Cognitive Human Factors for Telemedicine Systems

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Abstract

The recent integration of telephony systems with information and communication technology (ICT) enables us to design tools for building innovative telemedicine systems. The dissemination and widespread acceptance of telephony-based care monitoring systems poses challenges on how to take into account the psychological and social factors involved in the patient-physician interaction, and how they should shape the technological solutions. The paper proposes a model that describes the impact of socio-cognitive factors in the complex process of health care management. it has been to design and develop a telephony system for the management of hypertensive patients within the EU funded Homey project. Tthe knowledge contained in a widely accepted guideline for the care of hypertension has been represented and augmented through the proposed cognitive model. The final product is an intelligent system able to manage an adaptive dialog with the patients aimed at increasing their involvement in the management of their health status. This is achieved by promoting self-care through frequent virtual encounters which complement traditional face-to-face encounters with the caring physicians.

Keywords: health communication, telemedicine, ontology, self-efficacy, user satisfaction, hypertension.

Introduction

Hypertension is a diffused chronic health problem affecting about 20% of the adult population in the western countries. The aims of management of hypertension are to improve quality of life and prevent complications, decreasing mortality and morbidity. The most recent international guidelines for the management of hypertension focus on the direct patients' responsibility for their own health and treatment through their compliance with respect to modification of lifestyle and adherence to medication regimen. Unluckily, it is estimated that only 50% of hypertensive patients adhere to medication regimens well enough to bring their blood pressure within recommended limits [1]. In part, this is due to a poor management of patients' health education and frequent monitoring of therapy effects. Patients affected by essential hypertension, in fact, should be monitored frequently to acquire information about their blood pressure, heart rate, types of physical activities, and occurrence of any side effects, etc. To improve patients' compliance and the overall quality of medical service, we are carrying on a study which aims at understanding the mechanisms behind patients' adherence and the psycho-cognitive factors that could influence it, in order to develop a telemedicine system able to complement traditional face-to-face encounters with the caring physician. The recent integration of telephony systems with ICT enables, in fact, the design and development of innovative telemedicine systems.

Following the motivations presented above, in the E.U. funded project "Homey" we built an intelligent telephone-based dialog system to monitor patients with essential hypertension through an effective cooperation between them and their physicians [2]. We decided to improve the system performance by integrating into the dialog user-system interaction modes based on cognitive, behavioral, and emotional theories of behavioral change. Such an extension will provide direct benefits: the dialogue will be centered on user needs (improving understanding, decision making support and interactivity, and thus the overall patient satisfaction); the system will improve therapy outcomes and patient overall quality of life, reducing morbidity and mortality (shared decision and tailored communication improves compliance and adherence to medication); the system will decrease costs of health care (developing a framework to examine failure in health communication; considering the potential of e-health communication strategies; optimizing health communication to decrease costs of intervention).

Theoretical Foundations

Literature indeed stresses the importance of considering the cognitive structures and processes of the user (see, for instance, [3-5]). As defined by the World Health Organization (WHO) in [6], in fact, health is not just the absence of disease or infirmity, but rather "a state of complete physical, mental, and social well-being": a vision which embraces the perspective developed in some psychological theories, which deal with the problem of the subject and his behavior. For the design of our system we are currently taking into consideration three theories of behavior adoption: The Social Cognitive Theory (SCT) [7], the Health Action Process Approach (HAPA) [8], and the Trans-Theoretical Model (TTM) [9].

Social Cognitive Theory

SCT is a behavioral prediction theory that describes how health behavior change may be fostered. The reason why SCT is important for developing telemedicine systems is that it postulates that behavior change is determined by the reciprocal determined nature of *person*, *behavior*, and *environment*. It suggests to direct therapeutic and counseling efforts to all dimensions of personal (improving emotional, cognitive, or motivational processes), behavioral (increasing competencies and skills), and environmental (altering social conditions, allocating resources) factors. The main idea of the theory is that self-reflective skills play a critical role in people's capability to construct and understand reality, self-regulate, encode information, and perform behavior. Among the relevant factors, the central construct of SCT is *self-efficacy*, which is "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances ([7] p. 391)", the most important self-regulatory skill in mediating between knowledge and action.

Healt Action Process Approach

HAPA elaborates SCT, by synthesizing it with features from volition theory [10]. It suggests that it is possible to represent SCT constructs in a causal process model involving two main phases: the *motivation* and the *volition* phases. In the motivation phase, the individual forms an intention to either adopt a precaution measure or change risk behaviors in favor of other behaviors. The volition phase describes how hard people try and how long they persist in the chosen behavior.

