Adoption of Wearable Devices by Persons with Dementia: Lessons from a Non-pharmacological Intervention Enabled by a Social Robot

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1 Introduction

Wearable devices, specifically smartwatches and activity trackers, are the most pervasive Internet of Things (IoT) devices today. The wearable technology market, including activity trackers, is projected to grow, worldwide, from over $30 billion in 2016 to over $150 billion in 2026 [13]. Wearable devices can sense, gather, and store physiological data, which can be used to monitor and infer behavior toward support care for specific health issues. The proliferation of fitness trackers and smartwatches, the most popular wearable devices, has raised the interest in their use in healthcare research [15]. This is particularly true for studies that require an assessment of parameters associated with physical activity and sleep [32].

The use of wearable technologies in the domain of health care has increased in recent years, with studies reporting the use of a wide range of wearable devices for different health domains such as health maintenance [9], disease prevention [33], and patient and disease management [27].
The adoption of wearable technology has increased in different populations [1], including older adults. However, this technology is not widely used by this population, and there is a need to raise awareness to the benefits associated with use of these devices [16]. Although wearable devices are perceived as useful by older adults [21], there are certain drawbacks with their use, such as discomfort, itching, sweating, and hampered monitoring to sensitivity, which could affect their acceptance [16]. In persons (older adults) with dementia (PwDs), these issues can be exacerbated and added to others resulting from the disease such as memory problems, a tendency to forget or lose things, resistance to change, or just refusal to wear them [8, 14, 20]. Hence, the adoption of wearable technology by PwDs is still a significant challenge and a primary requirement for initiatives which considering a 24/7 monitoring for long periods.

In this work, we report on the adoption process of wearable fitness trackers by ten PwDs who participated, during nine weeks, in a cognitive stimulation therapy (CST) enabled by a conversational social robot. The study aimed to get an in-depth understanding on the factors and strategies that influence the adoption of wearable technology. This is a preliminary stage to establish an Ambient Assisted Living (AAL) setting for dementia care where the analysis of data gathered by wearable devices can personalize the therapeutic sessions guided by the social robot and care plans for the needs and characteristics of each PwD. In the next section, we present a literature review about the use and adoption of wearable devices in older adults and PwDs. Section 3 describes the importance of wearable device adoption as part of the envision of an AAL setting where PwDs are monitored to tailor their care plans and a non-pharmacological intervention (NPI) guided by a robot social. In Sect. 4, we describe a study to monitor an NPI for dementia using wearable devices. Section 5 shows the results concerning the adoption process of wearable devices. In Section 6, we describe lessons learned and recommendations for future initiatives of the use in wearable devices in dementia populations. Section 7 discusses the results of the study. Finally, we present conclusions and future work in Sect. 8.

2 Use and Adoption of Wearable Devices in PwDs

The emergence of new research-grade wearable devices (ActivPAL, Actiwatch and GeneActiv) and new placement sites (wrist, ankle and waist) has led to even more diversification in the methods and metrics that characterize various aspects of human physical behaviors [2]. There are two ways that wearable devices are currently being used in lifestyle medicine. First, they are used to measure physical activity over a period of a week or more, thus providing objective data on an individual’s habitual level of physical activity. In this way, they yield objective data on physical activity, eliminating the need to rely on patient self-report. Second, wearable devices are being employed in the area of behavior change, where they are used to motivate individuals to comply with a daily activity goal. From a patient standpoint, this increases accountability. From a healthcare provider’s standpoint, this is useful because it
provides information on compliance with behavioral recommendations [2]. Despite the increasing use of consumer wearables in medical research, these devices have not yet entered the mainstream of medical practice, and they have not been adequately validated in frail older adults or clinical populations [2].

There is also a need to determine whether wearable activity trackers are valid when worn by older adults and clinical populations, in particular PwDs. Most of the validation studies conducted thus far have involved young or middle-aged adults, and the results may not be generalized to older adults and individuals with disabilities [2]. However, this promising outlook is dampened by the large discrepancy between adoption rates and sustained use [28]. Findings from the USA show that, despite the estimated adoption rates higher than 35% by 2020, attrition rates are as high as 30% within the first six months of receiving it [18]. Variations in designs might better align with the preferences of various groups of users. What is adequate for users may not cover the needs of others. For instance, activity trackers for patients with chronic illness should focus on a customized regimen and specific levels of physical activities. In contrast, activity trackers for healthy office workers with sedentary behavior may include different features, such as reminding the user to engage in physical activities [29].

