Ambient Intelligence from Senior Citizens' Perspectives: Understanding Privacy Concerns, Technology Acceptance, and Expectations

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Abstract. Especially for seniors, Ambient Intelligence can provide assistance in daily living and emergency situations, for example by automatically recognizing critical situations. The use of such systems may involve trade-offs with regard to privacy, social stigmatization, and changes of the well-known living environment. This raises the question of how older adults perceive restrictions of privacy, accept technology, and which requirements are placed on Ambient Intelligent systems. In order to better understand the related concerns and expectations, we surveyed 60 senior citizens. The results show that experience with Ambient Intelligence increases technology acceptance and reduces fears regarding privacy violations and insufficient system reliability. While participants generally tolerate a monitoring of activities in their home, including bathrooms, they do not accept commercial service providers as data recipients. A comparison between four exemplary systems shows that camera-based solutions are perceived with much greater fears than wearable emergency solutions. Burglary detection was rated as similarly important assigned as health features, whereas living comfort features were considered less useful.

Keywords: privacy concerns, older adults, perception of privacy, technology acceptance

1 Introduction

Facing the demographic change in Europe, the number of elderly increases constantly [6, 11]. This poses enormous challenges on care systems, relatives, and

institutional caregivers. The need to reduce costs in health care conflicts with the wishes of elderly individuals to maintain personal freedom and social participation as long as possible. Ambient Intelligence can partly act as a solution to this problem by supporting people who are in need of care. It can also support caregivers and institutions in their daily routines. Such systems may communicate emergency situations to caregivers, for example, when a person falls down. Besides, safety features such as burglary detection, or convenience features such as automatic light controls, are of interest for this target group. Ambient Intelligence strongly relies on analyzing data perceived from a person's living environment. Especially when using cameras, privacy concerns are wide-spread. Moreover, people often do not accept wearing new and unknown devices. The same applies to interventions within the environment, such as when sensor-augmented carpets are deployed to detect emergency situations like falls. To some extent, the reluctance to accept technological innovations is a result of "wrongly designed technologies that have been developed without thinking about the real needs and capabilities of the users" [4].

Our new study, therefore, aims to shed light on the target group's expectations and fears related to innovations of ambient intelligence. We were particularly interested to learn which features and systems are perceived as most or least important, and which trade-offs between functionality and privacy are deemed acceptable. These in-depth insights into the needs and worries of potential users in Germany do not only extend our knowledge about elderly individuals' perspectives on Ambient Intelligence, they also suggest areas for more effective system development and marketing.

2 Related Work

The primary purpose of Ambient Intelligence in elderly care is the unobtrusive monitoring of persons in their home environment to detect critical situations (e.g. falls) as well as relevant changes in individuals' behavior and sleeping patterns [12, 13]. Convenience and safety features also play an important role. The implicit recognition of emergency situations is often accompanied by possibilities to communicate information explicitly, as applied in traditional wearable emergency button systems. Typical features comprise fall detection, intruder alarm, stove and oven safety control, as well as automatic lighting [9, 10]. In these cases, the overall goal is to enhance the independence of residents and to improve the quality of life. Most older adults indeed believe that Ambient Intelligence features would increase their quality of life [13]. Specifically fall detection, intruder alerts, and stove and oven safety controls were perceived as useful [5, 8, 9]. Two types of systems for senior citizens can be distinguished: personal systems, with wearable devices, and infrastructure systems that use sensors embedded in the room or the house [3]. Most in-home monitoring systems are infrastructure systems, as elderly people often reject wearable devices for fears of being stigmatized as frail or in need of special assistance [9]. While designed to aid older adults in gaining independence and being able to age in their own places, in-home moni-

toring is often seen as "designed for the oldest", and, as a result, are rejected [2, 7, 13]. Other factors related to the refusal of Ambient Intelligence technologies include the ease of use, ergonomics, stigmatization, visibility of devices, and fear of false alarms [7, 9, 17]. Previous studies often examined only individual aspects of technology acceptance, or approached this topic from the perspective of nurses and expert groups. In contrast, the current study examines the expectations of potential end users, viz. elderly individuals in Germany, and uses standardized measures to compare individuals' attitudes and worries towards six specific features and four system types in greater depth, particularly with regard to safety concerns.

