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Perceptions of seniors with heart failure regarding autonomous zero-effort monitoring of physiological parameters in the smart-home environment

Sherry L. Grace, PhD [a,b,*], Golnoush Taherzadeh, MSc [b], Isaac Sung Jae Chang, BASc [c], Jennifer Boger, PhD [d], Amaya Arcelus, PhD [d], Susanna Mak, MD [e], Caroline Chessex, MD [f], Alex Mihailidis, PhD [c]

[a] York University, School of Kinesiology and Health Science, Bethune 368, 4700 Keele Street, Toronto, ON, M3J IP3, Canada
[b] University Health Network, Toronto Rehabilitation Institute, Cardiorespiratory Fitness Team; 347 Rumsey Road, Toronto, ON, M4G IR7, Canada
[c] Institute of Biomaterials and Biomedical Engineering, University of Toronto, Rosebrugh Building, Room 407, 164 College St, Toronto, ON, M5S 3G9, Canada
[d] Toronto Rehabilitation Institute, 550 University Ave., 12th Floor, Toronto, ON, M5G 2A2, Canada
[e] Department of Medicine, Division of Cardiology, Mount Sinai Hospital, 600 University Ave, Murray Side, Rm 18-365, Toronto ON, M5G 1X5, Canada
[f] University Health Network, Cardiac Rehabilitation, Toronto Western Hospital, 399 Bathurst St. West Wing, 5th Floor, Room 469, Toronto, ON, M5T 2S8, Canada

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A B S T R A C T

Background: Technological advances are leading to the ability to autonomously monitor patient's health status in their own homes, to enable aging-in-place.
Objectives: To understand the perceptions of seniors with heart failure (HF) regarding smart-home systems to monitor their physiological parameters.
Methods: In this qualitative study, HF outpatients were invited to a smart-home lab, where they completed a sequence of activities, during which the capacity of 5 autonomous sensing modalities was compared to gold standard measures. Afterwards, a semi-structured interview was undertaken. These were transcribed and analyzed using an interpretive-descriptive approach.
Results: Five themes emerged from the 26 interviews: (1) perceptions of technology, (2) perceived benefits of autonomous health monitoring, (3) disadvantages of autonomous monitoring, (4) lack of perceived need for continuous health monitoring, and (5) preferences for autonomous monitoring.
Conclusions: Patient perception towards autonomous monitoring devices was positive, lending credence to zero-effort technology as a viable and promising approach.

Introduction

Heart failure (HF) is a complex cardiovascular disease requiring monitoring and management to optimize outcomes. Its burden is of epidemic proportions, affecting an estimated 26 million people worldwide in 2014.[1] HF is the leading cause of hospitalizations in Europe, the United States (over 1 million hospitalizations in both regions)[1] and Canada (305,000 Canadians hospitalized).[2] This is a significant burden to any economy.

HF is marked by symptoms such as breathlessness, orthopnoea, reduced exercise tolerance, fatigue and fluid retention. As such, heart rate, respiratory rate, blood pressure, and body weight, among others, are essential physiological parameters in monitoring the condition of HF patients, and whether they are self-managing appropriately in the community. Knowledge of these key parameters allows for provision of appropriate care and intervention, which may avoid acute decompensation, and hence expensive hospitalization.[3]

Indeed, HF self-management can mitigate the high-risk of mortality in this patient group. For example, HF patients are directed to weigh themselves daily, to ascertain whether they are retaining fluid and hence may be decompensating. If their weight

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* Corresponding author. School of Kinesiology and Health Science, Bethune 368, York University, 4700 Keele Street, Toronto, ON, M3J IP3, Canada. Fax: +1 416 736 5774
E-mail address: sgrace@yorku.ca (S.L. Grace).

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has increased, they can change their behaviours and seek care as appropriate, to mitigate decompensation and hence re-hospitalization. However, many patients may not follow advice to weigh themselves daily and hence autonomous assessment of weight could be very useful.

