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Feasibility and Acceptability of the Smarthealth Intervention for Dementia Caregivers. A Qualitative Analysis of a Single-Group Pilot Study

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ABSTRACT

Aim(s): To explore the feasibility and acceptability of acoustic monitoring and real-time recommendations for stress detection and management (i.e., smarthealth intervention).

Design: This qualitative study used a framework of acceptability for healthcare interventions.

Methods: From January 2021 to December 2023 in the U.S.A., we interviewed 10 family caregivers who had completed the 4-month smarthealth intervention. The caregivers shared their user experiences and feedback on the system's feasibility and acceptability. Data were analysed using abductive thematic analysis, incorporating the framework of acceptability for healthcare interventions and the collected data.

Results: Seven themes and 19 categories emerged: attitudes, burden, ethicality, intervention adherence, intervention coherence, perceived effectiveness and suggestions. Feedback on the smarthealth intervention was mixed. Some found it beneficial, citing accuracy, ease of use and increased awareness. However, others felt burdened during its use, primarily due to time constraints.

Conclusion: The smarthealth intervention can potentially improve caregivers' awareness of themselves and caregiving situations.

Implications for the Profession and/or Patient Care: Future directions should involve adapting the smarthealth intervention to consider diverse caregiving scenarios and incorporating a larger sample of caregivers.

Impact: This is the first study to offer a voice detection system and real-time stress management recommendations to caregivers of people living with dementia. An individualised approach should be considered to improve the system's effectiveness. This includes providing personalised intervention components, considering caregivers' time and establishing a user-friendly system with high accessibility. The findings can be a cornerstone for smarthealth interventions influencing dementia caregivers' self-care and emotional regulation.

Reporting Method: Standards for Reporting Qualitative Research.

Patient or Public Contribution: Members of the public and service users from a memory clinic and social media platforms contributed to the study by reviewing recruitment materials.

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Trial Registration: This trial's study protocol was registered with ClinicalTrials.gov (ID No. NCT04536701) on 3 September 2020 (https://classic.clinicaltrials.gov/ct2/show/NCT04536701)

1 | Introduction

The number of family caregivers for older adults in the United States reached 38 million in 2021 (Reinhard et al. 2023), including 11 million caregivers of people living with Alzheimer's disease and related dementias (ADRD) (Alzheimer's Association 2024). Family caregivers are individuals who provide unpaid care for their family members, relatives, friends or neighbours of people living with health issues (Reinhard et al. 2023). Caregivers provided a wide range of help, such as assistance in activities of daily living, conducting medical tasks for their care recipients, coordinating care and providing emotional support (Alzheimer's Association 2024; Reinhard et al. 2023). These caregiving tasks are more intensive for caregivers of people living with ADRD than those of people without dementia due to the nature of disease progression, causing a higher level of burden (Alzheimer's Association 2024). In turn, caregiver burden contributes to psychological morbidity, social isolation and poor physical and mental health for caregivers, leading to early care transition for care recipients from their homes to long-term facilities (Alzheimer's Association 2024; Rose et al. 2021).

To address caregiver burden, various interventions for caregivers of people living with ADRD have been implemented (Cheng et al. 2020; Walter and Pinquart 2020). These interventions have included cognitive behavioural therapy, psychoeducation, counselling, respite care, mindfulness-based interventions and social support (Cheng et al. 2020; Walter and Pinquart 2020). Such interventions have generally helped to reduce burden, stress and anxiety, ranging from small to moderate effects. Given advancements in technology, research focusing on technology-based interventions and technology-based caregiving support has emerged (Lindeman et al. 2020). The positive effects of technology-based interventions on the emotional health of caregivers suggested that such interventions could be an alternative to in-person programmes, offering a time-saving option for in-home caregivers (Zhai et al. 2023).

2 | Background

The integration of advanced technology into interventions for caregivers of people living with ADRD has been a growing trend in recent years (Cheng et al. 2020; Zhai et al. 2023). These interventions often involve wearable sensors, voice recognition systems, virtual reality, robots and systems implemented by artificial intelligence (AI) and machine learning (Lindeman et al. 2020). Notably, these innovative interventions have facilitated the development of user-centred designs, allowing interventions to be tailored to individual needs (Zhai et al. 2023). In addition, they have the potential to monitor and regulate individuals' emotions in real time within natural settings with high accessibility (Bettis et al. 2022; Mitsea et al. 2023). For example, acoustic monitoring combined with ecological momentary assessment (EMA) can detect stressful moments, provide in-the-moment strategies and help users regulate their emotions (Bettis et al. 2022). Yet, interventions for caregivers of people living with ADRD have predominantly been limited to web-based systems (Fernandez-Bueno et al. 2024; Zhai et al. 2023). Reviews focused on interventions using innovative technologies for family caregivers indicate that studies targeting caregivers of people living with ADRD have employed web-based approaches only, such as online video conferencing, telephone-based support, websites and mobile apps (Fernandez-Bueno et al. 2024; Zhai et al. 2023). Moreover, AI-based interventions have largely targeted dementia care management, highlighting the need for innovative interventions specifically to support the caregivers themselves (Xie et al. 2020). Therefore, it is pivotal to develop advanced technology-driven interventions tailored to caregivers, particularly considering their stress.

To address the research gap in innovative interventions for caregivers of people living with dementia, we developed and tested a smart health technology for audio-based stress detection and real-time stress management using reinforcement machine learning. This system incorporates stress management strategies based on mindfulness activities, providing opportunities to improve self-regulation skills regarding mental health and attitudes towards dyadic conflicts (Mitsea et al. 2023; Singh et al. 2023).

3 | The Study

3.1 | Aim and Objectives

We aimed to explore the feasibility and acceptability of intervention for stress detection and management amongst caregivers of people living with ADRD through acoustic monitoring (i.e., smarthealth intervention). Our primary objective was to identify user experiences and perceived effects of the intervention. The second objective was to gather the participants' suggestions to improve the quality of the intervention.

4 | Methods

4.1 | Design

This paper presented descriptive qualitative findings from a study using a multiple-methods design. The study was based on technology, real-time-based intervention using an acoustic monitoring system and an EMA-based mobile app (EMA app) (Rose et al. 2021). To gather qualitative data, we conducted semi-structured, one-on-one interviews with each participating caregiver at the end of the intervention.

4.2 | Theoretical Framework

We employed the theoretical framework developed by Sekhon et al. (2017) to facilitate the evidence-based assessment of the acceptability of a healthcare intervention (Sekhon et al. 2017). It offers a comprehensive approach to developing and evaluating healthcare interventions (Sekhon et al. 2017). This framework includes seven components: (1) affective attitude (an individual's thoughts or feelings about the intervention), (2) burden (the effort required for intervention adherence), (3) ethicality (an evaluation of the intervention's compatibility with an individual's values and circumstances), (4) intervention coherence (the extent of an individual's understanding of the intervention), (5) opportunity costs (the perceived benefits or values lost by participating in the intervention), (6) perceived effectiveness (the belief that the intervention fulfils its intended objectives) and (7) self-efficacy (an individual's confidence in their ability to adhere to the intervention as instructed) (Sekhon et al. 2017) (see Figure 1).

