HUG Smart Sticker: Enhancing Personalized Intelligent Medication Management for Community-Dwelling Older Adults with an AIoT Intervention

Medication and dietary supplement usage are prevalent in community-dwelling older adults. However, medication or dietary supplements non-adherence is a challenge, as are risks of misuse, abuse, and diversion (MAD). Due to the increased prevalence of progressive deficits in cognition among community-dwelling older adults, the ability to plan, organize, and execute medicine-management behaviors is further compromised, leading to an increased risk of unintentional non-adherence, medication errors, and preventable medication-related hospitalizations. HUG Smart Sticker is a personalized intelligent medication and dietary supplement management system promoting informed and safe medication usage for community-dwelling older adults. This Artificial Intelligent of Things (AIoT) intervention records users' medication usage in real-time, reports the latest alerts or potential side effects, and reminds users to ensure the safe usage of medications. With its unique 3R features (Record, Report, Remind) and aging user-friendly interface, the HUG Smart Sticker offers a tailored approach to medication and supplement management, empowering older adults to take control of their health and well-being. To develop and evaluate the HUG Smart Sticker, this paper conducted a prototyping study and a usability study with 25 older adult participants from Upstate New York. Our study highlights the significance of this AIoT-based medication and dietary supplement management intervention in improving medication adherence, enhancing the overall health outcomes of older adults, and contributing to aging populations' healthy lifespans.

CCS Concepts: • **Human-centered computing** → **Empirical studies in interaction design**; *Accessibility systems and tools*; • **Social and professional topics** → **Seniors**; • **Applied computing** → *Consumer health.*

Additional Key Words and Phrases: Artificial Intelligent of Things (AIoT); Aging populations; Community-Dwelling Older Adults; Medication Management Intervention.

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1 INTRODUCTION

In 2020, the US population aged sixty-five and older numbered 55.8 million, with older adults representing 16.8 percent of the population [14, 15]. Adherence to medication use among older adults especially for those with cognitive decline is a major challenge, as are risks of misuse, abuse, and diversion (MAD) of medication [49, 71]. Cognitive impairment interferes with the ability of older adults to comply with their medication regimen. The overall increase in longevity globally and greater rates of cognitive impairment and utilization of medications with older age suggest that the already large population of older adults exhibiting medication non-adherence will increase [35, 66, 78, 91].

The average medication nonadherence rate is 24.8%, according to a 2004 study [28**?**]. 89% of older adults report that they are currently taking any prescription medicine, and this usage tends to increase with age [1, 8]. However, the misuse and abuse of medications can have serious ramifications for older adults' well-being [12, 31]. It is estimated that medication nonadherence contributes to around 125,000 deaths per year in the United States [58]. Medication

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non-adherence results in an increased risk of misuse, abuse, and diversion-related (MAD-related) behavior [40]. MAD of medications is associated with increases in admissions to addiction treatment centers, emergency department visits, and a number of prescribed medication-related poisoning deaths.

Effective interventions are critically needed to promote the appropriate use of prescribed medications to optimize pain management and minimize risks of both intentional and unintentional MAD. Several strategies have been used to support medication-regimen management in patients with cognitive impairment. The current lack of potent, feasible, implementable, and scalable programs for community-dwelling older adults and their primary caregivers leaves this population, their families, and their communities at heightened risk for errors and likely contributes to the continuation of the increased prevalence of adverse drug reactions and potentially avoidable hospitalizations [57].

This paper investigates three research questions pertaining to medication management practices among community-dwelling older adults: **RQ1**: Based on their personal experiences, what are the most efficient and effective methods that community-dwelling older adults discover for managing their medications or supplements? **RQ2**: What features should be incorporated into the HUG Smart Sticker to address the medication management needs and convenience of community-dwelling older adults? **RQ3**: How can the HUG Smart Sticker Artificial Intelligence of Things (AIoT) intervention improve medication adherence, health outcomes, and overall community-dwelling older adults' well-being? To address these three research questions, we conducted a two-part study: Study 1 Prototyping Study involved 7 community-dwelling older adults to explore and address RQ1 and RQ2; Study 2 Usability Study, we engaged 18 older adults to analyze and enhance the HUG Smart Sticker prototype, specifically targeting RQ3.

This study refines and pilots test a novel AIoT medication management intervention - HUG Smart Sticker - to maximize adherence and minimize unintentional and intentional MAD behavior for households of community-dwelling older adults. HUG Smart Sticker builds capacity for improving medication safety and adherence for community-dwelling older adults experiencing age-related cognitive decline or cognitive impairment. Through our study, we aim to contribute to the field of aging-friendly intelligent medication management interventions, particularly promoting medications and dietary supplements' adherence, enhancing safety, and addressing the unique challenges faced by community-dwelling older adults. Employing the AIoT technology, HUG Smart Sticker provides a comprehensive and aging populations-centered solution that empowers older adults to navigate the complexities of medication management, leading to improved health outcomes and enhanced quality of life.

2 RELATED WORK

2.1 Challenges of Medication Non-Adherence Among Community-Dwelling Older Adults

Community-dwelling older adults living with cognitive impairment warrant specific attention because they are particularly vulnerable to medication nonadherence [39, 52, 89]. This can be attributed to the trend towards home-based care in lieu of residential care and the heightened intensity of medical therapy to treat chronic diseases, which together suggest that a greater number of community-dwelling older adults with cognitive impairment will need to manage increasingly more complex medication regimens at their homes [96]. Smith et al.'s study shows that the rate of medication adherence among community-dwelling older adults with cognitive impairment varied across six different studies. The lowest adherence rate recorded was 10.7%, while the highest rate observed was 38%, which is alarmingly low and raises concerns. [84].

