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Remote Health Coaching for Interactive Exercise with Older Adults in a Home Environment*

Holly B. Jimison [Member IEEE],

College of Computer and Information Science at Northeastern University, Boston, MA 02115
USA. Phone: 617-373-2381

Stuart Hagler, Gregorij Kurillo,

Department of Electrical and Computer Engineering, University of California, Berkeley, CA,
94720, USA

Ruzena Bajcsy [Life Fellow IEEE], and

Department of Electrical and Computer Engineering, University of California, Berkeley, CA,
94720, USA

Misha Pavel [Senior IEEE Life Member]

College of Computer and Information Science at Northeastern University, Boston, MA 02115
USA. Phone: 617-373-2381

Holly B. Jimison: h.jimison@neu.edu; Gregorij Kurillo: gregorij@eecs.berkeley.edu; Ruzena Bajcsy:
bajcsyg@eecs.berkeley.edu; Misha Pavel: m.pavel@neu.edu

Abstract

Optimal health coaching interventions are tailored to individuals' needs, preferences, motivations, barriers, and readiness to change. Technology approaches are useful in both monitoring a user's adherence to their behavior change goals and also in providing just-in-time feedback and coaching messages. User models that incorporate dynamically varying behavior change variables with algorithms that trigger tailored messages provide a framework for making health interventions more effective. These principles are applied in the described system for assisting older adults in meeting their physical exercise goals with a tailored interactive video system with just-in-time feedback and encouragement.

I. INTRODUCTION

The ability to address behavior-related research questions is timely because of the increasing cost and complexity of healthcare due to dramatically changing demographics in the United States. By 2050, the number of older persons (over the age of 65) will increase by 50% with profound implications for healthcare and social investment [1]. One of the goals of coaching is the modification of personal behaviors to achieve health goals (e.g. weight control, smoking cessation, cognitive functionality, etc.). The starting point for the development of an approach to modify patients' behaviors is taken from prior work on behavior

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modification. Several models from the health psychology literature exist [2], but as is highlighted in the diagram in Fig. 1, there is consensus on the following:

- Cognition and behavior go hand-in-hand: what people know and think affects their actions
- Most behavior changes require new knowledge, but knowledge alone won't be sufficient to cause change
- An individual's social environment has an important influence on his/her behavior

In routine practice, coaches generally use motivational interviewing techniques to determine an individual's motivations to change, barriers and triggers to those barriers. Additionally, many coaches assess a patient's readiness-to-change a particular health behavior in order to tailor a message or information provided. This approach is based on the trans-theoretical model of behavioral change[3,4]. This model characterizes the process in terms of five discrete stages representing various states of readiness-to-change behaviors that would lead to the desired health outcomes. These stages are used to characterize the ability of the patient to change in response to the messages encouraging the modification of the behaviors. Readiness-to-change has been characterized by the following five discrete states:

1. *Pre-contemplation* - "people are not intending to take action in the foreseeable future, usually measured as the next 6 months"
2. *Contemplation* - "people are intending to change in the next 6 months"
3. *Preparation* - "people are intending to take action in the immediate future, usually the next month"
4. *Action* - "people have made specific overt modifications in their lifestyles within the past 6 months"
5. *Maintenance* - "people are working to prevent relapse," a stage for health behaviors which must be continued throughout life"

Based on this framework, the approach to facilitate a behavioral change consists of assessment of the state of the individual, and then generating messages (suggestions) that are deemed to be the most appropriate to affect a change in the patient's state. Prior to the recent work on cognitive coaching [4], the state of the individual has typically been determined by an interview or a questionnaire, and as such it is contaminated by various subjective effects such as biases and memory lapses. Thus, the determination of the optimal intervention has been limited by this suboptimal state estimation process and by the subsequent inability to tailor these messages to the specific metrics of performance.

