

Towards Data-Driven Persuasive Coaching in a Heart Failure Telemonitoring Technology

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Abstract. Heart failure is a common disorder associated with high morbidity and mortality. Early diagnosis and treatment of exacerbations can lower the amount of (re-)hospitalizations. Patients can be supported to self-manage their disease by integrating persuasive coaching in a telemonitoring technology. The Twente TEACH Consortium is a multidisciplinary partnership, under which the iMediSense telemonitoring technology was developed. A mixed-methods approach was used to evaluate and improve the behavioral support of this platform. Methods included log data analysis, stakeholder interviews, usability tests, and a scoping literature review. Results showed that iMediSense is easy to use, achieving high adherence in a sixty days pilot study. A conceptual behavior change module grounded in goal setting theory was developed to provide persuasive coaching. We discuss the potential of our method, the implications of our findings, and present our ideas for further research to advance knowledge of a data-driven persuasive coaching approach to support behavior change.

Keywords: Heart Failure, Telemonitoring, Persuasive Coaching, Self-Management.

1 Introduction

Chronic congestive heart failure (CHF) is a chronic disorder in which the pumping function of the heart is impaired. CHF has an incidence of 5-10 per 1000 annually [1]. Re-hospitalization has a negative impact on both patient welfare and total cost. Because of this, supporting patients with CHF on the self-management of their disease, especially when they are at home, is a cornerstone for treatment.

Telemonitoring technology is a potential solution to provide self-management support, as it enables both the patient and the caregiver to check up on vital signs of the patient at home, which could decrease the number of visits to the hospital. However, providing patients with their own data is not enough to change behavior, strategies to sustain motivation and engagement are also necessary [2]. The omission of such

behavior change strategies could partially explain that high quality evidence of the benefits of telemonitoring to support CHF is still lacking [3, 4].

Filling the gap between collecting data and changing behavior can depend more on the design of engagement strategies than on the specific features or functions of a technology [5]. We define our approach as persuasive data-driven coaching, meaning the use of self-monitoring data to create tailored patient support, incorporating key persuasive and behavior change components such as reduction, personalization, praise messages, reminders, simulation, and goal setting [6, 7]. Therefore, in this paper we show how data-driven persuasive coaching on self-management behaviors can be integrated in a telemonitoring technology, to effectively support patients living with CHF. For purposes of this workshop, the paper describes research conducted to evaluate and improve iMediSense via two different studies. Study 1 focused on evaluating the system during a pilot implementation. Study 2 focused on exploring and generating a first concept of a coaching module for the platform.

2 Background

The Twente TEACH consortium is a partnership formed by the University of Twente, Thales, Ziekenhuisgroep Twente (ZGT), Vodafone, and by the healthcare insurance company Menzis. This multidisciplinary cooperation aims to support self-management of patients with CHF with the use of telemonitoring and data-driven persuasive coaching.

Following a holistic and participatory development approach [8], the first task was to develop a technical platform, which resulted in the creation of the iMediSense telemonitoring technology. iMediSense was designed to support care provided by a specialized heart failure outpatient clinic. During this study, iMediSense allowed patients to measure their blood pressure, heart rate, weight, and report on their experienced symptoms on a daily basis. Moreover, the platform also provided insight in these measurements for both patient and caregiver, in this case, specialized heart failure nurse practitioners. The overarching aim of our research was to determine the use, usability and usefulness for practice of iMediSense and to provide recommendations to improve the technology. In the following section, we briefly describe the technical components and structure of the iMediSense platform, and then we elaborate on the research that was conducted to improve its capacity to effectively provide self-management support via persuasive data-driven coaching to patients with CHF.

3 The iMediSense Platform

There are two main interfaces in the iMediSense platform: the patient interface, which consists of an Android application, and a web application that serves as interface for the caregiver. Both interfaces communicate with a central server.

3.1 Patient Interface

This interface operates on a tablet with an Android operating system. Two sensors communicate with the tablet via Bluetooth: a non-invasive blood pressure monitor and a digital weighing scale. This allows for automatic registration of measurement values. The iMediSense application transmits the encrypted measurement via the 3G/4G wireless network to a hospital network server. As a result, measurements can be performed anywhere, as long as there is a connection with the cellular network. The application menu provides the following main services: registration and transmission of measurements, historical review of measurements, message functionality with the caregiver, profile and settings, and user manual.

3.2 Caregiver Interface

For the caregiver, iMediSense is a web application, which can be accessed from a PC within the secured hospital network. The interface of this application consists of the following main features: patient analysis (e.g., to see measurement values), patient management (e.g., adjusting patient's alarm thresholds), alarm notification (e.g., if measurement value exceeds a personalized threshold), and message notification (e.g., to send and receive messages to the patients).

3.3 Technical Structure

The Android application communicates with the hospital network server through the regular wireless network connection. The caregiver can access the data on the network server from a PC within the hospital network. Figure 1 shows an overview of it.

