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Privacy Versus Autonomy: A Tradeoff Model for Smart Home Monitoring Technologies

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Abstract— **Smart homes are proposed as a new location for the delivery of healthcare services. They provide healthcare monitoring and communication services, by using integrated sensor network technologies. We validate a hypothesis regarding older adults' adoption of home monitoring technologies by conducting a literature review of articles studying older adults' attitudes and perceptions of sensor technologies. Using current literature to support the hypothesis, this paper applies the tradeoff model to decisions about sensor acceptance. Older adults are willing to trade privacy (by accepting a monitoring technology), for autonomy. As the information captured by the sensor becomes more intrusive and the infringement on privacy increases, sensors are accepted if the loss in privacy is traded for autonomy. Even video cameras, the most intrusive sensor type were accepted in exchange for the height of autonomy which is to remain in the home.**

I. Introduction

NEW delivery modes for healthcare are required to ensure quality as well as cost-effectiveness for the services provided to an aging demographic. Smart homes are proposed as one possible venue for long-term health monitoring and healthcare service delivery. To increase the acceptability of long-term monitoring technologies, which aim to let older adults age in their homes longer, older adults' perceptions of sensor technology is investigated. Understanding behavior that predict intentions to use can provide design and implementation guidelines by. Awareness of attitudes and factors contributing to the perceived obtrusiveness of technology is important because it can lead to better design and eventually help "predict acceptance of technical devices and their successful utilization [1]."

Our research group has years of experience introducing health monitoring technologies to adults 65 years and older. Observations within our research group over the course of many clinical projects have noted the variability in compliance observed in older adults. This research investigates support for a model we observed which hypothesizes that patients deciding to accept or reject a sensor make the decision as a tradeoff between privacy and autonomy. A literature search reviewed the perceptions of older adults towards smart home sensor technologies. The results are presented according to study type, and sensor type. The impact of context on the acceptance of monitoring is discussed, as is the effect of the older adults' self-perception on acceptance of monitoring. Finally we apply the tradeoff model to explain the acceptance of intrusive monitoring technologies.

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II. Methods

The literature review is limited to work published in English between 2004 and 2010, including journal articles, reviews and conferences articles. IEEE Xplore and PubMed were searched with the string: (acceptance or perception* or perspective* or focus group) and (smart home or ((home monitoring or sensor network or sensor technology) and (elderly or older adult))). The search was applied to 'words in document' to return the maximum number of articles and the databases were selected because they contain articles in the fields of biomedical, life sciences and engineering.

The database search returned 167 articles after elimination of duplicates. Reading titles and abstracts eliminated articles not meeting the requirement for: study type (technical analysis, discussions, drug trial, retrospective analysis), topic (single diseases, patient/doctor interaction, telecare, food safety, medication adherence, pain management and sit-to-stand approaches) or participants (doctors and caregivers, infants, adolescents, students, women <65, general population). Reading full papers further eliminated articles not meeting the criteria for study type, topic or participant. As shown in Fig. 1, 18 articles were included in the analysis.

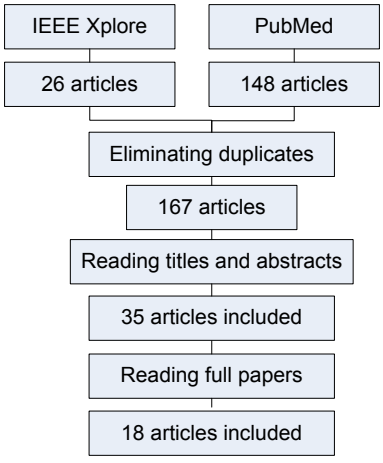

Figure 1. Method used in selecting articles

III. Data Set

Table I displays the number of participants in each focus group and pilot study. In total, 14 focus group studies and 5 pilot studies were included. One article included both study types [2]. On average, the number of participants in the focus group was larger than in pilot studies (average of 19 vs. 12 participants). Few studies explicitly referenced cost or time as limiting the study size, though the cost for equipment and time investments are significantly larger for pilot studies.