4.3 | Study Setting and Recruitment

4.3.1 | Smarthealth Intervention

The smarthealth intervention was conducted from January 2021 to December 2023 and was registered with ClinicalTrials.gov (ClinicalTrials.gov ID: NCT04536701). The 4-month trial was designed to identify moments of stress in caregiving dyads using acoustic monitoring and provide real-time stress management recommendations (Rose et al. 2021). The initial month served as a baseline period for emotion recognition by monitoring acoustic data through pre-trained deep-learning models, which helped detect stressful situations encountered by caregivers via changes in voice tone, tenor or speed (Gao et al. 2021; Rose et al. 2021). Participating caregivers received study equipment where the study team members have installed the voice activity detection system as well as EMA (e.g., a laptop, a smartphone and a Wi-Fi router), set up the study equipment based on the reading manuals and ad-hoc instructions of the study team members and recorded their voices into the system to monitor their stressful situations.

During the next 3 months (i.e., the implementation period), the system sent check-in messages along with a stress management tip (e.g., body scan, deep breathing, time-out and enjoyable activities) through the EMA app on the study smartphone when it detected caregivers' stressful situations or when interactions between each caregiving dyad were likely to occur (Gao et al. 2021). Caregivers were expected to engage in the recommended activity within 30–60 min of receiving the message and answer follow-up questions about whether they had implemented the activity and found it helpful or why they did not follow the tip (Gao et al. 2021; Rose et al. 2021). Based on their responses, the system determined caregivers' preferred stress management tips and delivered one tailored to their preferences using deep-learning techniques (Gao et al. 2021). At the end of the study, caregivers answered the same questionnaires that they completed at baseline. They also participated in individual, semi-structured interviews to share their experiences using the system and provide feedback or suggestions regarding the programme's feasibility and acceptability. Figure 2 and Table 1, respectively, illustrate an overview of the smarthealth intervention and the study procedure.

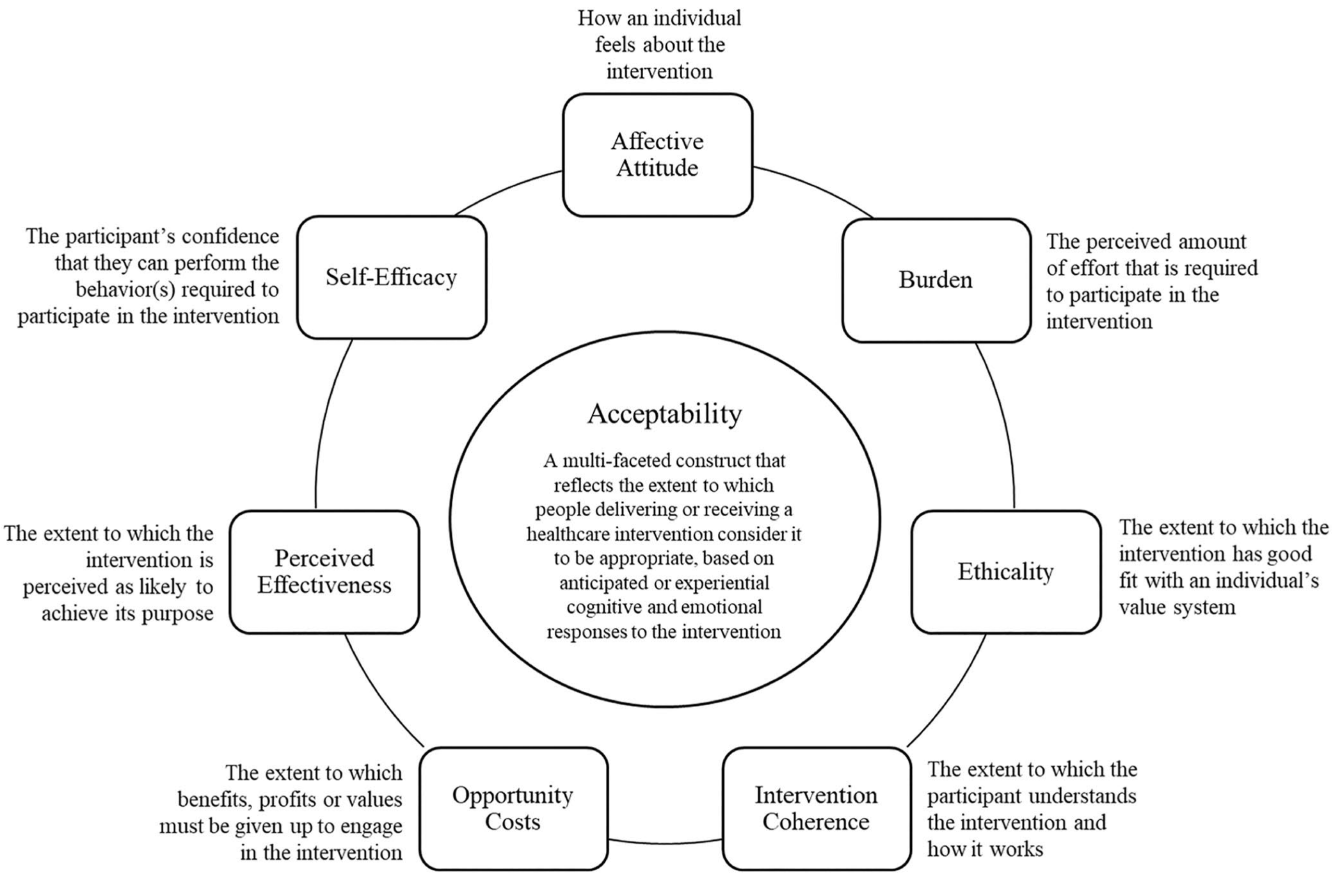

FIGURE 1 | Theoretical framework of acceptability. *Source:* This theoretical framework of acceptability was adapted from Sekhon et al. (2017).

4.3.2 | Recruitment

Participants were recruited using purposive sampling. A recruiter at a memory clinic in a Midwestern academic institution introduced caregivers of people living with ADRD. The staff then provided the research personnel (E.K., K.M.R.) with contact information for caregivers interested in the intervention, and the research personnel reached out to potential participants. The recruitment method was also conducted through social media and clinical trial platforms to recruit caregivers across the United States. We requested the social media recruitment service for the medical centre at the Midwestern academic institution. We uploaded the advertising posts to linked caregiver support groups on social media platforms, such as Facebook. Caregivers who accessed the study information online and were interested in the study contacted the principal investigator (K.M.R.) via phone or email.

4.4 | Inclusion and/or Exclusion Criteria

Eligible caregivers were adult primary caregivers of older adults living with ADRD and those who: (1) reside with their care recipients, (2) have access to home Wi-Fi for study participation and (3) score above three on the Revised Memory and Behaviour Checklist, indicating caregiver stress (Teri et al. 1992). Eligible caregiving dyads who agreed to participate proceeded with the verbal consent process during the screening call and signed the electronic consent form sent via a link.

We screened 201 caregivers, and amongst the potential caregivers, 22 caregiving dyads (22 caregivers and 22 care recipients) provided signed consent forms (Ko et al. 2025). The exclusion was mainly due to non-responsiveness, privacy concerns, a lack of interest, research-related burden and not meeting the criteria. Half of the 22 dyads ended up not participating in the study, and one caregiver dropped out (see Figure 3).

4.5 | Data Collection

One-on-one interviews with each participant via Zoom, which lasted an average of 71 min (46–110 min), were employed. The caregivers who participated shared their experiences with the system and suggested improvements. The interview questions focused on (1) system feasibility and acceptability, as well as (2) system effects on emotional regulation and relationship improvement between caregivers and their care recipients. Table 2 illustrates key interview questions.