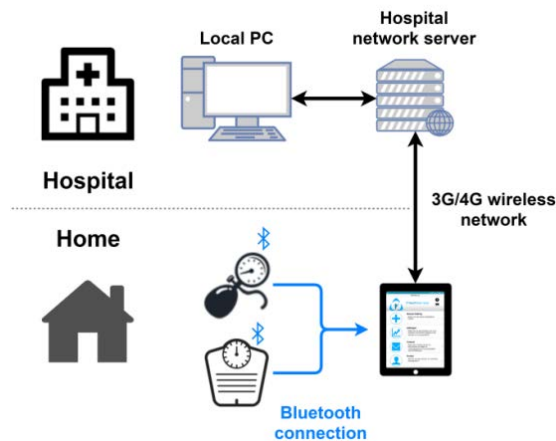


Fig. 1. Simplified overview of the iMediSense platform and architecture

All transmitted and stored data is encrypted. This includes measurements, messages, settings, and log data. Although not visible in Figure 1, data stored within the system is

secured via a Demilitarized Zone environment, which acts as a buffer and communicates with both the internal hospital network and the outside world. Individual environments are separated by firewalls, and transfer between them makes use of security technologies.

4 Methods

4.1 Study 1: Use, Experience, and Usefulness of the Technology

A pilot was conducted to determine the use, usability, and usefulness for practice of iMediSense. Specifically, the intention was to know how the patients use, experience, and perceive usefulness of the technology. The leading question on behavioral support was “How should these patients be coached?” Thus, this pilot can be seen as formative evaluation of the current design of iMediSense. The goal was to deliver recommendations to further improve the system in preparation for a large scale implementation.

The pilot included in total twenty-five patients with CHF, who used iMediSense daily during a period of around sixty days each. Patients were selected using the following inclusion criteria: age >18 years; New York Heart Association (NYHA) functional classification II-III; stable CHF, stable symptoms, stable on medication and no admissions within 1 month; and able to provide written informed consent. After obtaining consent, patients received a personal introduction and training from either the researcher or a research nurse in the use of the technology. The training included practice in using the tablet, using the digital blood pressure meter and using the digital weighing scale. During the training patients had to execute at least one measurement by themselves. The training was considered to be completed if the following four conditions were met: 1) execution of at least one (guided) measurement; 2) patient had seen and/or used all menus of the system; 3) patient was confident about conducting measurements themselves; 4) trainer had the confidence that the patient is able to conduct measurements independently.

For the duration of the pilot, patients were instructed to conduct one measurement every morning after the first micturition but before breakfast (including blood pressure, heart rate, weight, and filling up the short questionnaire on health issues). Adherence was therefore defined as the compliance of patients to that instruction (one completed measurement per day). In case of emergencies or health issues, they were instructed to follow the regular guidelines in case of health issues or emergencies.

This study included both qualitative and quantitative research methods: questionnaires, interviews, usability testing, and log data. Questionnaires were used to determine the quality of life (via the Dutch version of the EQ5D5L QoL assessment [9]) and eHealth literacy of patients (via the Dutch version of the EHEALS questionnaire [10]). Semi-structured interviews with patients were used to provide insight into the use, experience with, and perceived usefulness of the technology. The interviews included questions about the life with CHF, self-management, the use of devices with access to the internet and positive and negative experiences or opinions about the technology.

Interviews were recorded, transcribed verbatim and quotes were coded for different categories.

Usability testing was performed to determine the use and usability of the technology. The ‘think aloud’ method was employed [11]. Patients were instructed to perform different tasks related to the functionalities of the technology. The tasks for the patients were: 1) log in, 2) perform a measurement, 3) review measurements, and 4) send a message. The patients were instructed to say whatever they were looking for, doing, feeling, or noticing at each moment.

To create an optimal fit between patients and the technology, the usability tests also included two “non-users”, these were patients recruited only for the usability tests, without any experience or training with the iMediSense technology. This was important to assess because improving intuitivity of the system could increase its efficiency, since requiring no extensive training would facilitate the use of the technology. The tests were recorded, transcribed verbatim, and coded for the use of different parts of the technology. For the analysis, the design observations were sorted according to several levels [8]: “content” (material and information of the technology, including text and images), “service” (services provided by the technology), and “technology” (hardware related). Observations were also ranked either as [12]: “positive”, “minor” (issue or potential improvement), “serious” (if it hindered the execution of the task), and “critical” (if the task couldn’t be executed because of it).

Log data was used to provide insight in the actual use of the technology. A log data protocol was applied to collect, transform, and analyze the log files [13].

User	Time Stamp	Action	Extra information
1	January 12; 01:14 p.m.	Login	
1	January 12; 01:21 p.m.	Login	
2	January 12; 01:20 p.m.	Login	
2	January 12; 01:22 p.m.	Opening monitoring	
2	January 12; 01:47 p.m.	Adding monitoring value	Blood pressure
3	January 21; 10:11 a.m.	Login	
3	January 21; 10:12 a.m.	Opening mailbox	
3	January 21; 10:13 a.m.	Opening monitoring	
3	January 21; 10:13 a.m.	Opening mailbox	
3	January 21; 10:21 a.m.	Send message	To general practitioner
1	January 23; 10:11 a.m.	Login	
1	January 23; 10:13 a.m.	Opening mailbox	
1	January 23; 10:15 a.m.	Send message	To nurse practitioner

Fig. 2. Fictional example of log data, adapted from [13]

All button clicks in the application for both the patient and the caregiver were registered in an automatic log file. For each click in the platform, a new row is generated containing: a case ID (unique incremental number) identifying the individual users, sex and age of the user, a specification of the action, and the date and time of the action, Figure 2 shows a fictional example of log data.