Medication non-adherence is both varied and complex, and previous research has described the ability to manage medication as a delicate balance between patient factors, healthcare professional factors, and medication regimen-related

factors [29, 34, 36, 51, 55]. Typical medication non-adherence reasons cited by patients for not taking their medications included forgetfulness (30%), other priorities (16%), decision to omit doses (11%), lack of information (9%), and emotional factors (7%) [68]. Others identify solutions to counter nonadherence and the respective barriers to implementation. Gathered insight shows that a combination of strategies is more effective than any single intervention and identifies the need for multifaceted and individualized approaches. The lack of comprehensive solutions leaves providers unable to coordinate with each other and meet the complex needs of their patients [7].

There are measurable economic benefits to improved medication adherence among older adults with cognitive decline [9, 10, 58]. The downstream cost associated with medication non-adherence is staggering and can have far-reaching consequences, with one estimate suggesting that medication non-adherence results in as many as 100,000 preventable deaths and as much as $100 billion in preventable medical costs per year in the United States [44, 49]. The lack of medication adherence disrupts the continuum of care and necessitates additional medical visits, interventions, and potentially more expensive treatments. On the positive side, studies have found that in certain disease states, adherence improves health outcomes and reduces annual prevention costs by 10-17% [11]. Despite the evaluation of intervention strategies and medication adherence devices, there is no standardized approach to sustaining success [33, 85]. Several strategies have been used to support adherence, yet little research underpinning the use of these strategies exists, and few have sought to turn these approaches into routine practice [35].

As cognitive deficits progress, older adults may experience challenges in planning, organizing, and effectively managing their medication, resulting in a heightened risk of unintentional non-adherence, medication errors, preventable hospitalizations related to medications, and medication-associated harm, such as unintentional opioid poisoning or overdose [86, 93]. These consequences can be particularly severe for community-dwelling older adults with cognitive impairments who are prescribed controlled substance medication, as these medications are commonly used in such cases. The compromised ability to manage medications poses significant risks and underscores the importance of tailored interventions and support for this vulnerable population.

2.2 Previous Studies on Medication Management Systems

Medication adherence monitoring systems are categorized into different types: sensor-based, fusion-based, or vision-based [2]. Previously, several studies have focused on the development of personalized and intelligent medication management systems or devices [4, 60, 65, 90]. Examples of such systems include MedRem on wearable devices [61], electronic pillbox MedTracker [38], time/schedule calendar [25], assistive robot [13, 74], and short message service (SMS)-based medication adherence system [75, 88]. These studies utilized softwares [16, 87, 92], wearable devices, and intelligent hardware devices [3, 5, 43, 53, 54], to create user-friendly and intelligent tracking devices. There are also some low-technology or non-technology conventional medication management methods, such as calendars, journals/books [45], and medication organizers/planner boxes. However, one common drawback of these interventions is that they are complex and ineffective for end users, particularly community-dwelling older adults with cognitive issues [64].

In addition, there are several guidelines for designing and developing intelligent medication management interventions. Palen and Aaløkke [69] analyzed older adult's medication management practices and summarized five design principles: 1) Employ assistive Internet Technology (IT) for personalized medication management across the home using spatial arrangements that align with routines; 2) Prioritize elders' benefit in medication management through computational design; 3) Enable remote assistance through distributed, modular, and physical-digital systems; 4) Introduce technology through invitation to respect user autonomy; 5) Conceptualize "health" broadly for in-home health IT-based assistance [69]. Cramer highlighted the issue of "Poly-dosing" (multiple daily doses) and outlined key factors

for healthcare providers to consider in prescribing, including dosage regimen, schedule, cues, devices, and monitoring [21, 48]. Additionally, Patel et al.'s study on electronic medication adherence products for older adults developed a guide for prescribing clinicians, which the electronic medication adherence products (eMAPs) should have product-specific features (e.g. maximum number of alarms, number of days products can accommodate based on daily dosing regimen, allows for portability, and locking feature) and the ease of use (e.g. average time to set device, number of steps to set device, average usability, average workload) [72].

2.3 AIoT-based Integrations in Medication Management Systems

AIoT system is a combination of Artificial Intelligence (AI) and the Internet of Things (IoT) that facilitates the connection of physical objects and equipment. This integration empowers these entities with perception, cognition, and communication capabilities. AIoT technologies enhance the intelligence of previously non-intelligent devices, ultimately connecting them to the Internet by leveraging embedded devices, Internet protocols, sensor networks, communication protocols, and various applications [73].

Prior research has focused separately on AI and IoT integrations in medication management systems to improve efficiency and effectiveness. Studies on AI tools can be used to measure and increase medication adherence in patients with non-communicable diseases (NCDs) [6]. AI technology could also detect errors and improve accuracy in medication self-administration by analyzing the wireless signals in the patient's home [95]. The smart AI pharmacy system could automate routine tasks, provide personalized treatment plans, and reduce costs without relying on redundant manual processes [46]. In conjunction, IoT devices create optimal medication environments by controlling factors like temperature and humidity [82]. The Smart Medicine Dispenser (SMD) IoT system ensures accurate dosages and timely dispensing [70]. Integrating AI and IoT offers potential for enhanced medication management, including adherence monitoring, error detection, automation, personalization, and precise delivery.

The AIoT systems, combining the power of AI algorithms and IoT techniques, have been used in multiple fields, such as smart homes [30], robotics and automation, environmental science, and agriculture. There is limited research on AIoT integrations in the medication management field, but the AIoT systems enable intelligent and autonomous decision-making, data analysis, and communication among interconnected devices which can build a community-dwelling older adults-centered medication management system and benefit the increasingly aging populations [56].

