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CTASS: a framework for contextualized travel behavior advice to cardiac patients

Tooba Batool[a*], Yves Vanrompay[a], An Neven[a], Davy Janssens[a], Geerts Wets[a]

[a] *Transportation Research Institute (IMOB), Hasselt University, Diepenbeek, Belgium*

Abstract

Current cardiac rehabilitation programs intending to increase physical activity of patients suffer from a lack of knowledge about effective patient's activity profiles and their associated behavior. This leads to the fact that therapies are not completely tailored to the patient causing non-adherence to the proposed treatment schedule. An important potential for increasing the physical activity level of patients is available in their daily travel behavior that can be made more active. To validate this potential, we propose a Cardiac Travel Advice Support System (CTASS) digital framework for contextualized travel behavior advice to cardiac patients. The patient's travel behaviour is monitored by a smartphone application which objectify their daily activity schedules. The data from the schedules is analysed semi-automatically by the CTASS. Based on this analysis the doctor can provide a treatment that is personalized to the specific contexts of the patient. In this way, we try to optimize their travel-related physical activity and detect non-adherence to the therapy.

Keywords: Active travel behaviour, smart cardiovascular rehabilitation, physical activity level, travel behavior

1. Introduction

Cardiovascular diseases (CVDs) are considered the principal cause of the majority of global deaths. 17.5 million people die due to CVDs annually, which constitutes 31% of the global deaths[1]. CVDs are the set of diseases which are caused by the ailment in blood vessels and the heart itself. Risk factors of CVDs include obesity, physical inactivity, hypertension, dyslipidemia, alcohol, smoking cigarettes, social exclusion and aggression. Among the

[*] Tooba Batool. Tel.: +32 (0) 11 26 91 11; fax: +32 (0) 11 26 91 99.
E-mail address: tooba.batool@uhasselt.be

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other risk factors of CVDs, physical inactivity is an important factor. Physical inactivity has caused 3.2 million global deaths among the non-communicable disease patients, of which CVDs are considered a subset[2].

A recent study focusing on behavioural risk factors for CVDs identified physical inactivity as a significant behavioural risk factor for CVDs[3]. CVDs are controlled and treated by *"cardiac rehabilitation"* (CR) programs, which can help reducing morbidity and mortality caused by the disease. Cardiac patients need long term care after they had a cardiac event such as stroke or heart failure. A multidisciplinary rehabilitation program is introduced to improve the clinical and behavioural life of the patients to lead a better quality of life. These CR programs target the risk factors of CVDs in patients. An element that strongly influences the success of these CRs is the extent to which the patient continues the agreed upon mode of treatment, especially in the case of limited supervision. Therefore, non-adherence to the cardiovascular therapy is a serious contributor towards increased treatment costs and poor health prospects[4].

The importance of physical activity (PA) in primary and secondary prevention of CVDs demands to achieve a certain patient-specific level of active lifestyle. Physical activity for CVD patients is not necessarily limited to exercise and training sessions, but also refers to part of their daily routine work such as mowing grass, climbing stairs or bicycling, which are also called Leisure Time Physical Activity (LTPA). LTPA refers to discretionary time allotted to an activity which increases the energy expenditure[5]. The patients are recommended to attend CR programs regularly, however attendance still varies between 21% to 75% internationally[6]. CR programs mainly focus on dedicated exercise and training sessions, while patients remain sedentary in their other life routines. Persistent sedentary lifestyles in chronic patients have encouraged doctors to look at physical activity opportunities from a broader perspective. A potential for achieving a more active lifestyle can be found in the day-to-day displacements that people make and specifically in the associated travel modes of the trips. Moreover, travel behaviour data is not only useful to motivate people into active travel modes but also provides a unique opportunity of getting a deeper insight into the patient's sedentary lifestyle. This provides a treatment tailored and contextualized to the patient. To monitor, analyse and present the patient's daily routine (contexts like which trip they carried out at what time of the day and the duration), we propose a semi-automatic framework which will be able to support the key actors (patients and doctors) in achieving the travel-related active lifestyle.

Routine travel behaviour data generally includes six dimensions: 1) where? (location) 2) what for? (activity type), 3) when? (start and end time), 4) how? (transport mode), 5) with whom? (travel partner), and 6) for how long? (duration)[7]. The use of travel partner information has been proven that social interactions play an important role in mode choice and travel behaviour patterns[8]. These six dimensions constitute the daily schedules of an individual. The combination of this information along with other contextual information[9] (e.g. demographics, attitudes, norms and perceived behaviour) provides a rational understanding for sedentary routine in travel behaviour. This information can be used by the doctor to advice the patient to change his lifestyle.

