixed the iPad, she was not trained on it, likely because the iPad was not ready when she was first admitted. This lack of training created even more confusion.

> **P4:** *They didn't tell me which icon to hit so it took a while to find the right icon. [. . .] I tried about five or six before I went, oh, maybe it's the U.*

P6 expressed the need for additional training.

> **P6:** *At one point they sent up a guy from the physical therapy department who sat here and messed with it and got it working with the voice control, but I've long since forgotten how to do that.*

For people less familiar with technology, a single training session may not be enough. It was useful when other hospital employees were familiar with the SPR. P3 was grateful that his nurse was able to help him with the iPad.

> **P3:** *But one thing that would be better with [the iPad] is with the brightness of the screen. It took me forever to find that, how to adjust the screen brightness. It was so dim. I couldn't hardly read what was under everything. So I couldn't find settings on it. And I'm not an Apple person. So, I didn't know where to find settings on it. Luckily, last night, I finally had one of the nurses show me how to make it brighter.*

Unsurprisingly, an increase in the amount and complexity of technology employed in a hospital environment increases the need for initial and ongoing training and support to maximize the value of the new technology. This new technology necessitates additional requirements and training for the hospital staff to help onboard, educate, and troubleshoot issues that arise with the technology for the patients.

4.2.4 People have broader expectations for onboarding and technical support than just how to use the app.

In addition to supporting the technology in the SPR, this additional technology appears to have also increased patient expectations for technical support by hospital staff beyond just troubleshooting the SHT of the room. For example, P6 had issues with the AirPlay feature on his cell phone connecting to the Apple TV. His PT helped to get it working on his device, but shortly after that, his device stopped working with AirPlay. P6 expects that there should be dedicated technical support to help troubleshoot these types of issues, even though the problem was with his personal device and not necessarily with the SPR.

> **P6:** *Anyway, somehow mirroring was important, and he had it working. And by the time he got out to the elevator, it wasn't working. There was some thought that he might come back, but he hasn't. And I don't really want him to. It'd just be; I don't want to take the time of somebody who's a dedicated physical therapist, who just happens to know how this works, as opposed to having a more or less formal introduction to everything and support from...a computer geek.*

This example demonstrates the expectation that technical support extends to any technology adding to the patient experience at the hospital, including personal devices. This new requirement creates an increased demand and a new staff role that hospital administrators must account for; they will have to set guidelines and policies for handling these technical support issues.

4.3 The hospital context presents unique problems for smart home technology

SHTs, by name and function, are designed primarily for the home. A home is a private and controllable space. Usually, the SHT in a home is selected, installed, and managed by a resident. When an organization scales up the SHT to an enterprise-level setting, such as a hospital, it creates new challenges. Here, residents only temporarily occupy the space; they are merely users of the technology with little control over its administration. Five themes — related to how SPR technology fits in a hospital setting — help answer RQ3.

4.3.1 The hospital is a hospital, not private or permanent like home. Although having the ability to control elements of the environment does provide feelings of at-homeness, for two patients specifically, the hospital did not feel like home. P15 expressed positive feelings despite not feeling at home when he said, "Not necessarily like home, no. It's more like a better feeling, I guess. Being able to not like stress about being able to turn off the lights and stuff like that." P14 shared a similar perspective, "I mean, it's a hospital no matter how you look at it." Hospital designers intended the patient room to feel like a personal space, but that does not mean it truly is. It was apparent through the interviews that several patients felt the hospital iPad was not theirs, making them hesitant to use it.

> **Interviewer:** *How have you been controlling the elements of your room? Have you been using the iPad or mostly the remote?*
> **P8:** *Remote*
> **Interviewer:** *Remote, OK. Did they bring an iPad into your room? I guess the iPad is right here.*
> **P8:** *Yeah, but that belongs to somebody else.*

Interestingly, P8 uses the TV and the hard-wired bed remote — that is also hospital property; however, she will not use the hospital iPad because she feels it does not belong to her.

4.3.2 SPRs cause patients to question all aspects of the room. Although we were trying to explore SHT specifically, the presence of the SHT seemed to prompt our participants to question whether any room feature was smart or not. All room elements — like the architectural design, bathroom fixtures, medical equipment, etc. — become part of the *SPR*. For example, four patients discussed the placement of the digital clock in the room:

> **P4:** *My biggest complaint is the placement of the clock that's just really stupid. [. . .] I can't see the hour, you know, and I see the minutes and the seconds, and I'm thinking you know. I woke up last night at 3:45 and I had no idea what "45" it was.*

Another patient highlighted an architectural problem with the blinds in the room. The window is partitioned into four sections — separated by structural columns — with motorized smart blinds for each section; however, this creates a problem.

> **P15:** *Another thing about the blinds though is, I'll be laying in bed and you see all those gaps. The sun will be like just exactly like in my eye. Like even with the blackout blinds all the way down there's still a gap.*
> **P15c:** *I had that problem yesterday. I was lying right here and the sun was coming through this little gap right here. I just had to scoot down a little bit, but it wasn't that big of a deal.*

This example highlights that there is no delineation between SHT and the traditional equipment in a hospital room. When hospital designers implement this technology into the patient room, the entire room becomes a smart space in the eyes of the inhabitants.