Trans-Theoretical Model

TTM integrates current behavioral status with a person's intention to maintain or change his pattern of behavior, and it is focused on the decision making of the individual. It allows to identify several *stages of change*, from pre-contemplation, the stage in which there is no intention to change behavior in the foreseeable future, to maintenance, goal behavior has been achieved and in which should be working to consolidate gains and prevent relapse. The states represent ordered categories along a continuum of motivational readiness to change and adopt a behavior. Each stage identifies and acts on particular variables, ranging from *consciousness raising* to *stimulus control*, in order to modify behavior.

We will enhance Homey using the mentioned theories, to center it on users' needs, and to improve users' understanding, satisfaction and adherence to the medical regimen proposed by the caring physician. Hence, first we will isolate, from the mentioned theories, several interesting predictors, to build a cognitive model which will inform the process of dialog design. To make the system fully automated we will then develop an explicit conceptual model of the involved domain knowledge: the information represented in a widely accepted guideline for the care of hypertension will be structured according to the variables identified by the proposed cognitive model.

Assumptions for a Cognitive Model

Figure 1 shows the cognitive model we developed. It constitutes the cognitive foundation which aims at understanding and how knowledge, personal cognitions and behavior interacting in the complex self-regulation process of health care action, for building intelligent dialog systems.

The model includes three categories of entities: cognitive entities (white boxes), clinical entities (diagonal stripes), and situational entities (dotted). The clinical entities are used to describe how the state of a pathophysiological system (for instance, the cardio-circulatory system) could be modified in order to achieve the expected health outcomes (managing hypertension to attain a lower blood pressure). We are interested in understanding how the proposed theoretical constructs interact in the process of health care decision making, so that we will be able to intervene on different variables, to advise the patient and to guide him to adopt a healthy lifestyle.

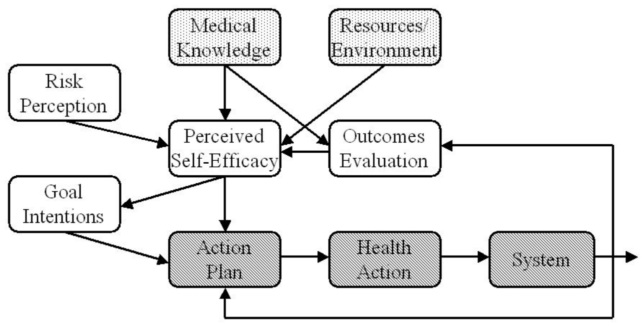

Figure 1 – The proposed disease self-management model

Several assumptions justify the model we developed, which describes the *mutual influences* among the components of the disease self-management model. The variables identified by the model are responsible for shaping up the behavior.

Assumption 1: *performing an action should be preceded by making explicit goal intentions and setting a proactive planning*. People cannot act if they don't have a motivation and do not know what they want to achieve. Setting up goal intentions is not sufficient. Intentions should be transformed into instructions (goals and sub-goals) before executing the desired action.

Assumption 2: *goal intentions and actions are strongly influenced by perceived self-efficacy*. Self-efficacy centrality is based on the assumption that people's behavior depends largely on their beliefs to operate as active agents. As people proceed from shaping up a behavioral intention, contemplating detailed action plans, to actually performing health behaviors, they begin to crystallize beliefs in their capabilities to initiate a change.

Assumption 3: *awareness of one's own situation is the obvious prerequisite for activating the entire process*. Under the label of "risk perception" we grouped several theoretical constructs, such as *risk perception*, *outcomes expectancies*, and *behavioral capabilities*. These factors are directly responsible of raised awareness in the complex process of clinical negotiation.

Assumption 4: *environment and collective knowledge are inevitably related to self-referent beliefs and action evaluation*. Medical counseling, social support and resourse allocation and availability may affect the way people understand, perceive, and modify situations.

We have identified several predictors which we have kept into consideration in the design of Homey system. We will apply them in the way described in Table 1.

Table 1 – Application of behavioral predictors to Homey

Predictor	Application to Homey
Self-efficacy	To increase patients' perceptions of their self-efficacy, Homey encourages and helps patients in setting achievable goals and sub-goals.
Education	Homey repeatedly informs the patients on: • risk factors and negative outcomes; • improvements derived from adhering to prescribed regimen; • suggestions on how to incorporate these desirable behavioral patterns into their daily lives.
Reinforcement	System investigates patients' adherence to regimen. Patients receive praise and encouragement for being adherent to the medication regimen.