For the analysis, sessions were identified from the raw data. A session was defined as a period of activity ended by a period of at least 30 minutes of inactivity. For each session, the used functionalities were determined, enabling analysis, for instance, of the

registration and transmission of measurements, the review of the measurements (history), and the messaging function.

4.2 Study 2: Design of a Goal Setting Module

The aim of the second study was to develop a first concept of a behavior change module for the platform by learning from the evidence of previous research. For this, goal setting was proposed as the most viable key component because of its added value to support this target group, as “the act of goal setting motivates the development and use of self-management skills that increase the likelihood of goal attainment” (p. 431) [14]. Therefore, the leading question was: “How can the iMediSense technology improve its feedback and coaching to support behavior change through the implementation of a goal setting module?” Due to the nature of this question, a scoping review method was employed [15, 16]. A database search was conducted on CINAHL, PsycInfo, Scopus, and Web of Science, using the terms “goal setting”, “heart failure”, “self-management”, and “eHealth” (Including related terms for each). Goal Setting Theory [14] was then used to theoretically ground this module for coaching, and with this framework in mind our objective was to identify the existing implementations of coaching within eHealth technologies that also targeted CHF populations with goal setting and telemonitoring support as key components. The constructs of goal setting theory [14, 17] were used to identify and extract the theoretical foundation of the eHealth technologies targeting CHF populations, as identified from existing literature (See Figure 3). Self-care operationalization [18, 19] of goal setting (focused on maintenance, monitoring, or management), and design principles from the Persuasive Systems Design (PSD) model [7] were also extracted according to state-of-the-art papers and guidelines on each subject (see respective citations).

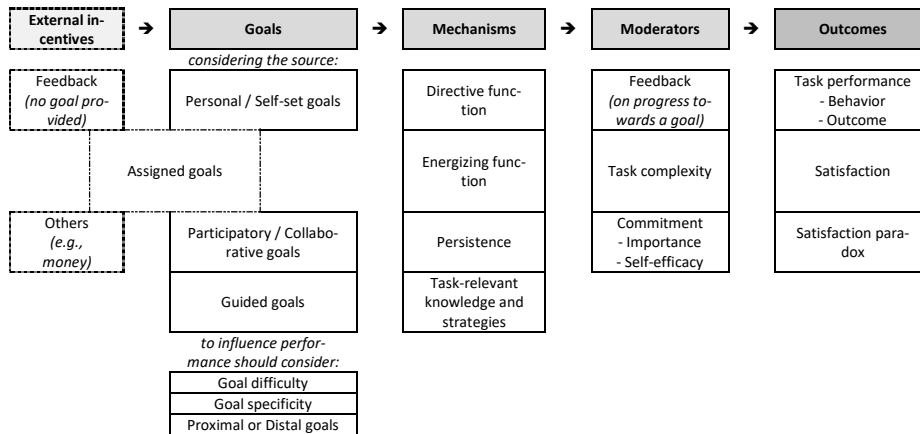


Fig. 3. Conceptual model of Goal Setting Theory (Derived from [14, 17])

The literature findings were complemented with an additional analysis of the log files from Study 1. This second log data analysis aimed to provide insight and a deeper

understanding of the usage of the platform at an individual level. The analysis followed the same protocol from the pilot study [13], but this time three individual cases were chosen according to distinctive or representative characteristics of adherence during the pilot study. The three cases were described as:

- Case 1 – Lower adherent: A user that wished to stop participation but, through an intervention of a nurse practitioner, was motivated to continue. The interaction between patient and nurse was known to be based on the self-care goals, and the indication to perform measurements was since then tailored to this individual, from daily measurements to one every two or three days. The user fully complied with the new recommendations from that point on until the end of the study, therefore, the point of interest was that the user became adherent through coaching.
- Case 2 – Adherent: A user that complied with the recommendations almost perfectly, missing sending a measurement in only one day during the full study. A representative case of the majority of participants from the pilot.
- Case 3 – Adherent and high self-monitoring: A user that did not only show perfect adherence but also exceeded the recommendations. The user performed measurements two or three times a day for around forty days. The user recognized well-established habits of staying informed about the disease (e.g., looking up information on the internet), and frequently monitoring the medical status through several devices (e.g., traditional weighing scale).

5 Results

5.1 Study 1: Use, Experience, and Usefulness of the Technology

The participants were predominantly in NYHA functional class 2, 10 out of 25 had a history of hospitalization for decompensated heart failure. Comorbidities were frequent among the sample: There were 8 cases also diagnosed with hypertension, 7 with atrial fibrillation, 7 with diabetes mellitus, 7 with cerebral vascular accident or transient ischemic attack, and 4 with chronic obstructive pulmonary disease.

