A Development Methodology for a Stroke Rehabilitation Monitoring Application

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Abstract: The capabilities of mobile devices (e.g. flexibility, portability, and the ability to retrieve information quickly) have been leveraged for the development of clinical performance monitoring applications. In this paper we assess the suitability of a methodology for development of clinical performance monitoring applications to support stroke rehabilitation. We use a case study, with two use cases of patients recovering from stroke events, to design a monitoring application at a conceptual level and compare it to other clinical performance monitoring applications.

1 INTRODUCTION

Healthcare information technology (HIT) has the potential to enhance care delivery by providing timely access to data that can be used to deliver patient centred care (IOM, 2012). A particular benefit of HIT is the ability to monitor care delivery across providers and settings (Xu et al., 2015). Mobile devices can be particularly valuable for monitoring care delivery. The capabilities of mobile devices (e.g. flexibility, portability, and quick information retrieval) have been leveraged in the development of clinical performance monitoring applications for practice profiling and community care (Ferenchick et al., 2010; Ferenchick and Solomon, 2013; Chamney et al., 2014).

Monitoring care delivery across diverse care providers and settings requires defining measurement goals and then consolidating data from fragmented data sources to monitor the goals (Vincent et al., 2014). For example, a clinical process can involve multiple healthcare actors (e.g. doctors, nurses, therapists, pharmacists) that generate and store data in heterogeneous systems (e.g. electronic health record systems, paper based charts). Also, the same process may have different workflows across providers, generating inconsistent data. The overarching challenge is that data needed to monitor a process may not be available at the right time using existing data sources.

Developing performance monitoring applications is a bounding problem as one needs to define the objectives and goals to be monitored and then identify and integrate the data needed for monitoring to occur. There is also a need for user involvement in the design of such applications, owing to the high rate of failure in the implementation of HIT (Avison and Young, 2007; Novak et al., 2012) that occurs from a disconnect between clinicians and the HIT development team (Avison and Young, 2007).

The predominant question is how to define the goals and metrics to enable collecting the right data, at the right time, for the right metrics. Much of the existing work in this area has focused on reactive responses to problems where issues are identified after the fact (Kuziemsky, 2015). A better solution would be to pro-actively identify and manage data collection and integration issues so they can be dealt with in real-time. However, doing that requires a method that is robust enough to define and obtain the necessary metrics and data but is flexible enough to enable goals or metrics to be adapted as needed (Vincent et al., 2014).

In this paper we assess the suitability of a methodology for development of clinical performance monitoring applications to support stroke rehabilitation. We use a case study, with two use cases of patients recovering from stroke events, to design a monitoring application at a conceptual

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level. Finally, we compare the development of the stroke monitoring application against two other clinical performance monitoring applications we developed in previous research. We conclude with a discussion of the implications for designing clinical monitoring applications to support different types of monitoring in healthcare delivery.

2 BACKGROUND

Stroke rehabilitation is the care processes that occur after a patient has been stabilized from a stroke event. Early rehabilitation interventions may positively impact rehabilitation outcomes (i.e. recovery of functional disabilities) and an integrated multidisciplinary approach is key to ensure optimal recovery (Duncan et al., 2005). Depending on the severity of the event, the rehabilitation team may include more than one care provider (e.g. physical therapist, speech therapist, occupational therapist, physician, nurse, or pharmacist). Family members may also be involved in the rehabilitation process (Gresham et al., 1997). Regular communication between the care team on patient’s progress towards common goals can positively impact patient's rehabilitation outcomes (Cifu and Stewart, 1999).

An individualized stroke rehabilitation plan is designed for each patient and it includes specific rehabilitation goals and targets for each of the exercises. The goals are defined in agreement with the patient, family and care team (Gresham et al., 1997). Monitoring progress of the patient’s plan towards meeting rehabilitation goals and exercise targets is important in order to identify gaps and make adjustments as needed (Gresham et al., 1997). One of the most commonly measurements used to assess patient rehabilitation progress is the Functional Independence Measure score (FIM) (Duncan et al., 2005; Brown et al., 2015).

HIT is one way to increase quality of patient care through efficient coordination and deployment of resources in the community (Chukmaitov et al., 2014). Recent studies have explored the use of mobile applications in clinical settings to support the provision of better care (Baarah et al., 2012; Ferenchick and Solomon, 2013).