The purpose of this research is to provide a smart CVD rehabilitation framework for increased active travel-related physical activity in the patients. For this purpose the daily schedules of a patient are first obtained in a way that does not burden the user through using smartphone applications (data collection). The data is processed in a semi-automatic advice support system which helps the doctors to prescribe a contextualized and personalized physical activity scheme taking into account the travel behaviour of the patients. In case of non-adherence to the prescribed therapy, the system allows to detect the deviation from the prescribed and agreed pattern. Travel data is gathered by a smartphone app, aggregated, analysed and visualized to the doctor by means of a web-based dashboard which is part of the Cardiac Travel Advice Support System (CTASS).

This paper is organized as follows. Section 2 gives an overview of related work, after which section 3 describes the different steps in the patient-doctor flow. Section 4 details the components and architecture of the framework, after which we conclude and discuss future work.

2. Related work

An integral part of CR programs is the assessment of the physical activity of patients. In the past this was mainly done by patient's self-reporting through questionnaires such as the International Physical Activity Questionnaires (IPAQs)[10], Global Physical Activity Questionnaire (GPAQ)[11] and Physical Activity Questionnaire for Older Children (PAQ-C)[12]. Physical activity level are also monitored by motion sensors such as accelerometers, which provide more objective measurements than questionnaires. However, such technologies also have some limitations.

The patients usually have to place the accelerometers on a proper position (hip) leading that it cannot distinguish between sitting and standing still and neither are able to give information on body posture[13]. More importantly, they provide only basic metrics without any contexts such as duration, time of the day, with who and which kind of activities they are performing.

Recently, smartphone apps which require minimal user intervention to provide rich information on patient physical activity, have increased their use in cardiology. Smartphone-based cardiac health provision is delivered in two ways: 1) outpatient and inpatient continuous multi-parametric sign monitoring, and 2) prevention of cardiac events through risk factor management apps (weight management, physical inactivity, blood glucose control, smoking cessation)[14]. Studies have proved the positive role of smartphone technologies in increasing the adherence of the patient to the proposed therapy and in providing more cost effective solutions. A meta-analysis by Park et al. concluded that text messaging, mobile applications, and tele monitoring via mobile phones effectively improved prevention and management of cardiovascular diseases. These studies also stressed the importance of personalized and tailored advice to maximally target CVD risk factors[15,16].

Indeed, exploiting ICT-solutions in capturing, analyzing and promoting physical activity offers substantial improvements in physical activity level. A recent meta-analysis concluded that patients who follow advice and support material on social media are more active. Smartphone apps and self-monitoring devices such as pedometers succeed in providing the means for feedback to the patient in the form of situation-tailored advice to improve the physical activity level[17]. Examples range from rather complex fitness gadgets such as Fitbit, Garmin, Mio Global and Samsung Gear Fit2 to smart phone apps such as RunKeep and Strava Running. Additionally, Paper-pen travel diaries are proved to adversely affect the data quality due to under-reporting of participants and they tend to have a high cost. A recent study by Safi et. al compared four technologies (web-based, H-tracker, S-tracker and ATLAS-II data collection methods) for travel surveys and concluded that smartphones provide better accuracy of data[18]. Many sophisticated systems have been developed so far to semi-automatically detect and record digital travel diaries, including FMS (Future Mobility Sensing), MoveSmarter, Sparrow and SmartMo[19–21]. Health apps (e.g. Moves) related to physical activity provide the information on most of the parameters (location, timing, duration and distance) of travel behavior. The remaining parameters (transport mode, activity type and travel partner) are obtained by our Moves connected app, described in section 3.1. Travel diary systems like FMS, MoveSmarter and Sparrow use web-based recall survey diaries which require explicit and rather elaborate input from the users. SmartMo records trips of a user but requires to manually start and stop a trip and provide trip information. We propose a novel integrated solution for objectively measuring the daily activities of patients and adding the needed travel related parameters using smartphone app in a way that requires minimal user input.

Until now, the integration of health and mobility has been rather limited in exploring the health impacts of active transport modes. Existing studies have focused on the following areas in integrating health and mobility: 1) policy-related measures like transportation goals and investments, 2) improving the built environment, e.g. road networks and accessibility[22], and 3) economic values, e.g. the health cost of motorized transport[23].