Concerning the adoption of wearable activity trackers among older adults, in [17], the results revealed that older adults in different tracker use stages liked and wished for different tracker features. Long-term users developed a habit of using the devices, while various strategies had to be used with the other participants to maintain interest in them. Social support through collaboration was the main motivation for long-term users, while the competition was for short-term users. Users who abandoned their devices indicated that their use was driven by curiosity to quantify daily physical activity rather than a desire to increase it. Long-term users indicate a greater number of pros in device use, whereas the others focused only on the cons. In general, a positive attitude was found in older adults toward the adoption of new technologies [25], having a clear understanding of its value for their lives [26]. Wearable activity trackers were uniquely considered more personal than other types of technologies; thereby, the equipment characteristics including comfort, aesthetics, and price had a significant impact on the acceptance in the elderly. Finally, the authors in [26] acknowledge that privacy was less of concern for older adults, but it may have stemmed from a lack of understanding of the privacy risks and implications.

Very few studies have been conducted about the use or adoption of wearable activity trackers in people with dementia. Three studies in which wearable activity trackers are used with this specific population are summarized below. The first [24] was focused on measuring sedentary behavior and physical activity of 37 older adults with and without dementia, living in residential aged care, using an actigraph sensor. In a second study [10], the authors assess the sleep patterns across the 24 h day in 15 community-dwelling people with dementia using an Actiwatch-2, while in a third study [30], the risk of dementia was evaluated in a controlled study with 87 older adults from the measurement of physical activity levels using a Fitbit Zip during waking hours. Regarding adoption studies, in a previous work [22] the design and preliminary results of a cognitive stimulation therapy for people with dementia in
which participants were monitored using activity trackers were reported. Finally, in a study on wearable research in dementia [12], it was found that although it is an emerging area, there was good support from patients and the public for this type of research.

3 AAL Setting for Dementia Care

Tertiary prevention seeks to reduce the impact of established disease, in the case of dementia, by softening the negative impacts of the dementia-related symptoms and maximizing potential years of quality life [3, 23]. Thus, therapies and NPIs are commonly an essential component of tertiary prevention by care providers. However, PwDs experience the disease in different ways, based on their initial predisposing factors, lifelong events, and environmental conditions [4]. Hence, it is essential to support person-centered models to assess the individual needs and effectiveness of treatments in order to provide personalized NPIs as part of a tertiary prevention for the care of those who are living with dementia.

We envision an AAL setting to address individual needs and emotional reactions through a personalized intervention using a social robot, called Eva. The robot Eva has been used to conduct therapeutic sessions for PwD, who participate in recreational activities such as reminiscence, music therapy, cognitive games, and relaxation [6]. The approach is based on the use of wearable devices to monitor and assess participants’ behavior to modify the content of the therapeutic sessions and the interaction strategies of the robot (see Fig. 1). Besides, primary caregivers can use the gathered information to define or modify a personalized care plan for each person.

![Fig. 1](image-url) An ambient assisted living setting for dementia care where wearable devices are used to gather information from PwDs in different situations (interacting in a therapeutic session with the social robot Eva, performing their ADLs) in order to generate personalized interventions and healthcare plans for the specific needs of a PwD
However, as we established in Sect. 2, it is not clear if a PwD accepts and adopts wearable devices for 24/7 monitoring throughout long periods. Thus, the adoption of wearable devices by PwDs is a prerequisite toward establishing an AAL environment with personalized interventions using the robot Eva.

4 Monitoring a Non-pharmacological Intervention for Dementia Using Wearable Devices

We conducted a study to assess the effects on the behavior of PwDs, who participated in a cognitive stimulation therapy (CST) conducted by the robot Eva. Results have shown that the CST had a positive impact on the frequency and severity of dementia-related symptoms (detailed results can be consulted in [7]). During the study, participants used wearable devices in order to get 24/7 monitoring, which provided useful information to validate changes in participants’ behavior. Additional to these results, we analyzed the adoption of wearable devices by PwDs in this context. In this work, we focus on adoption findings during the CST as well as the challenges and opportunities to use wearable devices for PwDs.