The results from the EHEALS eHealth literacy showed the median of the score as 3 (out of 5) with an interquartile range of 0.9. This suggests acceptable levels of comfort and perceived skill in using information technology for health among the sample. The mean score on the EQ5D5L was 8.2 on a scale from 5 to 25, which indicates a good quality of life with slight problems or health issues. No differences in quality of life were observed after 2 months of use of the technology.

During the usability tests, all subjects were able to log in, execute a measurement and review their measurements (8 users and 2 non-users). Four users and both non-users were not able to send a message to the caregiver using iMediSense. Regarding potential coaching support, some positive observations for the “technology” (hardware related) were that the system was easy to use and that it does not take a lot of time, plus the automatic transmission of data was perceived as a useful feature. On the other hand, some critical observations on the “service” (provided by the technology) were that some

patients did not understand how to send a message, due to being unclear which box from the interface had to be used to write it.

All patients were interviewed, 8 face to face, and 17 over the phone. After independent coding of 10% of the quotes by two raters and discussing of disagreements, an inter-rater agreement (Cohen's Kappa [20]) of 0.82 was reached. The overarching themes that were identified are as follows: difficulty of living with CHF, self-management, performing a daily measurement with iMediSense (blood pressure, weight, etc.), and the usefulness of the technology. Fifteen out of 25 patients mentioned that the technology was useful to them. Contributing factors that were reported are: having more insight in your vital signs, feeling supported by the hospital, confirming your stability, automatic registration and presentation of data and having more attention for your own health.

The log data results showed that all patients were able to use the technology at home and that it was predominantly used as intended. In total, 1572 sessions were identified (See Table 1). Twelve out of 25 patients showed perfect or nearly perfect adherence (one measurement every day). Some patients were unable to perform measurements for several days due to technical issues, while others were less motivated to continue the measurements and stopped performing them before the end of the study period. An analysis of the navigation routes was performed to identify the most common routes within one session. 1442 sessions were included, eliminating the routes that were followed less than 10 sessions. It was found that the most common route was: 1) conducting a measurement after login (n=1341), then 2) sending the measurement (n=1282), and finally 3) quitting the application (n=418). Finally, as can be seen in Table 1, certain features of iMediSense were barely used by the patients, such as the message function.

Table 1. Global use of iMediSense by patients as measured by log data

Action	n	% of total sessions	Individual patients
Submit a measurement	1426	90.7	25
Not finishing a measurement	78	5.0	21
Open measurement history	612	38.9	25
Open contact menu	126	8.0	19
Send a message	38	2.4	13
Open profile menu	75	4.8	19
Open profile menu & use >1 button	11	0.7	8
Open user manual	13	0.8	8
Open user manual & go to second page	11	0.7	7

5.2 Study 2: Design of a Goal Setting Module

Scoping Review. Thirteen studies were selected from the scoping review that described or discussed eHealth technology focused on supporting self-management of CHF (or related conditions) with goal setting and self-monitoring as key components. Among them, five different technologies were described or evaluated. The SMART2/CHF

PSMS system [21-24], the HeartCycle E&C program [25, 26], the CHF-CePPORT platform [27, 28], the MyCor platform [29], and a conceptual e-coach [30]. Although explicit identification by the authors was rarely present, several constructs of goal setting theory were identified. Here we mention only the most prominent. Mapping it onto the theoretical model, for external incentives, feedback (when no goal is provided) was included in three out of five different technologies (HeartCycle E&C, SMART2 and CHF-CePPORT). As goal constructs, collaborative goal setting was facilitated through four out of five systems (SMART2, CHF-CePPORT, MyCor and the conceptual e-coach). Personal or self-set goal setting was also facilitated by four out of five technologies (HeartCycle E&C, SMART2, CHF-CePPORT and the conceptual e-coach). As moderators, feedback (on progress towards a goal) was integrated by all technologies. Likewise, self-efficacy was addressed by three out of five (HeartCycle E&C, SMART2 and CHF-CePPORT). Mechanisms and outcomes as constructs were barely addressed or discussed in the articles. In terms of operationalization, goal setting focused on behaviors (rather than health outcomes) and on self-care maintenance (reducing risk factors, improving health, and adhering to recommendations) by all of the technologies (rather than to promote monitoring or management of CHF). Reduction, self-monitoring, and tailoring (primary task support) were identified as PSD model principles in all five technologies. Praise (dialogue support), real-world feel and surface credibility (system credibility) were principles identified in four out of five platforms..

The Conceptual Model. Having analyzed the literature and the existent technologies as case studies, the components previously mentioned were selected based on their added value to the current state of the system, and to be included as base in the design of the conceptual model for the iMediSense goal setting module. Our simplified conceptual model for a goal setting module can be seen in Figure 4.