4.3.3 The smart room technology is an integration of several commercial OTS products, creating visible seams. The SPR enables control over many aspects of the room through the iPad SPR app; however, there are still many features that patients want to be integrated into the app. As mentioned in 4.1.5, control of the hospital bed is one such feature. The underlying problem is that the bed manufacturer keeps their interface with the bed proprietary and will not allow the app development team to control the bed from the app. Edwards et al. mention this challenge of impromptu interoperability [14]; many of the COTS SHTs and medical devices are incompatible and operate as isolated islands of functionality, creating visible seams and holes to the user.

Another issue with seamless integration is incorporating voice control into the SPR app. Since the iPad is an Apple device, the command to open the SPR app is, "Siri, open the smart room app." Then once the app is open, it captures all further commands and processes them directly, bypassing Siri. The voice commands for the SPR app all begin with the hot word "Mac" or "Sam." These hot words were a design choice made by the development team with input from the STs, who identified "Mac" and "Sam" as the most accessible names for individuals to say that have common speech impairments due to an SCI. However, this creates confusion about which hot word to use in what situation.

> **P2:** *And this is actually a little bit frustrating. You have to open Siri, and then tell Siri to open smart room. I don't know why you can't just open smart room. I mean, I don't know why you have to go to Siri, then open smart room. But I'm sure it's just the way the iPad works. And then the command of your smart room is "Mac" instead of "Siri." So, you open with "Siri" and then you have to change channels with "Mac." Which, I don't even know why I have to call it a name. I don't know why I can't just go "volume up," "volume down," rather than "Mac, volume up, volume down." But that's what you do.*

Seamless system integration is a recurring theme brought out through our interviews. The SPR is a conglomeration of many systems. Many of them work well together, like the lights, blinds, and TV; however, other technologies create challenges to integration, like the hospital bed and Apple's Siri.

4.3.4 The technology in the room is not just limited to patients. Some visitors and hospital staff use it.

Introducing SHT into a shared space makes it a shared resource; any stakeholder entering the SPR becomes a potential user. Caregivers, staff, and other visitors all use the SPR app to control the room along with the patient. Furthermore, several examples emerged where the hospital staff used SHT for other tasks — namely patient education and rehabilitation. P1 and P7 spoke to us about how the patient educators would pull up iPad content to help them visually convey material during education sessions. P3 talked explicitly about how his OT was working with him and the SPR app as tools for his rehabilitation. With his neurological condition, he struggled with arm mobility and finger dexterity early on in his stay at the NRH; however, the desire to want to control aspects of his room led him to learn an adaptation of using his knuckle to control the iPad.

> **P3:** *Because it [hospital iPad] teaches me what fingers have held, what fingers I tried to use, and what I can't in order to operate it. And I'm getting so I can get my thumb out there myself enough to use the thumb, but my finger can't straighten enough to touch it directly like with my index finger or whatever. And so I've learned to use the top of my knuckle quite a bit to touch things.*

He also spoke about how using the iPad helped him gain even more movement and dexterity as he continued pushing himself to do more and more, helping his rehabilitation.

4.3.5 A hospital is a trusted place.

As part of the study, we wanted to determine how the technology in patient rooms affected feelings of privacy and security and asked about it directly. Patients were aware of the hospital's policies and procedures regarding patient discharge and preparing the room to receive the next patient. When the staff onboard the patient, the patient is notified that the hospital-furnished iPad and Apple TV will be "digitally reset" upon discharge, clearing all personal information and data from the systems. Since patients knew how the hospital would manage their data, they seemed to be more accepting of the privacy and security implications of using the SPR. Overwhelmingly — with 14 participants stating it clearly — they had no concerns with the privacy and security of the technology in their room. However, seven participants brought up how cameras and microphones could invade their privacy, and two showed interest in how the hospital uses their data. Four expressed concern with the security of their accounts on the iPad or Apple TV. Regardless, even though they brought up these privacy and security concerns, no participant indicated it was a significant enough issue to change their behavior or the way they used the smart features of the room.

This finding was surprising. We hypothesized that introducing SHT into patient rooms would create a breadth of new privacy and security challenges for the hospital to overcome patient fears. As we examined the data, we learned that because the hospital is a trusted place, patients are less concerned about their privacy and security. For P4, it was a defeatist attitude that there is no privacy in a hospital setting, "Yeah, you gave up all of it, so there's no privacy." Whereas for P6, it is that privacy and security is not a priority because their life was suddenly changed forever by an injury.

> **P6:** *Oh, I suppose there are a lot of things recorded on that, that one might consider rather embarrassing, but once you're in a situation like this, it's like, that's the least of your problems because nobody really wants to see that stuff.*

Lastly, P19 brought up that the reason privacy and security are not a concern is that it is just part of being in a hospital.

> **P19:** *It's a hospital like they could watch, or they can see me. [. . .] I'm paralyzed, and let me tell you what, I have no dignity left. It is just part of being in the hospital when you are paralyzed.*

Since the patients consider the hospital a trustworthy place — because they are there for medical care — they approach privacy and security concerns with a different perspective.

5 DISCUSSION

Integrating SHT into a hospital setting brings the future of *smart hospitals* one step closer to reality. Modern technology has the potential not only to help patients control their surroundings but also to aid in rehabilitation, improve mental-wellbeing, enable autonomy, and greatly improve the patient experience. However, hospital decision-makers must consider important factors when implementing new technologies in these settings. Based on our findings, we provide insights into the potential integration of SHT into other hospital environments beyond the one we studied. We also offer additional thoughts on onboarding and transitions into and out of the hospital. Lastly, we distill three important design considerations for a successful deployment of SHT in patient rooms.