II. QUANTITATIVE MODELING FRAMEWORKS

Using a system-theoretic approach, the development of optimal coaching strategies will require a mathematical characterization of the systems in terms of its inputs, outputs, states and the rules describing state transitions. To describe the behavior of an individual in our coaching scenarios we use a multistate approach comprising three levels and three g three different aspects of the older adults' behaviors:

1. Modeling the relationship between physical movements and cognitive processing such as gait, pointing or coordinated movements such as in dancing. We have demonstrated that seemingly simple actions such as pointing with a mouse is indicative of cognitive functionality.
2. Modeling of the relationship between the performance, e.g., decisions that a person makes playing computer games and the underlying cognitive processes. An example of this is a characterization of performance on the game of concentration in terms of a model of working memory. This model can be used to assess the effectiveness of cognitive exercises on the individual's instantaneous cognitive state.
3. Modeling the readiness to change – the most influential determinant of successful coaching is the ability to assess the state of the older adults with respect to his motivation to change. As discussed in detail below, the individual's state combined with his or her activities should determine the optimal coaching messages and the rate of progression.

Using these models for inferences regarding the health state of the individual we deployed a coaching platform to help the older adult participants to improve their performance by encouragement and guidance. The models combined with the unobtrusively collected data from the activity level and computer games informed the coach about likely state of the participants. In order to estimate the patient state we integrated interview responses with behavioral metrics. Given an estimate of the participant's state, we attempted to optimize the intervention to maximize the expected progress towards the mutually agreed goals between the coach and the patient – thus transitioning towards the “Maintenance” state.

The ability to optimize the machine-generated coaching messages and suggestions requires a detailed description of the state transition model shown in Fig. 2. This model is similar to that described by Visser [10] and more recently by Seto and Bajcsy [11], but it differs in fundamental ways. In particular, this model to be useful must incorporate a number of observations from prior coaching practice including the following:

- At any time, an individual is in one and only one of the six mutually exclusive states.
- The states are strictly ordered in terms of the readiness to change.
- The state transition process can be represented in discrete times, for example on daily or weekly basis, to be determined empirically.
- The state transitions are not deterministic and must, therefore, be represented by probability distributions of the corresponding random process.
- The probability of transiting from one state to another (moving forward or regressing) depends (1) the current state and (2) on the intervention messages from the coach.
- Without intervention the individual will, over time, more likely regress to a prior state.

- The probability of transitioning to the next state *depends* on the time spent in the current state.
- The performance and functionality is independent of the readiness-to-change state.

These observations suggest that although there are six discrete states, the underlying process is not Markov. For example, the transition from a given state to the next one actually does depend on how long the participant remained in the current state. As a result, this process is at best consistent with a semi-Markov model in which the distribution of the dwell times in each state is not exponential but requires that we postulate a distribution on a positive real interval [12] that would be consistent with the observed data. The state transition model in Fig. 2 also differs from a traditional Markov chain because the transition probabilities are influenced by the coaching instructions. For example, a successful coaching session would increase the transition probability from the “Contemplative” to the “Preparation” state.

III. HEALTH COACHING PLATFORM

The approach we have taken in implementing a health coaching platform that incorporates these principles of health behavior change is outlined in Fig. 3. The information flow between modules of the system highlight the inference used for specifying a dynamic user model. Initial input on health status, preferences and health behavior change variables are obtained at baseline with an interview by the human coach (via videoconferencing). Current estimates of these variables, as described earlier, are updated based on sensor data from the home providing information on patient state, context, activities, and adherence to goals. These new estimates may then trigger alerts (patient, family, or coach) and generate tailored messages. The messages are generated using concatenated selected phrases based on the current estimates of user goals, motivations, barriers, health state, adherence level, etc. The messages comprise a tailored greeting, feedback on previous performance, recommendations, encouragement and a closure statement. The messages are generated as coming from a human health coach with whom the user has already developed a relationship, however, the coach also has the ability to further edit the messages if needed before they are sent.

We currently have coaching modules for interactive physical exercise (using the Kinect camera), cognitive exercise (based on our adaptive computer games), sleep management, and socialization exercises. The focus of this paper is on the coaching approach to using health behavior change and computational modeling to delivering an interactive video system for remote coaching of older adults in the home.