Table II indicates which types of sensors were included in focus groups and pilot studies, when stated explicitly. Wearable sensors were predominantly location and physiological monitoring. Environmental sensors included switches, stove temperature sensors, video and infrared cameras, bed occupancy and bed-based heart rate and respiration monitoring. A few focus groups presented implanted physiological and location monitoring chips to participants.

Table I Type of Study

	Number of participants	References
Focus	21-30	[3],[4], [5], [6]
Group	10-20	[7],[8], [9],[10],[11], [12], [13], [14],[15]
	1-10	[2]
Pilot	21-30	[16]
	11-20	[17]
	1-10	[2],[18],[19]

Table II Type of Sensor Presented in Focus Group or Used in Pilot

	Wearable	Implanted	Environmental
Focus Group	[3],[4],[5],[6], [8],[9][12],[15]	[8],[14]	[2],[3],[5],[6],[7], [8],[9],[10],[11], [12], [13],[14],[15]
Pilot	[16],[17],[18],[19]		[2],[17]

IV. Results

A. Levels of Privacy in Information

We present in table III, a ranking sensors according to the information they capture. A number indicating the sensor preference reported by participants, with the number 1 indicating the most preferred. Explicit and implicit rankings were available in half of the retained papers. Comparison presented between at least two types of sensors are presented in the table below with sensors divided into four categories according the amount of data they reveal about the wearer or smart home occupant to represent the level of privacy to be traded: On/off (e.g. user activated health line alarms), Intermittent physiological information (e.g. blood pressure monitoring cuff), Continuous Physiological (P) information (e.g. wearable heart rate monitor), Activities of daily living (ADL) (e.g. sensors in bathroom and kitchen), Location and position (L&P) (e.g. computer vision for fall detection), and Complete Visual information (C) (e.g. video camera).

Table III Sensor rankings

	On/Off	P	ADL	L&P	C
[6](40-59)	2	1	4	3	5
[6] (65+)	1	2	4	3	5
[7]		1	1	1	2
[8]	1	2	4	3	5
[9]	1	1		2	3
[11]				1	2
[13]			1	1	2
[14]		1			2
[15]		1		2	
[17]	1	2			
[19]	1	2			

V. Discussion

The perceived advantages and concerns of smart home technologies are classified by theme and presented in tables IV and V. This review was limited by keywords, study topic and participant age to best investigate support for the tradeoff hypothesis.

A. Privacy Versus Autonomy

Trends in table III allow the creation of a harmonized ranking which was created by determining the global trends in sensor preference. The ranking is as follows from lowest to highest level of private information captured: On/off, P, L&P, ADL, C, which is congruent with 9/10 of the papers containing sensor rankings. None of the referenced studies compared intermittent monitoring to a second type of monitoring, however it was included in the harmonized ranking.

As the acceptability of sensors decreases, the information captured by the sensors becomes increasingly revealing. We hypothesize that the gain from accepting the sensor technology must be bigger to be traded against the loss of privacy and intrusion of the sensor. The tradeoff for the help-line is getting to the emergency room more quickly. There is little loss of privacy as the user has full control of the sensor and a little gain in autonomy from being able to activate it. The P type sensor prevents wearers from having to go to the clinic as often. There is a slight loss of privacy for a slight gain in autonomy. In the case of the ADL monitor, the older adult is able to avoid home visits or going to a retirement home. This monitor confers a moderate loss of privacy by way of continuous monitoring however there is a moderate gain in autonomy. In the case of L&P monitoring, there is a moderate to high loss of privacy and a moderate gain in autonomy). Video monitoring has a high loss of privacy and a moderate gain in autonomy hence it is ranked last.