4.1 Study Design

The study consisted of a CST that included 14 therapeutic sessions, two per week, where the robot Eva interacted with groups of three PwDs. A therapeutic session includes elements of music therapy, reminiscence, cognitive games, and relaxation, which combined lasted around 30 min. The study was conducted in the facilities of a nursing home where all participants live. Family members and caregivers who approved the participation of their relative were required to sign a consent letter. Ethics approval for this study was granted by the Bioethics Commitment of CICESE (CBE/PRES-O/001).

The type of wearable devices used in the study was commercial fitness trackers. We provided them for all participants to evaluate the adoption through prolonged periods. The use of the devices and issues emerging from it was monitored and documented in coordination with caregiver staff.

4.2 Materials and Methods

We used two models of fitness trackers by Fitbit: Charge 2 and Alta. The relevant data for the study were activity level, steps, and sleep monitor. Besides, we collected heart rate (HR) data from participants who used Charge 2 model. A preprocessing stage
was conducted in order to standardize the collected data. We used the Fitbit WebAPI to gather data for each participant, including steps per minute, heartbeats per minute, and sleep minutes (day and night). Then, there were moved periods where the device did not record data, such as battery life, and participants did not wear it. We only included in our analysis those days where there were records for at least 50% of the minutes of the day.

The first method to analyze the adoption was the quantity of collected data. Thus, the number of days that participants wore devices is a first overview of their adherence to the wearable. In addition, we interviewed caregivers after the intervention to obtain their perspective on the adoption process. Three caregivers provided information for each participant. The interview script included questions about adherence, common uses, useful and new features, and significant issues of use and strategies to deal with them.

We analyzed the interview transcripts and framed the issues regarding the device’s adoption by an extension of the Unified Theory of Acceptance and Use of Technology (UTAUT) for PwDs [8]. Moreover, we conducted an analysis to establish recommendations for adoption and redesign of wearable devices based on the Dementia Design Considerations for Smart Health Technologies [11] framework, developed to guide the design of smart technologies for dementia.

4.3 Strategies to Promote the Use of Wearable Devices

In coordination with the staff of caregivers, we defined a set of strategies to avoid and deal with possible common issues of the use of wearable devices in PwDs. The strategies focus on aspects such as acceptance and everyday use, loss prevention, and battery charge and data synchronization. Moreover, we defined a quick data validation to detect unusual data during the synchronization process.

1. **Acceptance and everyday use.** Present the devices to the participants as a classic hand watch with additional features to track some of their activities, such as number of steps walked.
2. **Loss prevention.** The caregivers’ supervisor defined a plan to monitor the use and localization of the devices. Each caregiver has to report on the location of the device at the end of their work shift.
3. **Battery charge and data synchronization.** We programmed visits by a member of the research team to the residence at least once a week to charge all activity tracker, synchronize the data from the internal memory to the cloud server, and review any contingencies caregivers might have regarding the devices.
4. **Quick data validation.** We analyzed data gathered at least once a week to detect unusual patterns of activity (e.g., null activity, an excessive number of steps, strange sleep activity). If unusual data are detected, we called caregivers (as soon as possible) to validate or discard this data from the dataset.
5 Results

Ten PwDs (6 females and 4 males), aged between 72 and 95 ($M = 82.4, SD = 8.4$) (see Table 1), participated in the study. Scores for Mini-Mental State Examination (MMSE) denote mild to moderate dementia ($M = 14.57, SD = 3.57$). Five of the participants wore a Fitbit Charge 2 h, while the other five used a Fitbit Alta. On average, they wore the devices for 54.4 days (see Fig. 2). After 22 days of use of the device, P3 left the residence and the study. After this, P10 was incorporated into the study to complete the therapy groups. We initially provided the wearable activity trackers to some of the participants to familiarize caregivers and participants with the device and the procedures implemented for their care, the handover with each change of shift, for charging the devices and synchronizing data. Due to technical difficulties, configuring two devices P8 and P9 received the device after the second therapy session.