3 METHODOLOGY

This study is divided into two parts: study 1 prototyping study and study 2 usability study. Study 1 aimed to develop AIoT-based medication management services to 1) effectively manage community-dwelling older adults' medications or dietary supplements without altering their original behaviors [41]; 2) provide personalized 3R functions - Record, Remind, Report - to improve older adults' education on the medications that they are taking; 3) predict users' medication adherence and behaviors to maximize the medication or dietary supplements' effectiveness. Both studies were approved by IRB. In Study 1, we shadowed at a local medical center with four caregivers from the outpatient care department and conducted pilot interviews with seven community-dwelling older adults residing in Upstate New York. Then, we co-designed and developed the HUG Smart Sticker AIoT prototype [63]. Study 2 involved usability testing on HUG Smart Sticker with 18 community-dwelling older adults in the same region. The shadowing activities are in-person and the interviews were conducted virtually via Zoom. The data were collected between September 2022 to July 2023.

The recruitment criteria for community-dwelling older adults are aged 65 years or older, living independently in their own homes without the need for assistive living or nursing care, and taking/managing one or more medications

or dietary supplements on a regular basis. We recruited the older adult participants through university email listservs, local offices for the aging, and senior citizen centers. Both studies recruited a total of 25 participants (17 females and 8 males). All participants indicated their interest in participating in the study by responding via email, demonstrating a basic level of digital literacy and familiarity with telemedicine.

In Study 1: prototyping study, our interview process consisted of four components: participants' demographics, exploring their current medication management process, discussing challenges and mistakes encountered, and co-designing potential future improvements [81]. Similarly, in Study 2: usability testing study, our interviews contain five parts: participant's demographics, exploring their current medication management strategies, showcasing the HUG Smart Sticker, gathering suggestions and comments, and seeking input on HUG Smart Sticker's future enhancements.

After each interview, we transcribed each interview using the six-stage theme for our data analysis [19]. We first thoroughly read through the interview transcripts, identify the codes (Examples of codes include "neglected older adults' needs," "medication consumption patterns and preferences," "community-dwelling older adults' education," and "technical issues"), and cluster the codes into potential themes. Then, we collaboratively and iteratively consolidated and refined the themes among the authors.

4 STUDY 1: PROTOTYPING HUG SMART STICKER

In study 1, we recruited 7 community-dwelling older adult participants (Mean = 72.14 years, SD = 2.48 years) to understand their demands and challenges in managing the medications or supplements. (Table 1)

Study 1 Participant ID	Age	Gender	Education Level	Race	Family Income Level (estimate)
P1	73	F	Ph.D.	Caucasian	70k
P2	71	F	M.S.	Caucasian	30k
P3	73	F	M.S.	Caucasian	120k
P4	73	F	M.S.	Caucasian	80k
P5	71	F	M.S.	Caucasian	50k
P6	76	F	Ph.D.	Caucasian	60k
P7	68	M	Ph.D.	Caucasian	65k

Table 1. Study 1 Participants Information

4.1 Shadowing Activities and Pilot Interviews' Study Results

4.1.1 The lack of knowledge about medications or dietary supplements. The problem of inadequate knowledge about medications and dietary supplements is a prevalent issue experienced by community-dwelling older adults. Rather than inquiring specific medical recommendation from clinical professionals, society or surrounding environment has negative influence on getting accurate knowledge about medications or dietary supplements, which highlights the impact of a knowledge deficit: "*I have limited knowledge about my medications. I have been advised by my friends to take certain medications occasionally, such as calcium, Vitamin D, and other supplements that are relevant to my age or a general multivitamin.*" (P1) In the absence of clinical suggestions or advice, the independent decision-making regarding medication intake poses potential risks for older adults: "*I've been taking a daily multivitamin called 'Centrum for Women' for years now. I must admit, my decision to start taking it was more out of routine and societal influence than a specific medical recommendation.*" (P6)

In addition, insufficient understanding regarding the usage, benefits, and potential risks associated with these substances poses a considerable challenge, which may generate false belief: "*I don't have a lot of knowledge about certain dietary supplements, and I have reservations about taking them. I believe in getting my dietary supplements from my food.*" (P3) P3 voiced a preference for obtaining essential nutrients from their food rather than resorting to medications, which mistakenly dismissing the role of medications in meeting their nutritional needs.

4.1.2 Limited tracking of medications and dietary supplements in non-traditional formats. 3 participants raised concerns regarding the types of containers used for medications or supplements. They noted that not all medications or dietary supplements are in solid form, with some being in powder, liquid, cream, or bag formats. "*But some medication cream or powder is hard to take care of or put in my medication pillbox. A smart sticker on the original package would definitely help a lot, I believe.*" (P2) Tracking these non-pill medications in a medication organizer or pill box proves challenging, as these formats do not fit easily within the designated compartments.

The local medical center's outpatient care officer has raised concerns regarding the management of medications and dietary supplements in various formats during each medication refill visit. Specifically, the officer faces challenges when dealing with non-pill types of medications and dietary supplements, such as powders, syringes, and liquids. The unique characteristics of these non-pill formats cause difficulties for the officers in terms of storage, management, and dispensing. As a result, these officers encounter obstacles in ensuring accurate and timely provision of these medications and dietary supplements to older adults: "*The complex nature of handling and organizing non-pill formats demands additional attention and strategies to streamline the process and ensure optimal aging populations care.*"

4.1.3 Fragmented information across multiple healthcare softwares. The current landscape of healthcare software, including healthcare portals, platforms, and various applications, presents a challenge as each system typically provides only partial or limited information. This fragmentation of information poses inconveniences for community-dwelling older adults who strive to comprehensively understand their medications and dietary supplements systematically.