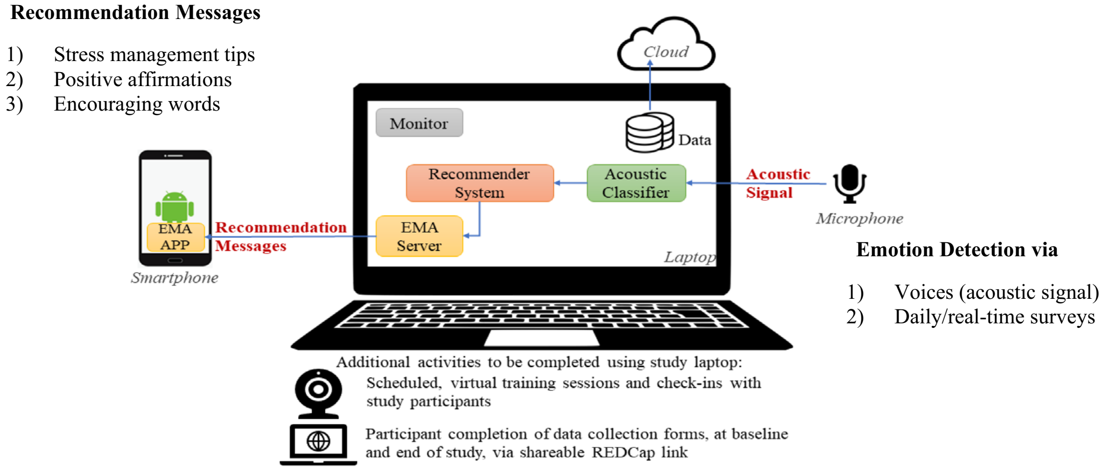

FIGURE 2 | An overview of smarthealth intervention. EMA = ecological momentary assessment; REDCap = research electronic data capture. *Source:* The overview of the smarthealth intervention was retrieved from Rose et al. (2021).

TABLE 1 | Study procedure.

Before study	Baseline period (1 month)	Implementation period (3 month)	Final
• Screening/consenting • Equipment setup • Baseline surveys	• Monitor acoustic signals of caregiving dyads through conversations • Collect caregivers' daily mood states via self-reported surveys	• Monitor acoustic signals of caregiving dyads through conversations • Collect caregivers' daily mood states via self-reported surveys • Daily messages for stress reduction ◦ Stress management tips ◦ Positive affirmations and encouraging words ◦ Daily self-care goal	• Final surveys • Interview

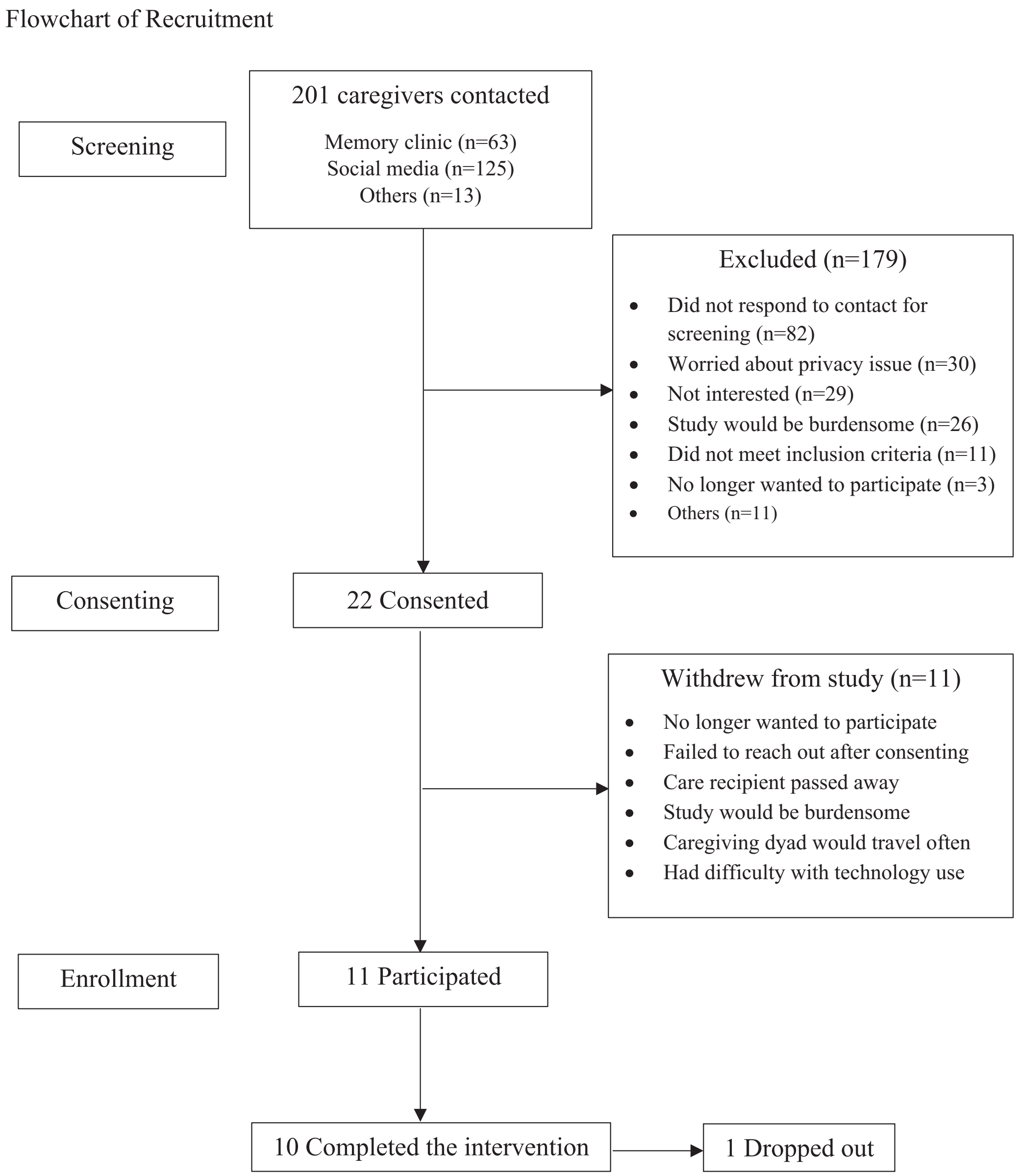

FIGURE 3 | Flowchart of recruitment. This image was adapted from our previous publication, Ko et al. (2025). Several of the 179 respondents were excluded due to multiple reasons for non-participation.

4.6 | Data Analysis

Participants' demographic data were analysed using descriptive statistics, including frequency, percentage, mean and standard deviation. The interviews with the caregivers were recorded via Zoom and transcribed verbatim. Two authors read the transcripts multiple times and analysed the interview transcripts separately to improve trustworthiness. The two authors compared and refined the initial codes generated independently during regular discussions. Any code disagreement was resolved through regular meetings involving the other authors. Subsequently, the refined codes were categorised and thematically organised through the similarities in the characteristics of the codes and the theoretical framework of acceptability. We used Microsoft Word, Excel and NVivo, released in March 2020 (QSR International Pty Ltd. 2020), to analyse and describe participants' data.