Table 1 Information of PwDs who participated in the study

| Id  | Gender | Age | Days using the wearable device |
|-----|--------|-----|--------------------------------|
| P1  | M      | 74  | 71                             |
| P2  | F      | 76  | 39                             |
| P3  | F      | 86  | 22                             |
| P4  | F      | 95  | 70                             |
| P5  | F      | 71  | 66                             |
| P6  | M      | 90  | 63                             |
| P7  | M      | 88  | 71                             |
| P8  | F      | 86  | 62                             |
| P9  | F      | 86  | 66                             |
| P10 | M      | 72  | 14                             |
| AVG | 6F/4M  | 82.4 | 54.4                         |

Fig. 2 An ambient assisted living setting for dementia care where wearable devices are used to gather information from PwDs in different situations (interacting in a therapeutic session with the social robot Eva, performing their ADLs) in order to generate personalized interventions and healthcare plans for the specific needs of a PwD.
Six caregivers also participated in the study (4 females and 2 males), including a supervisor who set some of the guidelines for the handling of the wearable device. They have an average of 3.2 years of experience as a caregiver in the nursing home. Three caregivers provided information for each of the participants. Thus, 27 interviews, which inform by nine participants (P3 was not included), were analyzed the adoption of wearable devices.

While one of the main advantages of using wearables in health studies is their capacity to record data 24/7, adoption and adherence are issues frequently faced in the use of these devices. Older adults, in particular, might find it uncomfortable to wear the device at night, or they might forget to put it on [19].

We framed the issues regarding the adoption of the device using the Unified Theory of Acceptance and Use of Technology (UTAUT) model [31] extended with two additional constructs: resistance to change and technology anxiety, deemed appropriate for technology adoption by older adults [8].

As shown in Fig. 3, the extended UTAUT model includes 6 constructs (performance expectancy, effort expectancy, social influence, facilitating conditions, technology anxiety, and resistance to change) that influence behavioral intention and actual use behavior. We present our adoption results with respect to each of the six primary constructs with regard to both the people with dementia and the caregivers.

### 5.1 Performance Expectancy

This construct relates to the perceived usefulness of the technology. In this regard, we told PwDs that by wearing the devices they would provide useful data to our study. Some of them reacted quite positively to this, and so did all the caregivers.
As a personal benefit, we told PwDs they could use the device to know the time of the day (none of the participants wore a watch when the study started), and that they could also track the number of steps they walk. Two participants expressed interest in this feature, with one of them asking the researcher several times how many steps she ought to walk each day. Also, caregivers used the devices as a subject of conversation with the residents and to convince them to use the device. As stated by two of them:

C5: “At the beginning she liked it a lot [P2], and she used it. We asked her what time it was and she would answer.”

C3: “I even used the watch [as a strategy] when he [P1] became aggressive. I told him: “[P1] look you can see the time here, the steps and also this” and he [P1] got distracted. So I used the watch [wearable] to distract them and change their demeanor.”

### 5.2 Effort Expectancy

This relates to the perceived ease of use of the technology. For the PwDs, we aimed at the device being as comfortable and innocuous as possible. The format of a wrist-watch helps in this regard. Still, one participant refused to wear the device at night and would take it off and put it on her night stand. Also, two of the participants often refused to take off the device when it required charging and it took some convincing to make them give it up. In one instance, we had to wait until the battery ran off to convince P1 to give us the device to charge it. In another case, the caregiver gave P6 his own watch for several minutes while we charged the activity tracker. We left both of these participants the device for a few days after the study ended, until they agreed to give it up. In some of these instances, the device proved to be disruptive, as stated by one caregiver:

C3: “…it was difficult to convince him [P1] to take it off, and we had to put it [the device] in a place where they could see it. For example, when he took a shower, he had to see it.”

With respect to the caregivers, the use of the device put some additional work load on them. We supported them with a research assistant in charge of charging the device, and uploading the data, but still, they were responsible for making sure the device was used as much as possible and not be lost. In a couple of instances, a device went missing for several hours and once they realized this, it took a couple of caregivers several minutes to locate it.

### 5.3 Social Influence

This construct refers to how the social environment affects the behavior of the individual. At the start of the intervention, we told PwDs that other residents were also using the device, as an argument to convince them to wear it. One of the caregivers also reported that at least one of the PwDs encouraged others to use the device:
C3: “[P4] used to tell [P2] and [P3] the functions of the watch in her own way: “It has this function, and to see how we sleep” to try to convince them to use it [the device].”

With respect to the caregivers, they were instructed by the main caregiver to follow certain procedures regarding the use of the trackers. This is a form of social influence that had a positive effect on the caregivers to promote the adoption of the device.

5.4 Facilitating Conditions

This relates to the individual believing that there is an organizational and technical infrastructure to support the use of the system. Before the start of the study, we met with family members and caregivers to explain the objectives and procedures of the intervention, as well as their involvement. We also explained them the technical support we were going to be providing and means to contact the research team with any doubts or observations they might have.