"*As a patient I used several platforms, such as hospital's patient platform, insurance system platform, and an application for my primary care provider. Specialists have different platforms, so there isn't a single place I can go to get all my information. I do look up the information from the platforms or applications, but I have to go to 3 different healthcare providers platforms to get a full picture of type of medications that I go through.*" (P4)

The absence of a consolidated and holistic view of their healthcare data undermines the ability of older adults to attain a comprehensive understanding of their medications and dietary regimens. With fragmented information spread across multiple platforms, it becomes increasingly difficult for them to piece together a complete picture of their medications and dietary supplements. This lack of a centralized view often results in confusion, gaps in knowledge, and potential misconceptions.

4.2 Design and Develop the Older Adults-Friendly HUG Smart Sticker

Based on the five design principles of developing intelligent medication management systems [69], we started to design our first version of prototype (Figure 1). HUG Smart Sticker is designed as a two-arm intervention composed of an intelligent sticker and of digested alerts for promoting informed and safe dietary supplement usage. It is intended to optimize the health span of the average older adult, as medications and dietary supplements are commonly used by the public in hopes of maintaining or improving health outcomes.

To achieve precise monitoring of users' medication or dietary supplements usage, we conducted extensive testing on various sensor types, including accelerometer, proximity sensor, and button sensor. Through multiple rounds of

rigorous testing, we determined that the pressure sensor exhibited the highest level of accuracy and provided the best user experience among all the sensors evaluated. We also tested different types of visual, audio, and Bluetooth/WiFi data transmission sensor in order to form seamless communication and integration between sensors.

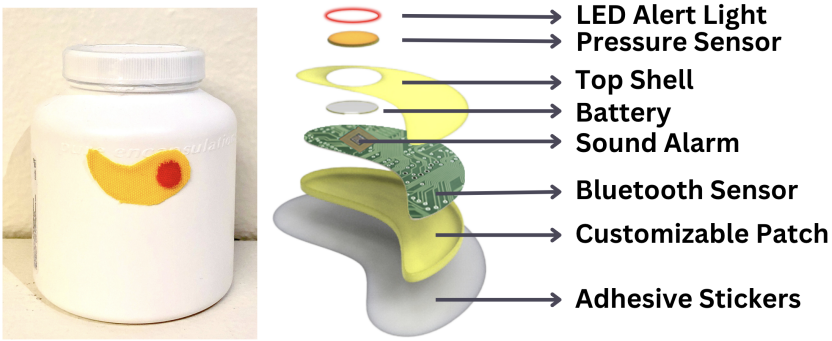

Fig. 1. HUG Smart Sticker Prototype Look and Explosion Image of the Inner Functions

Each HUG Smart Sticker hardware module features an LED button light, a pressure sensor, a Bluetooth transmitter, an audio signal generator, batteries, and a silicon rubber casing. The LED button light serves as a visual indicator, lighting up to remind users when it's time to take their medication. The pressure sensor is integral to tracking medication usage, registering the pressure change when a medication container is accessed. The Bluetooth transmitter is responsible for sending this information to the paired software application, allowing users to monitor and track their medication usage. The audio signal generator aids in this process, generating sound alerts based on users' medication schemes. The sticker's power source is an energy-efficient battery that ensures long-lasting operation. The adhesive silicon rubber patch encloses all these components, providing a robust and durable shell that can withstand daily wear and tear. The casing also allows users to customize the sticker easily, cutting and adjusting it to fit and attach to a specific medication container or any other packagings for tracking purposes.

One of the notable features of the HUG Smart Sticker is its customization capability. Users have the flexibility to easily modify and tailor the sticker to fit their specific medication containers or any other preferred location for tracking purposes. The sticker can be conveniently cut and adjusted according to individual preferences, ensuring seamless integration into the user's daily routine and enhancing user-friendliness. This customization feature adds versatility and adaptability to the HUG Smart Sticker, making it a practical and adaptable solution for medication management.

4.3 User flow of HUG Smart Sticker: Combining the Hardware and Software Modules

For the software application, it generates information about the 3R functions (Record, Remind, and Report) based on the users' data. To use the HUG Smart Sticker software alert system, users or caregivers (under permission) first match each hardware sticker with the corresponding medication's QR code. After confirming the medications or dietary supplements' doses and durations, users can check the medication usage report on the preferred devices. The intelligent HUG Smart Sticker can then be attached to the desired supplement container. The wireless pressure sensor in the HUG Smart Sticker is able to detect the user's frequency of supplement usage based on the time duration and amount of pressure applied to the container. For example, each time the user takes a medication, the label will record this one-time usage based on the pressure it senses from the user's grip on the local surface. The pressure sensor will then transmit