Architecture of the System

This section will give a sketch of the operation of the telephony-linked system which we used as a prototype to test the ideas described in this paper (Figure 2).

The system is backed by a comprehensive Electronic Health Record (EHR). Two actors may enter clinical data into the health records: in the first place, the physician uses a conventional (graphics, keyboard and mouse) interface to store and update patient information. On the other hand, the patient is also allowed to enter the data that he can acquire at home by himself and transfer them to the care-providing centre, by the means of a telephone. Physicians, in fact, instruct their patients to periodically call a dedicated telephone number; when they do so, they engage in a dialog with the system, which talks and interacts with them to acquire clinical data, monitor their style of life and investigate the efficacy and adverse effect of prescribed therapy.

The call is handled by a computerized call center, which answers users' calls and passes the task of the interaction to a *dialog manager*. The dialog manager contains a series of prescriptions for handling the call: the user is first authenticated with a numeric password. The dialog engine then reads a *state vector*, which is a set of data, associated to each patient, which encode his health state and other associated information: age, sex, prescriptions, outcomes of previous encounters, pending laboratory tests, etc. Next, the interaction with the user is carried on in accordance to what is encoded in both the dialog description and the state vector.

The system relies on speaker-independent automatic speech recognition provided by ITC-irst [11]. The dialog manager contains the associations between the various dialog steps and the corresponding grammars, which are activated in turn to recognize user's utterances. Grammars explicitly define the set of sentences that the user is expected to pronounce at each dialogue step. The automatic speech recognition (ASR) component of the system tries to match the audio signal sampled from the microphone to the closest sequence of words allowed by the grammars active at a given time.

The domain knowledge necessary to accomplish the interaction, according to the proposed architecture, could be integrated into the system, either having it built-in into the dialog system (hand-coding it into each dialog step) or, in a more complex scenario, extracted at run-time from an external source. The following section describes one way we propose to develop the second solution and represent the knowledge contained in a widely accepted guideline for the care of hypertension, structured according to the theoretical framework introduced in the previous section.

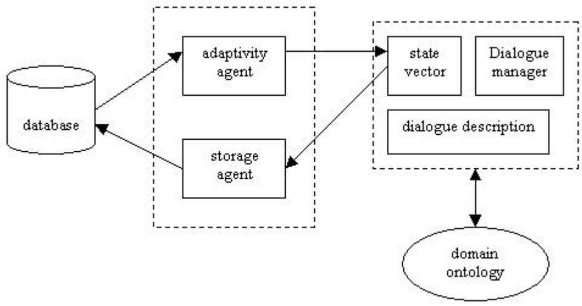

Figure 2 – Architecture overview. The ontology interacts with the data acquisition module in order to direct the system.

Managing Hypertension Through Cognitive Factors

The guidelines for hypertension management developed by the European Society of Hypertension [12] suggest that the appropriate treatment of a hypertensive patient must take into account factors influencing total cardiovascular risk, and not just the blood pressure values. Blood pressure together with secondary risk factors, in fact, determines the prognosis and the subsequent therapy. Hence we must treat all the modifiable risk factors identified. Achieving such a goal will engage the patient in two directions: adherence to medication, and modification of his lifestyle. The original prototype of Homey has been designed to monitor adherence and side effects. The new system, developed according to the theoretical foundations we introduced, can manage an incremental dialog with the patients, managing their health status and counseling them about their clinical condition.

To improve the "intelligence" of the system is the introduction of a conceptual model of the domain knowledge involved. The knowledge represented in a widely accepted guideline for the care of hypertension has been structured accordingly to the cognitive predictors identified. Using the Protégé knowledge-base editor [13], we developed an ontology to make the system "aware" of the tasks it assigns to the patient, to improve system adaptability and to promote patient empowerment.

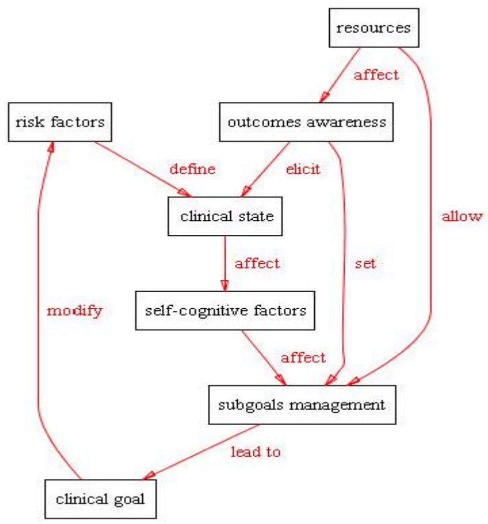

Figure 3 – The ontology which integrates best-practice guidelines knowledge and cognitive factors makes the system "aware" of the situation