5.1 Broader context of smart home technology applied in other hospital environments

An important outcome of this study is documenting the value that SHT provides to patients in the RH. In addition to effectively providing them with the ability to control their surroundings, it facilitated positive feelings of autonomy, control, and at-homeness; it also appeared to have a positive impact on patient mindsets and perhaps their mental health as they come to terms with their changed abilities. When looking through the lens of Strengers' "3Ps" for SHT — protection, productivity, and pleasure — we can confirm that it partly applies to the application of SHT in a hospital context as well [53]; namely, productivity from increased patient accessibility and as a rehabilitation tool, and pleasure from the entertainment provided by the Apple TV and soundbar. However, our findings are likely integrally tied to the particularities of an RH, like extended patient stays and the limited mobility experienced by many patients. For example, when patients discussed their sense of autonomy and how the SHT enabled them to control their space, their responses were deeply tied to their physical abilities and whether or not they would be able to control the same things if the SHT was not there. Another example is that participants exhibited a learning curve from first admittance and onboarding through discharge. The extended stay in the RH makes it worthwhile for the patients to invest time up-front to learn how to use the system.

In other hospital settings, the circumstances are different. Patients may not have the same disabilities or impairments, and their stays in the hospital might be more on the order of days rather than the typical stay of 8-12 weeks in an RH. The goal of an acute care facility is to stabilize and treat patients and then discharge them when treatment is complete or transfer them to long-term rehabilitative care. This rapid pace and short duration for patients could make the challenge of deploying a practical shared smart space even more difficult. In the NRH, it takes time to onboard and train patients on how to use the features of their SPR. Upon discharge, the room is "digitally reset" for the next patient by wiping the contents of the iPad and Apple TV back to an initial state, removing any data from the previous patient, and physically cleaning the iPad. It takes additional time to thoroughly clean and digitally prepare the room for the next patient. This extra time to onboard, train, and reset the room after the patient's discharge may not be a good fit for a high-tempo acute care facility.

One possible solution is for the hospital not to provide a device, such as the iPad, and instead rely on most patients using their own devices. This solution would obviate some of those factors but might introduce other challenges concerning compatibility and other kinds of technical support. In the near future, SHT may also become the norm, where using an app to control all aspects of a room's environment is so commonplace that it does not require any demonstration or training. It remains an open question whether the value of the SHT that we observed in this hospital setting will be translated into other hospital contexts. Perhaps, with fewer disabilities, patients will more easily adopt the technology and still benefit from feelings of at-homeness by having complete control of the environment and entertainment in their patient room.

5.2 Emphasizing the importance of onboarding

The common practice in the NRH is to give patients access to the iPad and provide them onboarding training when they first enter their room — as long as their medical provider has determined they are cognitively appropriate to use the iPad. However, the patient's transition from acute care to the RH can be overwhelming, and there are some critical elements to consider when onboarding — adapted from a list of physical factors listed in Kabir et al.'s work [32]:

- When first admitted, patients are just starting their rehabilitation; movement, strength, and dexterity are at their worst, and they can vary over time, sometimes unpredictably.
- Patients may struggle to accept the potential permanence of their life-altering illness or injury and therefore resist learning technology they believe they may not use afterward.
- Many patients are very fatigued and under the influence of strong pain medications when first admitted; this can affect cognitive abilities, especially memory and learning.
- Many SCI patients are on a mechanical ventilator when they first enter the RH, which can make controlling the room with voice commands much more difficult.

Onboarding and availability of retraining are especially important since patients may be dealing with some of these factors. In this hospital, an OT, PT, nurse, technical support, or health unit coordinator does the onboarding, and each person might train the patient differently. One way to improve the process would be to introduce a checklist of all the SPR features to cover during onboarding. This way, the patient can learn to use all aspects of the SPR early on. Additionally, since learning and memory can be challenges for the patient, there should be an easy way for the patient to request follow-on training. This request for additional training was common in our findings, but as mentioned in section 4.2.4, patients are not always willing to ask for it. It is a good idea for trainers to occasionally prompt patients if they need additional training just in case they are too timid to ask for help. The opportunity for further training is vital for rehabilitation patients because their abilities can change or improve over time, and since their abilities can change, how they control the room can change — e.g., transitioning from voice control only to using the iPad touchscreen.

5.3 Technology can help with transitions and other tasks within the hospital

Even though transitioning from acute care to the NRH can be difficult, our results suggest that the SHT in patient rooms can help ease stress and uncertainty. Since patients can regain control over their lives through technology, it can positively affect their mental well-being. However, using SHT is not the only opportunity to aid transitional care. As mentioned, individuals with SCI/D may experience respiratory impairment requiring mechanical ventilation. To manage the chance of secondary complications, it is a goal for the patient to wean from the ventilator, when possible, as part of their rehabilitation progress in the hospital. There are numerous ways the SHT, or adjacent technology, might help with the mechanical ventilator weaning process, possibly by helping the patient to relax during the weaning session using the patient room soundbar, smart TV, or other technology like virtual or augmented reality devices to distract them from the weaning process [36, 41].