Some previous research has demonstrated that in-home health monitoring works in HF patients, and may even result in greater risk factor control,[4–6] improve quality of life, improve the quality of patient-provider relationships, shorten lengths of hospital stay, reduce mortality, all at much lower cost.[7–11] However, many seniors are unfamiliar with the methods, frequency or actions required to self-monitor their HF, or are unable to operate the devices required to do so. Indeed a recent review concluded technological acceptance and perceptions of usability in older adults, including those with cardiovascular diseases, are low.[12] Progress has been made in the development of "zero-effort technology" which autonomously monitors physiological parameters without any conscious effort from users.[13] The availability of this technology could facilitate accurate and continuous ambient monitoring of important physiological parameters for HF patients, without any patient burden, patient-related error or failure.

However, for such a system to be implemented, it must be acceptable to the user. Thus, the objective of this study was to understand the perceptions of seniors with HF regarding a smart-home system to autonomously monitor their physiological parameters, namely heart rate, blood pressure, temperature, weight, and respiration.

Methods

Design

This was a qualitative sub-study of a larger cross-sectional observational study designed to design and pilot test a smart-home system. The design of the technology and the development of the interview guide were informed by the Human Activity Assistive Technology (HAAT) theoretical framework.[14] This is a model to guide assessment, prescription and evaluation of assistive technology solutions, which focuses on persons with disabilities, their activities and social context. Ethics approval was obtained from participating hospitals.

Procedure

Participants were recruited from one of 4 ambulatory clinics: 2 heart function clinics and 2 cardiac rehabilitation programs at 4 academic hospitals downtown Toronto, Canada. Where patients provided written informed consent, clinical data was extracted from participants' medical charts. If they met inclusion/exclusion criteria, a testing session was scheduled for participants in the lab.

On the day of the test, participants were first oriented to the test procedures and asked to complete some questionnaires. Then participants performed a predefined set of activities of daily living throughout the smart-home as shown in Table 1. They involved regular daily activities such as watching television on the couch, walking, performing light housework duties, reading at the dining room table, and lying in bed. The system was simultaneously tested against gold standard measures of the physiological parameters being assessed (i.e., wearable heart and respiratory rate monitors, blood pressure cuffs, a weight scale, a clinical thermometer and motion trackers). Results regarding the accuracy of these technologies in comparison to gold standard measures will be reported elsewhere.

Each testing session was concluded with the semi-structured interview, which is the focus of this paper. The interviews were led by a registered nurse or nurse-trainee. Participants were asked for verbal consent to digitally record the interviews. The interviews were recorded and later transcribed verbatim, except to preserve anonymity.

Setting

The smart-home system was designed, set up and pilot-tested on healthy adults in the HomeLab at the University Health Network- Toronto Rehabilitation Institute, in Ontario Canada. The HomeLab resembles a typical single-storey dwelling with a bedroom, bathroom, kitchen, dining room and living room, as shown in Fig. 1. There was also a set of stairs to a small second floor landing area. The lab has functional electrical wiring and plumbing.

The smart-home was crafted by embedding passive sensors into the HomeLab and commonly-found objects and furniture. The research team used commercially-available sensors, and added novel post-processing software to obtain the highest signal strength and most reliable measurements from the smart-home context. The following 5 sensing modalities were tested: (1) A network of 16 accelerometers installed on a blanket (used in the bedroom) to capture chest motion and calculate respiration; (2) Capacitively-coupled (CC) electrodes and load cells installed on a chair (used in the dining area) to record electrocardiogram (ECG) and ballistocardiogram (BCG), which can be used to measure heart rate and blood pressure; (3) Load cells employed under the legs of the bed to measure body weight; (4) Infrared thermometry for non-contact body temperature recording from a person's face while he

Table 1
Activity sequence.

