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Designing an Abnormal Posture Detection System to Prevent Accidents During Meal Assistance for Older Adults: A User-centered Design Approach

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Abstract. This paper proposes a user-centered design (UCD) method and demonstrates the assistive device design, incorporating user involvement and the risk management approach throughout the design process, in a Japanese day-care facility for older adults. The study focused on the lunchtime problem, where there is a limited number of nursing staff for meal assistance and supervision of users to ensure their safety. An abnormal posture notification system that met the technical/functional and user requirements was successfully designed by conducting participant observations and using human error-proofing principles. This approach enabled timely identification of proper solutions in the care facility and areas for improvement, and thus the discovery of users and use-cases that were not initially envisioned.

Keywords: User-centered Design · Assistive Technology · Abnormal Posture Detection · Older Adults · Day-care Facility

1 Introduction

The world is facing a super-aging society, and in 2015 Japan became the first country in which the proportion of people aged over 60 years exceeded 30% [1]. However, many countries are expected to reach a similar proportion of elderly people by mid century. Therefore, the challenges associated with a super-aging society are not just relevant for Japan, but for the entire world [1]. To meet these challenges, in recent years, many assistive devices have been actively developed, including meal assistive devices [2, 3] and movement aid devices [4–6], to assist not only in the cognitive and physical decline of older adults but also the work of caregivers [1, 7].

In this context, user-centered design (UCD) has received significant attention in the development of medical/assistive devices for older adults since stakeholder requirements must be incorporated into the design process [8]. UCD is a multidisciplinary approach that places users and their experiences of a product, system, or service at the center of the design process; it allows users to contribute to every design stage [9, 10]. UCD generally consists of *understanding and specifying the context of use*, *specifying* *the user requirements*, *producing design solutions*, and *evaluating the design*, as described in ISO 9241-210:2019 [11]. However, constrained environments make adopting UCD problematic. For instance, in a commercial setting, companies are reluctant to commit financial resources to a full UCD approach, preferring to opt in or out of elements of a user-centered approach [9]. In addition, especially in care facilities for older adults, it is difficult to identify suitable target users since their symptoms and disorders are diverse [5]. Additionally, few facilities have worked with researchers in the development of new technology, as most are too busy [5, 12, 13]. As a result, many scholars have only involved users in the later phase of the system/service development process, i.e., test and evaluation [14]. In contrast, as safety issues are significant for assistive/medical devices, recent studies have emphasized the importance of intensive user involvement and risk management from the early phases of the design process [14].

2 Objective

This paper proposes a UCD method and demonstrates the assistive device design, incorporating user involvement and a risk management approach from the beginning of the design process, in a Japanese day-care facility for older adults.

The study began with participant observations, i.e., internship, to understand the context, define the problems, and specify the user requirements. Although there is no set methodology for participant observation, it is a powerful tool aligned with the philosophy of UCD, since it is easier to discover issues hidden from outside researchers by participating in the closed society/community for a while to gain an inside perspective [15]. Then, the user requirements were specified, which is a major activity in most design projects [11]. As risk management affects the quality, safety, and efficiency of medical/nursing care settings [16], it should be incorporated in the early design phase; we incorporated it from the 'specifying the user requirements' phase. Specifically, we used five human error-proofing principles elucidated by analyzing 518 actual error-proofing cases [16] to decide our strategy and develop a prototype system to solve issues, and then validated the system based on those requirements.

3 Research Methodology

Fig. 1 shows the UCD approach we employed for the development of the assistive device, which was based on existing literature, including ISO 9241-210:2019 [11], participant observations [15], and error-proofing principles [16]. This study was approved by the Tokyo Institute of Technology Ethics Review Committee (A18006).

3.1 Understanding and specifying the context of use

The aim of the first phase was to identify the problems in the day-care facility. A 12-day internship was conducted in a day-care facility in Tokyo, Japan to observe the users. This allowed us to involve stakeholders at the beginning of the design process as well as provide some manpower to the busy facility. This paper describes what we experienced and heard through the internship and stakeholder interviews, which we used to define the problem. The narrative approach is considered an appropriate way to understand the diverse dynamics of people's minds and actions [17].

3.2 Specifying the user requirements

In the second phase, the solution strategy was elucidated by employing human error-proofing principles (Table 1) and the user requirements were described.

3.3 Producing design solutions

In the third phase, a prototype system was developed to meet the user requirements defined in sub-section 3.2. Our approach was based on ISO 9241-210, including *designing tasks and interaction between the user and system*, *designing the user interface*, *making design solutions more concrete*, and *altering the design solutions based on evaluation/feedback* [11]. Throughout the process, the research team frequently held in-person meetings to evaluate the current status of system development and refine the first version of our proposed system [11, 18].

