PATHway: Decision Support in Exercise Programmes for Cardiac Rehabilitation

Dimitris FILOS[a,1], Andreas TRIANTAFYLLIDIS[a], Ioanna CHOUVARDA[a], Roselien BUYS[b], Véronique CORNELISSEN[b], Werner BUDTS[b], Deirdre WALSH[c], Catherine WOODS[c], Kieran MORAN[c] and Nicos MAGLAVERAS[a]

[a] *Centre for Research and Technology Hellas, Institute of Applied Biosciences, Greece*
[b] *Katholieke Universiteit Leuven, Research Group for Cardiovascular and Respiratory Rehabilitation, Belgium*
[c] *Dublin City University, School of Health and Human Performance and The Insight Center for Data Analytics, Ireland*

Abstract. Rehabilitation is important for patients with cardiovascular diseases (CVD) to improve health outcomes and quality of life. However, adherence to current exercise programmes in cardiac rehabilitation is limited. We present the design and development of a Decision Support System (DSS) for telerehabilitation, aiming to enhance exercise programmes for CVD patients through ensuring their safety, personalising the programme according to their needs and performance, and motivating them toward meeting their physical activity goals. The DSS processes data originated from a Microsoft Kinect camera, a blood pressure monitor, a heart rate sensor and questionnaires, in order to generate a highly individualised exercise programme and improve patient adherence. Initial results within the EU-funded PATHway project show the potential of our approach.

Keywords. Telerehabilitation, Telehealth, Decision Support Systems, Cardiovascular Disease, Personalised Health

1. Introduction

Cardiovascular diseases (CVD) are the most common cause of death worldwide [1]. About 17 million adults died because of CVD in 2013 and there are predictions that this will increase in countries with aging populations [2]. In this context, there is a strong need to manage CVD properly so that patients can live longer and have a better quality of life. Cardiac Rehabilitation (CR) has been reported to bring significant health outcomes to CVD patients such as improvement in exercise tolerance, symptoms, psychosocial well-being, stress, and mortality [3].

The effectiveness of exercise-based CR is especially notable in relation to mortality, morbidity, health-related quality of life, and the improved management of CVD patients [4]. Today, exercise-based CR programmes typically include aerobic type of exercises supplemented with dynamic resistance exercises performed at least 3 times per week [5], and incorporate ECG telemetry monitoring when necessary and blood pressure measurements at rest and/or during exercise. However, these programmes

[1] Corresponding Author.

usually take place in supervised environments (e.g., gyms), requiring frequent patient travel and the dedicated support of rehabilitation experts. As a result, patients' uptake and adherence are often low and healthcare costs are high [6].

Exercise-based telerehabilitation at home has the potential to increase patient adherence and reduce healthcare costs. The development of various sensors which allow daily monitoring of health parameters such as heart rate, physical activity, blood pressure, etc., advances in wireless communications, the high availability of Internet and health information systems, can facilitate the enhancement of these CR programmes and their personalisation according to individual patient needs.

We present the design and development of a Decision Support System (DSS) aiming to optimise the effects of unsupervised exercise-based CR for CVD patients, through the provision of a dynamic and highly individualised exercise programme. The target of the system is three-fold: a) ensure patients' safety before starting and during exercise, b) continuously personalize and optimise the exercise programme according to data collected during the exercise sessions, and c) motivate patients toward increasing or maintaining their levels of physical activity. Although there has been research in exercise guidance [7], according to the authors' knowledge this is the first time that a DSS is designed and developed for sensor-based telerehabilitation aiming to provide continuous personalised adaptations of the CR programme. The initial development of the DSS system within the EU-funded project PATHway[2] shows its potential and virtue.

2. Methods

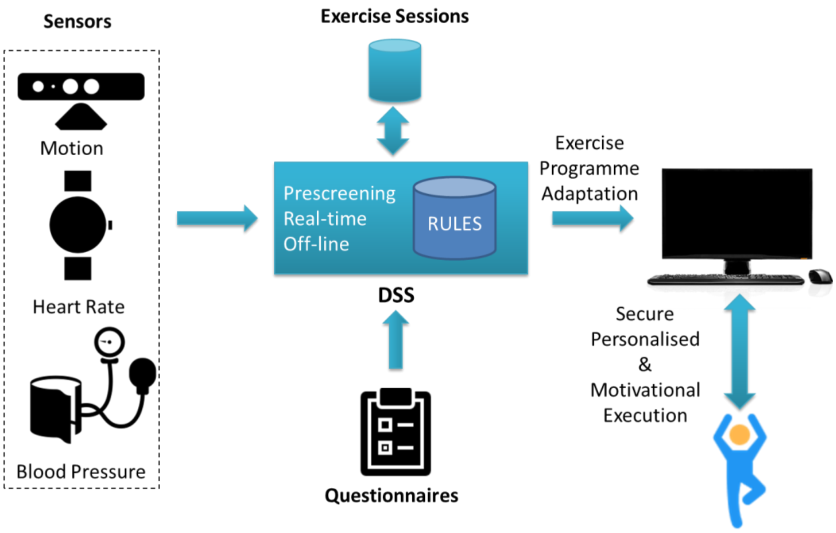

Figure 1. Overall DSS conceptual architecture.