Another way smart technology can help the rehabilitation process is with a more direct application for patient education and physical therapy. Interviews revealed that patient educators and therapists are exploring ways to use technology in their work with the patient. Educators use the iPad and smart TV to show and control educational content. While PTs use the capacitive touch screen as a rehabilitation tool for their patients, helping them to work on mobility. The patients like the iPad because it requires less force and dexterity than physical remotes while allowing them to control more features. Exploring different uses for the SHT in a hospital context beyond controlling the environment holds great potential for reaching beyond "we put a smart home into a hospital room" towards realizing the potential of a *smart hospital*.

5.4 Design consideration for future smart patient rooms

We propose some design considerations grounded in the patient interviews and observations presented above. For hospitals looking to implement SHT in their patient rooms, we highlight that the design must be: 1) seamless, 2) universal, and 3) properly supported.

5.4.1 Seamless. For a smart hospital to succeed, the systems integration must be seamless. As we highlighted in section 4.3.3 in our findings, patients notice the seams and holes in the patchwork of technologies employed in their room. There is a constellation of technologies — the iPad is an Apple product, the lights are a commercial Crestron product, and an Apple TV is connected to an LG smart TV and soundbar — and the in-house software developers tied all these technologies together the best they could, with a custom smart room app. A custom app was required because COTS SHT is not designed for an enterprise context like a hospital. Currently, it is not possible to take a Google or Alexa assistant and install it in a patient's room to control the lights, blinds, thermostat, and TV. That would increase complexity because Google and Alexa assistants require a personal account to set up the devices.

Another seam appears because the smart room app does not control other technologies in the room like the bed, overhead lifting crane, patient charting system, pulse oximeter, the primary nurse call system, and other medical equipment. Because they are all proprietary systems, they do not integrate with the SPR, or at least not easily. If we genuinely want to build a *smart hospital* and not just a hospital with SHT, all these systems need to work together seamlessly. We call on SHT engineers to develop enterprise solutions for contexts like hospitals, hotels, or businesses and medical device manufacturers to enable an interface with their products to leverage SHT's capabilities of control for hospitals.

5.4.2 Universal. The SPR needs to be universally accessible. The most considerable challenge we see for patients with little to no arm movement, hand function, or finger dexterity is that the voice control is cumbersome to use. This issue is a significant problem for an RH accommodating a patient population with varying levels of motor function. Recommendations to make smart technology more accessible include having a more robust voice control system. We propose this as future work to use machine learning to develop a new voice control model that can better handle speech issues common to patients at an RH. We must train the new voice control model to handle slow, slurred, or broken speech and speech dysarthria. The microphone setup and ability to invoke the voice control must also be more accessible.

SPRs can also be more accessible by having different-sized iPads. The hospital should not rely on patients to supply their devices for controlling their environment. In this situation, it would be better to have different size hospital-furnished iPads that the hospital staff could easily swap out based on the patient's abilities. Furthermore, as patients develop creative adaptations — like the stylus stuck in a stress ball for P6 — the hospital should invest in having some of them on hand to help other patients with similar motor function.

5.4.3 Properly Supported. As considered in section 4.2, introducing new technology into the patient's world creates an entirely new requirement for initial onboarding education, ongoing training, and technical support typically not required in a hospital. The NRH converted one of their OTs into a full-time SPR support personnel. However, from our observations and patient feedback, one person cannot service all 75 patient rooms. The first few days of a patient's stay can be tumultuous; they recently suffered a life-changing injury and can be more fatigued and less responsive due to medications. At this time, they receive the initial training on how to use the iPad to control their environment, which is good because they should be aware of the technology as soon as possible. Still, there is a need for continuing instruction and training during their stay as they engage more easily and gain more mobility, potentially altering how they can control the room. Moreover, just like with any technology, there is a potential for issues to arise, especially considering the sheer amount of added technology the SPRs bring. To avoid additional workload requirements falling on overburdened healthcare workers, which could contribute to burnout [46], dedicated and adequate technical support personnel should be employed to handle these training and technical support issues.

6 LIMITATIONS

While these findings paint a clear picture of our participants' experiences in the SPR, there are some limitations to our method. First, we conducted only a single interview with each participant, so we do not know how much their perspectives and experiences evolved throughout their hospital stay and afterward as they transitioned home. Second, we would like to have reinterviewed patients who expressed difficulties with UX elements that were updated to see how the improvements affected their experience. We acknowledge that reinterviews are only sometimes possible since the patients might have been discharged after the updates happened. Finally, we only interviewed patients and caregivers in this work, but the hospital employees also likely have additional perspectives on the SPRs that were not captured in this data.

7 CONCLUSION

SPRs have the potential to dramatically improve the quality of life of patients during their stay in an RH and possibly in other healthcare settings as well. We conducted semi-structured interviews with 20 patients and six caregivers to gain valuable insight into the implementation of SHT in the patient rooms of an RH. Our results showed that 1) SHT does improve patient wellbeing, 2) technical support, technical training for patients, and software/hardware bugs are new challenges brought by the SHT in patient rooms, and 3) the hospital context presents unique problems and exacerbates existing ones for SHT. Lastly, based on our analysis, we provided three primary design considerations for future implementations of SHTs in patient rooms. To be most effective, the design of the SPR should be *seamless*, *universal*, and *properly supported*. Even in the current imperfect state of the RH we studied, the impact of these rooms on patients is clearly significant. Yet, there remains so much room for the technology to continue to grow and develop into the workings of a truly *smart* hospital.

