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Health Empowerment for Older Adults through IoT: A case study of telecare for Chronic Heart Failure patients

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Abstract. The present work reports on the outcomes and valuable lessons from a six-month trial of a novel and non-intrusive healthcare system tested on a pilot with 150 older adults with chronic heart failure in the Region of Murcia, Spain. The system integrates an IoT setup in homes for environmental factors and daily routines, along with portable devices for real-time vital signs and health status tracking. It also includes a mobile app for older adults and their informal caregivers to manage and consult data monitored. Healthcare professionals configure alarms and monitor the collected data through a dedicated web application. The pilot aimed to evaluate the telecare solution's effectiveness in improving health outcomes, usability, self-care, empowerment, and reducing loneliness. The study highlighted the system's impact on both older adults and informal caregivers, revealing challenges in usability, disease monitoring, intervention effectiveness, and emergency detection. Key learnings underscore the critical role of integrating technology, with user engagement and human support, essential for the success of digital healthcare initiatives.

Keywords: Internet of Things, Telecare, Older Adults, Quality of Life, Health monitoring, Chronic Heart Failure.

Introduction

The progressive aging of the global population coupled with the increasing prevalence of chronic diseases presents formidable challenges to healthcare systems worldwide [1]. To address these challenges, continuous, effective, and non-intrusive smart care solutions are imperative, especially for managing chronic conditions such as heart failure. There are numerous proposals in the scientific literature and various projects exploring the use of new technologies to enhance the well-being of older adults [3] or focused on heart failure patients [4-6]. This paper delves into the implementation and

outcomes of a pilot project conducted under the European initiative Pharaon -Pilots for Healthy and Active Ageing- [2] in the Region of Murcia, Spain. The Murcia pilot aimed to introduce a new paradigm in telecare, moving beyond the traditional health and care service models that depend on patient-initiated requests for assistance. To achieve this, we developed an innovative telecare solution that incorporates Internet of Things (IoT) technologies to support individuals suffering from chronic heart failure (CHF). By leveraging sophisticated IoT devices for instantaneous health and daily routines monitoring and environmental sensing within patients' homes, the pilot resulted in the endeavored to elevate the quality of life for these individuals, augment the efficacy of care delivered by healthcare professionals, and fortify the capabilities of caregivers. Following the Monitoring and Assessment Framework for the European Innovation Partnership on Active and Healthy Ageing (MAFEIP) [7], the pilot is conducted over a twelve-month period, with this paper focusing on the outcomes and insights gleaned from the initial six-month trial.
The paper is organized as follows: Section 1 introduces the deployment and execution of the pilot, including detailed descriptions of the technologies used, participant engagement, and the evaluation framework established. Section 2 presents the preliminary results obtained after six months of piloting. Finally, Section 3 wraps up the discussion by examining the main findings, sharing success stories, and outlining avenues for future research.

1 Pilot deployment and execution

The Murcia pilot aimed to engage at least 150 participants suffering from CHF, integrating a comprehensive IoT ecosystem for non-intrusive monitoring of their daily activities and routines. This ecosystem included environmental sensors to monitor conditions within living spaces, sensors in furniture and electrical appliances to monitor daily routines at home and wearable devices to track vital health parameters such as heart rate, physical activity, blood pressure, and weight. The ecosystem featured a platform layer made of two distinct user interfaces or frontends, both utilizing the same backend, called Onesait HealthCare Data (OHC) (see Fig. 1). One interface is the Myhealth mobile app, designed to enable patients and caregivers to access real-time and historical health data, fill out health and psychological status questionnaires and access educational content aimed to foster self-care and disease management. Alternatively, health professionals accessed participant data via their professional desktop through the dedicated web application HomeCare (HC), which allowed them to monitor health statuses, configure personalized alarms, and manage intervention thresholds.