The DSS is a key intelligent service of telerehabilitation platforms as it processes data generated during the conductance of exercise sessions and provides rules encapsulating the logic according to which an exercise programme can be adapted and executed optimally by a patient (Fig. 1). The main DSS data sources are sensing devices for motion

[2] http://www.pathway2health.eu/

recognition, heart rate and blood pressure and questionnaires capturing subjective information before or after an exercise session related e.g. to medication compliance, exertion, or enjoyment. Rules to process data from the afore-mentioned data sources are designed according to standard clinical recommendations and guidelines or empirical knowledge. The DSS functionality is separated into three distinct modules, each one including rules executed at different time intervals; these are the prescreening, the real-time and the off-line modules, which are triggered before, during and after an exercise session respectively, as described below.

2.1. Prescreening

The rationale behind the prescreening component of the DSS is to check the patients' health status before starting an exercise session, thereby preventing patients with detected abnormalities from starting. To this end vital signs monitor devices and a questionnaire composed of two simple questions related to the compliance to prescribed medication and food consumption during four hours before the start of an exercise session are used. The evaluation of the vital signs - heart rate (HR) and blood pressure (BP) - is based on whether specific thresholds are exceeded according to the recommendations of clinical experts [8, 9].

2.2. Real-time

The goal of this component is to adjust the exercise session according to the patients' performance in order to guide them to a more beneficial execution of the CR programme. In this respect, the real-time component evaluates patient's heart rate and the accuracy of the performed exercise, through measurements taken from a wrist-worn HR sensor and a Microsoft Kinect® camera respectively.

Each patient is exercising according to an individualized exercise prescription taking into account the patients' medical history. To this end we use the peak HR (HRmax) of the CardioPulmonary Exercise Test (CPET) and resting HR in order to calculate the beneficial HR zones according to Karvoonen's formular [9]. CPET is a routine clinical examination which is applied among others to evaluate the exercise capacity in patients with CVD and determine the intensity of exercise training in CR programmes [10]. The goal of the real-time component is to ensure that their mean HR (HRmean) during a specific exercise stays within the prescribed HR zones adjusting the exercise intensity when necessary (e.g. moving from a low intensity exercise to one with higher intensity when HRmean is low). Finally, the phase of the exercise (warm-up, main exercise and cool-down), the duration of a specific exercise type (aerobic, stretching, etc.) and the duration of exercising main body parts are taken into account in order to recommend an appropriate exercise which is to be executed next according to general guidelines in exercise-based CR [5].

2.3. Off-line

The off-line module of the DSS focuses on the evaluation of the whole exercise session and personalization of the CR programme according to patient performance, compliance and preferences [9,11] and it is triggered at different times. The functionality of this component is three-fold. Firstly, each exercise session evaluation leads to the exclusion of specific exercises from the following session, the calculation of the duration for the next session, and its characterisation according to the perceived exertion and enjoyment as captured by questionnaires triggered at the end of each session. Secondly, the CR programme prescription is optimized weekly, in terms of parameters for Frequency, Intensity, Time and Type (F.I.T.T.). For instance if patients' compliance and enjoyment of a session at home is higher in comparison to outdoor physical activities, the patient might be instructed to exchange the outdoor activity (= Type) for an additional home session. Thirdly, the off-line module triggers appropriate messages to the patients toward increasing their self-efficacy and motivating them to reach their physical activity goals.

3. Results

A prototype DSS was integrated within the PATHway project. PATHway is an Internet-linked and sensor-based home exercise platform allowing remote participation in CR exercise programs at any time. In order to produce the appropriate rules for the DSS, an initial requirement analysis was performed in which the clinical experts (RB,VC,WB) proposed the rules which are applied in CR programmes for CVD patients in standard clinical practice. Deterministic rules in the format of condition-action (IF-THEN) were integrated in the prescreening, real-time and off-line system components. We used the Python programming language to implement the rules which offers useful characteristics for rapid prototyping such as dynamic and efficient memory management, cross-platform availability, and excellent code readability.

Within the prescreening component, the threshold for the resting HR (HRrest) was set to 75% of the HRmax as recorded during the CPET which is performed before the first use of the PATHway system. The threshold for the systolic blood pressure (BP) measurements was set to 180mmHg, above which a hypertensive crisis is implied [8]. When HR and/or BP are above the predefined thresholds, the patient will be instructed to rest for 5 minutes and then asked to re-measure her HR and BP. If the threshold is exceeded a second time in the same session, the patient will be instructed to postpone her exercise session. If this happens more than once in a week, the patient will be prompted to consult her medical doctor. An example rule of the prescreening module is shown in Table 1.