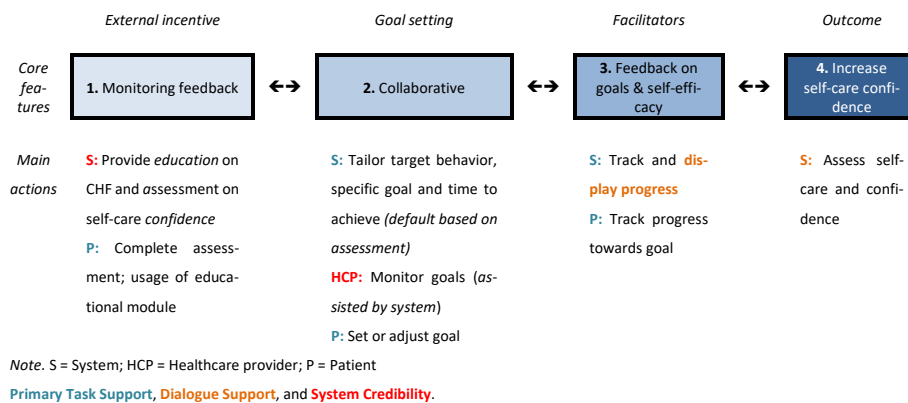


Fig. 4. Conceptual goal setting module to support self-care behaviors of CHF

The conceptual goal setting module focuses on enhancing self-care of CHF patients by aiming to increase their confidence to perform the recommended behaviors through facilitating education and practice over time. Furthermore, the module requires a general baseline assessment and enquiries on self-care behaviors, requesting the users to input their confidence in their skill to perform each of them (e.g., confidence to increase physical activity or to reduce salt intake). This derives on the system giving feedback and advice based on their results, the users are consequently prompted to set a goal for a specific one, and this is where the coaching begins.

Log Data Analysis. Log data analysis allowed to contrast the individual use and usage of the three representative cases. The case-by-case comparison can be seen in Table 2.

Table 2. Comparison of use and usage between representative cases

	Lower	Adherent	High self-monitoring
<i>Sessions</i>			
Total days of use	62	60	62
Total number of sessions	44	70	151
Days with ≥ 1 session	41	60	62
% days with iMediSense & ≥ 1 session	66.13%	100%	100%
Mean hour of first daily sessions	09:16:35	09:32:35	07:23:23
Mean duration of all sessions	00:03:26	00:06:11	00:04:54
Total time spent in application	02:30:43	07:13:25	12:20:02
<i>Measurements</i>			
Total measurements completed	42	60	136
Sessions with measurements completed	40	60	135
% sessions with measurements completed	90.91%	85.71%	89.40%
Mean duration sessions with measurements only ^a	00:02:49	00:03:03	00:03:39
Adherence ^b	62.90%	98.33%	100%
Mean hour of measurements	09:26:19	09:39:00	12:35:15 ^c
<i>History</i>			
Nr. of sessions with history opened	5	62	38
% sessions with history opened	11.36%	88.57%	25.17%
Mean duration sessions with history opened	00:05:41	00:06:36	00:08:11
<i>Messages</i>			
Nr. of sessions with contact menu opened	7	6	16
% sessions with contact menu opened	15.91%	8.57%	10.60%
Messages sent	1	4	2
Mean duration sessions with messages sent	00:06:28	00:32:50	00:19:34

^a Sessions with 'measurements completed' but no 'history opened' and / or 'message sent'

^b Adherence defined as compliance by the instructions: to conduct 'daily measurements'

^c Odd value due to multiple measurements being conducted at different points in the day

Moreover, the log data analysis of these cases also allowed to visualize the distinct patterns of activities across sessions for each individual. Although all users show acceptable adherence rates, the patterns in Figure 5 show how users varied in their use of the iMediSense platform. In Figure 5 the blue dots mark a session and its position in the left Y axis equals the duration of each. The X axis is divided by the log file "cases" and the beginning of every week is marked by a number (1st to 9th). The irregular distance between each week number represents a higher or lower number of interactions with the technology (cases registered in the log file).