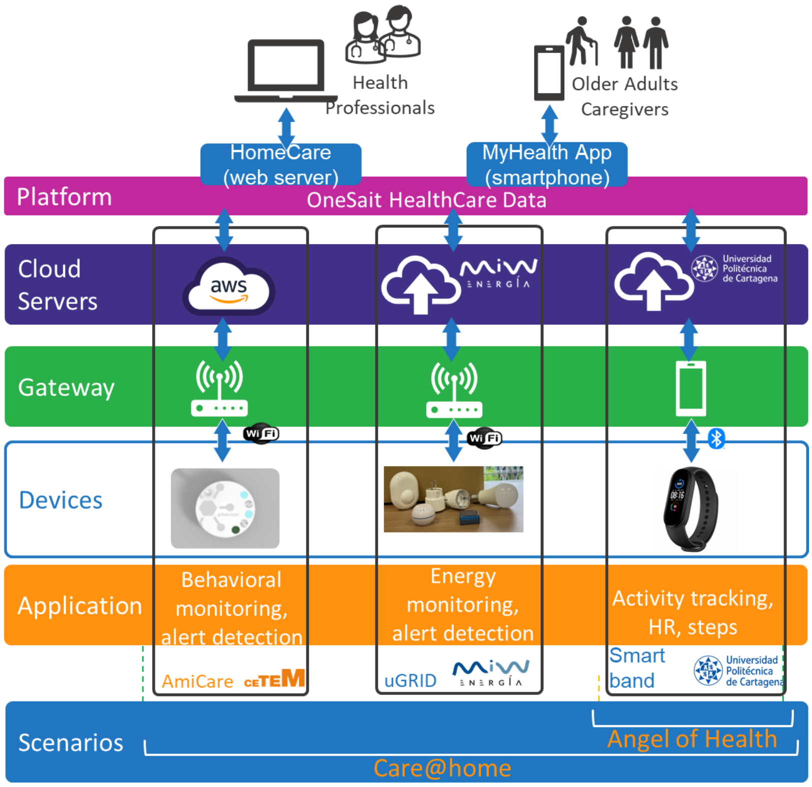

Fig. 1. Brief scheme of technologies deployed and scenarios covered in Murcia pilot

The timeline of Murcia pilot was organized in three phases (see Fig. 2): the co-design and co-creation phase, technology development and pre-validation phase and the pilot phase itself. The former two were discussed in depth in previous authors' contributions [8, 9].

Fig. 2 Timeline of Murcia pilot and target groups, from co-creation to piloting phase.

Technology deployed

The technologies deployed in Murcia pilot are integrated into a cohesive framework to enhance patient care, encourage healthy living, and swiftly detect emergencies, paving the way for a new era of digital healthcare provision. These technologies include (see Fig.3):

- uGRID system[1]: monitors participants' health through their daily routines and ambient comfort at home. uGRID tracks the electricity consumption of various devices and rooms in the participants' home and measures the ambient conditions temperature, pressure and humidity of the most used living rooms. The continuous tracking enables the detection of anomalies and emerging situations, e.g. an alarm triggers if one participant does not switch on the light of the bathroom during 24h. Informal caregivers can also receive alarms of this system in their mobile app.
- Amicare system: provides real-time daily routines by monitoring the use of smart furniture (sofa, chair, bedroom) and electrical appliances, like the fridge [10]. The smart capability is provided by specific sensors of presence, occupation, door-status, etc. Amicare also monitors the environmental conditions of the participants' home. The system can detect anomalies or potentially problematic situations, e.g. an alarm triggers in the professional desktop if the fridge is not open during 24h or if the participant is on bed after 12 o'clock in the morning. Informal caregivers can also receive alarms of this system in their mobile app.
- Smartband system: consists of a smart wrist configured to track real time daily activity of participants, tracking number of steps and heart rate, facilitating immediate responses to health abnormalities. E.g. if the heart rate is lower or higher than a threshold set by the health professional an alarm triggers in the professional desktop [11].
- A commercial smart tensiometer and scale[2] compliant with HL7[3] are also integrated in the IoT system because they offer accurate and regular monitoring of essential health parameters critical for the prevention and management of CHF. Alarms are configured to detect anomalies in the reported values. E.g., if the weight of an older adult increases by more than 2 kg in one day, an alarm triggers due to the risk of fluid retention associated with heart failure.
- Lastly, the OHC[4] serves as a centralized digital platform, aggregating data from the sources uGRID, Amicare, Smartband and smart scale and tensiometer. This enables patients and caregivers to actively engage in health management and intervention strategies through the Myhealth app, guided by health professionals via HomeCare.

[1] https://ugrid.miwenergia.com/
[2] https://www.aandd.jp/
[3] https://www.hl7.org/
[4] https://www.minsait.com/es/tag/361/Onesait-Healthcare

Fig. 3 Technologies deployed and participant's role associated.