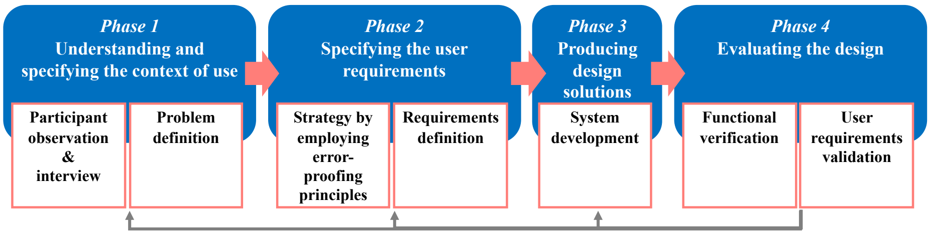


Fig. 1. UCD cycle for developing assistive devices in a day-care facility for older adults.

Table 1. Human error-proofing principles [16].

Principles	Descriptions
Exclusion	Eliminating error-prone tasks and the need for caution against danger.
Substitution	Replacing human tasks with machines or providing assistance so that people can work without mistakes.
Facilitation	Making tasks easier for people by clarifying and reducing changes and differences, or making tasks more suitable for human capabilities.
Abnormality detection	Detecting abnormalities caused by errors by recording or limiting actions or by checking results so that appropriate actions can be taken.
Mitigation	Mitigating impacts by incorporating functional redundancy or materials and equipment that minimize losses.

3.4 Evaluating the design

Video recordings of one of the facility users during meals were taken to functionally verify the developed system and examine whether it could measure the posture of older adults. The user, who was prone to collapse, required a meal assistant. Video images were taken on two days (during two meals), at a resolution of 1280×720 (HD) at a frame rate of 29.97 fps for 25 minutes from the start of the meal, and used as camera input for verifying the system operation. User tests and semi-structured interviews with four nursing staff at the facility and five medical/nursing staff at other facilities were also conducted to validate the user requirements. The interviewers addressed (i) acceptance of the system, (ii) notification function of abnormal posture, (iii) expected target user profile, (iv) issues, and (v) other comments and recommendations.

4 Results and Discussion

4.1 Understanding and specifying the context of use

A 12-day internship was conducted to clarify the user problems at the care facility. This day-care facility supports users in their daily activities such as eating and bathing, and provides functional and oral function training. About 10 nursing staff care for 30 to 40 users per day, many of whom have dementia, Parkinson's disease, or physical paralysis due to stroke. The staff perform functional training, physical condition management, bathing, and personal care, but due to a shortage of manpower, all staff must also help pre-pare lunch, which is not their role. During the internship, the researchers assisted the users during exercise and recreational activities, carried lunch and drinks, washed dishes and cups, and talked with them as interns. In addition to assigned tasks, the researchers surveyed tasks that were considered burdensome at the facility.

This research focused on the lunchtime problem, where there were insufficient nursing staff to assist with meals and watch over users to ensure their safety. The nursing staff not only had to help the users eat, but also check their safety, clean up the dishes, record the amount of food eaten, guide the users to the bathroom and brush their teeth. Lunchtime was also the nursing staff's meal and rest time, and sometimes only three staff were available during the lunch hour to oversee 30 to 40 users. One assisted with meals, and the other two did other tasks. As those who worked lunchtime could not rest, a reduction in workload was strongly desired. Despite the heavy workload, safety checks were required because older, weak adults could fall from chairs or aspirate during feeding, leading to dangerous situations.

4.2 Specifying the user requirements

This section discusses the approach to solving the problem based on the human error-proofing principles [16], as shown in Table 2, and defines the user requirements. Here, human error at lunchtime is defined as the collapsed posture of an older adult leading to a fall from the chair or aspiration.

For human error-proofing countermeasures during lunchtime, we decided to build a system that detects older adults' abnormal posture during meals. In developing the system, we considered the following user and functional/technical requirements, as shown in Table 3, and developed systems based on user research and interviews.

Table 2. Countermeasures based on five human error-proofing principles.

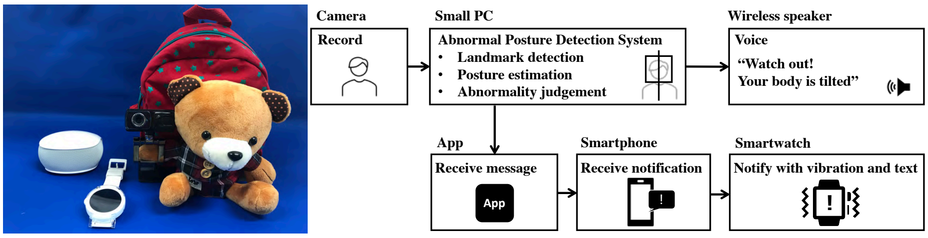
Principle	Countermeasures
Exclusion	We considered not offering lunch or providing care only in the morning/afternoon, but this would defeat the purpose of the care facility.
Substitution	We considered not offering various lunches and making the nursing food easy for everyone to swallow. However, this method is used for older adults whose swallowing function has already declined, and would deprive users who can still eat of the pleasure of eating.
Facilitation	At lunchtime, the older adults maintain their own sitting posture; though this seems effective, countermeasures are needed with measures for eating.
Abnormality detection	A collapse of posture that could be dangerous, causing a fall or aspiration, could be detected, the person alerted, and a caregiver notified to return the person to a normal posture. Compared with measures to facilitate posture change, this is very effective and can be applied to both sitting and eating actions concurrently.
Mitigation	We considered ways to mitigate choking on food or falling from a chair, such as placing a soft mat on the floor or an aspirator to remove food stuck in the throat. However, since falling or choking are dangerous for older adults, measures to mitigate their impacts may be effective but not optimal.