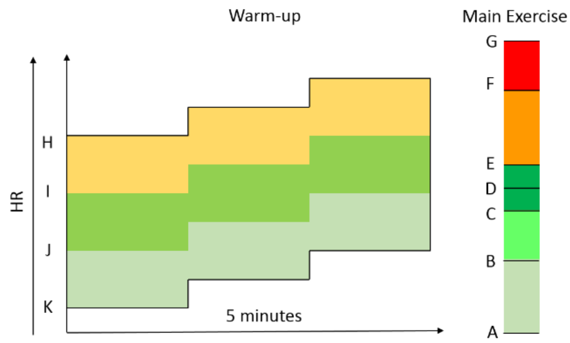

Figure 2. HR zones for different phases of exercise. The different colors represent different HR zones. The accurate limits are extracted as a percentage of the maximum HR based on the CPET [11].

Within the real-time DSS component, the accuracy of the patient's body movements (coordination) are determined relative to the movement of the virtual coach, as presented to the patient on their PC PATHway application. In this respect the accuracy is divided into three zones (low, medium and high) with predefined thresholds used to categorize exercise execution compliance. Additionally, the HR is divided into zones as depicted in Fig.2 [12]. Furthermore, the analysis of the HR is based on the thresholds of the least mean squares linear fit slope (W1/W2) which can imply a decreasing or increasing trend of the HR signal.

Table 1. Example DSS rules of the pre-screening (first row), real-time (second row) and off-line (third and fourth row) modules.

Rule Description	Condition	DSS action
Rule for checking if the patient didn't eat during the last 4 hours AND vital signs measurements are OK	If answer to question about eating during the last 4 hours, is NO AND systolic BP<180 AND HRrest <75% HRmax	Instruct patient not to start exercise before having a light meal
Rule for progressing to an exercise with higher intensity	If accuracy is medium/high AND [**(**HRmean<B**)** OR **(**HRmean>B AND HRmean<C AND slope<W1**)** OR (HRmean>C AND HRmean<D AND slope<W1) **]**	Increase exercise intensity
Rule for excluding specific exercise when HR value is high for more than 3 consecutive appearances of the exercise.	If exercise consecutive appearances >= 3 AND mean HRmean>F for the aforementioned sessions	Mark this exercise as excluded for the next 3 sessions
Rule to motivate patient when he/she is on track to meet the weekly goal near week's end	If (time is end of day 5 of the weekly exercise programme) AND SUM (session_durations) > 50% of weekly physical activity goal	Trigger message: "You have nearly reached your physical activity goal for this week. There are just two days left! You can do it!"

Table 2. An example of a web service operation provided by the real-time module of the DSS to progress to another exercise with higher intensity (rule shown in 2nd row, Table 1), and show a message to the patient.

Input JSON object	DSS response

{"targetHRzone": {
"high": 90, "low": 70},
"exerciseCumulativeAccuracy": 0.65,
"targetAcczone": {
"high": 0.7, "low": 0.5},
"vitalSigns": {
"hr": [65, 62, 64] }}
	{"result": "progression", "description": "While you performed the exercise correctly, your heart rate is still low. Let's move one level up now!"}

We used RESTful web services [13] to communicate the output of the DSS to other integral components of the PATHway platform such as the client PC application. REST is a popular way of communicating data between heterogeneous systems and building service-oriented architectures with emphasis on system scalability and interoperability. An example of a web service operation in terms of DSS inputs and outputs captured as JavaScript Object Notation (JSON) objects is given in Table 2.

4. Discussion

We presented the design and development of a system targeted at leveraging modern information technology and state-of-the-art sensors in the construction of the next-generation of cardiac rehabilitation programmes. These programmes are very likely to augment rehabilitation by providing rich, personalised and reliable information to the patients, thus facilitating their self-management and limiting the utilisation of costly healthcare resources. In this context the DSS system will be able to provide dynamic exercise sessions which are tailored to patient needs and performance characteristics, and help patients to maintain or increase their physical capacity and fitness.

Our approach constitutes the first step in the development of systems for CR with enhanced decision support. To this end, we focused on systematically addressing issues related to patient safety, individualisation of exercise programmes, and health behaviour change through the inclusion of rules in three distinct functional components, i.e., the pre-screening, real-time, and off-line components. The rules we have developed are based on clinical expertise and current best practice guidelines and recommendations.

Our future work involves the development of a richer rule-set in order to realise a more predictive, reliable, accurate, and effective system. These rules will enable us to predict compliance in exercise performance in terms of reaching the required accuracy and intensity level. Rules related to the tailoring of health behavior goals are also very important toward ensuring patients' adherence in reaching a healthy and physically active lifestyle. Therefore we aim to mine and associate health, psychological, behavioral, and social activity data to provide patients with personalised information which can help them accomplish their health targets. The DSS will be evaluated through validation of its outputs by clinical experts in a 6-month randomised controlled trial with CVD patients, which will enable us to assess the value of our approach in a real-life setting.

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