The fact remains that studies linking epidemiology and travel behavior lack in exploring complex causal relationships of contextual factors of patient lifestyles (day-to-day travel pattern/daily schedules). This contextual information provides insight into the less active lifestyle. In this way patients can be motivated to be more active in their lifestyle by agreeing on the advice recommended by the doctor. In this research we investigate the potential of integration of physical activity (which is objectively measured through an app) as a health factor and six dimensions of travel behavior in order to make patient more active in their day-today displacements.. The integration of socio-demographic information, personal attitude, norms and perceived health and travel behavior data is obtained through a framework which works as a digital cardiac physical health care advice assistant. This system will help in understanding the role of travel behavior parameters in increasing of the physical activity level of patients and realizing a flexible, patient-specific advice support system for doctors. The integration of travel behavior in CR program using a semi-automatic framework is a new perspective that potentially benefits achieving a certain level of PA.

3. Methodology

The CTASS framework described in section 4 will be integrated in the experiment which consists of the following stages:

1. We will recruit 200 Coronary Artery Disease (CAD) patients from the cardiology centre of our partner hospital. After getting the approval from the ethics committee, we will obtain demographic information, baseline health parameters, attitudes, norms, perceived behaviour and household information through an online survey. The data from this questionnaire will be saved in the data repository as explained in section 4.3.
2. Travel behaviour monitoring of the patients with using smartphone app will be carried out for at-least 3 weeks for the first period (retrieving data on six travel behaviour parameters). Patients have to annotate their information on the smartphone app on a daily basis. The smartphone app will send notifications each two days if there are some missing values present in the data. The data will be uploaded automatically to the server on regular time intervals. The patient identities are coded and the information retrieved from the smartphone application will be anonymised for research purposes, but the doctor will be able to identify the patients.
3. After the data is stored on the server, analysis and generation of reports starts. The system will know the patients identity and it will combine the survey information of that patient with the smartphone data. By combining survey data and travel parameters the automatic reasoner learns the heuristics, aggregates the data and generates the initial reports. The initial reports will assess the baseline physical activity level in travel behaviour. The patients will visualize this on their smartphone screens and doctors will see the reports on the web- based dashboard management system.
4. After patients receive the reports, an interactive feedback session between patients and doctor will be held. The doctor (physiotherapist) will discuss the aggregated physical activity level in travel behaviour, leading to contextual and customized advice taking into account different scenarios with patients.
5. After the interactive session (recommendation of advice) the patient will be asked to monitor his travel behaviour again for a second period (3 weeks at least). Monitoring of travel behaviour for first period, interactive session and monitoring for second period will take place simultaneously during the CR program which continues for 3 months. It will be complementary for the patients to continuously monitor the travel behaviour for the duration of the CR program (3 months).
6. The CTASS framework will perform a comparative analysis on the data before and after the interactive session to observe the resulting changes in patient’s lifestyle.
7. The patients will be advised to continue monitoring for a minimum 6 month period so that this data can be used for the development of the automatic advice reasoner. This reasoner will be developed based on contextual information and heuristic rules which will lead to the automatic identification of potential trips that can be substituted by active travel modes and the generation of advice based on contextual parametric information.

4. Components of the CTASS framework

This section provides the general overview of the components and stages that take place in CTASS framework. The following section will explain how data is collected then analysed and how that data can be used in motivating the patients to be more active.

4.1 Data collection: Health for travel behaviour (HTB) app

Baseline information of patients about demographics, health parameters, attitudes, norms, perceived behaviour and household information is gathered through an online survey. The Health for Travel Behaviour (HTB) app is developed for the study to connect to the physical activity app (Moves) to obtain complete overview of patient’s travel behaviour as mentioned in section 2. Parameters required in the app for travel diaries are based on National Household Travel Survey (NHTS) 2009, United states and OVG 5.1, Belgium. The HTB app collects the information of patients on transport mode, activity type and travel partner. Moves (the existing) app is leveraged as a state-of-the-art activity tracking system which provides information on activity and trip duration, activity location and transport modes. Information on parameters such as travel partner and activity purpose cannot be retrieved from Moves directly. Moves can provide information on walking, cycling and motorised transport modes. However for a motorised transport mode, the user needs to manually enter the exact information (car, bus, …). Manual annotation in Moves is not needed for the study as this information is obtained through the HTB app along with other two parameters (activity type and travel purpose). The HTB app together with Moves forms a complete digital travel diary that provides detailed (objectively measured) information using no custom device except for a smartphone. There is no need of web-based recall surveys and we include detailed measurements of all transport modes in a trip segment. This information is important for the study to keep track of physical activity levels achieved during the travel plan of the patient. The information is then sent to the data repository of the CTASS framework for processing. User interaction with the HTB app is illustrated in Figure 1.