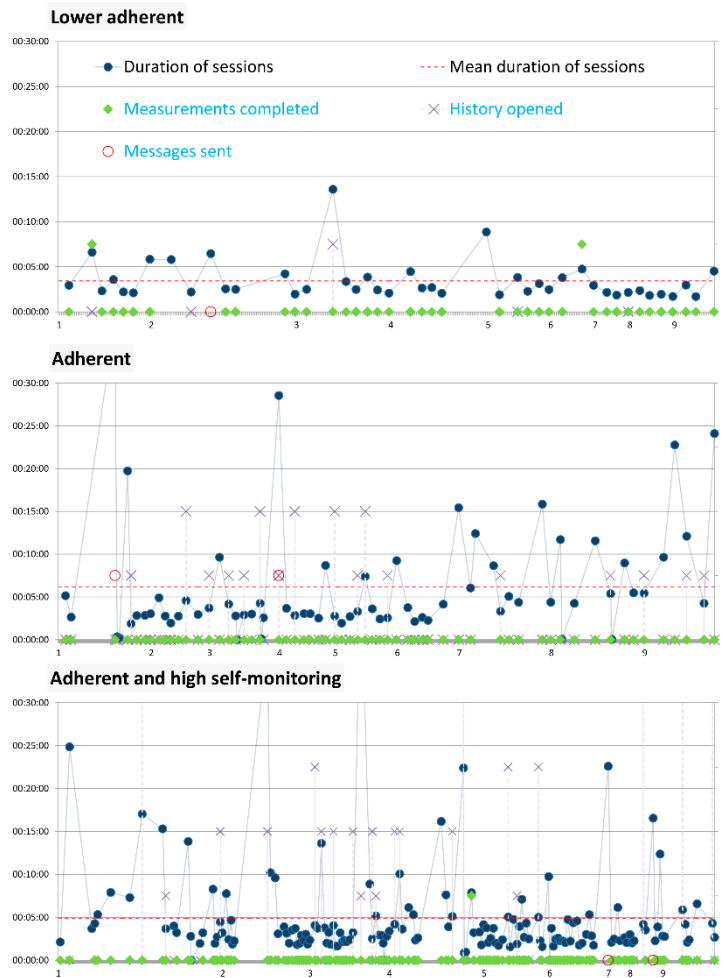


Fig. 5. Overview of activity during sessions for each representative case. The left Y axis measures the duration of each session. The right Y axis measures the frequency of measurements completed, history opened, and messages sent.

Matching the recommendations of usage, most sessions across all three cases consisted of one measurement being sent per usage session. It can be observed, from Table 2 and Figure 5, that the activity increases progressively when comparing the lower adherent with the adherent, and then again with the high self-monitoring. The high self-monitoring case showed a remarkably longer interaction with the technology during the 60 days of the pilot (In Table 2, “Total time spent in application”: 2.5 hours, 7 hours, and 12 hours), as well as a greater number of measurements not just during the morning but at several points of the day. In Figure 5, there are data points outside the scope of the “Adherent and high self-monitoring” graph due to sessions at several points in the day by this user, the range of the graphs was kept the same across all users for comparison purposes. However, it can also be perceived that both the adherent and the high self-monitoring case were actively browsing the history function. The difference in Table 2 in the percentage of sessions with “history opened” is mostly due to the higher amount of “measurement-only” sessions from the high self-monitoring individual. Usage of the message function was so low across all patients that no visible trends can be spotted in Figure 5.

6 Discussion

Overall, the research on the iMediSense platform has been successful not just for evaluation but most importantly to guide development seeking further improvement in terms of its persuasiveness and coaching support. One of the biggest achievements in terms of facilitating persuasive coaching is that the platform provides self-monitoring support using a simplified guidance of the users in a step-by-step process with a lack of redundant options. In a persuasive data-driven coaching approach, we hold as a premise that keeping self-monitoring as a simple process is important to promote adherence among the patients, which consequently assists on the identification of exacerbation in time through data analysis. From the usage and the usability tests we also know that some features require further improvement, such as the message function. We identified problems with the interface layout on this part of the platform, but even accounting for this the usage was lower than expected during the pilot.

The pilot study contributed to advance our knowledge regarding behavior support through the combination of telemonitoring and persuasive coaching. Findings from Study 1 provided key recommendations on how to coach CHF patients, namely to provide: education and training to use the technology as intended, personalized CHF education, support for the interpretation of measurement values, and support for achieving personal goals. Based on those grounds, the second study generated a first concept of a coaching module that made use of self-monitoring data, although further translation of the concept into actual functionalities, validation, and actual implementation is still due. Derived from our findings through the literature review, we know that a goal setting module can be potentially of added value for behavior support. According to what can be interpreted from the literature, self-management support through goal setting was found to be focused on maintenance goals (e.g., adhering to recommendations), with

the most frequent target being increasing the patient's self-confidence to perform specific and tailored self-management behaviors.

Indeed, an interesting finding derived from our theoretical basis is that the target of the module is not to directly strive towards health-related goal attainment, but instead focusing on a key self-care mechanism to promote sustained behavior. In line with the precepts of goal setting theory, feedback has been integrated in previous technologies to serve a double function. First, as an external incentive to prompt goal setting. Second, as a facilitator of behavior change when applied to show progress towards the goals that are set. The analysis of log data allowed observation of the distinct ways in which patients used the platform, which raised interesting questions regarding goal setting support. For instance, users showed diverse motivations to use iMediSense (observed by levels of adherence, usage of features, and interviews). However, the literature sometimes did not provide sufficient evidence on how to operationalize goal setting in terms of these needs. For example, the high self-monitoring case serves as an example that some patients already have self-set goals based on self-care behaviors (Case 3 aimed at self-monitoring symptoms around three times per day). Despite this representative case, the literature did not include any case where goal setting was implemented to influence monitoring, rather than maintenance of the disease. Additionally, support to other forms of goal setting operationalization was unclear when looking at both types of evidence, such as the approach of using this technique to "provide a safe learning environment to practice self-care" [18, 19].

Therefore, it is also possible to assume that our methods could not allow a full mapping of all of the possibilities by which goal setting can be of use when integrated in a telemonitoring technology. In the end, by leveraging on the strongest part of the evidence, the coaching module seeks to fit with the approach of the system in terms of its simplicity and avoidance of redundant options. For example, rather than allowing users to openly self-set goals, collaborative goal setting assisted by the system, the caregiver, or both, could provide support by making it easier to engage in coaching.

7 Future Work

Research on the iMediSense platform has delivered a lot of different and extensive data. Thus, we are able to envision the huge potential of a data-driven persuasive coaching approach once greater automatization and personalization is achieved.