IV. PHYSICAL EXERCISE INTERVENTION PROTOCOL

Exercise and exposure to unique stimuli are thought to improve cognition and delay the onset of dementia [13,14]. The mechanism for most lifestyle influences on cognitive health appear to be due to cardiovascular effects [14]. In that sense, recommendations for heart health should improve cognitive function as well. Physical activity probably has the most important influence on cognitive health; aerobic exercise has been shown to increase cortical capillary flow and has significant short-term effects on patients’ executive functioning

[16,17]. Our physical exercise protocols are designed to include sufficient variability and customization to keep participants engaged in aerobic exercise over a full year. We allow participants to choose their starting point for a physical exercise goal each week. Our clinical experts generally advise clients to start out with 15-minute sessions and work toward a goal of exercising at least 30 minutes a day, five days a week. The general advice is to begin with moderate exercise and gradually increase intensity until it is as brisk as possible (still be able to carry on a brief conversation). The protocols for physical exercise are initially set and tailored by medical personnel on the project. In our intake interviews with the current participants enrolled in our pilot field test, we discovered that several participants had been advised not to do walking exercises (due to arthritis or diabetes complications) but had other recommended activities instead. Our clinical experts ensure that our physical activity protocols cover the spectrum of needs of our participants.

V. OLDER ADULTS' EXPERIENCES WITH INTERACTIVE VIDEO EXERCISE

In earlier field tests of the health coaching platform with 40 older adults living independently in their homes [13] we used YouTube videos of chair exercises as the main component of our physical exercise intervention. The advantage of these videos were that they were readily available and free of charge. We could also monitor the use of the videos easily to obtain a level of adherence throughout the week for each participant. Additionally, we had motion sensors in each room that could detect actual activity during the time the video was playing. However, a disadvantage was that we would not be able to provide just-in-time feedback and make physical functioning measurements. This led us to develop an interactive video system using the Kinect camera. The contribution was that we could use the Kinect's skeleton representation to measure the movement of users in real time. The Kinect camera is capable of capturing color and depth images with 30 frames per second (fps). In our architecture the joint positions provided by the Microsoft Kinect camera software allow us to measure the following: (1) the performance of each exercise, (2) measure repetitions of the exercise, and (3) compare goal states to actual performance. The processing of the raw skeletal data is performed in real time, and this allowed us to generate tailored messaging to provide corrections or congratulatory feedback. To quantify the performance of each exercise, we first extract measurement primitives from the skeletal data, i.e., joint angles, angles relative to the vertical or horizontal plane, distances, and absolute positions. Additionally, we used embedded estimates of balance (based on center-of-mass estimates), strength, endurance and flexibility to monitor changes in physical functioning over time. Each of these features are important for feedback in coaching.

For our first iteration of the interactive video exercise system, we installed the computer with the image analysis software and video exercise system, including the Kinect camera in four homes to test participant use (at least 3 times per week) over a period of 2–3 weeks. We tested our ability to collect data, analyze results, and monitor activity over time. After improving interface and video content we conducted another pilot of the system in 8 homes. The study participants were selected from a pool of subjects of the Oregon Center for Aging & Technology (ORCATECH) Living Lab at Oregon Health & Science University [18] who were also enrolled in a health-coaching program. A total of six independently living elderly subjects (2 male, 4 female) participated. All the subjects were White with a mean age 81,

ranging from 74 to 91. The selection criteria included the ability to (1) speak and read English, (2) understand and follow instructions, and (3) ambulate without any assistive devices. All the participants had normal or corrected vision and none of the participants had any known health problems that would prevent them from using the designed system safely on their own.

The purpose of this pilot study was to test the usability, engagement and adherence to exercise goals. We used the Senior Fitness Test [19] and the Berg Balance Scale [20] as our standard clinical measures of performance and used these to validate our metrics. We were able to maintain adherence to the exercise goals for most participants, however there were many usability issues in initiating the program. Lessons learned related to 1) needing to switch from a computer monitor to using participants' digital TVs as displays, difficulty in finding sufficient room in participants homes, and challenges in the use of multiple remote control devices as people switched from the exercise system to the TV and back. We also found that even though our participants were fairly old (74–91 years of age), they all were in fairly good shape and topped out on the Berg Balance Scale. To show improvement in balance and a decrease in fall risk, we may need to select patients with initial balance problems.

VI. CONCLUSION

Physical functioning is one of the most important health goals, affecting nearly every other health issue. This is especially critical for older adults, who often have difficulty in accessing conventional exercise classes. Remote coaching technology paired with new developments in interactive video offerings provide a promising approach for delivering much needed physical exercise health interventions.

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Figure 1.
Framework for health behavior change

Figure 2.
A diagram of the transtheoretical state transition model.

Figure 3.
Information flow for the health coaching platform.

Figure 2. Sample display of the interactive video exercise system. The therapist demonstrating the exercises is shown in the center and the Kinect camera's skeleton representation of the user doing the exercise is shown on the right.