Participants

Participants in the pilot were classified according to their role and the technologies they used (see Fig.3). Older adults with CHF were divided into two groups: 150 actively participating in the pilot (OA) and 150 as a control group (CG) that did not use the technology and did not receive interventions. Each CG participant was matched with an OA participant, sharing similar profiles and levels of illness, with the aim of validating the technology's effectiveness based on the set key performance indicators (KPI). OAs were further categorized based on the technology set used during the pilot:

- 75 Silver participants: equipped with smartband, smart scale and tensiometer.
- 50 Gold participants: same as Silver but also including Amicare.
- 25 Premium participants: same as Gold but adding uGRID.

140 informal caregivers (IC), including relatives and non-professional caregivers, supported OA, though some OA participated without an IC. Additionally, 50 formal caregivers, consisting of health professionals (HP), participated in the pilot and used the HealthCare platform. There were no corresponding control groups for IC and HP. OA, CG and HP were denoted as experimental group (EG). During the pilot, the number of HP was reduced because a team of five full-time nurses was assigned to a Call Center to support and meet the needs, attending participants, managing alarms and anomalies, etc.

Tracking engagement

Throughout the six months of piloting, engagement and adherence of the OAs were assessed weekly. Participants were categorized into four groups based on their adherence levels:

- Ideal Performers: Regular users who recorded at least two blood pressure measurements and three weight measurements per week.
- Standard Performers: Regular users who recorded at least one blood pressure and one weight measurement per week.
- Resistant group: Participants who did not record measurements for more than three consecutive weeks.
- Dependent group: Participants requiring special support from health professionals for regular technology use and self-care routines.

Based on weekly adherence outcomes, a group of HP was dedicated to supporting OA in the pilot by scheduling workshops, activities, and calls to enhance user engagement. Fig. 4 shows the four groups at the end of the six-months period. After the six-month period, 40 OA, 38 CG, and 7 IC left the pilot due to different reasons: death, health decline, personal reasons, etc.

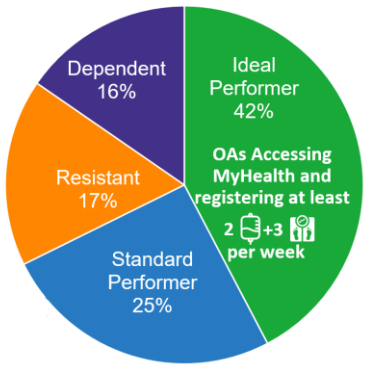

Fig. 4 Percentage of OA's adherence after six-months of pilot.

Evaluation framework

An evaluation timeline was established to assess the technology's effectiveness among intervention group participants. This was achieved using a set of standardized questionnaires to monitor various KPIs, focusing on health-related quality of life (HRQoL), usability, self-care, empowerment, and feelings of loneliness, to be administered in months 1 (M1), 6 (M6), and 12 (M12).

Table 1. KPI set, standardized questionnaires used, target groups and timeline.

KPI	**Standardized questionnaire**	**Month to monitor**	**To whom**
HRQoL	European Quality – five dimensions, 3 levels (EQ-5D-3L)	M1, M6, M12	OA, CG
Feeling of loneliness	UCLA Loneliness Scale	M1, M6, M12	OA, CG, IC
Quality of care	CareQoL	M1, M6, M12	IC
Users-acceptance, Usability	System Usability Scale (SUS)	M1, M6, M12	OA, IC, HP

The EQ-5D-3L questionnaire [12] is a widely utilized instrument for measuring general health status. It comprises five dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. Each dimension has three levels, indicating no problems, some problems, or extreme problems. The responses across these five dimensions are converted into a single summary index by applying a formula that attaches values to each level in each dimension. This index is used as a measure of HRQoL. Additionally, the EQ-5D-3L questionnaire includes a visual analogue scale (VAS), where respondents can record their overall health status on a scale from 0 (worst imaginable health state) to 100 (best imaginable health state), providing a quantitative measure of an individual's perceived health status. The analysis of this indicator is not included in this work.

The UCLA Loneliness Scale [13] is a psychological measuring instrument that gauges the subjective feelings of loneliness or social isolation. This scale ranges from 20 to 80, with higher scores indicating greater levels of loneliness. The scale is designed to understand the nuances of social connectivity and isolation among older adults and caregivers participating in the project. It serves as a critical tool in assessing the effectiveness of the interventions aimed at reducing feelings of loneliness and fostering a sense of belonging and community among participants.