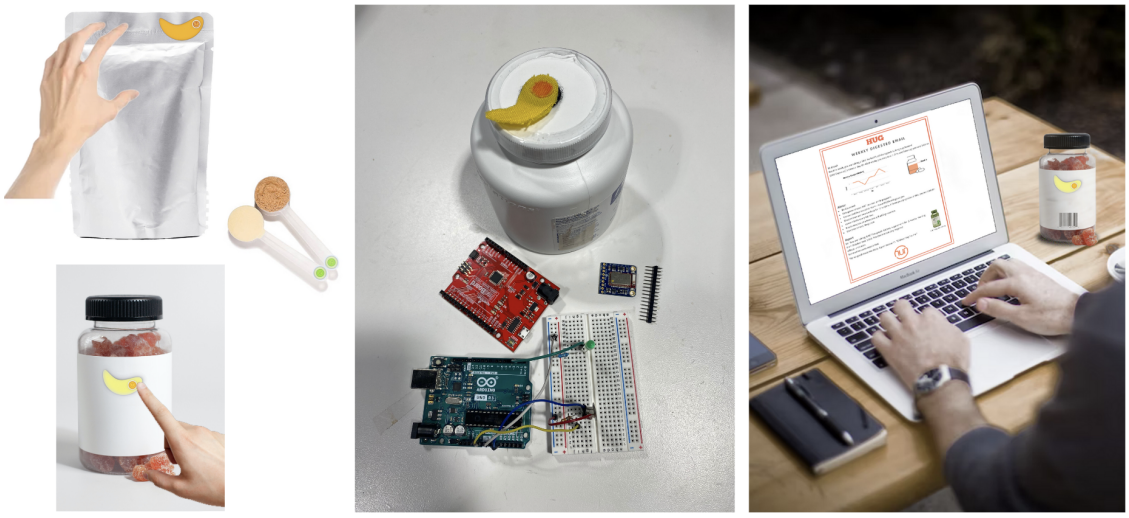

Fig. 2. (Left) HUG Smart Sticker on three different medication packagings; (Middle) HUG Smart Sticker's hardware module; (Right) HUG Smart Sticker's software module.

this medication tracking data via Bluetooth to the user's end through a weekly digested notification that will enable the user to monitor their supplement usage. Overall, the HUG Smart Sticker is intended to provide records of daily usage via the intelligent label, alerts on adherence to the supplement regimen, and evidence-based reports on the medication's safety.

Building upon users' data, the HUG Smart Sticker utilizes advanced AI algorithms to anticipate and predict users' future medication adherence behavior and patterns. This data-driven predictive feature contributes to a more personalized and patient-centric approach, ultimately promoting community-dwelling older adults' better health outcomes. It offers intelligent alerts and reminders to assist users in effectively managing their medication usage. Moreover, these predicted behavior patterns can be shared with clinical professionals, enabling them to gain insights into medication performance. For instance, in cases where older adult users frequently exhibit medication overdosing, clinicians may opt to explore alternative treatment options to optimize the health outcomes and overall well-being of users.

The combination of hardware and software modules form a comprehensive AIoT intervention, which offers community-dwelling older adults a convenient solution for real-time medication tracking and understanding of their medication usage. In the broader context, the medication usage data of each user can provide insights for clinicians to comprehend the performance of the prescribed medications. Since medication effectiveness is not solely reliant on the medication itself, it is also based on the consistent and regulated intake that maximizes its therapeutic benefits. Therefore, clinicians can gain a deeper understanding of medication performance and make informed decisions to optimize patient outcomes. (Figure 2)

5 STUDY 2: USABILITY STUDY WITH COMMUNITY-DWELLING OLDER ADULTS

We conducted usability testing with 18 community-dwelling older adults (17 females, 8 males). The age of participants ranged from 62 to 85 years (Mean = 69.89 years, SD= 7.00 years). 17 of them are Caucasians, while 1 of them is Asian. The interview questions were adapted and modified based on evaluation studies of medication management interventions

[26, 62, 77, 79], such as 8-item Morisky Medication Adherence Scale [26], Medication Management Instrument for Deficiencies in the Elderly (MedMaIDE) [67], Medication Management Ability Assessment (M1V1AA) [42], Drug Regimen Unassisted Grading Scale (DRUGS) [32]. (Table 2)

Study 2 Participant ID	Age	Gender	Education Level	Race	Family Income Level (estimate)
P8	67	M	Ph.D.	Caucasian	70k
P9	80	M	M.S.	Caucasian	80k
P10	71	F	M.S.	Caucasian	100k
P11	72	F	M.S.	Caucasian	50k
P12	71	M	Ph.D.	Caucasian	60k
P13	64	F	M.S.	Caucasian	80k
P14	63	F	High School	Asian	50k
P15	75	M	Ph.D.	Caucasian	85k
P16	63	F	N/A	Caucasian	90k
P17	63	M	High School	Caucasian	55k
P18	72	F	M.S	Caucasian	90k
P19	62	F	B.S	Caucasian	150k
P20	68	F	B.S	Caucasian	50k
P21	68	F	J.D	Caucasian	90k
P22	85	M	M.S	Caucasian	65k
P23	62	F	M.S	Caucasian	80k
P24	70	M	J.D	Caucasian	90k
P25	82	F	High School	Caucasian	40k

Table 2. Study 2 Participants Information

Based on study 1 and 2, we performed a comprehensive thematic analysis encompassing three distinct categories: community-dwelling older adults' cognition, memory, knowledge, and literacy [17]; caregiver related; and medication access and coordination. Within each category, we further developed sub-categories to gain deeper insights into the concerns and demands expressed by community-dwelling older adults. Subsequently, we selected some quotes from each sub-category for detailed analysis. (Figure 3)

5.1 Low Health Literacy Partially Contributes towards Medication Non-Adherence

Insufficient medical literacy among older adults poses risks in medication adherence (MAD). It is crucial for older adults to receive medication education to enhance their understanding of the medications they are currently taking [80]. Follow-up explanations provided after prescribing medications or purchasing dietary supplements from pharmacies can be valuable in this regard. 6 out of 18 participants (33.3%) expressed concerns about their lack of medical understanding and knowledge, which hindered their ability to effectively manage their medications. "*I don't know a lot about my medications. I know that I have been recommended to take certain dietary supplements here and there, like multivitamins and calcium with D and all of that, as it relates to my age.*" (P11) Similarly, P21 shows limitations in learning drug interactions as well as drug-and-food interactions, raising notable concerns: "*Every morning, I take my thyroid medication and my multivitamin along with my coffee. Although I am aware that combining medications with coffee might not be ideal, it has become an integral part of my routine.*" (P21)