First of all, although not addressed in this paper, some of our findings from the caregiver perspectives brought up the added value of eHealth technology like iMediSense in current care organizations. However, full integration of a data-driven approach usually means new work processes and skills for caregivers. How to accomplish this integration is an interesting topic for future research.

Moreover, another possible step is to create and validate user profiles that can be used to tailor support, and mock-ups that can lead design decision-making, especially as the technology scales up. For instance, since participants from the pilot were mostly stable CHF patients and had acceptable eHealth literacy, further validation with unstable patients, with lower literacy, and bigger samples will be required. Furthermore,

another topic for future work is the improvement of the system that generates the alarms, which is what guides the use of iMediSense, seeking to allow an early detection of deterioration of the CHF patient. In this matter, we also conducted research on improving the clinical significance of these alarms. This was done by testing and developing personalization algorithms for its alarm system. This analysis found that implementing a moving average algorithm could reduce the amount of false positives and increase the amount of true positives alarms generated by iMediSense. The most successful algorithm was based on systolic blood pressure and heart rate, and then comparing these to preset thresholds. Algorithms based on weight triggered alarms reduced false positives but did not generate alarms of clinical significance. An enhanced alarm system could have the potential to reduce the work load of caregivers by allowing them to focus on the priority cases that are being monitored by iMediSense. However, the trade-off between reducing false positives at the risk of also increasing false negatives demands further research. Finally, additional work is required to validate the mechanics of this goal setting module through iterative evaluation. For example, the underlying mechanisms and outcomes from the original theoretical model (Fig. 3) remain unaddressed by research. Expanding our simplified model by testing these assumptions could be a worthy aim for future studies.

Eventually, if positive results are found, the module could also be extended for new diseases by considering different self-care behaviors along with their key moderators (e.g., enhancing adherence to medication in patients with diabetes), or by integrating new sensors (e.g., adding a physical activity tracker). As the structure of the iMediSense platform allows for modular expansion, in the future we also plan to address other chronic conditions such as other types of cardiovascular diseases, diabetes, or diabetic foot and its complications.

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References

1. Mendez GF, Cowie MR. The epidemiological features of heart failure in developing countries: a review of the literature. *Int J Cardiol.* 2001 Sep-Oct;80(2-3):213-9. PMID: 11578717.
2. Miyamoto SW, Henderson S, Young HM, Pande A, Han JJ. Tracking Health Data Is Not Enough: A Qualitative Exploration of the Role of Healthcare Partnerships and mHealth Technology to Promote Physical Activity and to Sustain Behavior Change. *JMIR Mhealth Uhealth.* 2016 Jan 20;4(1):e5. PMID: 26792225. doi: 10.2196/mhealth.4814.
3. Ciere Y, Cartwright M, Newman SP. A systematic review of the mediating role of knowledge, self-efficacy and self-care behaviour in telehealth patients with heart failure. *J Telemed Telecare.* 2012 Oct;18(7):384-91. PMID: 23019605. doi: 10.1258/jtt.2012.111009.

4. Radhakrishnan K, Jacelon C. Impact of telehealth on patient self-management of heart failure: a review of literature. *J Cardiovasc Nurs*. 2012 Jan-Feb;27(1):33-43. PMID: 21558862. doi: 10.1097/JCN.0b013e318216a6e9.
5. Patel MS, Asch DA, Volpp KG. Wearable devices as facilitators, not drivers, of health behavior change. *JAMA*. 2015 Feb 3;313(5):459-60. PMID: 25569175. doi: 10.1001/jama.2014.14781.
6. Lentferink AJ, Oldenhuis HK, de Groot M, Polstra L, Velthuisen H, van Gemert-Pijnen JE. Key Components in eHealth Interventions Combining Self-Tracking and Persuasive eCoaching to Promote a Healthier Lifestyle: A Scoping Review. *J Med Internet Res*. 2017 Aug 1;19(8):e277. PMID: 28765103. doi: 10.2196/jmir.7288.
7. Oinas-Kukkonen H, Harjumaa M. Persuasive systems design: Key issues, process model, and system features. *Commun Assoc Info Syst*. 2009;24(1):28.
8. van Gemert-Pijnen JE, Nijland N, van Limburg M, Ossebaard HC, Kelders SM, Eysenbach G, et al. A Holistic Framework to Improve the Uptake and Impact of eHealth Technologies. *J Med Internet Res*. 2011;13(4):e111. PMID: 22155738. doi: 10.2196/jmir.1672.
9. Janssen MF, Pickard AS, Golicki D, Gudex C, Niewada M, Scalone L, et al. Measurement properties of the EQ-5D-5L compared to the EQ-5D-3L across eight patient groups: a multi-country study. *Qual Life Res*. 2013 September 01;22(7):1717-27. doi: 10.1007/s11136-012-0322-4.
10. Norman CD, Skinner HA. eHEALS: The eHealth Literacy Scale. *J Med Internet Res*. 2006;8(4):e27. doi: 10.2196/jmir.8.4.e27.
11. Jaspers MW. A comparison of usability methods for testing interactive health technologies: methodological aspects and empirical evidence. *Int J Med Inform*. 2009 May;78(5):340-53. PMID: 19046928. doi: 10.1016/j.ijmedinf.2008.10.002.
12. Molich R. Usable web design: Nyt Teknisk Forlag; 2008. ISBN: 8757132283.
13. Sieverink F, Kelders S, Poel M, van Gemert-Pijnen L. Opening the Black Box of Electronic Health: Collecting, Analyzing, and Interpreting Log Data. *JMIR Res Protoc*. 2017 Aug 7;6(8):e156. PMID: 28784592. doi: 10.2196/resprot.6452.
14. Locke EA, Latham GP. New developments in goal setting and task performance. Locke EA, Latham GP, editors. New York, NY, US: Routledge/Taylor & Francis Group; 2013. xxiv, 664-xxiv, p. ISBN: 978-0-415-88548-5 (Hardcover); 978-0-203-08274-4 (PDF).
15. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implement Sci*. 2010 Sep 20;5:69. PMID: 20854677. doi: 10.1186/1748-5908-5-69.
16. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*. 2005 2005/02/01;8(1):19-32. doi: 10.1080/1364557032000119616.
17. Michie SF, West R, Campbell R, Brown J, Gainforth H. ABC of behaviour change theories: Silverback Publishing; 2014.
18. Howlett JG, Chan M, Ezekowitz JA, Harkness K, Heckman GA, Kouz S, et al. The Canadian Cardiovascular Society Heart Failure Companion: Bridging Guidelines