ACKNOWLEDGMENTS

We thank our expert collaborators at the University of Utah Health Craig H. Neilsen Rehabilitation Hospital, including Dr. Jeffrey Rosenbluth, James Gardner, and Abby Call, for their direct support of our research efforts. We also thank Ashlyn Hansen, undergraduate researcher, for her assistance with conducting and transcribing some patient interviews. We especially thank our interviewees for their time and for sharing their experiences in the smart patient room. Finally, we appreciate the feedback from the anonymous reviewers, the HCC seminar, and our fellow lab mates; they truly helped improve this work. This material is based upon work supported by the National Science Foundation under Grant No. IIS-2146420.

REFERENCES

[1] Gregory D. Abowd and Elizabeth D. Mynatt. 2000. Charting Past, Present, and Future Research in Ubiquitous Computing. *ACM Transactions on Computer-Human Interaction* 7, 1 (3 2000), 29–58. https://doi.org/10.1145/344949.344988

[2] Mohammed Ibrahim Alhojailan. 2012. Thematic analysis: A critical review of its process and evaluation. In *West East Journal of Social Sciences*, Vol. 1. The West East Institute, West Chester, PA, USA, 39–47. Issue 1.

[3] Morgan Andersson. 2017. Caring Architecture: Institutions and Relational Practices. In *Caring Architecture*. Cambridge Scholars Publisher, Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK, 127–142.

[4] Morgan Andersson, Isabell Fridh, and Berit Lindahl. 2019. Is it possible to feel at home in a patient room in an intensive care unit? Reflections on environmental aspects in technology-dense environments. *Nurs Inq* 26, 4 (July 2019), e12301. https://doi.org/10.1111/nin.12301

[5] Anna Anåker, Lena von Koch, Ann Heylighen, and Marie Elf. 2019. "It's Lonely": Patients' Experiences of the Physical Environment at a Newly Built Stroke Unit. *HERD: Health Environments Research & Design Journal* 12, 3 (2019), 141–152. https://doi.org/10.1177/1937586718806696 PMID: 30336696.

[6] Belén Barros Pena, Rachel E Clarke, Lars Erik Holmquist, and John Vines. 2021. Circumspect Users: Older Adults as Critical Adopters and Resistors of Technology. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 84, 14 pages. https://doi.org/10.1145/3411764.3445128

[7] Timothy W. Bickmore, Laura M. Pfeifer, and Brian W. Jack. 2009. Taking the Time to Care: Empowering Low Health Literacy Hospital Patients with Virtual Nurse Agents. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Boston, MA, USA) *(CHI '09)*. Association for Computing Machinery, New York, NY, USA, 1265–1274. https://doi.org/10.1145/1518701.1518891

[8] Saba Rebecca Brause and Grant Blank. 2020. Externalized domestication: smart speaker assistants, networks and domestication theory. *Information, Communication & Society* 23, 5 (2020), 751–763. https://doi.org/10.1080/1369118X.2020.1713845

[9] Kelly Caine, Selma Šabanovic, and Mary Carter. 2012. The effect of monitoring by cameras and robots on the privacy enhancing behaviors of older adults. In *Proceedings of the seventh annual ACM/IEEE international conference on Human-Robot Interaction - HRI '12* (Boston, Massachusetts, USA). ACM Press, New York, New York, USA, 343–350. https://doi.org/10.1145/2157689.2157807

[10] Scott Carter, Jennifer Mankoff, Scott R. Klemmer, and Tara Matthews. 2008. Exiting the cleanroom: On ecological validity and ubiquitous computing. *Human-Computer Interaction* 23, 1 (1 2008), 47–99. https://doi.org/10.1080/07370020701851086

[11] Scott Carter, Jennifer Mankoff, Scott R Klemmer, and Tara Matthews. 2008. Exiting the Cleanroom: On Ecological Validity and Ubiquitous Computing. *Human-computer interaction* 23, 1 (2008), 47–99. https://doi.org/10.1080/07370020701851086

[12] Eun Kyoung Choe, Sunny Consolvo, Jaeyeon Jung, Beverly Harrison, and Julie A. Kientz. 2011. Living in a Glass House: A Survey of Private Moments in the Home. In *Proceedings of the 13th International Conference on Ubiquitous Computing* (Beijing, China) *(UbiComp '11)*. Association for Computing Machinery, New York, NY, USA, 41–44. https://doi.org/10.1145/2030112.2030118

[13] E A Eastwood, K J Hagglund, K T Ragnarsson, W A Gordon, and R J Marino. 1999. Medical rehabilitation length of stay and outcomes for persons with traumatic spinal cord injury–1990-1997. *Arch. Phys. Med. Rehabil.* 80, 11 (Nov. 1999), 1457–1463. https://doi.org/10.1016/s0003-9993(99)90258-7

[14] W. Keith Edwards and Rebecca E. Grinter. 2001. At Home with Ubiquitous Computing: Seven Challenges. In *Proceedings of the 3rd International Conference on Ubiquitous Computing* (Atlanta, Georgia, USA) *(UbiComp '01)*. Springer-Verlag, Berlin, Heidelberg, 256–272. https://doi.org/10.1007/3-540-45427-6_22