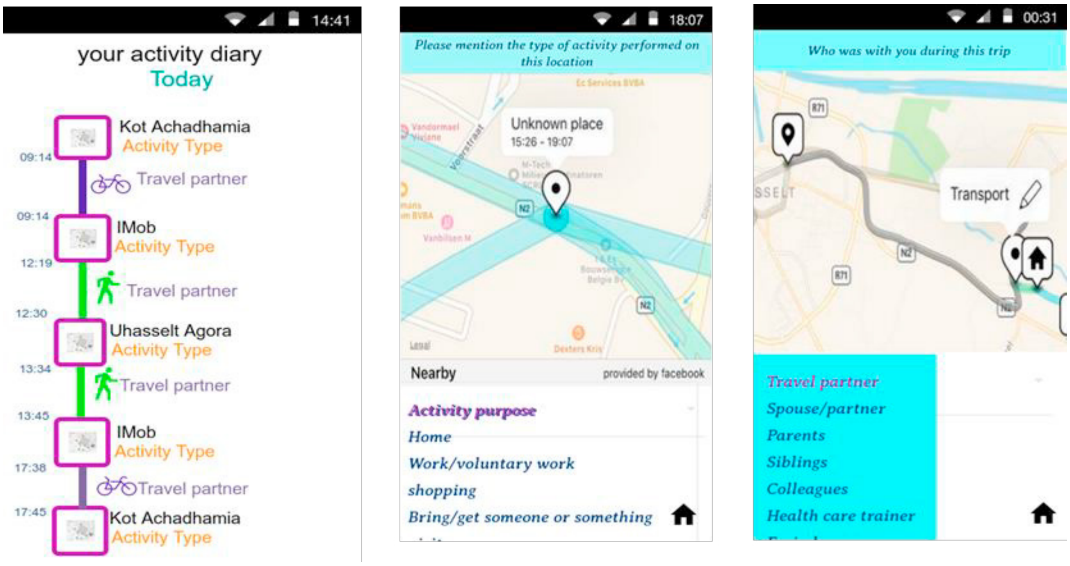

Fig. 1 User interface in HTB

4.2 Data analysis and visualization

Travel data is aggregated in the form of socio-demographic subgroups. These subgroups constitute personalised heuristics taking into account the behavioural profiles based on recorded travel behaviour. The aggregated health parameters of the initial report includes the total number of trips, trips by each mode, trips by the range of their physical intensity, distance covered by each mode and intensity, corresponding Metabolic Equivalents (METs) (Compendium, 2011) and the duration spent on each trip on daily and weekly basis.

After processing of the patient's information, the doctor is able to look at the reports on web-based visualizing tool. However, Patients get their personalized reports on their HTB app. Afterwards, in an interactive session, patient and doctor will together discuss and agree upon changes in the patient's travel behaviour to be more active. Patients will then be advised to monitor their schedules again in the second period of the study and the CTASS will inform the doctor about (non-) adherence to the revised active travel behaviour therapy. Furthermore, the framework will continue learning the information about underlying travel behaviour parameters (six dimensions) and contextual factors which will result into the automatic generation of advice. This will identify automatically the specific trips with their properties and recommend the potential substitution of transport modes (from car to bike) for trips based on doctor advice and contextual heuristics.

4.3 Cardiac Travel Advice Support Service Architecture

This section gives an overview of the architecture of the Cardiac Travel Advice Support Service (CTASS). The framework is developed to be open, generic, pluggable, easily extendable and configurable. As can be seen in Fig. 2. An API is provided which allows for third-party apps to connect to the system and act as information providers. The CTASS can also itself connect to the API of external branded health parameter sensors to get health data from devices like blood pressure meters and motion sensors. Typically a brand will push a notification to the CTASS

("Notification Listener") that new data is available, after which the data is pulled by calling their API. The HTB app (a Moves connected app, as described in the previous section), is one of the different health information providers plugged in to the CTASS. The HTB app will regularly post its collected data to the server, transparently for the user, when a known Wifi connection is available. The type of information provided by a plugin component is specified in XML together with a set of rules such that the "Data Preprocessor" and the "Intelligent health reasoner service" know what the data is and how to process it.