For example at the less intrusive end of the spectrum, an older adult at risk of stroke would likely accept intermittent use of a wearable blood pressure device, but not video cameras throughout the home. An older adult at risk of falls may be willing to accept motion monitoring. In this example, a bigger loss in privacy is traded to avoid not being found quickly after a fall. Older adults in this case would not likely accept video monitoring if a less obtrusive sensor is adequate. At the most obtrusive level, the privacy lost from accepting video cameras would only be acceptable if it could prevent transfer to a long term care facility which represents the greatest loss in autonomy.

TABLE IV POTENTIAL ADVANTAGES TO HOME MONITORING SENSORS TECHNOLOGIES AS REPORTED BY PARTICIPANTS

	Maintain Independence	Detect Decline	Improve/Maintain Social Contact	Socially Desirable	Information Sharing (doctors, family, caregiver)	Usefulness/Safety (Emergency, falls)
Focus Group	[4],[8],[17]	[4],[5],[17]	[5],[6]	[5]	[4],[5],[8],[11]	[4],[6],[8],[9],[10] [11],[15]
Pilot		[16]	[19]	[2]	[2],[16] , [17]	[2],[17][19]

TABLE V PARTICIPANT CONCERNS CLASSIFIED IN THEMES

	Physical	Human Interaction	Usability	Stigma	Privacy	Routine	Function	Cost
Focus Group	[3],[6],[8],[11], [12]	[3],[4],[6], [8],[9],[10]	[3],[6],[8],[9], [10]	[3],[8],[9], [11],[12], [13]	[3],[4],[5],[6], [7],[8],[9],[11], [12],[13]	[5],[8]	[3],[6],[8], [11]	[3],[6],[8],[9]
Pilot	[2],[16],[18],[19]	[17]	[16],[18],[19]		[19]	[16],[17],[19]	[2],[17],[18]	

The literature contains numerous examples of the extreme case of trading all privacy (allowing video cameras in the home) if it prevents a long term care placement [3], [4], [6]. The autonomy associated with aging-in-place is valued higher than privacy. The loss of autonomy associated with placement in a nursing home was felt to be worse than the loss of privacy associated with all types of sensors. Coughlin *et al.*'s focus group [3] was in agreement that loss of privacy 24/7 "cost the individual too much unless they are extremely frail or the only other alternative may be nursing care or living with an adult child." This was supported by Mihailidis *et al.* [6] who identified the tradeoff of "the perceived invasion of privacy versus perceived risk of injury". Across both study types over half of participants opposed the use of video cameras for monitoring because it was a violation of their privacy. Additionally 'some' or 'up to half' expressed privacy concerns [3],[5],[12],[13]. The infrared cameras used as proximity sensors in Demiris *et al.* [2] were seen as less intrusive and more acceptable.

B. Validation of the Tradeoff Model

There are many factors which may lead an older adult to accept home monitoring technologies (aging-in-place, increased cognitive and physical safety, information transfer to circle of care), and factors which direct them against acceptance (cost, privacy and technological burden).

The tradeoff model of privacy versus autonomy for sensor acceptance simplifies the decision to one dimension. A decision making model can be validated by recruiting older adults and presenting them with a questionnaire. To validate the harmonized sensor ranking, the questionnaire would present different disease levels and monitoring technologies and ask the participant which type of information they would provide (reduction in privacy by way of sensor) in exchange for maitaining the current level of autonomy.

C. Sources of Bias for Participants

1) Perception of Cognitive and Physical Need

Many older adults stated that they would acquire or use a device if they thought they needed it. However, one third of focus reported at least one participant with the difficulty of perceiving themselves as benefiting or even requiring smart home technology in the future [3],[4],[11],[13],[15]. Courtney *et al.* [13] provides a list of nine factors affecting older adults' perception of need for the technology, and noted that family, caregivers and health care provider's assessment of an older adults' need was not consistent with their own. These older adults associated monitoring technologies with frailty and stigma. This was also reported by Wild *et al.* [4] where family and caregivers were very interested in the smart home technology, and felt strongly about the benefits of information sharing and long-term monitoring.