- to Your Practice. *The Canadian journal of cardiology*. 2016 Mar;32(3):296-310. PMID: 26391749. doi: 10.1016/j.cjca.2015.06.019.
19. Riegel B, Moser DK, Anker SD, Appel LJ, Dunbar SB, Grady KL, et al. State of the Science: Promoting Self-Care in Persons With Heart Failure: A Scientific Statement From the American Heart Association. *Circulation*. 2009;120(12):1141-63. doi: 10.1161/circulationaha.109.192628.
 20. Cohen J. A Coefficient of Agreement for Nominal Scales. *Educational and Psychological Measurement*. 1960; 20(1):37-46. doi: 10.1177/001316446002000104.
 21. Jacelon CS, Gibbs MA, Ridgway JV. Computer technology for self-management: a scoping review. *J Clin Nurs*. 2016;25(9-10):1179-92. doi: 10.1111/jocn.13221.
 22. Bartlett YK, Haywood A, Bentley CL, Parker J, Hawley MS, Mountain GA, et al. The SMART personalised self-management system for congestive heart failure: results of a realist evaluation. *BMC Med Informatics Decis Mak*. 2014 November 25;14(1):109. doi: 10.1186/s12911-014-0109-3.
 23. Burns W, Davies R, Nugent C, McCullagh P, Zheng H, Black N, et al., editors. A Personalised Self-Management System for Chronic Heart Failure. 2010 Computing in Cardiology; 2010 26-29 Sept. 2010.
 24. Davies RJ, Galway LB, Nugent CD, Jamison CH, Gawley RE, McCullagh PJ, et al., editors. A platform for self-management supported by assistive, rehabilitation and telecare technologies. 2011 5th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth) and Workshops; 2011 23-26 May 2011.
 25. Stut W, Deighan C, Armitage W, Clark M, Cleland JG, Jaarsma T. Design and Usage of the HeartCycle Education and Coaching Program for Patients With Heart Failure. *JMIR Res Protoc*. 2014 Dec 11;3(4):e72. PMID: 25499976. doi: 10.2196/resprot.3411.
 26. Stut W, Deighan C, Cleland JG, Jaarsma T. Adherence to self-care in patients with heart failure in the HeartCycle study. *Patient Prefer Adherence*. 2015;9:1195-206. PMID: 26316725. doi: 10.2147/ppa.S88482.
 27. Nolan RP, Payne AY, Ross H, White M, D'Antono B, Chan S, et al. An Internet-Based Counseling Intervention With Email Reminders that Promotes Self-Care in Adults With Chronic Heart Failure: Randomized Controlled Trial Protocol. *JMIR Res Protoc*. 2014 Jan 30;3(1):e5. PMID: 24480783. doi: 10.2196/resprot.2957.
 28. Payne YMA, Surikova J, Liu S, Ross H, Mechetiuc T, Nolan PR. Usability Testing of an Internet-Based e-Counseling Platform for Adults With Chronic Heart Failure. *JMIR Human Factors*. 2015 05/08;2(1):e7. doi: 10.2196/humanfactors.4125.
 29. Ammenwerth E, Woess S, Baumgartner C, Fetz B, van der Heide A, Kastner P, et al. Evaluation of an Integrated Telemonitoring Surveillance System in Patients with Coronary Heart Disease. *Methods Inf Med*. 2015;54(5):388-97. PMID: 26395147. doi: 10.3414/me15-02-0002.
 30. Nooitgedagt A, Beun RJ, Dignum F, editors. *e-Coaching for Intensive Cardiac Rehabilitation*. 2017; Cham: Springer International Publishing.