[15] Marie Engwall, Isabell Fridh, Lotta Johansson, Ingegerd Bergbom, and Berit Lindahl. 2015. Lighting, sleep and circadian rhythm: An intervention study in the intensive care unit. *Evidensbaserd design inom intensivvård - en framtida utmaning* 31, 6 (2015), 325–335. https://doi.org/10.1016/j.iccn.2015.07.001

[16] Jesus Favela, Monica Tentori, and Victor M. Gonzalez. 2010. Ecological validity and pervasiveness in the evaluation of ubiquitous computing technologies for health care. *International Journal of Human-Computer Interaction* 26, 5 (5 2010), 414–444. https://doi.org/10.1080/10447311003719896

[17] Geraldine Fitzpatrick and Gunnar Ellingsen. 2013. A review of 25 years of CSCW research in healthcare: Contributions, challenges and future agendas. , 609–665 pages. https://doi.org/10.1007/s10606-012-9168-0

[18] Geraldine Fitzpatrick and Gunnar Ellingsen. 2013. A Review of 25 Years of CSCW Research in Healthcare: Contributions, Challenges and Future Agendas. *Comput. Supported Coop. Work* 22, 4–6 (aug 2013), 609–665. https://doi.org/10.1007/s10606-012-9168-0

[19] Radhika Garg and Christopher Moreno. 2019. Understanding Motivators, Constraints, and Practices of Sharing Internet of Things. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 2, Article 44 (jun 2019), 21 pages. https://doi.org/10.1145/3328915

[20] Stephen D Gill, Toni Hogg, and Pamela J Dolley. 2016. Loneliness during inpatient rehabilitation: results of a qualitative study. *International journal of rehabilitation research* 39, 1 (2016), 84–86. https://doi.org/10.1097/MRR.0000000000000139

[21] Shefali Haldar, Maher Khelifi, Sonali R Mishra, Calvin Apodaca, Erin Beneteau, Ari H Pollack, and Wanda Pratt. 2020. Designing Inpatient Portals to Support Patient Agency and Dynamic Hospital Experiences. *AMIA ... Annual Symposium proceedings* 2020 (2020), 524–533.

[22] Shefali Haldar, Sonali R. Mishra, Maher Khelifi, Ari H. Pollack, and Wanda Pratt. 2019. Beyond the Patient Portal: Supporting Needs of Hospitalized Patients. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3290605.3300596

[23] Neil A Halpern. 2014. Innovative designs for the smart ICU: Part 1: From initial thoughts to occupancy. *Chest* 145, 2 (Feb. 2014), 399–403. https://doi.org/10.1378/chest.13-0003

[24] Neil A Halpern. 2014. Innovative designs for the smart ICU: Part 2: The ICU. *Chest* 145, 3 (March 2014), 646–658. https://doi.org/10.1378/chest.13-0004

[25] Neil A Halpern. 2014. Innovative designs for the smart ICU: Part 3: Advanced ICU informatics. *Chest* 145, 4 (April 2014), 903–912. https://doi.org/10.1378/chest.13-0005

[26] Neil A Halpern and Diana C Anderson. 2020. Keeping a 2009 Design Award-Winning Intensive Care Unit Current: A 13-Year Case Study. *HERD* 13, 4 (May 2020), 190–209. https://doi.org/10.1177/1937586720918225

[27] Tom Hargreaves and Charlie Wilson. 2017. *Smart Homes and Their Users* (1 ed.). Springer International Publishing, Cham, Switzerland. https://doi.org/10.1007/978-3-319-68018-7

[28] S S Intille. 2002. Designing a home of the future. *IEEE Pervasive Comput.* 1, 2 (April 2002), 76–82.

[29] Timothy Onosahwo Iyendo. 2017. Sound as a supportive design intervention for improving health care experience in the clinical ecosystem: A qualitative study. *Complementary therapies in clinical practice* 29 (2017), 58–96. https://doi.org/10.1016/j.ctcp.2017.08.004

[30] Maia L. Jacobs, James Clawson, and Elizabeth D. Mynatt. 2014. My Journey Compass: A Preliminary Investigation of a Mobile Tool for Cancer Patients. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 663–672. https://doi.org/10.1145/2556288.2557194

[31] Swathi Jagannath, Aleksandra Sarcevic, and Andrea Forte. 2018. "We are not entirely replacing paper": Understanding paper persistence in emergency medical settings. In *Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW*. ACM, New York, NY, USA, 249–252. https://doi.org/10.1145/3272973.3274067

[32] Kazi Sinthia Kabir, Ahmad Alsaleem, and Jason Wiese. 2021. The Impact of Spinal Cord Injury on Participation in Human-Centered Research. In *Designing Interactive Systems Conference 2021* (Virtual Event, USA) *(DIS '21)*. Association for Computing Machinery, New York, NY, USA, 1902–1914. https://doi.org/10.1145/3461778.3462122

[33] Logan Kendall, Sonali R Mishra, Ari Pollack, Barry Aaronson, and Wanda Pratt. 2015. Making background work visible: opportunities to address patient information needs in the hospital. *AMIA ... Annual Symposium proceedings* 2015 (2015), 1957–1966.