Figure 3 represents the high level concepts represented in the ontology on which the dialog management is based on. *Risk factors* are described according to a medical ontology which represent the most important factors that may influence patient health (smoking, age, target organ damage, associated clinical condition, etc.). They will be used to organize the dialog into different context-specific modules. To evaluate a patient's clinical state, the system will therefore integrate different knowledge sources: a) the classification of hypertensive conditions developed by the European Society of Hypertension, which allows us to classify patients into different risk classes and helps us to select the most effective treatment plan; b) an algorithm based on the risk stratification classification for total cardiovascular risk described in the WHO/ISH guidelines [14] and the Framingham risk model [15-16].

As described in Table 1, *outcomes awareness* and *self-cognitive factors* also directly influence the dialog management: according to TTM the dialog will address particular issues according to the readiness state of the patient. In its first stage, for example, the dialog will instruct the patient about his medical condition and the importance of modifying his behavior in order to achieve healthy outcomes; then it will provide information on how to achieve feasible sub-goals (also considering available resources and user preferences), and how to persevere with them, providing reward and efficacy support.

Enhanced Structure of the Dialog

At the start of each telephone call the system identifies the user by asking for password. It then loads his personal history stored in an electronic health record (EHR). In this way, according to what we said in the previous section, the system assigns the patient to a clinical state. The history can be built by analyzing data collected during both virtual encounters and face-to-face encounters. In the latter case the physician is asked to enter patient data in the EHR. Hence, the system proceeds by asking the user data needed for monitoring the time course of his clinical history and assessing the present clinical situation and risk. The system closes the evaluation process by asking the patient for contingent collateral symptoms, which could be due to particular medications or to a worsening of his conditions. The system will then manage the second part of the dialog, related to secondary affecting factors, according to evaluated patient state.

Building awareness

The following is an example of interaction with a patient and of how the system can manage the dialog (within brackets the cognitive predictors system addresses). What we are trying to avoid is to encapsulate patients in a mechanical sequence of pre-designed questions-answers, which can discourage them, avoiding compliance.

System: Please, say your weight.

Patient: my weight is 90 kilograms.

System: your weight has increased by 3 kilograms since last call. I would like to remind you that your physician prescribed a particular diet and physical regimen. It is important for your health that you follow it [*reinforce*]. Relating to your weight condition, have you some problems with doctor <doctor_name> recommendations? [*education*].

At this point in the dialog, the system is working inside the specific context of factor influencing clinical state: weight. Thus it is able to query the ontology about factor influencing weight (eg. diet, physical exercise, etc.), setting the grammar (expected spoken input from patients) and the set of possible answers. The required information relations can be inferred from the domain-specific relation between entities, states and events discussed.

Patient: physical activity.

It is fundamental to supply the patient with those information he should understand to improve his awareness in order to get adherence to and benefits from treatment.

System: doctor <doctor_name> prescribed you regular physical activity because regular exercise improves mental and physical well-being. For example, why don't you start from a 10 minutes walk? [education]. I'm sure you can manage it. [self-efficacy]. Walking for 10 minutes a day may help you in acquire perseverance in physical activity. Don't you think?

Patient: ok!

System: good! Glad to hear it! [reinforcement]. Start from 10 minutes, then try if you can take longer walks [self-efficacy].

A similar mechanism can be repeated for any kind of issue the system is designed to interact with (medication regimen, smoking, physical exercise, diet, etc.). This strategy is primarily derived from TTM, and aims at guiding a patient, through recommending and monitoring actions, from a pre-contemplation stage to adopting a healthful behavior. The dialog ends with a "plan memorandum", which aims at reminding the patient what he has discussed during the dialog. Conversation content aimed at counseling and educating the patient is distributed among several calls to avoid too long calls.

7. Conclusions and Future Directions

We have proposed to improve an existing telemedicine system to make it a knowledge-based telecommunication tool that functions as at home health monitor, disease management counselor and educator. We proposed to enhance such a system by taking into consideration psycho-cognitive theories of health behavior. Central is also the integration into the system of a conceptual model of the domain knowledge involved. It allows us to represent relevant knowledge taken from an international guideline based an ontology interpretable by the system. The new system provides a health telecommunication service which is more interactive, empathetic. Moreover, it facilitates the patient empowerment in self-managing his/her health problem. According to several studies [17], this helps in promoting patients' adherence to physician recommended medical treatments.

Acknowledgments

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