	Activity	Test device (Embedded in)	Physiological Parameter
1.	Pt asked to get in bed; Covered with blanket fully and asked to lie for 5 min	Accelerometers (blanket) and force sensors (bed)	Respiration and weight
2.	Walked to washroom; While sitting down on a chair, place feet on floor tile for 1 min	Electrodes (Floor tile)	HR
3.	Stand still on floor tile for 1 min	Force sensors and electrodes (Floor tile)	HR, SBP, and weight
4.	Stand - Cold Pressor Test: - Insert one hand in cold water, leave for 1 min - Remove hand, compare BP and HR to baseline to ensure values are in normal ranges - Dry hand;	Force sensors and electrodes (Floor tile)	HR, SBP
5.	Simulate hand washing while standing for 1 min	Force sensors (Floor tile)	HR
6.	Walk to dining table; Sit at dining table, lean back on the chair; Drink tea, read newspaper for 5 min	CC-electrodes and force sensors (Chair)	HR, weight, and SBP
7.	Walk to couch; Sit on couch, watch TV for 5 min; Record body temperature using a thermometer	CC-electrodes (Couch) Thermal camera (beside television)	Body temperature and HR
8.	Walk to stairs; stair exercise: - Climb up and down stairs until HR is 20–30 bpm higher or until evidence of shortness of breath, up to 2 min	CC-electrodes and force sensors (Chair)	HR, weight, and SBP

HR = Heart Rate; SBP = Systolic Blood Pressure; CC = Capacitively-coupled.

or she is watching TV using a FLIR SC305 thermal camera[15]; and (5) A novel, custom-built instrumented floor tile which contained embedded dry electrodes and load cells to measure ECG and BCG signals. The development and testing of these devices will be reported elsewhere.

Participants

The study sample consisted of stable (i.e., no recent hospitalizations or HF exacerbations and stable medical regimen for the past 6 weeks) HF patients. The inclusion criteria were: (1) age 65 years and greater; (2) New York Heart Association class I or II[16]; (3) Living independently, rental or owned; and (4) Fluent in English. The exclusion criteria were: (1) serious cognitive impairments which would preclude being able to comprehend the study or provide feedback; and (2) severe mobility impairment that would render them unable to travel to and attend the test session. We aimed to recruit 20 male and 20 female participants.

Measures

Participants' clinical characteristics were extracted from their medical charts, including their age, sex, risk factors, and comorbidities.

The semi-structured interview guide is shown in Table 2, and sought to elicit input on impressions of the smart-home system. This included participants' views on sensor intrusiveness, recommendations with respect to their appearance, and general feelings toward the technology. Participants were also asked about how the system could be set up in their own homes, which may provide insight as to how the system could be tailored in the future to complement different environments (e.g., special models of chairs or beds, unique flooring). The interview was conducted in a private setting.

Analytic methods

Interviews were analyzed using an interpretive-descriptive method,[17] which is highly appropriate given the novel stage of this area. Interpretive description is a qualitative research methodologic approach aligned with a constructionist orientation, in which a sense-making structure is created for new knowledge. A stepwise data analysis plan was developed prior to analysis. Data transcription and analysis were concurrent with data collection, and involved inductively documenting emerging themes and patterns. Transcription analysis was conducted using NVivo version 11.[18]

As outlined above, initial coding was developed inductively. Following a number of iterations, pattern coding was used to develop a more coherent and conceptual sense of the data. When the first five interviews were complete, the nurse-interviewer and first 4 authors reviewed the transcripts and initial thematic coding.