Category	Sub-Category	Number of Agrees	Sample Testimonies
Cognition, Memory, Knowledge, and Literacy	Cognitive Issues (e.g. dementia, MCI, Alzheimer's disease)	(19)	*"I had MCI for 5 years. Always need to set up a lot of alerts and alarms to keep track of my medication or supplements' usage daily."* (P6)
	Forgetfulness (just forgot, Not cognitive impairment)	(11)	*"I forget to take my medication, or sometimes I forget if I already took my medication. That's the main difficulty."* (P10)
	Unfamiliar/Averse to Tech	(3)	*"Like technology, I am not a huge fan. I have downloaded some apps for health monitoring purpose but seldom used it."* (P22)
Caregiver-Related	Limited healthcare provider coordination	(15)	*"I don't take my medications because it makes me feel bad, or I sometimes don't see the results from it. I will stop it on my own without asking doctors."* (P24)
Medication Access and Coordination	Medication not Obtained/Refilled	(10)	*"I sometimes forget to refill my medication or supplements. And unfortunately, I can't adhere to my medications."* (P20)
	No Education or Follow-Up Visits when Medication Regimen Changes	(9)	*"Some people like me just cannot afford [the medication]. If it's too expensive or too hard to find, I will probably decide not to take it and switch to some alternate cheaper options."* (P14)
	Confusing/Unclear Process for Medication Management	(7)	*"I'm currently in a state of stability and remission on a maintenance dose of a drug that I take 21 days on and 7 days off for a 28 day cycle each month."* (P17)
	Meds are disordered, mixed up (i.e. can't separate b/c mixed)	(7)	*"Remembering to take medication is a huge task, especially when we have to manage five different medications with different schedules. "* (P19)

Fig. 3. Medication Management Study Results with Pictogram.

Furthermore, 10 out of 18 participants reported instances where certain medications or dietary supplements did not observe the desired effects or caused discomfort during the intake process, such as itchiness, pain, or adverse side effects. "*I will first believe in what the doctor says. But if the medicine makes me feel really bad, I will question it. And if the doctor still cannot give me any answer that makes me feel better, I will do some research myself and switch to some alternate options.*" (P14) The inability of these medications or dietary supplements to deliver the intended outcomes not only affected the perceived efficacy but also led to concerns about the overall effectiveness and safety of the treatment.

Understanding these instances of treatment inefficacy and discomfort is crucial in order to ensure improved medication management and enhance the well-being of community-dwelling older adults. "*Once, I felt uncomfortable with two medications, so I went back to the doctor. But the doctor was like, 'you should take it. It's good for you'. But I felt so bad and I just decided to decide on myself not using it.*" (P16) P8 also has a similar experience: "*I didn't come back to my caregiver for follow-up visits because the caregivers just kept saying you should take it, but I kept vomiting every time I took those pills. So I don't think there's good communication between the patients and caregivers sometimes.*" These quotes highlight the importance of addressing medical literacy gaps and ensuring proper communication and understanding between healthcare providers and older adults when it comes to medication management.

Misconceptions and misunderstandings about medications are also common. 2 out of 18 participants considered medications as negative and tried to avoid having them. Such prevalent misconceptions can have a detrimental impact on medication adherence and compromise the effectiveness of treatments. "*I am trying to avoid medications as much*

as possible. Taking a lot of medications for me is not healthy at all." (P10) When individuals consider medications in a negative perspective, it often stems from various factors such as fear of side effects, concerns about dependency, or a general mistrust of pharmaceutical interventions. These misconceptions can lead to a reluctance to comply with prescribed medication regimens and can undermine the effectiveness of treatments.

5.2 Cognitive-Related Issues Pose Challenges in Medication Management

8 out of 18 participants had mild cognitive impairment or above. The challenges of medication management increase when having cognitive-related issues, making the process prone to errors and complications. In Study 1, we further divided the category "cognition, memory, knowledge, and literacy" into three distinct subsections to delve deeper into specific concerns. These subsections included "Cognitive Issues," "Forgetfulness," and "Adverse to Tech," enabling a comprehensive exploration of the various factors impacting medication management among community-dwelling older adults.

The integration of medication or supplementary reminders, such as auditory alerts or visual cues, becomes crucial to support older adults with congnitive issues in managing their medications effectively. These reminders or alerts serve as valuable companions to traditional visual aids like pill boxes, offering an additional layer of assistance and enhancing medication adherence in this population. "*The primary challenge I face in managing my medications is the possibility of forgetting to take them, especially my evening dose. While my pill box system helps a great deal, it is still a challenge to remember to take my medication consistently.*" (P7)

Forgetfulness is another prevalent issue in medication management among community-dwelling older adults, often leading to significant medication management challenges:"*Remembering to take my medication and supplements hasn't always been flawless. I've had instances where I've become engrossed in a book or involved in a project and simply forgot to take my pills. At times, when my routine is disrupted, like when I travel or have guests over, it takes me longer to remember where I've placed my medication.*" (P1) It underscores the disruptive effects of distractions on medication adherence and highlights the necessity for strategies or tools that can help maintain consistent medication routines amidst daily diversions. The forgetfulness also include distraction, which can contribute to uncertainties and dosing errors in medication management. Without a reliable tracking system in place, the older adults find themselves in situations where they are unsure whether they have taken their medication or not. As a result, they may "*unintentionally double up on doses or miss a dose altogether*" (P3). Given the potential health risks associated with missed or overdosed medication, there is a pressing need for robust and reliable medication management strategies. These strategies aim to ensure accurate and consistent adherence, mitigating the adverse effects that may arise from medication errors.

The aversion to technology presents significant challenges in the realm of intelligent medication management. 3 out of 18 participants are adverse to tech and didn't use intelligent devices in a daily basis. "*If you require older adults to adapt this type of intelligent device [HUG Smart Sticker], you might have a hard time, because I am unfamiliar to them. I am facing a machine instead of a caregiver which I've been used to for the last 60 years. And letting me to try to do it and have a behavior change in my late stage of my life will be very difficult.*" (P10) The intelligent devices provide timely reminders, track medication schedules, and offer personalized alerts and notifications. However, the participants who were adverse to technology missed out on these benefits, potentially compromising their ability to adhere to their prescribed medication or dietary supplements regimens.