3 Methods

3.1 Sample

Sixty older adults and senior citizens (70% female; age: $M = 67.7$, $SD = 8.3$, $Min = 48$, $Max = 84$) were recruited during special events for the elderly in September 2014. The first event was an information day for senior citizens (*Darmstädter Seniorentage*), the second one was a public talk about patient directives and living will. Respondents had the option of completing the paper-and-pencil questionnaire either immediately or later at home by themselves. Personal assistance to fill out the questionnaire was offered. Three gift certificates were raffled off among all participants as an incentive for participation.

3.2 Questionnaire Design

The questionnaire started with a section that informed the respondents about the purpose of the study and the measures taken to ensure the participants' anonymity. It also provided a brief explanation of Ambient Intelligence systems for the elderly.

Overall Attitudes Towards Innovations in Ambient Intelligence Previous experience with Ambient Intelligence technologies was measured using a simple dichotomic scale (0 = "no", 1 = "yes"). Questions about the importance of certain assistive technology features (seven items), acceptable limitations (four items), and fears associated with the use of home-based assistive technologies (eight items) were measured using a five-point Likert scale (endpoint descriptions: 0 = "do not agree at all", 4 = "fully agree").

Comparisons of Six Ambient Intelligence Features Previous studies have shown that features like fall detection or intruder alerts are considered as particularly useful [5, 8, 9]. Based on these studies, we selected a set of six features for evaluation with our senior participants. Besides the previously mentioned features, we also included use-cases in energy saving and disease detection. The

questionnaire section included a short descriptions of the six features selected: (1) detection of emergency situations such as falls or accidents; (2) fall prevention (e.g., through automated room light control); (3) disease (e.g., dementia) detection through behavior monitoring; (4) energy-saving functionality through intelligent home control (e.g., automated heating control, or automated power supply shut-off if the apartment is empty); (5) burglary detection; and (6) living comfort features (e.g., automated light and heating control, reminders for medication, supply of health-related information). It was noted for all six features that data processing occurred solely inside the apartments and that no information was transmitted to other parties except in cases of emergencies. For each functionality, respondents indicated the extent that they would accept the recording of, as well as the transmission of, recorded information (ten items) and their overall acceptance (three items) on a five-point Likert scale (endpoint descriptions: 0 = "do not agree at all", 4 = "fully agree").

Comparisons of Four Systems Four different systems were presented in the next part of the questionnaire with a brief verbal description: (1) a wearable one-button emergency call system (calls the number of a predefined person if activated and can be worn on the wrist or on the neck); (2) a camera-based in-home emergency detection system (to detect falls or unusual behavior); (3) a sensor-based floor emergency detection system (also to detect falls or unusual behavior); and a (4) comprehensive emergency detection solution consisting of floor sensors and a wristband (to detect emergency situations such as falls, unusual behavior, and problematic health conditions such as fever). Especially the expectations towards data handling are an important aspect as previous studies have shown that many seniors do not fully understand the technical concepts and thus underestimate potential privacy risks [1, 3]. It was again noted for all four systems that data processing occurred solely inside the apartments and that no information was transmitted to other parties except in cases of emergencies. For each system, respondents indicated how much they were concerned about certain features (four items), acceptance of data collection while being in the bedroom or bathroom (two items) and general acceptance (two items) on a five-point Likert scale (endpoint descriptions: 0 = "do not agree at all", 4 = "fully agree").

Socio-Demographic Information Socio-demographic characteristics such as respondents' gender, age, and living conditions were collected in the last part of the questionnaire.

4 Results

The data collected was analyzed using IBM® SPSS® version 22. Two-sided t-tests were conducted to determine if mean differences between male and female respondents, or between experienced and inexperienced individuals, were

statistically significant ($p < .05$). Sidak-corrected post-hoc comparisons were conducted to determine if the means for the six features or the four systems differ significantly from each other ($p < .05$).