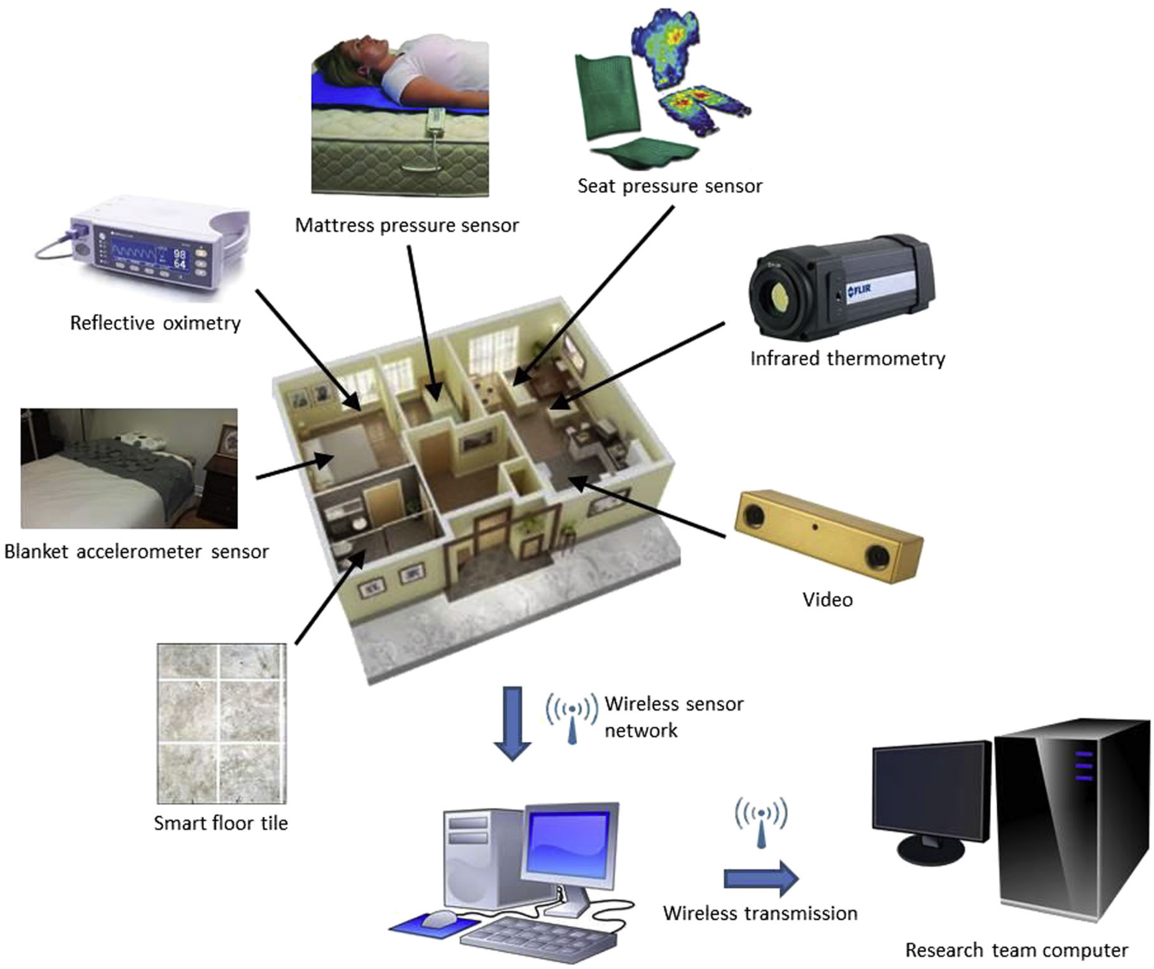

Fig. 1. Schematic of autonomous monitoring/smart-home system.

Table 2
Semi structured interview guide.

First of all, we would like to thank you very much for your participation in our study. Is it okay if we audio-record this interview? This would help us code the ideas that emerge from the interviews.

General technology use:

1. What type of technology do you currently have in your home? This could be for entertainment, meal preparation, etc.
2. What, if any, are some of the difficulties you find in operating the devices?
3. Are you currently using any devices to monitor your health? If so, what?
4. What, if any, are the difficulties you find in operating these devices?

Autonomous monitoring technologies:

Now I would like to turn our attention to some of the technologies we used in the study today. Feel free to comment on any of the devices that were used today, however, I would like to focus on the new technologies we used. Specifically, these are the floor tile, grey blanket on the bed, the dining table chair, the couch, and the thermal camera beside the TV.

5. Did any of the devices we used today interfere with your activities? If so, how?
6. Did any of the technologies make you uncomfortable in any way? If so, how?
7. Would you be interested in similar technology in your own home? If so, which one(s)? In which rooms?
8. Is there anything you can think of that would make this technology more acceptable?

Smart-home monitoring:

9. What are the biggest challenges about living in your home?
10. Had you heard about autonomous monitoring before this study (i.e., devices being able to monitor vitals by themselves)? If so, what were your feelings about it?
11. Have these feelings changed? If so, how?
12. Is there any additional health information that you would like to monitor regularly? If so, what?