Coordination between the caregivers, the main caregiver, and the research group proved effective. Visits to the facility by the researcher providing technical support were planned to be made three times a week, with additional visits made as requested.

5.5 Technology Anxiety

It relates to the fear of discomfort people experience when using technology, or thinking about using it. This construct negatively affects technology adoption and is commonly associated with aging.

Most participants did not experience anxiety with the activity trackers. Perhaps familiarity with similar devices (wristwatch) helped in this regard. However, P2 in particular expressed some reluctance to use the technology fearing that she could damage or lose the device. We tried different strategies such as telling her that the device was hers to keep and there was no problem if it got damaged. We also reminded her of the step counting feature, but she replied that she already knew how much she walked. Thus, we decided to withdraw the activity tracker but she continued to participate in the therapy sessions.

C3: “From the beginning, she [P2] was very suspicious. She asked a lot [about the device] and we told her that it was to measure her steps, see how her heart beats, and how she sleeps, and she kept wearing it, but the following morning she didn’t have it.”
5.6 Resistance to Change

This refers to actions taken by individuals when they perceive a change as a threat to them. It also has a negative effect on adoption, and it is argued to be more prevalent among the elderly.

As expected, participants would often forget why they were wearing the device or even that they had it on them. P5, for instance, wore the activity tracker most of the time, but she would occasionally take it off and leave it somewhere in the residence. In a couple of instances, caregivers and researchers had to look for her device in the residence for a few hours before they found it. She was not very conscious of the device. For instance, a couple of times when we asked her for the device to charge it, she would tell us that she did not have it. Then, we asked her to show us her wrist and she was surprised to see that she was actually wearing it. She used a Fitbit Alta with the original band which is relatively easy to remove. These issues, memory loss, associated with the disease, required caregivers to constantly remind some participants to wear the device and the reason for doing so. One of the caregivers told the strategy she used in these cases:

C3: “All of them when I took it [the device] off… what I did was to show them the functions it has, and with that, they kept using it.”

In summary, coordination with caregivers, technical support, and the form factor of the device were relevant enablers for adoption. But, due to memory impairment participants had to be constantly reminded to wear the device and they could change their opinion from one day to the other. Activities that made wearing the device more salient, such as the need to take it off to charge it or bathing, proved challenging with some participants.

6 Recommendations for the Adoption and Redesign of Wearables for Dementia

Findings from the study show that, in general, the activity trackers were successfully adopted by the PwDs and caregivers, and these devices provide useful data to assess behaviors of interest for tertiary dementia prevention, since they are associated with challenging symptoms of dementia. In the form of discussion, we provide recommendations for the adoption of this technology and propose how activity trackers could be redesigned to be more useful for dementia research and care. We frame our recommendations using the Dementia Design Considerations for Smart Health Technologies [11] framework, developed to guide the design of smart technologies for dementia. Our proposals are organized along four domains (Fig. 4): cognitive decline; physical decline; social; and development.
6.1 Strategies to Promote the Use of Wearable Devices

6.1.1 Intuitiveness and Familiarity

Our recommendation is to simplify the functionality of the device. The form factor of the activity tracker as wristwatch proved effective. Most participants expressed interest in using the activity tracker, as a watch. However, some of its features proved distracting to some of them. For instance, P10 mentioned that the wearable would suddenly turn on at night when he moved, while P1 would often tap repeatedly on the activity tracker to look at the different information displayed, such as the time and number of steps walked. It is desirable to customize for each user the information that can be displayed, such as deactivating notifications.

6.1.2 Effective Communication

Make sure caregivers understand and can explain to PwDs the purpose of using the device. Caregivers know the participants well and know how best to explain to them why they should use them and potential benefits to them. The explanation they provide could be different for different participants and even vary for the same person overtime. If caregivers have a clear understanding of the device and its importance to the study, they will be able to explain it adequately to them.
6.1.3 Onboarding Process

We introduced the device gradually to understand initial issues with adoption. This proved particularly effective with caregivers, as it gave them the opportunity to become familiar with the additional work and adopt strategies for tracking the device and promoting its use.

6.2 Physical Decline Domain

6.2.1 Sensory and motricity issues

While the display of the device is relatively small, none of the users had difficulties using the smartwatch. However, the additional information displayed when tapping on the screen was not always sufficiently responsive. In particular, one participant tapped on the screen repeatedly and his device had to be charged more frequently. We recommend limiting the amount of information provided by the device and the gestures required to show it.