4.1 Importance of Ambient Intelligence Features

Ease of use, particularly in case of emergency, emerged as the most important feature, and the safety of data as the second important priority (see Table 1 for details). Places three to five referred to the affordability of the system (low running and maintenance costs, energy-saving design, and affordability of the system). The lowest priority was given to a constant visibility of the system and a high number of features. No differences were found between senior citizens with and without previous experience with assistive technologies. Ease of use, however, was significantly more important for female than for male respondents.

		Respondents' Gender		Previous Experience	
	Overall (N = 60)	Male (N = 18)	Female (N = 42)	yes (N = 7)	no (N = 51)
System is easy to use, especially in cases of emergency	3.48 (.85)	3.06 [A] (.87)	3.67 [A] (.79)	3.29 (.76)	3.63 (.63)
System processes its data exclusively inside my apartment, and information is only shared in cases of emergency	3.31 (1.05)	3.56 (.70)	3.20 (1.17)	3.67 (.82)	3.33 (.99)
System produces low running or maintenance costs	3.19 (.86)	2.94 (.75)	3.29 (.89)	3.00 (.82)	3.27 (.75)
System is energy-saving	3.17 (.85)	3.11 (.68)	3.20 (.93)	3.33 (.82)	3.22 (.76)
System is inexpensive to purchase	3.05 (.94)	2.94 (.73)	3.10 (1.02)	3.00 (.89)	3.12 (.86)
System is constantly visible	2.24 (1.07)	1.94 (.94)	2.37 (1.11)	2.17 (.98)	2.31 (1.05)
System provides many features	2.10 (1.20)	2.00 (1.19)	2.15 (1.22)	2.33 (.52)	2.10 (1.24)

Table 1. Importance of system features. A rating of 0 corresponds to "I do not agree at all", while 4 corresponds to "I fully agree". $N = 60$. Depicted are means and, in brackets, standard deviations. Means sharing the same upper-case letter (gender) or lower-case letter (experience level) differ significantly (two-sided t test, $p < .05$).

4.2 Acceptable System Limitations

The necessity to change one's habits was deemed least acceptable, followed by the functionality of the system to identify which and how many persons are currently in the apartment (see Table 2). Whether other people could notice the use of assistive technologies was considered as least problematic. No significant differences were found between male and female respondents or between senior citizens with experience in using assistive technologies and those with no experience.

		Respondents' Gender		Previous Experience	
	Overall (N = 60)	Male (N = 18)	Female (N = 42)	yes (N = 7)	no (N = 51)
Okay if other people can see that I am using assistive technology	2.24 (1.30)	2.00 (1.19)	2.34 (1.35)	2.67 (1.03)	2.25 (1.31)
Okay if system can identify how many people are currently in my apartment	1.83 (1.28)	1.39 (1.20)	2.02 (1.27)	2.00 (1.41)	1.86 (1.27)
Okay if system can identify which persons are currently in my apartment	1.57 (1.27)	1.22 (1.11)	1.71 (1.31)	1.00 (.82)	1.69 (1.30)
Okay if I have to change habits to meet system requirements	1.15 (1.11)	.94 (1.00)	1.24 (1.16)	1.17 (.75)	1.18 (1.16)

Table 2. Acceptable system limitations. A rating of 0 corresponds to "I do not agree at all", while 4 corresponds to "I fully agree". $N = 59$. Depicted are means and, in brackets, standard deviations. Means sharing the same upper-case letter (gender) or lower-case letter (experience level) differ significantly (two-sided t test, $p < .05$).

4.3 Fears Associated with the Use of Ambient Intelligence Technologies

The greatest fear associated with the use of Ambient Intelligence technologies was the concern that criminals might misuse the collected data, followed by the fear that the system would not be sufficiently reliable (see Table 3). Moderate levels of fears were related to the possible transmission of inaccurate data, the monitoring of social interactions, the continuous monitoring, and the transmission of information to the wrong persons. The lowest causes for concern were the possibility that using the system would be too demanding or that its use would lead to a loss of independence. While no significant differences were found between male and female senior citizens in this regard, inexperienced respondents reported greater levels of concern than experienced senior citizens in four cases (fears of an unreliable system, of transmitting inaccurate information, of social interactions being monitored, and of constantly being monitored). This also resulted in a significantly greater overall fear score for this group.