5.3 Trusts between Older Adult and Healthcare Caregivers

Trust plays a vital role in ensuring medication adherence among community-dwelling older adults and their caregivers. 6 out of 18 participants claimed that they were raised in a family setting where they had regular access to a family doctor or caregivers. Consequently, they found it challenging to consistently seek assistance from external clinicians in the new healthcare setting. This lack of a closed loop between community-dwelling older adults and the final evaluation of medication performance or effectiveness became apparent. Older adults simply adhered to medication instructions without actively seeking feedback to enhance the effectiveness of their treatment. This situation can lead to issues of trust within the therapeutic relationship and potentially compromise the overall well-being of older adults. "*Once I was taking a blood pressure medication, but it's not actually reducing my blood pressure significant enough. I kept taking it and I didn't tell my doctor because I would like to follow what the doctor said. However, the medicine is not being effective as it should be until I go back to my doctor, which was 6 months from then. My doctor told me I should contacted the doctor sooner instead of waiting.*" (P24)

Without sufficient health literacy and timely feedback from healthcare professionals, older adults sometimes gained untrust towards the caregivers as well as the healthcare system. The absence of accessible information and limited opportunities for meaningful engagement can create a sense of uncertainty and frustration, eroding the trust that older adults place in their healthcare providers and the overall system: "*I would like to learn why I have to take medicine X and how it relates or helps with my disease. A lot of times, older adults like me are not clear about the relationship between medicine and disease. It will certainly contribute to a lack of trust in a treatment or a healthcare provider*" (P9). Since community-dwelling older adults are experiencing some dark sides of the medications' side effects, they may seek other unprofessional but timely help which creates barriers to accessing the most relevant clinical information: "*Having developed severe allergies to my first prescribed medication, the doctors helped me to switch to an alternative. However, when I experienced a recurrence of allergies with this substitute medication and lacked any documents or research on its potential side effects, doubts and uncertainties started to emerge. I was even thinking about changing to another doctor at that time point.*" (P10)

5.4 Acceptance and Adoption of AIoT system

4 out of 18 participants expressed concerns about the AIoT system, because of data confidentiality and privacy, accuracy, and AI predictions' reliability. "*I think AI or AIoT system is good and reliable. But you will get some push back, such as privacy and confidentiality issue.*" (P16)

Since AIoT is a relatively new concept and older adults are not familiar with this emerging concept [23], it is expected that the acceptance and adoption of implementing and using AIoT systems among older adults may face delays: "*I never used any AI-related interventions. Without knowing how [HUG Smart Sticker AIoT intervention] works, I may be skeptical before involving it in my medication management process.*" (P19). The skepticism or doubt is caused by the unfamiliarity with this emerging technology and the learning curve associated with its implementation. Hence, this age-related digital divide exacerbates by the lack of older adults-friendly digital interventions [47].

In addition, the successful implementation of the HUG Smart Sticker, which serves as a closing-loop medication management system, relies on specific environmental conditions. Stable at-home Wi-Fi or Bluetooth wireless connections, tracking intelligent devices, and sufficient battery power are essential components for building and operating the HUG Smart Sticker system effectively. The intransparent "*black-box*" (P20) AIoT system significantly increases older adults' uncertainty and adds to their confusion. For community-dwelling older adults to fully embrace and utilize this

technology, they need to understand the concept and ensure that the elements within their environment are stable and consistently connected [27]. It is important to implement targeted education and awareness programs that familiarize older adults with AIoT and its potential benefits. This may involve providing accessible and user-friendly resources that explain the concept and address any concerns or reservations they may have.

6 DISCUSSION

6.1 HUG Smart Sticker's Effective Medication Management Strategies

Effective and strategic interventions are severely needed to advance higher rates of medications adherence among community-dwelling older adults with cognitive impairment [20, 24, 50, 59]. The most promising interventions to improve medication adherence involve educational or reminding strategies [83]. In addition, elderly participants with mild cognitive impairment increased their medication adherence by utilizing medication reminder devices [84]. This suggests that older adults with cognitive impairment could become proficient at using such interventions. However, high-quality research supporting reminding strategies involving medication reminder devices and educational strategies is sparse [37].

We used comparative analysis based on the measurement adherence model [94] to show the comparisons between the existing medication management systems and the HUG Smart Sticker (Figure 4). By conducting a comparative analysis of the eight features implemented in the HUG Smart Sticker with those offered by five popular medication management services, it becomes evident that HUG Smart Sticker stands out by incorporating the 3R features (Record, Remind, and Report) and surpassing other services in key areas such as AI data prediction, personalization, and caregiver connections.