6.2.2 Durability

The device seems sturdy enough for everyday use by PwD. None of the devices we used was damaged in anyway. Furthermore, their cost is relatively low so that it could be replaced when needed.

The one issue with which we had additional care was water exposure. In this regard, we recommend using devices that are waterproof. During bathing, for instance, caregivers would usually take the activity tracker off, to which some participants offered resistance, or they might forget to put the device on again. The newer generation of activity trackers are waterproof and can be used in the shower. The use of waterproof devices can ease some of the burden on caregivers and reduce periods when participants do not wear the device.

An additional area of opportunity relates to charging the batteries of the device. While we charged the devices on our weekly visits and did not burden caregivers with this task, it would have been useful to have them periodically charge the devices for short periods, during activities such as bathing.

6.2.3 Inconspicuous Design

The wrist band format proved adequate for our study. However, for some participants other form factor might have facilitated adoption, for instance, by discreetly placing in a belt or shoe.
6.3 Social Domain

6.3.1 Humanize

This issue relates to promoting the device as a tool for socialization and independence. Some caregivers used the device as a topic of conversation with PwDs, for instance, by asking them the time of the day. The device could potentially be used to manage repetitive questions, if a person often asks when are they eating, the caregiver could encourage them to look at the watch to explain them how much time is left before lunch. This strategy provides them with anchors to reality and can help reduce anxiety.

6.3.2 Engagement

One of the participants expressed interest from the beginning on the step counting feature, asking a caregiver how many steps she was supposed to walk. These interests could be used to promote appropriate behaviors, for instance, inviting users to walk to increase the number of steps or helping them realize that it is time for bed or to take a bath. It would be desirable for the device to be customized with messages appropriate for each individual.

6.4 Development Domain

6.4.1 Stakeholder Involvement

Involving caregivers early in the process proved critical in achieving high adherence and understanding participants’ behavior regarding the use of the activity trackers. This is an essential difference with respect to other studies with this type of device, which relies only on the participant. On the negative side, tracking the location of the device and promoting its usage impose additional burden on caregivers. Our recommendation is to add an additional personal or redistribute work load to account for these additional responsibilities. It would also be desirable to modify handover formats to track the location and usage of the device at the end of each shift.

Estimating participant dropout is recommended for studies involving older adults and particularly those with dementia [5]. When using activity trackers, these attrition rates should be increased to account for those not willing to use the device at some point in the study.
6.4.2 Tailoring

We used the wristbands that ship with the activity tracker in our study. However, some proved to be too big for their wrist. It would be convenient to have different sizes and materials and even encourage them to select one to their liking, even allowing them to change it during the study. Having bands of a different color and material would also be useful to distinguish the device of each participant. In one instance, a caregiver mistakenly switched the devices of two of the participants, until he realized this a couple of hours later.

6.4.3 Multilevel Interactions

Being able to personalize the functionality and information provided by the device would be useful. For some PwDs, it might be desirable to minimize functionality, perhaps just displaying the time of day. In contrast, other users might be interested in tracking the number of steps they walk or might benefit from receiving messages indicating it is time for them to go to bed. This tailoring could be similar to that provided in some activity trackers that are being commercialized for children, such as the Fitbit ACE, which requires parental consent and allows parents to customize the services the user can access.

Finally, some of these commercial activity trackers only provide summative data, reporting the number of minutes of different levels of activity per day. Having access to raw accelerometer and gyroscope data could allow using alternative activity and behavior recognition classifiers tailored to frail older adults to improve precision. In addition, researchers could be able to calculate heart rate variability that is associated with changes in mood and the manifestations of anger. There is also early work on detecting anxiety using heart rate variability and accelerometer data that could be particularly useful for the assessment of symptoms of dementia. In addition, including an audio sensor could allow to perform speaker diarization and thus assess behaviors associated with socialization.

Table 2 shows a list of dementia-related symptoms that are associated with behaviors that can be measured with activity trackers. This includes measures we obtained in our study, such as daytime sleep and activity changes, as well as others (indicates in italics), measures that can be obtained from new sensors (also in italics), or that could be derived from existing sensors if raw data were available.