Abductive thematic analysis was employed as the data analysis method. Thematic analysis helps interpret respondents' meaning by creating codes and themes (Braun and Clarke 2006), whilst abductive data analysis engages researchers equally in collected data and current theories or knowledge regarding the topic (Braun and Clarke 2006; Thompson 2022). Researchers can use this method to align the collected data with existing theories and bridge the gap between theory and reality when the existing literature or theory differs from the data explanation (Thompson 2022). The abductive thematic analysis begins by using prior theoretical knowledge and observing the participants' data. It then proceeds through matching the data with prior knowledge and proposing a theory to find the most suitable explanation for a phenomenon (Thompson 2022). We initially coded participants' interviews and categorised and thematised them based on Sekhon et al.'s framework (Sekhon et al. 2017). Additionally, we used the theme of 'intervention adherence',

TABLE 2 | Key questions for interview.

Items	Questions
Feasibility of the system	• Tell me about your experience using the Smarthealth system • What could make this system improved? • Have you had any concerns whilst using the Smarthealth programme? • How would this programme positively or negatively affect other caregivers like you?
Helpfulness of the stress management tips	• Tell me about the provided stress management activities • Overall, how have your emotions changed before and after the intervention? • How has the intervention helped you improve conflict situations with [care recipient]? • How has this programme improved the way you care for [care recipient]?

defined as the extent to which participants adhere to the intervention as intended (Lipschitz et al. 2022), without addressing opportunity costs and self-efficacy in the acceptability framework based on the collected interview data.

4.7 | Ethical Considerations

The Institutional Review Board at The Ohio State University (#2019B0406) approved this study. Before collecting data, all participants provided written informed consent.

4.8 | Rigour and Reflexivity

To enhance the rigour of this qualitative study, we applied four criteria of trustworthiness: (1) credibility (i.e., similarities between the empirical data and researchers' representation of the data; internal validity), (2) transferability (generalizability and external validity), (3) dependability (i.e., reliability and the consistency of research findings) and (4) confirmability (i.e., the neutrality of research findings) (Lincoln and Guba 1985; Nowell et al. 2017). Two authors (E.K., K.D.W.) were involved in the data analysis and shared the data interpretations amongst all authors to raise credibility (Nowell et al. 2017). We also used direct quotations when describing the themes and categories, allowing readers to deeply understand the participants' experiences (Thompson 2022) and wrote memos to reflect on our experiences and roles during the data collection and analysis (Nowell et al. 2017). We followed the Standards for Reporting Qualitative Research guidelines to report study findings and improve study transparency (O'Brien et al. 2014).

TABLE 3 | Baseline characteristics of participants.

	Caregivers ($n = 10$)	Care recipients ($n = 10$)
Age (mean [SD])	62.4 (11.75)	77. 3 (8.23)
Gender (female, *n* [%])	7 (70%)	3 (30%)
Race (non-Hispanic White, *n* [%])	8 (80%)	9 (90%)
Education level (above high school, *n* [%])	10 (100%)	7 (70%)
Employment status (employed, *n* [%])	3 (30%)	0 (0%)
Marital status (married, *n* [%])	7 (70%)	8 (80%)
Caregiving hours/day (mean [SD])	20.9 (6.64)	
Caregiver duration (months, mean [SD])	35.1 (21.34)	
Household member (mean [SD])	2.3 (0.67)	

Note: n = number; SD = standard deviation.

5 | Results

5.1 | Characteristics of Participants

5.1.1 | Demographics

Table 3 illustrates the demographic data of the participants. This study included 10 caregiving dyads (10 caregivers and 10 care recipients), and all the caregivers completed interviews. The average age of caregivers was 62.4 years, whilst that of care recipients was 77.3 years. Caregivers were mainly females (70%), as opposed to the percentage of female care recipients (30%). The caregiving dyads were predominantly White (80% of caregivers and 90% of care recipients). All caregivers had tertiary education levels above high school; care recipients also reported a high education level above high school, accounting for 70%. Three caregivers were working and providing caregiving. Seven of them were married and cared for their spouses. On average, caregiving hours per day and duration per month were around 21 h and 35 months.

5.2 | Qualitative Results

Seven themes and 19 categories emerged regarding the acceptability and effects of the smarthealth system (see Figure 4).

5.2.1 | Attitude

The theme '*Attitude*' in this study referred to the extent to which an individual feels about participating in an intervention and assesses the intervention based on their user experience. This theme encompassed affective and cognitive

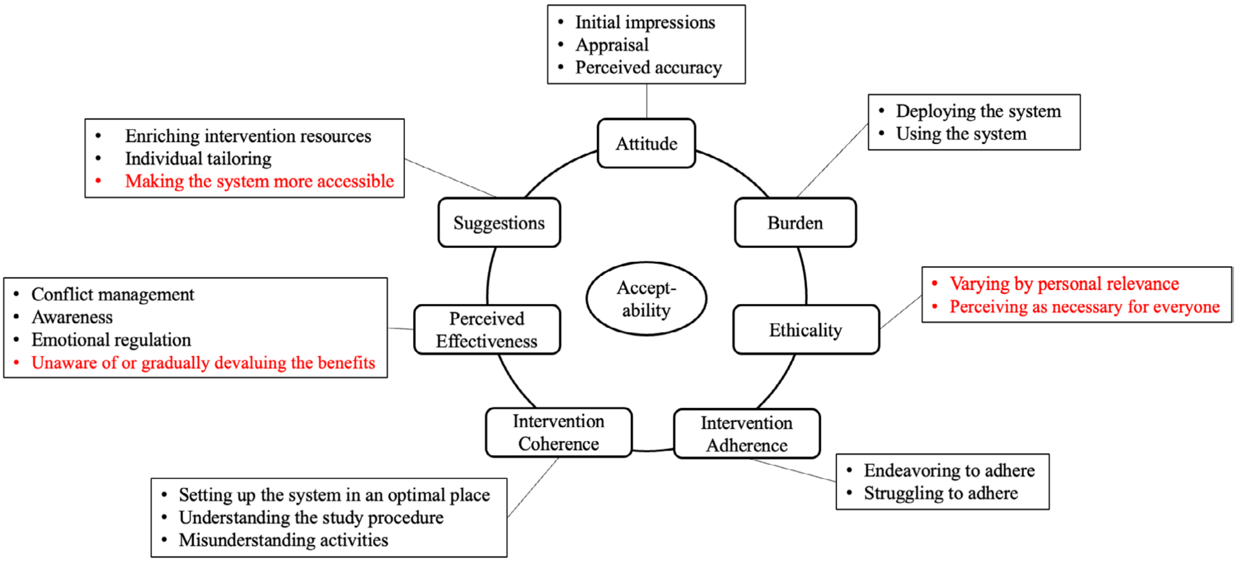

FIGURE 4 | Themes and categories related to the acceptability of a smarthealth intervention. The themes are listed in the circle, and categories are listed in the outer rectangles that correspond to the theme. *Source:* This map was based on the framework presented in Sekhon et al. (2017).

attitudes and included three categories: (1) *initial impressions*, (2) *appraisal* and (3) *perceived accuracy*. Sekhon et al. (2017) placed affective attitude as one of the components in the framework of acceptability and defined it as 'how an individual feels about taking part in an intervention'. This component can include individuals' impressions, fondness or comfort towards the intervention. In contrast, cognitive attitude reflects individuals' assessments and perceptions of products based on their user experiences (Zahid et al. 2024). These two aspects contribute to the overall meaning of attitude. Therefore, we replaced affective attitude in the original framework with 'Attitude' to encompass participants' cognitive and emotional considerations.

Participants in this study initially had various impressions regarding the intervention, such as concerns or expectations, which could change over time. For example, some were worried about setting up the system on their own or had privacy concerns. However, these concerns diminished over time as the participants became used to the system and paid less attention to them.