The CarerQoL questionnaire [14] measures the quality of life of caregivers. It focuses on the well-being of individuals who provide care to patients with various health conditions, considering both the positive and negative aspects of caregiving. This measure includes an assessment of fulfillment from caregiving, support from others, financial well-being related to care tasks, and the balance between caregiving and other life domains. As part of the evaluation framework within the Pharaon project, CarerQoL helps to understand the impact of the interventions on caregivers, providing valuable insights into the caregiving experience and the effectiveness of support systems implemented for caregivers.

The System Usability Scale (SUS) [15] is an effective tool for measuring the usability and acceptability of various technologies. It provides a quick yet comprehensive assessment, offering a reliable gauge of user satisfaction with a system's ease of use. It consists of a 10-item questionnaire with five response options ranging from Strongly Agree to Strongly Disagree. The scores from this questionnaire are converted into a composite score ranging from 0 to 100, where higher scores represent better usability. In the context of Pharaon, SUS helps to understand how user-friendly the technologies are perceived by older adults, informal caregivers, and health professionals, ensuring that the solutions are not only innovative but also practical and approachable for daily use.

2 Pilot results - analysis

In the analysis of the results, the Interquartile Range (IQR) was used to provide a measure of statistical dispersion. The IQR is the difference between the third quartile (Q3) and the first quartile (Q1) and is used to describe the variability within a dataset. It is particularly useful for identifying and understanding data dispersion around the median, as it is less sensitive to extreme values compared to the standard deviation. In our figures, the IQR is represented by the boxes in the box-and-whisker plots (see Fig. 5, 6, 7, and 8), with the horizontal lines within the boxes indicating the median.

Preliminary results demonstrated notable improvements in the intervention group across the KPIs analyzed. Fig. 5 presents the distribution of HRQL scores for OA from both CG and EG at baseline (M1) and intermediate (M6). Table 2 summarizes the statistical results.

Initially, OA from the EG reported a median of 0.72, which showed a marginal uptick to 0.71 by the M6 mark, aligning with an overall increase in the mean score. Conversely, the CG's median remained steady at 0.69-0.68, despite a decline in their mean score from 0.62 to 0.59. The 'whiskers' illustrate the score variability, remaining stable for the CG but narrowing for the EG, suggesting a homogenization of health perceptions in this group. The emerging pattern indicates a stabilization or slight improvement in the EG's self-reported health status, which could be attributed to the pilot intervention, in contrast to the unchanged profile in the CG.

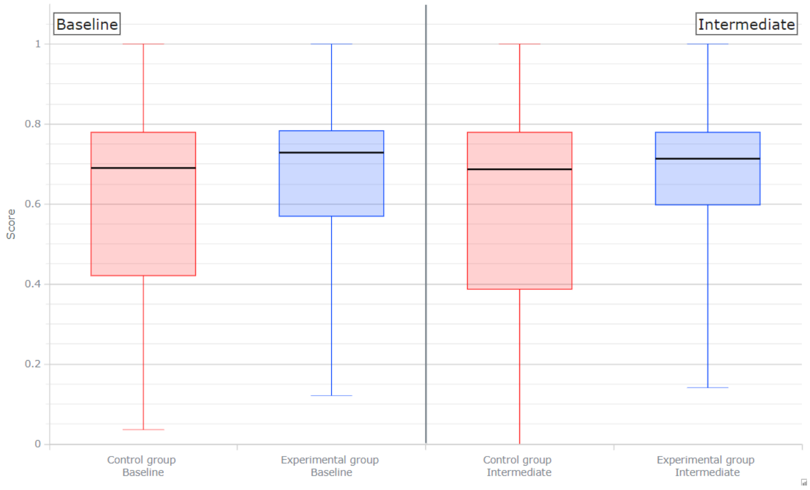

Fig. 5 Comparison of EQ-5D-3L results: EG vs CG in baseline and intermediate period. Box graphic with median.

Table 2. EQ-5D-3L results in terms of average, median, Q1, Q3 for EG vs CG in baseline and intermediate period.