A Clinical Performance Monitoring Application (CPMA) is a type of Business Intelligence application (Chamney et al., 2014) that collects and integrates data from various data sources in order to compute metrics to instantiate goals related to the performance of a particular clinical task or process. In previous research, we developed a methodology for development of CPMAs (Mata et al., 2015). Two applications were used to show proof of concept of the methodology: the Standards and Indicators Dashboard (SAID) (Mata et al., 2014) and the Resident Practice Profile (RPP) (Chamney et al., 2014).

One core aspect of the development methodology is to leverage user-centred design methods to ensure user acceptance and adoption. User centred design involves “users for a clear understanding of user and task requirements, iterative design and evaluation, and a multi-disciplinary approach” (Vredenburg et al., 2002).

3 DEVELOPMENT METHODOLOGY FOR CPMA

The development methodology for CPMA is a user-centred design approach that engages users, developers and project champions in an iterative process of application modelling, implementation and evaluation. Figure 1 depicts the three main phases in the development methodology.

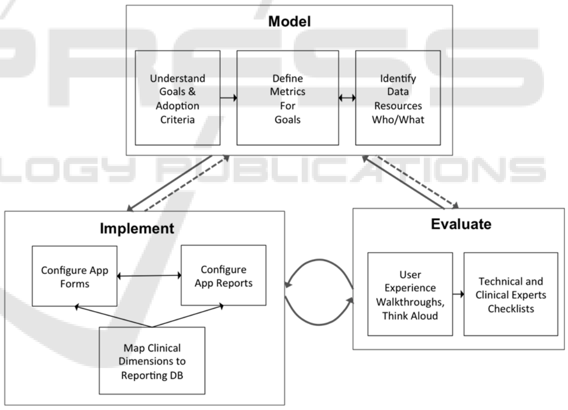

Figure 1: CPMA Development Methodology.

The first phase in the methodology is the modelling of goals, metrics and data sources. This phase is led by clinical and technical experts with the aim to understand the clinical process and define goals for monitoring. Next, they identify and define adoption criteria to ensure adoption and acceptance of the technology (refined later during the evaluation phase). Analysis of the metrics, linked to goals and data sources used to compute the metrics, is carried out to provide meaningful insights on the clinical process. The point is to define who will collect what data, how and when, in order to compute the metric.

During the implementation phase, the clinical process or task monitored is mapped to a star-schema database model (Kimball, 2013) that is optimized for fast querying and reporting. Data related to the clinical process or task monitored is mapped to a fact table. Clinical dimensions are mapped to dimensional tables that represent the attributes used to compute metrics. Each dimensional table is linked to a control in a form and, values in dimensional tables supply the values for each of the controls in the form. Same values are used for grouping, labelling and filtering metrics in graph and chart reports.

The evaluation phase embraces user-experience walkthroughs and think-aloud sessions in order to understand the context and thought processes of the users as they use the application. Clinical and technical experts analyse the feedback obtained from these sessions to generate checklists for development of the application. Checklists are often the result of trade-offs made between user needs and adoption criteria and limitations and constraints of the technology. This tension drives creative solutions and innovations in user interface design.

The cycle of Model, Implement, and Evaluate is repeated until no significant innovations and barriers to user acceptance and adoption are identified during the evaluation phase. The end of a cycle is reached when clinical users and the development team are in sync and only minor adjustments are required.

4 CASE STUDY: STROKE REHAB PROGRAM

In our case study, we first define two use cases that help us conceptualize the application development by following the development methodology for CPMA described in section 3.

Table 1: Use Case 1. Rehabilitation Plan - Betty.

Goal	Therapy	Target	Metrics
Increase Mobility (ADLs)	Physical-walking	75%	# Steps (Day_n-Day_{n-2}) > 10
	Physical-Treadmill	75%	Maximal heart rate <= beats of predicted maximum +20
Improve retrieval of words	Retrieval of words	90%	# Words Retrieved (Day_n-Day_{n-1}) >5

For the first use case, we have patient Betty. She suffered a severe stroke event and after she was stabilized from the event, the team at the acute care unit in the hospital assessed her condition. Her diagnosis included disabilities in more than one area and the care team recommended her to be admitted to the In-Patient Rehabilitation Unit. Physical therapy and speech therapy were included in her rehabilitation plan. The therapists at the In-Patient discussed rehabilitation goals with Betty and her family members. Table 1 shows goals, metrics by therapy and, expected rehabilitation outcome targets for each of the therapies. Information in table 1 is just an example as metrics can change frequently as the patient progress in her rehabilitation program.