		Respondents' Gender		Previous Experience	
	Overall (N = 60)	Male (N = 18)	Female (N = 42)	yes (N = 7)	no (N = 51)
Fear that criminals will misuse the data collected by the system	2.32 (1.25)	2.44 (1.25)	2.27 (1.27)	2.50 (1.38)	2.33 (1.23)
Fear that the system will not be sufficiently reliable operating	2.22 (1.10)	2.33 (.97)	2.17 (1.16)	1.29 [d] (.95)	2.38 [d] (1.03)
Fear that the system transmits inaccurate or wrong information (e.g., false alarms)	2.15 (1.20)	2.28 (1.07)	2.10 (1.26)	.67 [c] (.52)	2.35 [c] (1.11)
Fear of constantly being monitored	2.03 (1.16)	2.28 (1.18)	1.93 (1.16)	1.29 [a] (.76)	2.16 [a] (1.16)
Fears that social interactions are being monitored (e.g., visits from friends)	2.12 (1.26)	2.39 (1.29)	2.00 (1.24)	1.17 [b] (.41)	2.25 [b] (1.26)
Fear that the system transmits information to the wrong people	2.02 (1.31)	2.06 (1.39)	2.00 (1.29)	1.43 (1.13)	2.12 (1.31)
Fear that system use will be too demanding or straining for me	1.73 (1.27)	1.83 (1.29)	1.69 (1.28)	2.00 (1.29)	1.71 (1.27)
Fear to lose my independence when using the system	1.41 (1.19)	1.83 (1.42)	1.22 (1.04)	1.17 (.98)	1.43 (1.20)
Overall fear score (mean)	2.00 (.93)	2.18 (1.08)	1.92 (.86)	1.45 [e] (.35)	2.09 [e] (.92)

Table 3. Fears and worries associated with system use. A rating of 0 corresponds to "I do not agree at all", while 4 corresponds to "I fully agree". $N = 60$. Depicted are means and, in brackets, standard deviations. Means sharing the same upper-case letter (gender) or lower-case letter (experience level) differ significantly (two-sided t test, $p < .05$).

4.4 Detailed Feature Comparison

The comparison between different features indicates that safety functionalities (emergency detection and burglary detection) are perceived as considerably more useful than disease detection and living comfort features. Fall prevention and energy savings features fell in between (see Table 4 for details). Particularly for burglary detection extra costs are accepted, while the acceptance is much less for living comfort features and disease detection functionality. The comfort functionality is also rated as significantly less likely to be used than the burglary detection feature.

Interestingly, no differences emerged between these features for five items relating to the recording of information. The only difference in this regard is that respondents are more likely to accept the recording of information while being in the living room or in the kitchen if the system serves for emergency