[34] Julie A. Kientz, Shwetak N. Patel, Brian Jones, Ed Price, Elizabeth D. Mynatt, and Gregory D. Abowd. 2008. The Georgia Tech Aware Home. In *CHI '08 Extended Abstracts on Human Factors in Computing Systems* (Florence, Italy) *(CHI EA '08)*. Association for Computing Machinery, New York, NY, USA, 3675–3680. https://doi.org/10.1145/1358628.1358911

[35] Predrag Klasnja, Andrea Hartzler, Christopher Powell, Giovandy Phan, and Wanda Pratt. 2010. Health Weaver Mobile: Designing a Mobile Tool for Managing Personal Health Information during Cancer Care. *AMIA ... Annual Symposium*

proceedings 2010 (2010), 392–396.

[36] Merel Krijn, Paul MG Emmelkamp, Ragnar P Olafsson, and Roeline Biemond. 2004. Virtual reality exposure therapy of anxiety disorders: A review. *Clinical psychology review* 24, 3 (2004), 259–281. https://doi.org/10.1016/j.cpr.2004.04.001

[37] Berit Lindahl and Ingegerd Bergbom. 2015. Bringing research into a closed and protected place: development and implementation of a complex clinical intervention project in an ICU. *Critical care nursing quarterly* 38, 4 (2015), 393–404. https://doi.org/10.1097/CNQ.0000000000000087

[38] Berit Lindahl and Sue Kirk. 2019. When technology enters the home – a systematic and integrative review examining the influence of technology on the meaning of home. *Scandinavian Journal of Caring Sciences* 33, 1 (3 2019), 43–56. https://doi.org/10.1111/SCS.12615

[39] Kelly Mack, Emma J. McDonnell, Venkatesh Potluri, Maggie Xu, Jailyn Zabala, Jeffrey P. Bigham, Jennifer Mankoff, and Cynthia L. Bennett. 2022. Anticipate and Adjust: Cultivating Access in Human-Centered Methods. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, Louisiana, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, 18 pages. https://doi.org/10.1145/3491102.3501882

[40] Michael Massimi and Carman Neustaedter. 2014. Moving from Talking Heads to Newlyweds: Exploring Video Chat Use during Major Life Events. In *Proceedings of the 2014 Conference on Designing Interactive Systems* (Vancouver, BC, Canada) *(DIS '14)*. Association for Computing Machinery, New York, NY, USA, 43–52. https://doi.org/10.1145/2598510.2598570

[41] Kevin D McCaul and James M Malott. 1984. Distraction and coping with pain. *Psychological bulletin* 95, 3 (1984), 516.

[42] Andrew D. Miller, Sonali R. Mishra, Logan Kendall, Shefali Haldar, Ari H. Pollack, and Wanda Pratt. 2016. Partners in Care: Design Considerations for Caregivers and Patients During a Hospital Stay. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing* (San Francisco, California, USA) *(CSCW '16)*. Association for Computing Machinery, New York, NY, USA, 756–769. https://doi.org/10.1145/2818048.2819983

[43] Sonali Raj Mishra. 2019. Designing Technologies to Support Patient Engagement in the Hospital.

[44] Dan Morris and Amy Karlson. 2011. Dynamic Accessibility Requirements for Hospital Patients. In *CHI 2011 Workshop on Dynamic Accessibility* (chi 2011 workshop on dynamic accessibility ed.) (Vancouver, BC, Canada). ACM, New York, NY, USA, 1–5. https://www.microsoft.com/en-us/research/publication/dynamic-accessibility-requirements-hospital-patients/

[45] Laura Pfeifer Vardoulakis, Amy Karlson, Dan Morris, Greg Smith, Justin Gatewood, and Desney Tan. 2012. Using Mobile Phones to Present Medical Information to Hospital Patients. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI '12)*. Association for Computing Machinery, New York, NY, USA, 1411–1420. https://doi.org/10.1145/2207676.2208601

[46] Igor Portoghese, Maura Galletta, Rosa Cristina Coppola, Gabriele Finco, and Marcello Campagna. 2014. Burnout and workload among health care workers: the moderating role of job control. *Saf Health Work* 5, 3 (June 2014), 152–157. https://doi.org/10.1016/j.shaw.2014.05.004

[47] Xiaobo Quan, Anjali Joseph, and Upali Nanda. 2017. Developing Evidence-based Tools for Designing and Evaluating Hospital Inpatient Rooms. *Journal of interior design* 42, 1 (2017), 19–38. https://doi.org/10.1111/joid.12091

[48] Harry T. Reis, Kennon M. Sheldon, Shelly L. Gable, Joseph Roscoe, and Richard M. Ryan. 2000. Daily Well-Being: The Role of Autonomy, Competence, and Relatedness. *Personality and Social Psychology Bulletin* 26, 4 (2000), 419–435. https://doi.org/10.1177/0146167200266002

[49] Martin Saebu, Marit Sørensen, and Hallgeir Halvari. 2013. Motivation for physical activity in young adults with physical disabilities during a rehabilitation stay: a longitudinal test of self-determination theory. *Journal of applied social psychology* 43, 3 (2013), 612–625. https://doi.org/10.1111/j.1559-1816.2013.01042.x

[50] Curtis N. Sessler. 2014. Evolution of ICU Design: Smarter Is Better. *CHEST* 145, 2 (2 2014), 205–206. https://doi.org/10.1378/CHEST.13-2746