Conclusion:

13. Do you have any questions for us?
14. Is there anything else you would like to share with us?

Thank you for your time.

Codes were refined, and the coding of the initial transcripts was revised accordingly.

As data collection continued, a constant comparative and iterative approach to analysis was used. During this period, memoing was used so thoughts were recorded for consideration later in the analysis. Proposition development then enabled formalization and systematic arranging of a coherent set of themes which enhanced understanding and interpretation of the data. Authors met on two further occasions to review and refine themes.

Initial overall interpretation was then presented at multidisciplinary HF rounds to augment reflective, critical examination of the data, as well as to test and challenge preliminary themes. With this verification as well as modification based on input, interpretive conclusions were then drawn.

Results

Respondent characteristics

One hundred and twelve participants were approached to participate. Ten (8.9%) were ineligible and many declined. Twenty-six (23.2%) patients consented, of whom all agreed to the exit interview and digital recording. Respondents' characteristics are shown in Table 3. Most participants reported having computers, televisions, stereo systems and blood pressure monitors in their home, and that they could use these technologies fairly comfortably.

Key themes

A diagram of the themes is shown in Fig. 2. Five main themes emerged, namely: (1) perceptions of technology, (2) perceived benefits of autonomous health monitoring, (3) disadvantages of autonomous monitoring, (4) lack of perceived need for continuous health monitoring, and (5) preferences for autonomous monitoring.

Theme 1: perceptions of technology

Participants made reference to broad perceptions about technology in general, and health technology in particular. Participants voiced strong opinions regarding whether they liked or disliked technology. Four sub-themes arose. First, participants reported difficulty in operating general technology they currently have in their home. For instance, one participant noted "… *the technology in the computer leaves us cold at times … It's not something we have grown-up with, but we manage*" (#51). These comments were conveyed in such a way to suggest that having technology that worked without effort on their part would be welcome. The second sub-theme related to feelings of discomfort with, or the design of, technology at home. So for example one participant stated: *"No, I don't like technology. I'm so old-fashioned. I don't want anything to do with technology"* (#65). Another participant noted "*except with each different system I got another remote. So I have 5 remotes*" (#64). The third sub-theme related to perceptions regarding health monitoring technology specifically in the home. The final sub-theme related to previous exposure to remote health monitoring. For example, some participants had been asked to monitor their ECG from home following a major cardiac surgery. Their experience with this technology, positive or negative, seemed to correspond to their perception of the smart-home concept.

Theme 2: perceived benefits of autonomous health monitoring

Participants reported six main benefits they could derive from autonomous health monitoring. The first benefit was health status information availability. Participants perceived their health care providers and family members would benefit from being able to access information about their well-being remotely. The second benefit was independence. Participants desired to stay in their own home for as long as possible. For example, one participant stated "*it would be impossible to live in my own home if there weren't other people in the home*" (#97). Participants thought the availability of this technology might afford them the capacity to live longer in their own home in the future. The third benefit was re-assurance or

Table 3
Sociodemographic and clinical characteristics of participants, N = 26.

Characteristic	n (%)/mean ± SD
Sociodemographic	
Age	74.96 ± 6.69
Sex (% Male)	19 (73.1%)
Clinical	
NYHA Class (% II)	7 (27.0%)
LVEF	36.26 ± 14.37
Risk Factors (% yes)	
Dyslipidemia	15 (57.7%)
Hypertension	14 (53.8%)
Obesity	5 (19.2%)
Diabetes	4 (15.4%)
Comorbidities (% yes)	
Cancer	7 (26.9%)
Musculoskeletal or joint issues	7 (26.9%)
Renal Disease	4 (15.4%)
Depression	2 (7.7%)

NYHA = New York Heart Association; LVEF = Left Ventricular Ejection Fraction; SD = Standard Deviation.

Fig. 2. Main themes.

security. For instance, one participant stated: *"They are going to warn me if something is off right? … Versus me actively going to the doctor and getting myself checked out. This is passive technology that kinda alerts me*" (#53).