> Initially, it felt weird to know that there was a recording going on the whole time and privacy issues. [...] but then, after a while, after about two or three weeks, you just forget about it.
>
> [P02, male, spousal caregiver, retired]

Some other caregivers expected that the intervention would improve their reactions to their care recipients and improve their emotional health. The perceived satisfaction with using the system varied amongst participants.

When it came to *appraisal*, participants determined the values of system functions and intervention components, sharing both positive and negative feedback. Participants found the system procedure thoughtful, not invasive and remotely available. They also enjoyed the intervention over time and hoped the study would continue. Some caregivers valued following the intervention components, even for a short period. They found these tips beneficial and appreciated the self-care goal messages and encouraging words, contributing to the overall positive experience of using the system.

> I think it's a really good program that you're having. It's very, it's understandable, and it doesn't have a whole lot of things, but it's still personal things that you have.
>
> [P09, female, spousal caregiver, retired]

However, negative feedback on the intervention was also raised for several reasons, such as receiving texts in non-stressful moments and facing challenges in performing activities in real-time when they received messages. Additionally, some caregivers reported comments specific to the intervention components, including that the body scan activities did not work for them, encouraging words seemed superficial and the time-out activities sounded too childish.

Interaction with research staff was also one of the important aspects that contributed to the appreciation of the intervention. Some caregivers were satisfied with the staff notifying them of the issues promptly. In contrast, others pointed out the need for more frequent communication with the users to enhance the overall support system (Ko et al. 2025). Sharing visualised data with users also served as a key to encouraging participants to engage with the system. Some participants found that the visualised data indicated the system captured their emotions accurately. In contrast, others noticed discrepancies between the data and their perceptions. Sharing these data during the interviews positively influenced their emotional awareness.

The other category of *attitude* was the *perceived accuracy* of the system. Participants assessed the system's accuracy with mixed feedback. Some reported that the system was quite accurate, rating it 65%–90%. Considering that the system sent alerts in stressful situations, there were some moments when the system detected non-stressful situations as stressful.

> There were times when there was stress, and it picked it up appropriately. But then, again, there were times where I wasn't there and say, that I'm stressed, you know.
>
> [P10, male, adult child caregiver, employed]

By contrast, other participants felt that the system was less accurate, even rating it at 20% accuracy. They reported that the system failed to detect stressful moments, as the participants received messages indicating stress despite not experiencing it. Apart from mistaking non-stressful situations for stressful ones, other reasons were addressed regarding a lack of accuracy, such as capturing non-caregiving stressful situations, not being angry but frustrated and not verbalising stress when stressed.

> Sometimes it gets aggravating when you have to say things three or four times, so it's not really anger, it's just frustration, you have to explain complicated concepts.
>
> [P02, male, spousal caregiver, retired]

In sum, participants had mixed *attitudes* towards using the system, which might affect their involvement. Furthermore, another theme named '*burden*' could potentially influence the study participants' behaviours during the assessment of the system's acceptability.

5.2.2 | Burden

According to Sekhon et al. (2017), *burden* refers to the perceived amount of effort required to participate in the intervention. The burden regarding the smarthealth intervention is associated with situations when participation requires too much time, expense or cognitive effort, indicating that the burden is too great. Participants in this study discussed the burden of *deploying the system* and *using the system*.

Participants experienced both challenges and positive experiences whilst *deploying the system*. For example, a caregiver who had positive experiences using the intervention felt uncomfortable and frustrated whilst setting up the system, particularly amongst caregivers who were not tech-savvy. However, caregivers generally found the system easy to set up. Specifically, the manual for system set-up was well described, and the colour-coded labelling reduced their burden during the system set-up process.

> I'm not the most tech-savvy. But the instructions about everything how to set it all up, you know, it was easy to follow. It didn't require a rocket scientist type, degree, or anything.
>
> [P07, female, spousal caregiver, retired]

However, the participants experienced various challenges in *using the system*. One challenge was the timing of the messages sent. Caregivers frequently received alarms when they were busy or received excessive messages in non-stressful situations, potentially leading to frustration with the system. A caregiver who was stressed whilst providing care felt annoyed by the need to answer questions, which added to their stress and considered the system an extra, time-consuming task rather than a helpful tool.

> The alerts that I would get would always happen at the worst possible time when I was right in the middle of something.
>
> [P04, male, adult child caregiver, not currently employed]

We also identified several technical issues, including system and software interface glitches. In addition, some participants suggested that the system should be more flexible and less intrusive, considering the user's schedule and movement at home and outside.

> I'm not a regimented person, I don't take a shower every morning, at 7:45. [...] I have the flexibility of 'Eh, if I want to take a last-minute shower before I go, why?' If I take a shower, and nobody cares.
>
> [P03, female, spousal caregiver, employed]

5.2.3 | Ethicality

In the framework of acceptability, *ethicality* was explained as the extent to which the intervention has a good fit with an individual's value system (Sekhon et al. 2017). This definition can be rephrased as the perceived fairness of the intervention for users with specific conditions (Sekhon et al. 2022). Participants in the study shared their thoughts about whether the intervention would suit their situation, and two categories emerged: *varying by personal relevance* and *perceiving as necessary for everyone*.

They revealed that the system seemed particularly effective for non-working individuals, such as those who are retired or work from home whilst providing care or for people with high stress levels and conflicts with their care recipients.

> I think for somebody who is not working, and who is just at home and focuses on the person that they are caregiving for, it[smarthealth system] probably works really well.
>
> [P03, female, spousal caregiver, employed]

> It could potentially be very positive if you get people that are, um, more trouble handling the stress of caregiving or maybe if you come back to me in 2 years.
>
> [P02, male, spousal caregiver, retired]

Another concern raised by a participant who had previously worked in the technology field was that non-tech-savvy users might struggle to use the system effectively due to limited familiarity with technology, indicating a need for additional support or training for these individuals. However, caregivers who reported themselves as 'non-tech-savvy' believed the system would benefit caregivers regardless of their familiarity with technology. One participant stated that the intervention should be provided to those who are just starting their caregiving journey and are in greater need of support from both the community and themselves.

> I think it would be really helpful for caregivers. I really don't think there's enough things for the people in the community.
>
> [P05, female, spousal caregiver, retired]

5.2.4 | Intervention Coherence

Intervention coherence was associated with how appropriately participants understood the intervention, including its purpose, procedure and expected effects, which is related to 'the face validity of the intervention' (Sekhon et al. 2017). *Intervention coherence* in this study included the categories of (1) *setting up the system in an optimal place*, (2) *understanding the study procedure* and (3) *misunderstanding activities*.

System deployment in an appropriate place at home is crucial. Participants' locations for system deployment varied, including the family room, kitchen or corridors between the two areas at home. However, all the caregivers understood and agreed to locate the system far from televisions (TV) or radios to avoid interference and in places with many interactions to help the system catch their interactions with their care recipients.

> We placed it, like, in the area between our living room and our kitchen. I think that was good because it was far enough away from the TV. I think it was a good place, like the area of the house where we spent the most time.
>
> [P03, female, spousal caregiver, employed]

Participants stated that they understood the complexity of the smarthealth intervention, the study's purpose and its value. This comprehensive understanding helped participants align with the study's goals and constantly engage with the intervention.

> I know that there was a recorded period in the beginning, where they did a baseline. And they tried to capture, you know, his..., how things sounded normally and then they would, you know, look for a deviation from that.
>
> [P05]

However, although participants understood the study procedure, they also misunderstood certain stress management tips. The misunderstanding was particularly apparent about the concept of 'enjoyable activities' and 'time-out'. Some caregivers initially didn't consider the importance of engaging in enjoyable activities with their care recipients. Similarly, a few believed they needed to change locations, but their understanding improved after further explanation.