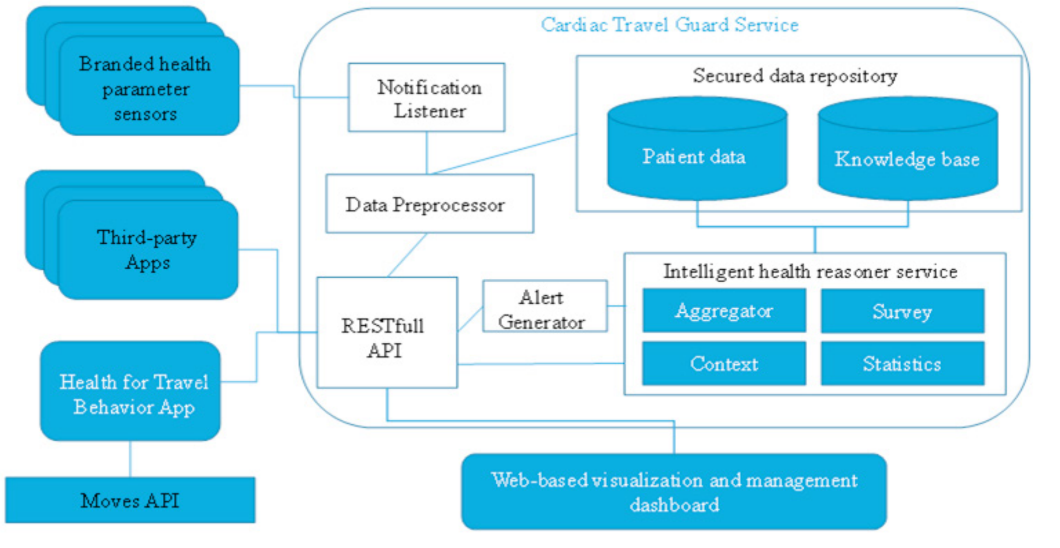

Fig. 2 Architecture of CTASS

After the received patient data is preprocessed automatically to treat missing values by the data preprocessor component, it is stored in a database in a secure data repository. The database resides in a private cluster only accessible by the CTASS service, and personal data is scrambled such that measurement data cannot be linked to specific patients. This repository also contains demographical data about the patients, health parameter specifications and patient contextual data which is obtained through filled-in questionnaire. The "Intelligent health reasoner service" aggregates this data on a regular basis, produces statistics and adds contextual information and survey info to that statistics. If a patient's health parameter is not within a (configurable) range, a warning is triggered by the "Alert Generator". This warning can trigger pushing a message to the patient's HTB app to ask the patient for the context in which the alert was received so that the doctor can assess its severity.

Aggregated information and statistics of each patient are presented to the doctor by means of a "Web-based visualization and management dashboard". This allows the doctor to get an in-depth insight into the physical parameters and travel behavior of each patient and CTASS acts as a decision support and advice system to tailor and adjust the treatment to the specific context of the patient.

5. Conclusions and future work

In this research, we propose a digital framework (CTASS) for contextualized travel behavior advice to cardiac patients. Patient travel behavior is monitored by an app, objectifying the activity of a patient. Behavior is analyzed semi-automatically by means of a smart decision support system that helps doctors in providing a treatment that is personalized to the specific contexts (e.g. daily activity routine and demographic etc.) of the patient. In this way, travel related physical activity is optimized and non-adherence to therapy is detected.

The system at this stage offers only advice about the physical activity level of patients during their trips but its architecture is generic and pluggable. Information from other external sensors and medical apps can be plugged into the system in order to extend the patient monitoring to cover additional relevant risk factors. For instance information from a heart rate monitor can also be integrated in the framework to continuously compare the evolution in cardiac health through an increase in active travel activities and other fitness activities during CR programs.

A group of patients is currently being gathered to start conducting the study. With the CTASS architecture in place, our first research challenge will be to investigate the combined effect of travel behavior determinants on health parameters (physical activity). In the second phase we will try to optimize physical activity generated by travel but including underlying contextual factors of patient profiles (demographics, household interactions, daily utilities). A patient-doctor feedback mechanism through the interactive CTASS framework will effectively incorporate contextual changes to the proposed therapy. Once patient-tailored feedback is given, patients will be monitored again to evaluate the effectiveness of the personalized therapeutic advice on their physical activity level. If the experiments show an increase in physical activity level in travel related trips, the system will be extended with more intelligent learning mechanism. These reasoners can support the notification to the patients if they deviate from the agreed advice pattern from doctor. This will help home-based self-monitoring CR programs and can result in an improved adherence rate to the CR programs.

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