Table 3. Defined user requirements.

Requirements	Descriptions
Functional/ technical	✓ Non-invasive and non-contact measurement of the user's posture ✓ Can be measured without requiring the user to wear any devices ✓ Abnormal posture that may lead to falling/aspiration can be detected ✓ When detected, notifications can be sent to the person and nursing staff who are not in the field of view ✓ Autonomous operation including power supply; easy to carry and install
User acceptance	✓ Natural appearance and atmosphere when installed in a facility ✓ The appearance should be friendly to older adults ✓ Notifications should not be unpleasant for staff, users, or others ✓ Should be portable, compact enough for a tabletop, and easy to use ✓ The notification should be easy to recognize immediately

4.3 Producing design solutions

An abnormal posture notification system was developed consisting of a camera to capture the user's posture and calculate the tilt from a vertical posture. When detecting the abnormality, it notifies the user and nearby people by voice/vibration, and the nursing staff by text message. Fig. 2 shows an overview of the system.



(a) (b)

Fig. 2. Overview of the developed system. (a) Appearance of the system. (b) System flow.

The system program was written in Python (v3.6.5) and built using OpenCV (v3.4.1.15) and Dlib [19] (v.19.15.0). The system estimates the position of the face based on HOG (Histograms of Oriented Gradients) features from the captured image; it estimates 68 landmarks on the face using a shape regression model [20]. For posture detection, the position of the corner of each eye among these landmarks was used and the face angle was defined as the angle between a straight line connecting the corner of each eye and a horizontal line. If the face is tilted, the center of gravity of the body is likely to be shifted to the side. Therefore, if the estimated angle of the face exceeds the preset threshold, the posture is judged to be abnormal. Due to the performance of the control system in this study, the posture measurement cycle is set to around 2 fps (frames per second) and the maximum angle of face detection is ± 40°.

When developing a system, acceptability to the user must be considered. In our initial prototype, the system was placed in a paper bag with a discreet small hole for the camera. However, as this made the user feel uncomfortable as if being secretly recorded, the camera was visibly installed on the outside so that the users could see they were being recorded before using the system, increasing their trust in the system. Further, the user and the system needed to face each other squarely for posture to be measured correctly, so it was considered important to make the user familiar with and interested in the system. A small backpack with a child's stuffed animal was used as the system case and the camera was attached to the stuffed animal's arm to ensure that the users were actively aware of and familiar with the camera.

4.4 Evaluating the design

Recorded videos of a facility user's meals were used to verify the prototype functionality. User posture was successfully estimated in 81,369 frames out of 89,910 frames (approximately 91%). The results indicated that the system functioned sufficiently provided the user faced forward and other objects did not obscure their face. Further, it was confirmed that the system could detect abnormal postures non-invasively and notify both the nursing staff and older adults, thus satisfying the functional and technical requirements.

User tests and semi-structured interviews with four nursing staff at the facility and five medical/nursing staff working at other facilities were conducted. The system appearance was positively evaluated by the staff and users of the facility. The system can be operated by touch, is easy for the staff to understand, and the notifications can be received by a smartwatch that can be worn at all times. It is portable and can be used anywhere in the facility, thus satisfying the requirements for user acceptance.

The nursing staff mentioned several problems, including being unable to detect users with a collapsed posture because they could not observe all users at once and needed to leave their seats to check on users during meal assistance. Regarding these problems, the staff were very positive about the developed system and its ability to address problems; typical comments included "(the system) is appreciated" and "the system is necessary". This confirms the demand for an abnormal posture detection system in the day-care facility. The results also indicated that our system could be applied to users in other situations, such as after lunch when drowsiness increases or for older adults who are more likely to fall from their chair due to their movements. However, some staff pointed out that the proposed system is not ideal when mainly used for people with dementia, indicating that system needs to be improved to meet the demands of specific users and conditions.

5 Conclusion

This study aimed to develop a safe and acceptable system that could solve the problems experienced by a day-care facility by involving users and employing a risk management framework from the initial phase of the design process. Participant observations and human error-proofing principles were incorporated into our UCD method. An abnormal posture notification system that met the technical/functional and user requirements was successfully designed. The UCD approach enabled us to quickly identify proper solutions in the care facility setting and improvements needed, and thus also discover users and use-cases we had not initially envisioned.

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