The fourth perceived benefit was that autonomous monitoring could potentially be life-saving. As an illustration of this, one participant stated "*When I had my heart attack, I was by myself and I had to call 9-1-1, and I suppose if I had passed out that might have not happened … and so I think this technology will be helpful in situations where the person is by themselves*". (#97) The fifth benefit was risk mitigation, as one participant stated: "*Yes, I am at higher risk of something and this will help me to monitor, and therefore mitigate the danger that something might happen*". (#97) The last perceived benefit associated with autonomous monitoring was unobtrusiveness. One participant expressed: *"the blanket is just putting what you would normally do anyway"* (#60). Another stated: "*I would like to see this available for consumer to have, for … the elderly in general…, because of personal experiences with my Mother who did not want gadgets – who was like I mean, out-of-sight out-of-mind … and the fact that it's hidden and constantly monitoring someone*." (#62)

Theme 3: perceived disadvantages of autonomous monitoring

The participants communicated six disadvantages associated with autonomous monitoring. The first sub-theme was affordability. As an example, one participant explained: *"And I think it would all depend on what you can afford because I think there is a lot of money involved- a tremendous amount of money involved- and I don't think most people ever have this available to them"* (#59). The second sub-theme was related to data use. Participants expressed concerns about access (i.e., "*but I don't think with these autonomous things… Can you actually see your results?*" [#67]), ownership of the data, and the measures used to protect the privacy of individuals. Equipment malfunction concerns were the next sub-theme identified. The fourth disadvantage was fear of technology obsolescence. For example, one participant stated: *".. the only problem maybe is that what you're using today, in five years from now would be obsolete. So there has gotta be a medium, where you know, you're using state-of-the-art stuff*" (#62). The fifth sub-theme was multi-user concerns. Participants raised questions around concurrent use of the autonomous monitoring devices by different members of the household. The final sub-theme was participants' concern that information about their health status could be troubling or stressful. For instance, one participant asserted: *"I don't know whether I would embrace it comfortably, because I would be afraid that I would get so wrapped in 'oh my God I gained another 5 pounds, what am I going to do' … I don't want to dwell on the bell going off, and I think oh this is it … I would regard it as being invasive in a helpful but also worrisome way"* (#45).

Theme 4: lack of perceived need for continuous health monitoring

Some participants expressed strong views that there was no need for continuous health monitoring. A participant noted: *"you don't have to have 15 different ways to take your blood pressure. As a practical man, I don't see what their contribution is … Yeah my* *opinion is it's redundant"* (#101); while another participant suggested*: "maybe [for] people who are worse off than I am … Maybe somebody who is older who is more infirm and has more difficulty maybe they would value being monitored all the time"* (#60).

Theme 5: Preferences for Autonomous Monitoring

The final theme encompasses the participants' preferences for autonomous monitoring, in five areas. The first sub-theme was participants' preferred parameters monitored during the trial. These were most often blood pressure and pulse. The second sub-theme was preferred rooms to place the monitoring devices. Most participants found comfort in having the devices placed in their bedroom to be monitored while asleep. For example, one participant stated: *"In our bedroom on our mattress, because I think a lot of things happen at night to seniors"(#59).*

The third sub-theme was preferred objects in the home in which to embed monitoring technology. Participants made reference to several objects in their home. A participant noted: *"Yeah couch is fine, but I don't sit on the couch. I sit in chair, easy chair" (#7)*, while another participant explained: "*… yes I would say to my husband don't touch my blanket just leave it, probably would cover him with it too" (#87).*

The fourth sub-theme was the noted comfort in having the sensor in the home; as one participant noted: "*I felt secure in a sense that someone was monitoring my progress" (#97)* and another that "*… because it would be a way that I would be able to not only monitor, but steer my way maybe through this, with the help of doctors and therapists and all this … And you would see the improvement as you go along*" (#60). The final sub-theme addressed additional parameters which HF patients would like monitored. This sub-theme included an array of responses. As an example of this, a participant stated: *"Well, as I mentioned I get a blood test for INR about once a month or so. I wouldn't mind having some sort of measure in house, so I don't have to go get stabbed every month"(#64),* While another participant suggested: *"something which monitors .. my red blood my red blood count my —hemoglobin … do that because in past that wound up being the problem which was not monitored except weekly"* (#101).