Table 2: Use Case 2. Rehabilitation Plan - John.

Goal	Therapy	Target	Metric
Increase Mobility (ADLs)	Physical-walking	90%	# Steps (Day_n-Day_{n-1}) > 20
Improve retrieval of words	Retrieval of words	50%	# Correct pictures selected (Day_n-Day_{n-1}) >10

The second use case refers to patient John. He suffered a moderate stroke and was also assessed by the team at the acute care unit in the hospital. The team determined he had physical and speech deficiencies. Table 2 depicts John's rehabilitation plan in terms of goals, metrics by therapies, and rehabilitation outcome targets. Although Betty and John's rehabilitation plans are similar in terms of the therapies they both require, the metrics for each of their therapies vary, and the rehabilitation outcome expectations before discharge are also different. Therefore, the stroke rehabilitation monitoring application needs to have sufficient flexibility to accommodate different goals, metrics and targets that drive the plans.

Following the development methodology for CPMA described in section 3, we review the modelling, implementation and evaluation phases for designing a Stroke Rehabilitation Monitoring Application.

4.1 Model

Modelling goals and metrics for a stroke rehabilitation application is complex. The first step is to understand goals and adoption criteria. Rehabilitation programs require the collaboration of a multidisciplinary team of healthcare providers and information needs from each of the providers need to be integrated seamlessly into one single application that reports the overall progress of the patient and the effectiveness of the care team.

Goals can be defined at two levels. First, goals related to the overall rehabilitation program (all patients) that provides insights on performance of the healthcare team. Second, we need to define goals that provide insights on individualized rehabilitation plans. Definition of metrics linked to goals at the patient level is complex as rehabilitation goals are tailored to specific needs of each patient by therapy. For example, in our case study, at the patient level, both Betty and John's rehabilitation plan include physical walking therapy. However, the number of steps each patient is expected to take and frequency of the therapy varies (10 steps for Betty every two days and 20 steps for John daily). Also, the metrics and benchmarks can vary as the rehabilitation progresses.

Many data sources are needed as multiple technologies (e.g. fitness tracking bands (i.e. FitBit), speech apps) are used to support rehabilitation plans. In our case study, we assumed that patients performing the same exercise use the same technology. This way we can standardize data formats and define a set of pre-defined values for each exercise by therapy that allows us to track progress of therapies at both the patient and program level.

4.2 Implement

The development methodology leverages the use of QuickForms (Baarah et al, 2014), which is an application framework optimized to collect data directly into a reporting database. The database model is a multi-dimensional model, i.e. star-schema, with one fact table and multiple dimensions linked to the fact table. Table 3 depicts the database configuration of the Stroke Rehabilitation application.

Individualized metrics can be assigned to each patient in table *Exercise_Multi* and personalized reports can be generated from the data that show patient progress. In Table *Exercise,* we assign standardized repetition values by exercise that is used for reporting metrics on exercises at a program level. Finally, by setting individual therapy goals in table *Patient*, we can report on the overall progress of the patient.

4.3 Evaluate

The evaluation of the Stroke Rehabilitation application is complex given the multidisciplinary nature of stroke rehabilitation which involves the collaboration of multiple actors, all of whom are candidates for data collection. Therefore, we need to select at least one user representing each of disciplines (e.g. physical therapist, speech therapist, occupation therapist, pharmacist, and physician) as part of the evaluation process. In addition, the application is intended to empower patients and family members/caregivers in decision-making and enactment of a rehabilitation plan. Patients in a stroke rehabilitation program have multiple needs, which will require a careful selection of user representatives that can participate in the evaluation sessions. To understand how the application will impact and be received by the various actors we use a variety of usability evaluation approaches including think-aloud and walk-throughs (Kushniruk et al, 2013).

Table 3: Stroke Rehabilitation Database Schema.