> I was a first-grade teacher. So, for me, it[time-out] meant go in the corner and be a bad girl. I didn't associate it right.
>
> [P06, female, spousal caregiver, retired]

5.2.5 | Intervention Adherence

To explore intervention acceptability and feasibility, addressing both intervention adherence and coherence is important. *Intervention adherence* can refer to how participants follow the intervention as intended (Lipschitz et al. 2022). Two categories were generated: *endeavouring to adhere* and *struggling to adhere*. During the intervention, some participants tried to answer phone surveys as much as possible and follow activities, even though the timing was not the same as when they received the messages. They planned to keep using stress management tips even after completing the study.

> I could do it on my own when I had the time. When I found a couple of minutes space, I would just do the deep breathing exercise.
>
> [P10, male, adult child caregiver, employed]

In contrast, some participants were challenged to be involved in the study as intended. The barriers were multifaceted. One common barrier was a lack of time to participate actively in the study. Participants struggled with the following activities due to the uncertainty of caregiving situations and high care responsibilities. Whilst some tried their best to participate in the study, others wanted to take a rest instead of following the stress management recommendations. Such a reason might reduce caregivers' intention to engage in the study and perform stress management activities. Another reason was forgetting about the system, especially on weekends, or forgetting to receive messages altogether. Participants also found it difficult to respond to messages and participate in activities because they had placed their study smartphones away from their physical locations. They missed some messages when they were in another room or left the study phone somewhere in their home, but not close to them. In addition, they needed to leave home during the day due to other prioritised activities, such as a care recipient's hospitalisation, work obligations or running errands, which resulted in missing or skipping answering the messages.

> I would just forget, I would hear the alarm and I'll take, I'll go over there, in a second, and then I forget about.
>
> [P04, male, adult child caregiver, not currently employed]

Some participants encountered technical issues with the system due to system malfunctions or other unforeseen circumstances. For example, some did not receive regular messages or were not able to see messages appropriately, whilst others experienced power outages that disrupted receiving and answering messages and following activities on time.

> I don't know… I mean, even lately, I haven't even heard the first one command in the morning.
>
> [P01, female, spousal caregiver, retired]

> We had a power, storm that went through, and so there were some windows of time where we weren't connected.
>
> [P05, female, spousal caregiver, retired]

Overall, participants tried to engage in the intervention as intended, but several barriers to adherence existed.

5.2.6 | Perceived Effectiveness

Understanding the study procedure and following the interventions appropriately is essential to assessing the effectiveness of an intervention. Sekhon et al. (2017) refer to *perceived effectiveness* as 'the extent to which the intervention has achieved its intended purpose'. Participants in this study recognised the positive influence of the smarthealth intervention. The benefits included (1) *conflict management*, (2) *awareness* of caregiving situations, emotions and self-care needs and (3) *emotional regulation*.

Participants reported they improved how they cared for their care recipients (i.e., *conflict management*). Participating in the intervention made them more conscious of their reactions to care recipients. They also attempted to understand their care recipients' behaviours, which included calming them down, filtering words and focusing more on their hidden meanings than their apparent behaviours. Additionally, caregivers sought positive interactions to understand their care recipients better.

Regarding *awareness*, participants revealed that the intervention raised their awareness of caregiving situations. They became aware of their own lives and caregiver roles and tried to think about their caregiving journey, despite still feeling it was hard to be aware.

> It made me become more aware of how to continue to be that supportive person without me feeling guilty or without me feeling like 'I'm not doing as much as I should or could'.
>
> [P07, female, spousal caregiver, retired]

Participants were also more conscious of focusing on themselves and finding more time for themselves. For example, one participant neglected self-care activities whilst performing caregiving duties, but he noticed the importance of self-care by following the activities.

> It's very easy just to ignore yourself and not think about that. [I'm] maybe more aware of 'Oh, I need to… not necessary blow off steam', through breathing or something whatever it is, because we accumulate stress and it does have a negative effect.
>
> [P02, male, spousal caregiver, retired]

Moreover, participants became conscious of their emotions, the connection between voice and emotions, the stress-inducing factors, their reactions to stress and stress management. For instance, they stated that the alarms served as a reminder of the need to alleviate stress.

> [I'm] more aware of my limitations as a human being, and that I need to work on certain things. […] When I was stressed regardless of why and the phone would alert me. It was kind of like a take a step back, like, 'Okay, maybe you're getting a little, little over-threshold', kind of a thing.
>
> [P08, female, adult child caregiver, employed]

Participants learned how to regulate their emotions (i.e., *emotional regulation*). Adhering to the intervention helped them become more patient, mindful and controlled emotionally.

> I feel a little more emotionally healthy. […] I think I'm more patient in my dealings with him. I think it's like more mindful of. It just, you know, and by doing that more and more, that has become a go-to behavior for me, you know, instead of getting angry or commenting about something. I just let it go.
>
> [P05, female, spousal caregiver, retired]

Although some participants reported the effects of the intervention during the interviews, others were *unaware of or gradually devalued the benefits*. A caregiver who addressed positive aspects of the intervention regarding emotional awareness did not consider that the smarthealth intervention helped improve self-care behaviours. Another caregiver stated that the intervention seemed useful, but did not prefer the real-time-based approach as it would add additional tasks and stress whilst providing care.

> That is useful, but it's not really useful to get a prompt. […] So, like, 'Okay well now is not a good time'.
>
> [P04, male, adult child caregiver, not currently employed]

Interestingly, a participant noted that the perceived value of the intervention components appeared to diminish over time due to increased familiarity with the system. However, she still recognised the system's helpfulness.

> It does not necessarily mean that was really, truly less helpful. That, it may be more of getting used to it. You're taking your morphine and it's really working at first, so you're like, 'Yeah!' And then it was timing more and more below… So uphold on that it's getting used to it in fact.
>
> [P03, female, spousal caregiver, employed]

5.2.7 | Suggestions

In addition to feedback and comments on the smarthealth intervention, participants also provided *suggestions* that would improve the quality of the intervention in the future. This theme includes three categories: (1) *enriching intervention resources*, (2) *individual tailoring* and (3) *making the system more accessible*.

First, caregivers suggested that the current tips in the intervention should be modified by providing a more detailed explanation of stress management tips, such as enjoyable activities and time-out practice. Participants also suggested adding extra advice, such as engaging in physical activities, listening to music, creating a customised list of enjoyable activities and incorporating elements related to caregiving skills.

> There's some [care recipient's] behaviors that I find difficult to deal with. At times, it would be nice to have specific fixes for those things.
>
> [P05, female, spousal caregiver, retired]

Another suggestion was an individual tailoring approach to improve the acceptability and feasibility of the smarthealth intervention. Caregivers proposed that users should be more involved by initiating messages themselves and following activities on their own time, receiving a call from a human or AI instead of messages and noticing the time they receive messages. Monitoring the visualised data during the intervention, such as using a time graph that shows stress levels instead of receiving real-time messages, could be beneficial.

> What would be nice is if I could either, just on my own time, track, like, how many times a day, 'Did you do a breathing exercise', like 'I'm going to do, breathing exercise now, because mom's in bed or she's napping'.
>
> [P04, male, adult child caregiver, not currently employed]

> You have no idea of knowing, you know, whether it's a stressful day or calm day or, you're just sending messages to me.
>
> [P05, female, spousal caregiver, retired]

Additional needs regarding an individual-tailored approach included considering each caregiver's technology literacy and caregivers' situations (e.g., stress from non-caregiving situations and their care recipient's health decline), customising prompts and selecting tips according to individual preferences.