	$\bar{x}$	$\tilde{x}$	Q1	Q3	n
CG (M1)	0.62	0.69	0.42	0.77	140
EG (M1)	0.69	0.72	0.56	0.78	145
CG (M6)	0.59	0.68	0.38	0.77	102
EG (M6)	0.72	0.71	0.59	0.77	101

Fig. 6 and Table 3 shows the results of UCLA Loneliness Scale for OAs from both the CG and EG in baseline (M1) and intermediate (M6). Initially, the EG group had a mean loneliness score of 28.78, with a median of 26, as shown by the central line in the box, and a spread of scores indicated by the box and whiskers, which had a substantial variance of 81.39. At the intermediate stage, their mean score dropped to 24.84 with a lower median of 23, and the significantly reduced variance of 30.73 reflects a narrowing of score dispersion. This decrease in scores and variance suggests that the EG felt less lonely over time. In contrast, the CG began with a slightly higher mean of 30.21 and median of 28, which slightly increased to a mean of 30.76 at the intermediate stage, with the median remaining stable. The consistency in their variance, showing little change from 76.51 to 75.43, indicates that the CG's feelings of loneliness remained stable throughout the period. The results underscore the potential positive impact of the intervention on reducing loneliness among the EG group.

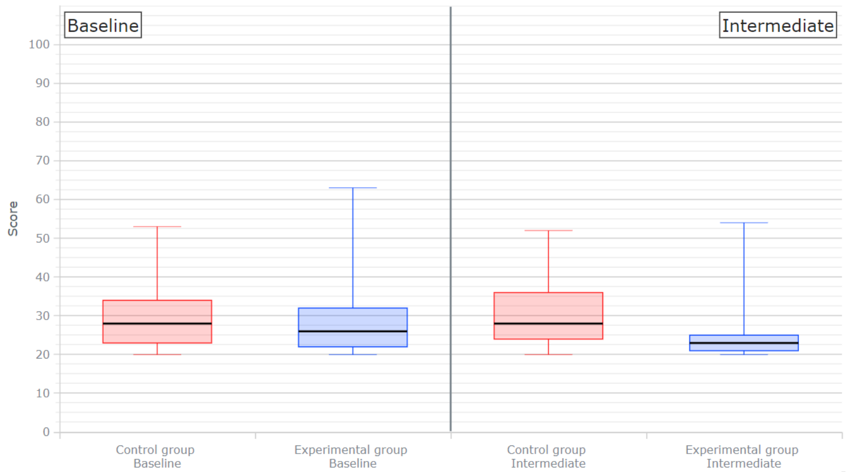

Fig. 6 Comparison of UCLA results: OA vs CG in baseline and intermediate period. Box graphic with median.

Table 3. UCLA results in terms of average, median, Q1, Q3 for EG vs CG in baseline and intermediate period.

	$\bar{x}$	$\tilde{x}$	Q1	Q3	n
CG (M1)	30.21	28	23	34	140
EG (M1)	28.78	26	22	32	146
CG (M6)	30.76	28	24	36	102
EG (M6)	24.84	23	21	25	101

The UCLA Loneliness Scale was also analyzed for informal caregivers (IC), with results depicted in Fig. 7 and Table 4, that differentiates by gender to ascertain any disparities throughout the intervention. The box plots for both baseline and intermediate stages show the varying effects on male and female ICs. Initially, male IC exhibited a broader range of scores and a higher median than females. However, by the intermediate stage, a significant reduction in scores was observed for both genders, with the decrease being more pronounced for males. The convergence of scores at the intermediate stage suggests that the intervention had a consistently positive effect on reducing loneliness among IC, irrespective of gender. Overall, IC demonstrated a marked decrease in loneliness from baseline to the intermediate stage, with the average score declining almost 3 points in males and more than 6 in females and the latter also the median from 27 to 23.

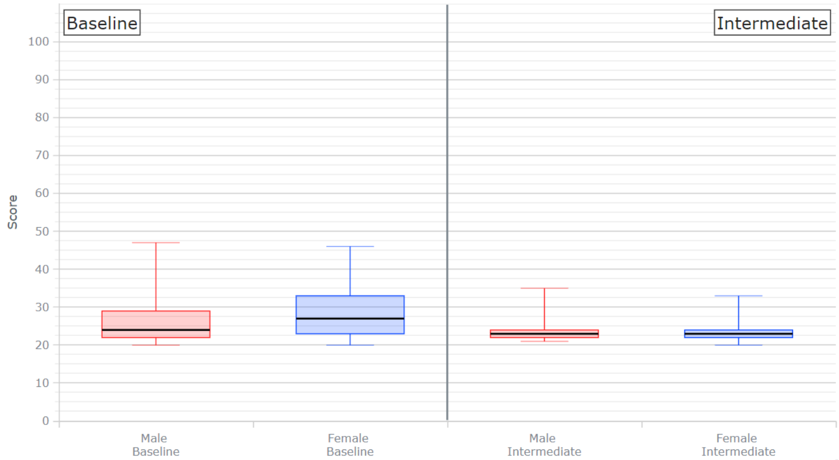

Fig. 7 Comparison of UCLA results in IC, comparison by gender in baseline and intermediate period. Box graphic with median.