7 Discussion

We conducted a study on the adoption of wearable devices by PwDs toward an AAL setting for dementia care. In this setting, individuals are monitored by wearable devices to personalize their care plan, including tailoring an intervention enabled by a social conversational robot. The results provide evidence of the feasibility of the
| Dementia-related symptom (NPI-NH) | Behavior | Measure                                                                 | Sensor                  |
|----------------------------------|----------|------------------------------------------------------------------------|-------------------------|
| • Isolation                      | • Daytime sleep | • Minutes of sleep during the day • Sleep periods during the day | • ACC<sup>a</sup> • PPG<sup>b</sup> |
| • Depression                     |          |                                                                        |                         |
| Apathy                           | • Activity level • Socialization | • Number of steps • Minutes of light/moderate/intense activity • Number of social interactions • Balance of social interactions | • ACC • Microphone |
| Aberrant movement                | • Aimless wandering • Restless movement | • Number of steps • Frequency of abrupt changes in movement • Respiratory rate | • ACC • PPG |
| Agitation/aggression             | • Mood changes • Screaming/verbal aggression | • HRR<sup>c</sup> • HRV<sup>d</sup> • Blood pressure • Number of screams | • PPG • Blood pressure • Microphone |
| Anxiety                          | • Restless movement | • Number of steps • Minutes of light/moderate/intense activity • HRV | • ACC • PPG |
| Nighttime behavior               | • Night wandering • Restless movement | • Sleep duration • Sleep interruptions • Steps between sleep periods • Nighttime sleep | • ACC • PPG |

In italics are sensors and measures not currently available in the devices used in the study but that could be incorporated or derived from current sensors

<sup>a</sup>Accelerometer sensor  
<sup>b</sup>Photoplethysmography sensor  
<sup>c</sup>Heart rate reactivity  
<sup>d</sup>Heart rate variability

sustained use of activity trackers during prolonged periods by PwDs. However, there are issues and lessons learned which we (and other research teams) should consider for successful adoption of this kind of wearables on the dementia population.

According to our literature review, there are only a few studies that report the use and adoption of wearable devices by PwDs. However, previous studies reported adoption findings that agree with ours. In [17], authors established that social support through collaboration was the primary motivation for long-term use of wearable devices.
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devices in older adults, while our results show that the caregivers played a crucial role in motivating and promoting the use of devices. Due to dementia-related symptoms such as memory impairment, and disorientation in space and time, it is necessary to enact strategies to motive the adoption through social interactions. Nevertheless, it should be considered that personality, beliefs, and the way in which each individual experiences the symptoms of dementia can create tension in the use of the device; therefore, other types of strategies should be explored.

The results show a proper adoption of wearable devices for long periods. Some of the participants even showed excessive attachment to the devices. However, due to symptoms such as delusions exhibited by the false belief that their things could be stolen, this became a problem for caregivers who had to deal with this situation when they had to remove them for personal hygiene activities or battery recharging. Therefore, future initiatives have to consider each individual’s symptoms to prevent these kinds of problems and enact appropriate strategies to deal with it.

The analysis of the data gathered from wearable devices can complement results for specialized instruments to assess behavior and quality of life in dementia. However, not all domains and symptoms can use such data for an in-depth analysis. Restrictions about the type of data and sensors of the device should define what can be measured. In Table 2, we proposed features (sensors and type of data) of wearable devices for a set of dementia-related symptoms, but future studies need to consider what they will measure and which device they will use to collect useful data.

8 Conclusions

We conducted a study to assess the behavior of ten PwDs who participated in a CST guided by a social robot. Participants were monitored 24/7 using a wearable fitness tracker to assess behavior changes reported by their caregivers via specialized instruments. Besides this objective, we conducted a parallel analysis for the adoption of wearables during the CST. Thus, this work focused on how PwDs use wearable devices and how their caregivers perceive the adoption process.

Our results on adoption provide evidence of the feasibility of using wearable devices in studies with PwDs, when the device needs to be used 24/7 for a prolonged period. Lessons learned and recommendations can be useful for researchers with similar studies, including high participation of caregivers to motivate the use of devices, considering that some PwDs can refuse their use or stop their use without any particular reason. We also proposed redesign considerations such as the addition of sensors and raw data collection to monitor and infer behaviors associated with dementia-related symptoms to provide personalized NPIs and care plans. As future work, we will focus on the proposed AAL setting for dementia care through the personalization of the social robot’s intervention based on data collected by the wearable devices.
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