> Everybody's experiences are different. It's not like a one-size-fits-all kind of thing.
>
> [P07, female, spousal caregiver, retired]

The other key suggestion was to make the system more accessible. Caregivers suggested providing additional devices or accessories to facilitate easier device setup or phone portability. One caregiver also suggested carrying the phone outside to avoid more stressful situations. Additionally, caregivers recommended integrating the system into their personal devices.

> I would think that the end product, like the app of the future, it wouldn't have the computer listening in on your voice whether it is stressed or not.
>
> [P03, female, spousal caregiver, employed]

Along with the updates on hardware, caregivers proposed that there should be an effort to edit the stress detection algorithm to enhance the accuracy and reliability of the voice detection system. Renovating the application design, such as adding additional features to the EMA app or allowing multiple caregivers to be involved in the system, is another key consideration to make the system more accessible and user-friendly.

> It would have been cool if when I missed tasks or didn't do the suggestions, if like, there were more options to explain why. Or if there was like, you know, like a free form.
>
> [P08, female, adult child caregiver, employed]

6 | Discussion

We described the user experiences and perceived benefits of smarthealth intervention, a 4-month intervention using acoustic monitoring and interactive recommendations for stress reduction amongst caregivers of people living with ADRD. We classified the findings into seven sections: (1) *attitude*, (2) *burden*, (3) *ethicality*, (4) *intervention adherence*, (5) *intervention coherence*, (6) *perceived effectiveness* and (7) *suggestions*. Participants expressed initial thoughts about the system and evaluated its function and accuracy for stress detection (*attitude*). Some participants encountered difficulties deploying and using the intervention (*burden*) and considered whether it aligned with their values (*ethicality*). Participants also discussed how they adhered to the intervention and what hindered their involvement (*intervention adherence*). They understood the intervention's purpose and procedures accordingly, although some misunderstood stress management tips (*intervention coherence*). The *perceived effectiveness* of the system varied amongst participants, but there were improvements in conflict management, awareness of caregiving situations, emotions, self-care needs and emotional regulation. *Suggestions* for improvement were considering each user's unique characteristics, such as enriching intervention resources, tailoring the system to individual needs and ensuring system accessibility.

Some participants who entered the study with initial concerns reported a decrease as they became more familiar with the system, and none of the participants raised any issues about privacy invasion during the study. The transition from initial discomfort to a neutral or positive outlook highlights the importance of giving users time to adjust and determine the system's genuine effect. This adaptation process may be necessary to improve the effect of interventions that rely on ongoing monitoring or other intrusive technologies. Despite these adjustments based on actual participants' feedback, we faced recruitment challenges and could only enrol 10 individuals, due in part to concerns about privacy, lack of interest and the perceived burden of participation. These barriers may stem from low digital literacy and limited trust in technology (Hassan 2020), making individuals hesitant to engage in technology-based interventions. Moreover, prior research on dementia caregivers' technology use indicates that their primary purposes for technology use are to coordinate care, access hands-on support and find information about medications or care strategies (Block et al. 2020). These uses are predominantly focused on supporting care recipients rather than addressing caregivers' health needs, possibly contributing to caregivers' limited interest in our intervention.

To reduce caregivers' perceived burden and concerns about the smarthealth intervention, we employed several strategies, such as providing detailed instructions with pictures and colour-coded labels on the study equipment and ensuring that they did not need technological literacy, as the participants used the system in a passive monitoring manner. The comprehensive instruction of the system and minimal involvement in controlling the system may reduce caregivers' concerns about advanced technology use (Gao et al. 2021). However, unfamiliar technical terms or the need to instal additional devices may still concern less tech-savvy participants. Engaging caregivers of people living with ADRD across varying levels of technological familiarity and encouraging them to focus on their health is essential. To support this, interventions could be conducted with accessible devices (e.g., smart watches, personal smartphones or rings) and non-technical language for older caregivers. Moreover, incorporating peer support and offering personalised feedback on changes in caregivers' stress may motivate them to prioritise their own health. Sharing existing users' feedback and providing multicomponent interventions that address the needs of both caregivers and care recipients may also improve participant engagement.

Whilst some participants reported high accuracy in stress detection through acoustic monitoring, the limitations in the smarthealth intervention's accuracy were also noted. The feedback might highlight challenges in interpreting acoustic signals for stress, likely due to individual differences in stress perception and expression. For instance, some participants raised their voices to vent stress, whereas others did not. Caregivers of people living with ADRD are also likely to hide their emotions; this may be related to the increases in caregiving burden and depression (Khalaila and Cohen 2016). Additionally, background noise and environmental factors may also disrupt the acoustic monitoring, complicating the analysis of vocal stress indicators. This issue may be further related to the participant's perception that the system may not be suitable for their caregiving situation and stress. Future studies on developing more refined algorithms considering individual emotional expression mechanisms in diverse caregiving contexts may be warranted. Additionally, we should not ignore the situation in which unrecognised stress affects the subtle body response, as voice is one of the factors indicating stress (Pisanski et al. 2018), suggesting the possibility that participants might not recognise their stress or negative emotions when the system detected subtle changes in their voice. To help users more reliably recognise stressful moments, additional biological measurements, such as heart rate variability or skin conductance response, could be used along with the voice recognition system.

In addition, there were burdens and challenges regarding the real-time-based approach. A real-time approach has the potential to regulate emotions (Bettis et al. 2022). However, caregivers of people living with ADRD tend to provide a wide range of caregiving responsibilities to their care recipients (Alzheimer's Association 2024), which may hinder caregivers from engaging in real-time-based interventions. It can also cause the variability of participants' feedback on the smarthealth intervention. To effectively implement a real-time intervention for caregivers of people living with ADRD, it may be necessary to integrate real-time monitoring whilst assisting caregivers' responsibilities through comprehensive support. For example, it would be beneficial if the voice activity detection algorithm could identify caregiving tasks, such as assisting with activities of daily living, to avoid sending alerts during these times. Additionally, the stress notification method could be customised based on each participant's preference (e.g., sound, vibration, light, display of number). This approach can help users reduce the intervention-related burden and improve adherence to the smarthealth intervention. Moreover, although most participants acknowledged the intervention's purpose and procedures, some misunderstood certain intervention components, such as time-out and enjoyable activities. This suggests a need to enhance understanding through frequent communication and follow-ups, helping caregivers perceive more benefits from the smarthealth intervention.

Regarding the ethical aspects, participants noted that the intervention may be particularly suitable for caregivers who are unemployed or experiencing high levels of stress. This is likely because the intervention involved installing devices in participants' homes and using EMA apps and smartphones to monitor emotions and provide stress management tips. The intervention was developed during the COVID-19 pandemic, when many caregivers were confined to their homes and facing increased stress and burden (Rose et al. 2021). This background may have made the intervention more relevant to in-home primary caregivers and those with higher stress levels. To serve a broader range of caregivers, future adaptations may need to include more flexible delivery options, such as asynchronous settings that can be accessed at the caregiver's convenience or tailored modules based on individual stress levels. Nevertheless, participants appreciated the intervention's role in raising emotional awareness and acting as a reminder of their stress. Their feedback suggests that the intervention helped them acknowledge the challenges of caregiving and offered emotional support, indicating its potential as an ethical and widely applicable support tool.