Table 4. UCLA results in terms of average, median, Q1, Q3 for IC-Male vs IC-Female in baseline and intermediate period.

	$\bar{x}$	$\tilde{x}$	Q1	Q3	N
IC-M (M1)	27.17	24	22	29	23
IC-F (M1)	29.30	27	23	33	81
IC-M (M6)	24.46	23	22	24	13
IC-F (M6)	23.20	23	22	24	63

Fig. 8 and Table 5 provides an insight into the CareQoL outcomes for IC through the lens of gender at both baseline and intermediate. The numerical results show the improvement of caregiving-related QoL for both male and female IC. Female caregivers showed a more significant improvement, evidenced by their higher median and increased Q1 and Q3 values at six months. In the figure, the box plots further substantiate this improvement, showcasing a contraction in score distribution for both male and female caregivers and an elevated median, particularly evident in the shorter 'whiskers' of the intermediate box plots. This shrinkage of score range aligns with the quantitative data, signaling that the intervention may have contributed to a uniformly better CareQoL for IC across genders.

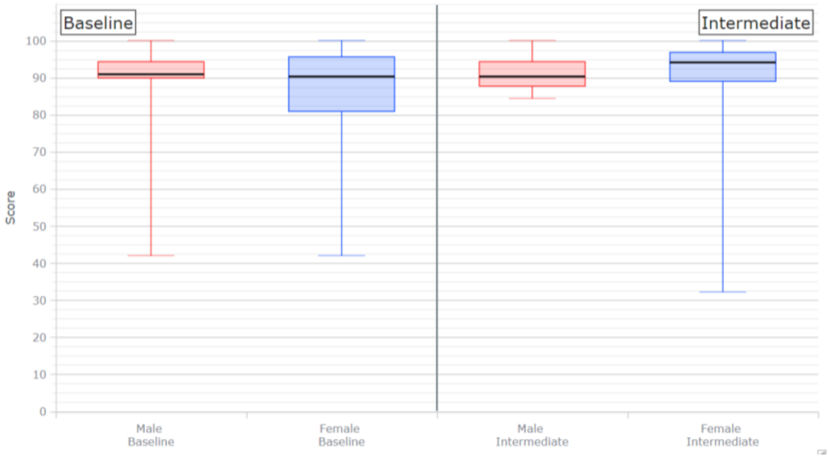

Fig. 8 Comparison of CareQoL results in IC, comparison by gender in baseline and intermediate period. Box graphic with median.

Table 5. CareQoL results in terms of average, median, Q1, Q3 for IC-Male vs IC-Female in baseline and intermediate period.

	$\bar{x}$	$\tilde{x}$	Q1	Q3	n
IC-M (M1)	89.04	91	90	94.4	23
IC-F (M1)	86.69	90.4	81	95.7	81
IC-M (M6)	92.31	90.4	87.8	94.4	13
IC-F (M6)	91.31	94.2	89.1	96.9	63

Finally, the SUS results, plotted and summarized in Fig.9 and Table 6 for OA, Fig. 10 and Table 7 for IC and Fig. 11 and Table 8 for HP, reveal interesting trends from baseline to the intervention phase. In all cases, the results are compared by gender, since there are no control group in any of the profiles.

In OA, for both genders, there is a notable increase in both mean and median, indicating a significant enhancement in perceived usability. Females showed a larger increase in mean and media.

In IC, it was maintained a high usability scores for males and significantly improved for females. Note that male caregivers' mean remained stable, increasing slightly. with a high median of 92.5. Female caregivers' mean increased significantly, more than twelve points.

In HP, males experienced a decrease in perceived usability, while females showed a considerable increase, reflecting a remarkable improvement, as indicated by higher Q1 and Q3 values. It is important to note that the number of samples in the intermediate period decreased by more than 50% for both genders compared to the baseline, making the sample size too low to draw definitive conclusions.