Clinical Dimension	Table	Type	Attributes
Rehabilitation Plan	Rehabilitation_ Progress	Fact	Exercise_Multi_ID; Exercise_Summary; Date; Therapist_ID; Patient_ID; Therapy_ID; Age_ID; Gender_ID; Severity_ID; Facility_ID
Tracking	Date	Dimensional	Date; Day; Month; Year; Week
	Therapist	Dimensional	Therapist_ID; Name; Email; Type
	Patient	Dimensional	ID; Physical therapy target; Occupational therapy target; Recreational therapy target; Speech therapy target; Pharmacist therapy target
	Therapy	Dimensional	Therapy_ID; Label
Demographics	Age	Dimensional	Age ID; Age label
	Gender	Dimensional	Gender ID; Label
	Severity	Dimensional	Severity ID; Label
	Facility	Dimensional	Facility ID; Name
Care	Exercise	Dimensional	Exercise ID; Therapy ID; Domain; Category; Repetitions
	Exercise_Multi	Fact	Exercise_Multi_ID; Exercise_ID; Metric; Completed

5 DISCUSSION

In this paper we have described our work in progress research at developing a CPMA for stroke rehabilitation.

A key contribution from our work is an understanding of how CPMAs design for stroke rehabilitation differs from CPMA design in other domains. We compare the development of the Stroke Rehabilitation application against the two other CPMA's we developed in previous research, RPP and SAID (see Table 4). In terms of modelling, RPP and SAID are much less complex as both applications can be defined based on one single generic performance model with the same set of goals and metrics for all users. The clinical process for RPP and SAID is clearly defined. For the Stroke Rehabilitation application, there is no one single clinical pathway but rather goals and metrics are defined based on each patient's specific plan. In the case of RPP and SAID, attributes to compute metrics come from a set of predefined values. The multiple clinical pathways in the stroke rehabilitation program require consideration of multiple metrics and possible values for the attributes used to compute the metrics.

The implementation phase for the Stroke Rehabilitation application also introduced new challenges. Metrics are defined according to each patient rehabilitation plan, which dramatically increases the number of attributes required to include in the application. As reports and forms are linked together via the same reporting database, the configuration of the reports is also complex. Multiple are the reports that can be generated, and the values that can be used to group and labelling data in the reports. RPP and SAID, both have one generic performance model, and attributes to compute metrics can be easily mapped to forms.

The evaluation phase for the Stroke Rehabilitation application is complex as it involves multiple users with heterogeneous information needs, including the patient. This is the first application we have designed that brings the patient into the evaluation group. Users of RPP and SAID are homogeneous in terms of information needs, and a smaller group of users with a smaller set of user requirements suffices for evaluation purposes.

Table 4: CPMA Development Methodology - App Comparison.

	Methodology	RPP	SAID	Stroke Rehabilitation App
Model	Understand Goals & Adoption Criteria	Generic goals (program curriculum). Homogeneous users.	Generic goals (outcomes of care). Homogeneous users.	Individualized goals (Patient rehabilitation goals). Heterogeneous users.
Model	Define Metrics For Goals	One generic model.	One generic model.	Customized model for each patient.
Model	Identify Data Resources Who/What	Homogeneous users. Well-defined data needs.	Homogeneous users. Well- defined data needs.	Heterogeneous users. Highly variable data needs. Data sources are varied Technologies as a driver (monitoring and empowerment)
Implement	Map Clinical Dimensions to Reporting Database	Well-defined clinical dimensions.	Well-defined clinical dimensions.	Well defined clinical dimensions.
Implement	Configure App Forms	Fixed form attributes.	Fixed form attributes.	Variable form attributes depending on patient's rehabilitation plan.
Implement	Configure App Reports	Common metrics.	Common metrics.	Highly variable metrics.
Evaluate	User Experience Walkthroughs, Think Aloud	Homogeneous users.	Homogeneous users.	Heterogeneous users.
Evaluate	Technical and Clinical Experts Checklists	Residents Programs directors	Administrative (training, case manager) Clinical (nurses)	Patient Clinical (physicians, therapists, caregivers)

6 CONCLUSION AND LIMITATIONS

Some adjustments to our development methodology for CPMA are needed for development of applications to support stroke rehabilitation programs. The first consideration is due to the variable clinical pathways that can be followed in a stroke rehabilitation program, which adds complexity to the definition of the performance model -no one single model can be defined-. Second, the implementation of the application is challenging as the configuration of forms and reports must be flexible to tailor to the specific information needs of each patient. Third, this is the first application that targets the patient as a user. As multiple are the clinical pathway that can be followed during rehabilitation, multiple are the information needs for each patient. A careful selection of patient representatives is key to ensure success during the evaluation phase.

This paper presents our in-progress research on the development of a stroke rehabilitation application following a specific methodology for development of CPMAs. We acknowledge our analysis is limited in that we have not yet developed a prototype to evaluate proof concept of our approach.

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