I find it acceptable if ...	Emergency Detection Feature	Fall Prevention Feature	Disease Detection Feature	Energy Saving Feature	Burglary Detection Feature	Living Comfort Feature
... the system records information while I am in the living room or in the kitchen	2.90 [E] (1.01)	2.60 (1.21)	2.48 (1.24)	2.40 (1.38)	2.58 (1.35)	2.33 [E] (1.15)
... the system records information while I am in the bedroom	2.58 (1.32)	2.47 (1.31)	2.43 (1.31)	2.17 (1.48)	2.66 (1.31)	2.15 (1.31)
... the system records information while I am in bathroom	2.54 (1.34)	2.48 (1.35)	2.31 (1.37)	2.15 (1.43)	2.63 (1.31)	2.12 (1.26)
... the system records personal information such as my weight or my temperature	1.98 [A] (1.37)	1.53 [A] (1.44)	1.75 (1.40)	1.58 (1.55)	1.60 (1.42)	1.64 (1.33)
... the system records information about my behavior and my movement patterns	2.12 (1.38)	1.90 (1.49)	2.12 (1.46)	1.85 (1.46)	1.96 (1.47)	1.90 (1.29)
... the system records information about my sleeping habits	2.06 (1.34)	1.70 (1.48)	1.91 (1.48)	1.81 (1.54)	2.02 (1.50)	1.70 (1.31)
... the system transmits data to my primary care person	2.89 [ACDE] (1.09)	2.55 [AGHI] (1.23)	2.58 [JKL] (1.29)	1.83 [CGJ] (1.41)	1.94 [DHK] (1.43)	1.92 [EIL] (1.31)
... the system transmits data to family members	2.57 [BCDE] (1.32)	2.36 [I] (1.36)	2.21 [B] (1.46)	1.83 [C] (1.45)	2.11 [D] (1.40)	1.77 [EI] (1.37)
... the system transmits data to my doctor or to the police	2.47 [CE] (1.31)	2.36 [GI] (1.35)	2.25 [L] (1.43)	1.64 [CGM] (1.47)	2.77 [MO] (1.14)	1.72 [EILO] (1.32)
... the system transmits data to commercial service providers (e.g., electricity provider, insurance company)	.57 (1.01)	.57 (.93)	.57 (1.07)	.87 (1.16)	.75 (1.11)	.66 (1.02)
I perceive this feature as useful	3.13 [BE] (.94)	2.74 (1.16)	2.40 [BK] (1.28)	2.60 (1.28)	3.08 [KO] (1.02)	2.43 [EO] (1.15)
I would like to use a system with this functionality	2.43 (1.22)	2.28 (1.20)	2.23 (1.25)	2.26 (1.33)	2.51 [O] (1.20)	2.00 [O] (1.24)
I am willing to accept extra costs for this feature	1.98 (1.33)	1.78 (1.33)	1.75 [K] (1.37)	2.00 (1.34)	2.25 [KO] (1.32)	1.69 [O] (1.24)

Table 4. Acceptance and overall assessment of six system features. A rating of 0 corresponds to "I do not agree at all", while 4 corresponds to "I fully agree". $N = 58$. Depicted are means and, in brackets, standard deviations. Means sharing the same upper-case letter differ significantly (Sidak-corrected multiple comparison, $p < .05$).

detection in contrast to living comfort features. Despite, several differences between features were found regarding the transmission of information to external recipients. This was considered least acceptable for energy-saving functionality, but very acceptable for emergency and fall prevention functionality.

4.5 Comparison of Four Ambient Intelligence System Types

The in-depth comparison between the four system configurations revealed that these systems were rated differently in all but one dimension (see Table 5 for details). The wearable one-button emergency call system consistently elicited the lowest levels of concern, was perceived as the most useful, and respondents could also most likely imagine themselves using this system. The sensor-based indoor floor emergency detection system scored second on most dimensions. The camera-based behavior and emergency detection system, in contrast, was perceived as significantly more worrisome and less useful than the other two systems. The combined comprehensive emergency detection solution scored largely identical to the camera-based system, even though people reported lower levels of fear of constantly being monitored and indicated a higher acceptance of the system recording them while being in the bedroom or bathroom.

	Mobile One-Button Emergency Call System	Behavior and Emergency Detection System	Indoor Floor Emergency Detection System	Emergency Detection Solution
Overall fear score (mean)	1.20 ^{AC} (.86)	1.72 ^{AD} (.88)	1.44 ^{D} (.94)	1.58 ^{C} (1.03)
Fear of being constantly monitored	1.31 ^{A} (1.18)	2.49 ^{ADE} (1.22)	1.73 ^{D} (1.27)	1.75 ^{E} (1.38)
Fear of negative health effects through system use (e.g., due to electromagnetic radiation)	.89 (.99)	.89 (1.05)	1.04 (1.09)	1.18 (1.22)
Fear that personal information are spied out	1.40 ^{A} (1.26)	2.04 ^{AD} (1.39)	1.47 ^{D} (1.20)	1.65 (1.32)
Fear that the operation of the system is too difficult in emergency situations	1.18 ^{C} (1.09)	1.47 (1.23)	1.51 (1.20)	1.73 ^{C} (1.24)
I find it acceptable if the system records information while I am in the bedroom.	2.85 ^{AC} (1.19)	1.39 ^{ADE} (1.42)	2.56 ^{DF} (1.21)	2.06 ^{CEF} (1.37)
I find it acceptable if the system records information while I am in the bathroom.	2.91 ^{AC} (1.19)	1.27 ^{ADE} (1.35)	2.62 ^{DF} (1.25)	1.95 ^{CEF} (1.28)
I find the system useful.	3.46 ^{ABC} (.73)	1.91 ^{AD} (1.37)	2.67 ^{BDF} (1.23)	2.21 ^{CF} (1.36)
I can well imagine myself using this system.	3.34 ^{ABC} (.79)	1.73 ^{AD} (1.36)	2.54 ^{BDF} (1.13)	1.93 ^{CF} (1.28)