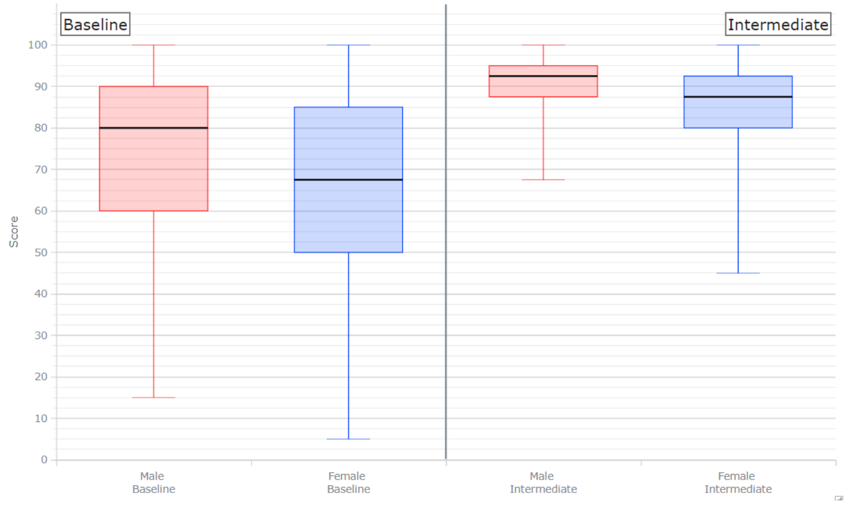

Fig. 9 Comparison of SUS results for OA by gender in baseline and intermediate period.

Table 6. SUS results in terms of average, median, Q1, Q3 for OA-Male vs OA-Female in baseline and intermediate period.

	$\bar{x}$	$\tilde{x}$	Q1	Q3	n
OA-M (M1)	75.30	80	60	90	99
OA-F (M1)	65.81	67.5	50	85	58
OA-M (M6)	90.71	92.5	87.5	95	56
OA-F (M6)	85.35	87.5	90	92.5	35

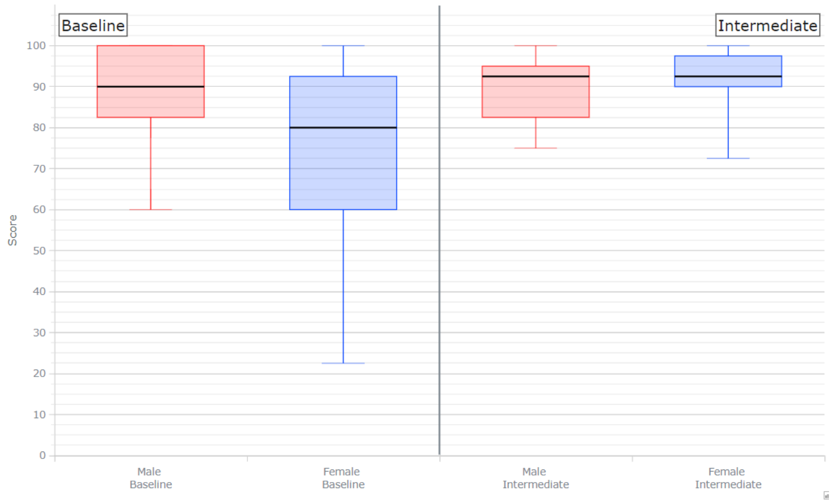

Fig. 10 Comparison of SUS results for IC by gender in baseline and intermediate period.

Table 7. SUS results in terms of average, median, Q1, Q3 for IC-Male vs IC-Female in baseline and intermediate period.

	$\bar{x}$	$\tilde{x}$	Q1	Q3	N
IC-M (M1)	89.16	90	82.5	100	24
IC-F (M1)	77.38	80	60	92.5	63
IC-M (M6)	89.31	92.5	82.5	95	11
IC-F (M6)	92.32	92.5	90	97.5	42