[51] Katie A. Siek, Gillian R. Hayes, Mark W. Newman, and John C. Tang. 2014. Field Deployments: Knowing from Using in Context. In *Ways of Knowing in HCI*, Judith S. Olson and Wendy A. Kellogg (Eds.). Springer New York, New York, NY, 119–142. https://doi.org/10.1007/978-1-4939-0378-8_6

[52] Meredith Skeels and Desney S. Tan. 2010. Identifying Opportunities for Inpatient-Centric Technology. In *Proceedings of the 1st ACM International Health Informatics Symposium* (Arlington, Virginia, USA) *(IHI '10)*. Association for Computing Machinery, New York, NY, USA, 580–589. https://doi.org/10.1145/1882992.1883087

[53] Yolande Strengers, Jenny Kennedy, Paula Arcari, Larissa Nicholls, and Melissa Gregg. 2019. Protection, Productivity and Pleasure in the Smart Home: Emerging Expectations and Gendered Insights from Australian Early Adopters. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300875

[54] Fredrika Sundberg, Isabell Fridh, Berit Lindahl, and Ingemar Kåreholt. 2021. Visitor's Experiences of an Evidence-Based Designed Healthcare Environment in an Intensive Care Unit. *HERD: Health Environments Research & Design Journal* 14, 2 (2021), 178–191. https://doi.org/10.1177/1937586720943471 PMID: 32734781.

[55] M. Tamm. 1999. What does a home mean and when does it cease to be a home? Home as a setting for rehabilitation and care. *Disability and Rehabilitation* 21, 2 (1999), 49–55. https://doi.org/10.1080/096382899297963

[56] Charlotte Tang and Sheelagh Carpendale. 2008. Evaluating the Deployment of a Mobile Technology in a Hospital Ward. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work* (San Diego, CA, USA) *(CSCW '08)*. Association for Computing Machinery, New York, NY, USA, 205–214. https://doi.org/10.1145/1460563.1460596

[57] Charlotte Tang and Sheelagh Carpendale. 2009. A Mobile Voice Communication System in Medical Setting: Love It or Hate It?. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Boston, MA, USA) *(CHI '09)*. Association for Computing Machinery, New York, NY, USA, 2041–2050. https://doi.org/10.1145/1518701.1519012

[58] Ellen Taylor, Alan J. Card, and Melissa Piatkowski. 2018. Single-Occupancy Patient Rooms: A Systematic Review of the Literature Since 2006. *HERD: Health Environments Research & Design Journal* 11, 1 (2018), 85–100. https://doi.org/10.1177/1937586718755110 PMID: 29448834.

[59] Peter Tolmie, Andy Crabtree, Stefan Egglestone, Jan Humble, Chris Greenhalgh, and Tom Rodden. 2010. Digital Plumbing: The Mundane Work of Deploying UbiComp in the Home. *Personal Ubiquitous Comput.* 14, 3 (apr 2010), 181–196. https://doi.org/10.1007/s00779-009-0260-5

[60] Wayes Tushar, Tao Wang, Lan Lan, Yunjian Xu, Chathura Withanage, Chau Yuen, and Kristin L Wood. 2017. Policy design for controlling set-point temperature of ACs in shared spaces of buildings. *Energy Build.* 134 (Jan. 2017), 105–114. https://doi.org/10.1016/j.enbuild.2016.10.027

[61] Kenton T. Unruh, Meredith Skeels, Andrea Civan-Hartzler, and Wanda Pratt. 2010. Transforming Clinic Environments into Information Workspaces for Patients. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Atlanta, Georgia, USA) *(CHI '10)*. Association for Computing Machinery, New York, NY, USA, 183–192. https://doi.org/10.1145/1753326.1753354

[62] David K Vawdrey, Lauren G Wilcox, Sarah A Collins, Suzanne Bakken, Steve Feiner, Aurelia Boyer, and Susan W Restaino. 2011. A tablet computer application for patients to participate in their hospital care. *AMIA ... Annual Symposium proceedings* 2011 (2011), 1428–1435.

[63] Stephen Verderber, Seth Gray, Shivathmikha Suresh-Kumar, Damian Kercz, and Christopher Parshuram. 2021. Intensive Care Unit Built Environments: A Comprehensive Literature Review (2005–2020). *HERD: Health Environments Research & Design Journal* 14, 4 (2021), 368–415. https://doi.org/10.1177/19375867211009273 PMID: 34000842.

[64] Lauren Wilcox, Dan Morris, Desney Tan, and Justin Gatewood. 2010. Designing Patient-Centric Information Displays for Hospitals. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Atlanta, Georgia, USA) *(CHI '10)*. Association for Computing Machinery, New York, NY, USA, 2123–2132. https://doi.org/10.1145/1753326.1753650

[65] Charlie Wilson, Tom Hargreaves, and Richard Hauxwell-Baldwin. 2015. Smart Homes and Their Users: A Systematic Analysis and Key Challenges. *Personal Ubiquitous Comput.* 19, 2 (feb 2015), 463–476. https://doi.org/10.1007/s00779-014-0813-0

[66] Xiaomu Zhou, Mark S. Ackerman, and Kai Zheng. 2009. I Just Don't Know Why It's Gone: Maintaining Informal Information Use in Inpatient Care. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Boston, MA, USA) *(CHI '09)*. Association for Computing Machinery, New York, NY, USA, 2061–2070. https://doi.org/10.1145/1518701.1519014