EXISTED MEDICATION MANAGEMENT SERVICES	RECORD	REMIND	REPORT	PERSONALIZED	NEEDS TECH?	REAL-TIME MONITOR?	AI?	EXTERNAL CAREGIVER CONNECTIONS?
HUG Smart Sticker AIoT prototype	✓	✓	✓	✓	✓	✓	✓	✓
Medication Tracker Applications	✓	✓	✓		✓	✓		✓
Medication Tracker Journal/Book	✓							
Memory-aid Timer Cap				✓	✓			
Medication Organizer/Planner Box	✓			✓				
Medication Tracking Digital Calendar		✓		✓	✓			

✓ >70% of the Participants Agree (from 18 participants)

Fig. 4. Tasks Analysis with eight categories of existing medication management services

HUG Smart Sticker designs to remove barriers and empower older adults, their family/friend caregivers, and providers who care for them to reduce their risk of nonadherence and the negative consequences, therefore reducing the burden on providers and costs to the community. A current estimate of the economic cost of medication non-adherence puts the range of 'all causes' non-adherence from $5,271 to $52,341 per person per year [22]. HUG Smart Sticker improves

medication intake safety, reduce risks associated with medication misuse, and reduce the burden on care providers, family, and patients. Preventing missed doses or over-medicating protects the older person from unnecessary side effects and prevents visits to the emergency room and other avoidable healthcare utilization [76]. HUG Smart Sticker improves individuals' functional independence and their ability to remain in their home environment for a longer duration, thus reducing the need to relocate to nursing care facilities. It improves caregivers' and loved ones' comfort level to support the older person in managing their medications, especially if they live alone at home, and reduces stress and unnecessary burden.

Furthermore, this project indirectly enhances health equity by providing patient-caregiver dyads with education on various crucial health-related matters that they may not be well-versed in. By doing so, it endeavors to alleviate the burden on home-care nurses and the healthcare system at large, especially as home care assumes a more significant role in the medical system in response to the ongoing COVID-19 pandemic.

6.2 Data Generations and AIoT Systems

With the combination of HUG Smart Sticker's hardware and software modules, the generated data provides valuable insights into the medication or supplement adherence of community-dwelling older adults. By capturing and analyzing this data, a comprehensive medication usage summary can be obtained, offering older adults and their cargivers a clear understanding of their medication usage patterns. Building upon existing data, HUG Smart Sticker utilizes AI algorithms to forecast and predict users' future medication usage patterns, which enables caregivers or prescribing physicians to understand the user's experiences, behaviors, and preferences. By leveraging AI capabilities, HUG Smart Sticker can provide proactive information that assists healthcare providers in making informed decisions, tailoring care plans, and enhancing medication management strategies for the user. This knowledge empowers them to take control of their health and make informed decisions regarding their medication regimen [18].

Furthermore, the availability of such data can have long-term benefits for pharmacies and pharmaceutical companies. It allows them to explore the effectiveness of medications and supplements from a user-centered perspective. By analyzing adherence patterns and correlating them with health outcomes, pharmaceutical companies can gain insights into the real-world effectiveness of their products. This user-centered approach promotes the development of tailored interventions, improved medication designs, and targets healthcare systems that better cater to the needs of older adults. In the long term, the utilization of HUG Smart Sticker-generated data not only benefits community-dwelling older adults by enhancing their awareness of medication usage, but also facilitates research and innovation in the pharmaceutical industry, which ultimately leading to improved healthcare outcomes for this population.

7 LIMITATIONS

This study has multiple limitations. For the hardware modules, there is a possibility of generating error data if the user inadvertently moves the medication containers or accidentally touches the pressure sensor, leading to unintended data recordings. Although users have the option to delete the error recordings through the HUG software modules, the potential for errors to occur still remains. Also, the HUG Smart Sticker couldn't measure the number of medications or dietary supplements that users take each time but only the number of times. While it can accurately record the frequency of medication intake, it does not possess the capability to measure the precise quantity consumed at a given time. The convenience of the HUG Smart Sticker for traveling purposes may be compromised, particularly for community-dwelling older adults who frequently engage in travel activities. This limitation could potentially impact the reliability and effectiveness of the system in such scenarios.

The recruitment process for both studies presented challenges in achieving diversity among participants. Due to the specific and stringent requirements of the recruiting criteria, the majority of participants were found to be Caucasians and possessed high levels of education and socioeconomic status. This lack of diversity raised concerns about the representativeness of the results and analyses generated from the studies. The skewed participant demographics may introduce biases that limit the generalizability of the findings to other groups of community-dwelling older adults. The experiences, perspectives, and demands of aging populations from different racial and ethnic backgrounds, varying educational levels, and socioeconomic statuses may differ significantly. Thus, the results obtained from a predominantly homogeneous sample may not accurately reflect the broader population of community-dwelling older adults, leading to potential gaps in understanding their unique challenges and requirements.

Conducting virtual interviews posed limitations as it restricted our ability to directly observe participants' living environments and medication arrangements. For instance, the home environment, as well as the presence of family members, can have a substantial influence on medication management practices. By not being able to witness their current medication methods, we were unable to fully assess the potential impact of the HUG Smart Sticker on their medication management routines. The absence of in-person observation hinders our ability to gather comprehensive insights into the contextual factors that could affect the effectiveness and feasibility of implementing the HUG Smart Sticker in community-dwelling older adults' daily lives. Future research should consider incorporating in-person assessments to provide a more holistic understanding of the medication management process and to evaluate the real-world impact of innovative interventions.

8 CONCLUSIONS

In summary, the HUG Smart Sticker stands out as a unique and innovative intervention in comparison to conventional medication management methods, which has not been previously reported in the existing literature. With its AIoT systematic approach and 3R features, this aging-friendly intervention allows community-dwelling older adults to seamlessly integrate medication and supplement management into their existing routines without the need for behavior modifications. The hardware module records usage data, while the software module provides reminders and generates personalized reports for users. This intervention proves particularly valuable for aging populations with cognitive impairments, enabling them to efficiently and effectively manage their medication and dietary supplement usage in real-time. In the long term, the widespread adoption of the HUG Smart Sticker could greatly assist millions of families with aging populations to intelligently manage medication usage. This AIoT system optimizes medication usage and minimizes the risk of medication MAD in community-dwelling older adults living with cognitive impairment. This study contributes to the health and safety of community-dwelling older adults, empower them and their caregivers to reduce medication non-adherence consequences and risks, and enables older adults to continue to live at home while managing their health and well-being.

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