Coughlin *et al.*[3] reported "few adults of any age see themselves as 'old' and even fewer as 'frail'" and that technologies, especially wearable monitors, would be a stigmas to frail adults rather than taking charge of their health and independence. This is supported by Wild *et al.*'s finding that participants had an "inability to anticipate one's own cognitive decline" [4].

2) Impact of Context on Acceptance of Video

Participants in one focus group that reported privacy concerns when discussing the concept of video monitoring had reduced concerns when assuming that there was a proven need for monitoring with video [13]. Courtney [12] showed that older adults' "own perceptions of their need for the technology can override their privacy concerns." Participants felt the privacy intrusion was tolerable in exchange for feeling safe in their own homes [8]. Participants in many studies stated they would accept the use of video monitoring if it allowed them to stay in their homes longer [12], [17]. The concept of video monitoring seemed to participants to be a violation of privacy, but when alternatives and usefulness were considered, some concerns were diminished. In all cases, video compared favorably to a nursing home environment.

D. Challenges Comparing Focus Group and Pilot Results

The questionnaires presented to pilot participants were not published in the five pilots retained for the review, though they may be published in a separate article. Information presented to focus groups to elicit responses was published alongside results in Wild *et al.* [4] and Beaudin *et al.* [5], and most focus group studies discussed in depth the methodology and topics covered. Privacy concerns were reported in 9 of 14 focus groups compared to only 1 of 5 pilots as seen in table IV. Two of sixty individual

participating in pilots withdrew from studies (none from focus groups): one due to obtrusiveness of video camera [17] and the other because they suffered a stroke during the pilot and experienced problems using the wearable device [18]. Perhaps the concept of monitoring conjures thoughts on the surveillance end of the spectrum rather than 'just checking', and that the negative feelings towards surveillance are more likely to surface in focus groups where there is not actual firsthand experience to ground these perceptions. Coughlin *et al.* suggest that "digital divide between adopters and non-adopters of technology," the user's mental model of how technology should work, the hassle factor" [3] and education in technology to explain barriers to use and initial suspicion.

This difference in the prevalence of privacy concerns may be due to limited interaction with technology, something takes getting used to or difficulties in conceiving technology without interacting with it (abstraction in focus groups).

E. Challenges in Defining "Obtrusive"

The definition of unobtrusive, invasive, passive, active and nonintrusive sensors for monitoring differs depending on the application and in comparison to the invasiveness of the traditional clinical approach. Courtney *et al.* [20] and Hensel *et al.* [21] defined obtrusiveness as having a quality that is "perceived as undesirable and physically and/or psychologically prominent" and identified eight dimensions affected from privacy, cost, fear of embarrassment, to the effect on relationships. 'Obtrusive' is used differently because it is context dependent. Obtrusive compared to not having the device is different to obtrusive when considering device options. For example a home telemedicine center with video camera was so obtrusive that no participant wanted to use it, but when a wooden box with picture frame was put on it when not in use the same technology was accepted by 95.5% of participants [22].

VI. CONCLUSIONS

The desire for autonomy is a primary driving factor of the positive view towards home monitoring sensors. Numerous examples of older adults circumventing the use of medical devices such as alert pendants, hearing aids, fall sensors and cameras abound in the literature. Understanding which aspect of the sensors makes them obtrusive to users can help reduce intentional non-compliance and increase user acceptance. This review highlights the overall positive attitude of older adults towards unobtrusive sensor technologies in smart homes when they perceive the need and when they allow an older adult to age-in-place.

As the information captured by the sensor becomes more intrusive and the infringement on privacy increases, sensors are accepted if the loss in privacy is traded for autonomy. Even video cameras, the most intrusive sensor type were accepted in exchange for the height of autonomy remaining in the home.

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