Discussion

Remote patient monitoring refers to the use of digital technology to collect clinical data from individuals in one location and transmit it securely to healthcare providers in a different location for consideration and action.[19] While technologies exist that can support remote monitoring of the physiological parameters required to manage HF (e.g., CARDIAC, MyHeart, Biotronik, CardiMems), older patients with HF may not be comfortable operating the required equipment, lack the dexterity to operate the devices, resent the intrusiveness of having devices in their home, not have the cognitive capacity or desire to take measurements on a reliable basis, and/or fail to report the results.[13,20–24] In-home monitoring of HF could be improved by circumventing these issues with "zero-effort" technology.[25] Moreover, such autonomous monitoring could mitigate reactivity that may affect measurements due to the patients being observed; patients are readily examined within the context of their natural environment rather than contrived experimental settings, and therefore the data gathered is much more accurate. Zero-effort technology may also achieve higher user acceptability compared to conventional monitoring techniques which are highly invasive, require more time investment to maintain and are usually disruptive to the daily routine of patients. Indeed, the purpose of this study was to understand the acceptability of autonomous monitoring in a complex patient population who arguably could particularly benefit from it, namely those with HF.

Overall results suggest HF patients did report difficulties in operating technologies currently in their home, both health-related and non. Indeed, a previous review established low technological acceptance in older adults.[12] Patients did nevertheless perceive many benefits to autonomous monitoring of their physiological parameters, as has been reported in previous research,[12] such as the independence it could bring should the technology enable them to live independently in their home for a longer period of time (i.e., aging-in-place). They also reported some potential drawbacks, that similarly have been reported in previous research,[12] such as privacy issues and multi-user concerns.

The findings reflect valid challenges for the implementation of autonomous monitoring for healthcare. Of note, patients raised concerns regarding affordability, however the cost of implementing these technologies if they could be commercially-available is not known. Findings also underline the importance of employing practices such as privacy by design (i.e., where the highest level of privacy is the technology's default). Finally, there was some variability in perceptions and attitudes, which are likely based on the variety of personal characteristics represented in the sample, such as sex, cognitive abilities and personality traits (e.g., early vs late technology adopters).

Future research is needed to ensure health information resulting from autonomous monitoring is presented to technology users in a way that is acceptable and informative, as well as to understand how best to detect and report out-of-range values to users, their caregivers and healthcare providers. Detection thresholds should take into consideration how context (e.g., place and activity captured via video camera) impacts the physiological parameters. False-positives, flashing or beeping alerts, and a low threshold for alerts is a turn-off for users and clinicians alike. The feedback system should be empowering, such that it encourages patients to continue to be informed about their health status and promotes patients to self-manage their HF.

Caution is warranted when interpreting these results. An important limitation of this study is that it reflects the particular devices employed in these trials; different devices may elicit different opinions. Moreover, participants sometimes commented on the non-autonomous gold standard monitoring devices rather than the prototype autonomous ones, given how unobtrusive they truly were. Second, generalizability is limited to fairly high functioning HF patients. Third, there may be bias in the sample due to the small sample size and low consent rate. Finally, these trials were conducted in a controlled environment as the technology development is at the proof-of-concept phase; the findings may have been different if the technology had been embedded in the homes of HF patients.

Conclusion

Given the high prevalence of HF, the high costs of associated hospitalizations resulting from poor self-management, and limitations in patient self-monitoring of their disease, the need for cost-effective, autonomous, home-based health monitoring is increasing. For the first time, this study qualitatively investigated HF patients' perceptions regarding a smart-home monitoring system for autonomously tracking physiological parameters that are integral to managing HF. Overall, the perception towards autonomous monitoring devices was positive, lending credence to zero-effort technology as a viable and promising technique for collecting physiological parameters from seniors with HF. Besides refining the capabilities of the system to monitor patients with HF, future work should focus on detecting early signs of HF decompensation, as well as optimizing feedback in a usable and acceptable manner to users and clinicians.

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