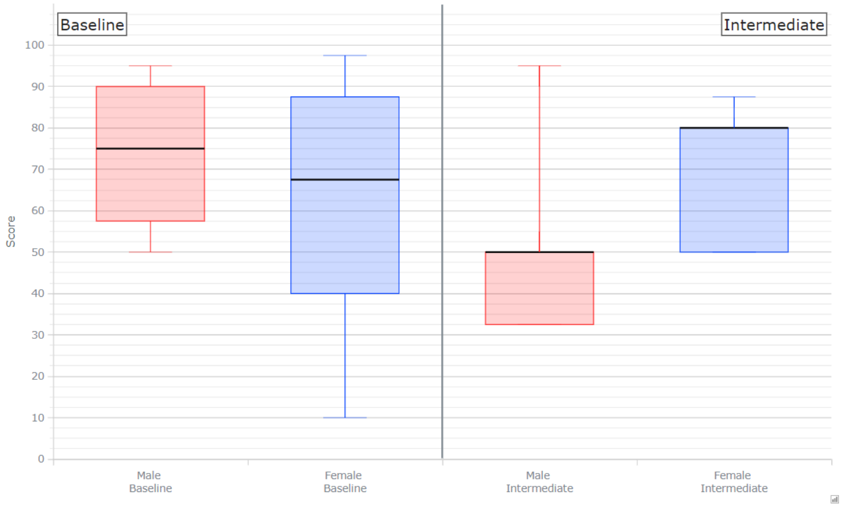

Fig. 11 Comparison of SUS results for HP by gender in baseline and intermediate period.

Table 8. SUS results in terms of average, median, Q1, Q3 for HP-Male vs HP-Female in baseline and intermediate period.

	$\bar{x}$	$\tilde{x}$	Q1	Q3	n
HP-M (M1)	76.59	75	57.5	90	11
HP-F (M1)	65	67.5	40	87.5	20
HP-M (M6)	62.5	50	32.5	50	4
HP-F (M6)	72.08	80	50	80	6

A summary of the analyzed results is as follows:

- Self-care and empowerment: there was an association between increased engagement with the IoT telehealth monitoring system and higher levels of self-care and empowerment among OA in EG, suggesting improved management of their condition.
- Loneliness: both OA and IC reported a reduction in feelings of loneliness, likely attributed to the enhanced connectivity or feeling of telecare with caregivers and healthcare professionals facilitated by the system deployed.

- Usability: the IoT devices and mobile app were highly rated for ease of use, contributing to positive OA engagement and adherence. However, the adoption of the HomeCare by HP showed a slight decrease.
- Comparative analysis: The CG, which did not participate in the IoT system intervention, exhibited no significant changes in these indicators, highlighting the potential impact of the IoT-based telehealth solutions on the management of CHF.

3 Conclusions, lessons learnt and future work

This work has summarized the six-months experience of piloting a pioneering telecare intervention for chronic heart failure patients in the Region of Murcia (Spain), elucidating the multifaceted impact of IoT technologies on health outcomes and quality of life. The results highlight improvements in self-care, empowerment, and a reduction in loneliness among older adults and informal caregivers, with tangible advances in system usability. Particularly noteworthy is the increased engagement with the telehealth platform, correlating with an enhanced capacity for self-management of CHF.

However, the findings also indicate a slight decrease in usability ratings from health professionals, underscoring a potential discrepancy between user expectations and system design. Despite this, the overall trend suggests that IoT-based telecare systems can offer substantial support to CHF patients, potentially leading to improved clinical outcomes.

A set of lessons learnt have been identified during the process. These insights could pave the way for future research, especially concerning long-term adherence to telecare systems and their sustained impact on health outcomes. They are summarized as follows:

- User engagement and trust: building a successful telecare system requires fostering a deep sense of trust among users. Engagement is critical, and it is amplified by the perceived reliability and responsiveness of the technology.
- Customization and support: the diverse reactions to the technology underscore the need for customizable solutions that can adapt to the varying needs of patients, caregivers, and health professionals.
- Technical challenges: it is crucial to anticipate and manage technical challenges, ensuring that users have the necessary support to overcome barriers to technology adoption.
- The human factor: perhaps most importantly, this pilot reinforces the idea that technology should complement, not replace, the human elements of healthcare. The role of personal support, understanding, and the human touch remains irreplaceable.
- Iterative design: continuous feedback loops between users and developers are necessary to refine the system, improving usability and functionality in real-world settings.

For future work, a comprehensive analysis will be conducted upon the completion of the twelve-month pilot. This analysis will delve deeper into the full scope of outcomes, examining how the various KPIs are influenced by the participants' profiles, including gender, educational level, digital literacy, age, and other relevant demographic factors. By doing so, we aim to uncover nuanced insights into the differential impact of the telecare system across diverse user groups. These findings will be instrumental in tailoring future iterations of the telehealth platform to meet the specific needs and preferences of distinct user populations, ultimately enhancing the efficacy and user experience of IoT-based health interventions. Additionally, future research should focus on collecting long-term data from the different devices used in this study. Evaluating trends in physiological parameters such as heart rate, weight, and physical activity could provide deeper and more objective insights into users' health status. This information could be valuable for adjusting interventions and further improving the effectiveness of telecare solutions.

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