Table 5. Comparison of four assistive systems. A rating of 0 corresponds to "I do not agree at all", while 4 corresponds to "I fully agree". $N = 57$. Depicted are means and, in brackets, standard deviations. Means sharing the same upper-case letter differ significantly (Sidak-corrected multiple comparison, $p < .05$).

5 Discussion & Summary

To gain a better understand of how different features and system approaches are perceived by the target group, the current study explored older individuals' expectations and concerns related to different innovations in ambient intelligence.

5.1 Limitations

Several limitations affecting the generalizability and external validity of our findings should be noted. A convenience sample of elderly individuals was examined, in which females were overrepresented. Participants were recruited at information sessions for seniors and might thus be more interested and open-minded regarding technological innovations than the average person of their age group. Yet it could be argued that this group represents potential buyers relatively well. It is also unclear to which extent the findings can be generalized to individuals from other countries, as attitudes towards technology are likely to be influenced by cultural norms and expectations.

5.2 Main Findings

Overall, a relatively positive attitude towards ambient intelligence was observed. All six features, as well as all systems without behavior observation through cameras, were perceived as generally valuable. Respondents rated emergency detection and burglary detection as particularly useful and important, particularly in contrast to living comfort features. It is notable that senior citizens perceive burglary detection functionality as more useful than disease detection and living comfort features, and are willing to accept higher costs for it. Similar to the findings from previous studies [5, 7, 10], ease of use and affordability were elderly seniors' top priorities. This emphasizes the need for systems that are easy to use as well as easy to understand.

It is noteworthy that in the comparisons of the systems, the camera-based system is relatively poorly rated, although it is easy to use. Contrary to the abstract review of the requirements for Ambient Intelligence systems, privacy seems to be more important for respondents than ease of use. Yet, aspects of data protection and misuse of information did not appear to be important for them. Their privacy definitions seemed to focus more on aspects of system visibility to others and an avoidance of shame. The floor-based system received largely positive appraisal. Fear of electromagnetic radiation, which we expected to be an issue for elderly individuals, was not observed. Participants also did not consider it a general disadvantage that their behavior and motion patterns were recorded.

The relative positive attitude and openness to technical assistance systems are consistent with the findings from other studies [14, 16]. At the same time, substantial worries regarding the type of recorded information and data safety were noted, as well as a low willingness to change daily habits. These results suggest that fears of technology were more pronounced among individuals with little or no previous experience with Ambient Intelligence, thus confirming the

assumption that technological acceptance depends on each individual's experiences and previous contact with such technologies [15]. The fact that most respondents knew about the wearable mobile one-button emergency call system due to its high market penetration may partly explain the largely positive attitudes towards this system. While several studies [7–9, 17] expressed concern about older adults feeling stigmatized and labeled as too frail when using assistive technologies, such concerns could not be confirmed in our study.

The willingness to accept extra costs for certain features, however, was mediocre. Again, it is striking that the willingness to pay for security features is larger than for functionality related to health protection or living comfort enhancement. To some extent, this phenomenon might be specific for Germany, where costs of health care systems are expected to be fully covered by health insurance.

6 Summary

As our central scientific contribution, we present an extensive study on ambient intelligence with 60 German participants aged 65 or older. We analyze multiple factors including fears, desired features, and privacy trade-offs.

Our study shows that elderly persons in Germany have a relatively positive attitude towards Ambient Intelligence systems. It is conceivable that associated fears on privacy and reliability can be reduced significantly with technology pervasion. Nonetheless, usage of cameras or data exchanges with commercial service providers are generally not accepted.

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