Participants' perceived effectiveness of the smarthealth intervention needs to be highlighted. Previous literature on interventions targeting family caregivers of people living with ADRD has reported significant effects on reducing stress, depressive mood, anxiety or burden amongst caregivers (Murfield et al. 2021; Sun et al. 2022) These findings can align with the increase in emotional regulation addressed in this study. However, previous research has still underexplored the other effects reported in this paper, such as the intervention's effects on caregivers' awareness of caregiving situations, emotions and self-care needs and their ability to manage conflicts with care recipients. Sun et al. (2022) revealed that the effects of interventions might vary depending on the type of intervention, such as support groups improving quality of life and psychoeducation mitigating anxiety, depression and burden. Therefore, it is necessary to explore which types of interventions are most effective in specific aspects of caregivers' emotions or needs.

The smarthealth intervention, which delivers real-time messages when the device detects caregiver stress, is likely to stimulate individuals' auditory systems and motivate them to engage in a certain activity or recognise what actions are necessary (Cochrane 2023). This feature of the smarthealth intervention may encourage participants to conduct stress management strategies or identify their emotions, conflict situations and needs at the moment, potentially preventing the accumulation of stress. However, not all participants experienced these benefits. For instance, some found the digital alarms in real-time stressful and overwhelming. Therefore, future studies on real-time-based interventions should develop more personalised alert systems, ensuring that they raise participants' awareness of emotions and self-care needs without adding unnecessary stress.

Participants' suggestions that the intervention be more individually tailored are consistent with previous literature findings (Cheng et al. 2020; Zhai et al. 2023). The system is designed to provide participants with a preferred tip from the incorporated stress management strategies, based on their responses to questions following each recommended tip, using reinforcement learning (Gao et al. 2021). Despite these efforts, participants did not perceive this approach as a tailored solution. It might be due to insufficient intervention duration or the limited number of tip choices rather than open-ended options. Moreover, although participants understood the system and intervention appropriately, they might not always have been able to be actively involved in the intervention due to various factors, such as both caregiving and non-caregiving tasks disrupting their understanding of the intervention process. Hence, the system should consider offering explicit, customised stress management tips to each participant by allowing them to address their preferred stress management tips before starting the intervention or by using clearer language that highlights 'customised' features to improve their recognition of its tailored solution.

6.1 | Limitations and Strengths of Work

This study has several limitations. The smarthealth system used for this study is still in development, leading to technical problems (e.g., error messages on the EMA app). Environmental issues (e.g., a lack of battery power, power outages or an unstable Internet connection) also caused difficulties for the study team. Whilst such issues were resolved quickly, they may have bothered the caregivers. Additionally, due to equipment costs, we were limited to four deployments at a time, each lasting 4 months, with extra time needed to retrieve and reset equipment for other participants. System development and technical setup took several years, possibly shortening implementation time. These factors may have contributed to low participant recruitment and deployment rates.

Although this pilot study intended to generate insights and inform future research rather than produce robust evidence, the small sample size and limited race and gender distribution amongst participants limit the generalizability of results. Female caregivers are more likely to experience stress and burden than male caregivers and lean towards emotional coping strategies rather than using a problem-focused method (Swinkels et al. 2019). Race and ethnicity can also make differences in caregiver stress and the well-being of caregivers of people living with ADRD (Alzheimer's Association 2024).

However, the findings address the need for smarthealth interventions for dementia caregivers. This programme could help participating caregivers increase awareness of their stress and caregiving situations and regulate emotions and conflicts with care recipients. Applying this intervention to the caregiver population may encourage them to accept changes in their feelings. This acceptance can be one factor in developing a protective process for individuals when overcoming a challenging situation that may cause deficits in daily functioning (Poe et al. 2023).

6.2 | Recommendations for Further Research

To improve the accuracy of stress detection through acoustic monitoring, it may be necessary to improve the algorithms used for stress detection by embedding the individual threshold of stress and emotions and considering noisy environments using voice activity systems (Liu et al. 2024). This modification may customise the smarthealth intervention, ensuring its relevance to the participants' situations and values, thereby increasing its effectiveness and acceptance amongst the caregiving population. To enhance the system's accuracy, it is also necessary to incorporate additional data sources for stress, such as heart rate variability or cortisol levels (Pisanski et al. 2018). Moreover, future studies also need to consider situations where no verbal actions but non-verbal language do occur, as non-verbal communication is also associated with negative aspects of caregiving (Kim et al. 2024). Applying this solution to a small number of participants and generalising the system may be challenging. To generalise these findings, we should expand the use of the intervention to a larger sample.

As this study showed the potential of the smarthealth intervention to enhance self-perception of emotion and conflicts with care recipients amongst the participating caregivers, this benefit is worthy of further observation with a larger sample. The tips provided will offer caregivers coping strategies they can use in demanding circumstances. Therefore, we should continue to examine, develop and further generalise the smarthealth intervention to help caregivers of people living with ADRD recognise their emotions and mitigate potential health risks. Future studies should develop and monitor a revised version of a real-time-based smarthealth intervention and explore its feasibility with a larger sample.

6.3 | Implications for Policy and Practice

Self-awareness is a component of self-care interventions recommended by the World Health Organisation (WHO), and it can facilitate the demand for self-care behaviours (World Health Organization 2022). Given that the participants perceive benefits from the smarthealth intervention, such as improved awareness of self-care and emotional regulation, our findings align with the WHO's guidelines on self-care interventions for health and well-being. Therefore, our study can potentially enhance self-care behaviours and well-being amongst caregivers of people living with ADRD. This study also relies on acoustic monitoring to detect stressful situations and collect real-time data. Considering different caregiving situations and stress expression mechanisms may help health professionals provide ongoing, customised support and follow-ups, building rapport with dementia caregiving dyads.

7 | Conclusion

This study explored the feasibility and acceptability of smarthealth intervention from caregivers of people living with ADRD. Participating caregivers understood the intervention properly, although they had faced some challenges whilst participating. The interventions could also help caregivers increase their awareness of emotions and caregiving situations and regulate their emotions and conflicts with their care recipients. However, there should be a need for an individualised approach considering the various caregiving situations of different caregivers. Future efforts should be necessary with a focus on refining such innovative interventions for caregivers of people living with ADRD and their emotions, assessing their feasibility with a larger sample size.

Author Contributions

All authors have agreed on the final version and meet at least one of the following criteria (recommended by the ICMJE; https://urldefense.proofpoint.com/v2/url?u=http-3A__www.icmje.org_recommendations_&d=DwIFaQ&c=slrrB7dE8n7gBJbeO0g-IQ&r=jplYERK1ljEQpBq8Gq3J_g&m=-18s5AmLhdwKB3ePsHBoRCIQ_ms4b1RRJ5mlT8Y3bWCl7JFqlrWpTX_45P7huSTa&s=K_b7jglpVTTukDo4DMOwCApu7-kfBUCt7GkgRkjODwU&e=): (1) Substantial contributions to conception and design, acquisition of data or analysis and interpretation of data; (2) Drafting the article or revising it critically for important intellectual content.

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Disclosure

Permission to Reproduce Material From Other Sources: We do not reproduce any materials from other sources that require permission. All materials used in our work are original content.

Ethics Statement

The Institutional Review Board approved this study at the Ohio State University (#2019B0406).

Consent

Before data collection, we received signed informed consent from all participants. We informed participants of the study's objectives, methodology, data storage, potential benefits and risks associated with participation and the contact details of the primary investigator.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research, supporting data are not available.

Peer Review

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