A Computer-Assisted System with Kinect Sensors and Wristband Heart Rate Monitors for Group Classes of Exercise-Based Rehabilitation

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Abstract

Exercise-based rehabilitation for chronic conditions such as cardiovascular disease, diabetes, and chronic obstructive pulmonary disease, constitutes a key element in reducing patient symptoms and improving health status and quality of life. However, group exercise in rehabilitation programmes faces several challenges imposed by the diversified needs of their participants. In this direction, we propose a novel computer-assisted system enhanced with sensors such as Kinect cameras and wristband heart rate monitors, aiming to support the trainer in adapting the exercise programme on-the-fly, according to identified requirements. The proposed system design facilitates maximal tailoring of the exercise programme towards the most beneficial and enjoyable execution of exercises for patient groups. This work contributes in the design of the next-generation of computerised systems in exercise-based rehabilitation.

Keywords

Exercise • Rehabilitation • Computer-assisted systems • Sensors • Kinect

Introduction

Chronic conditions such as cardiovascular disease (CVD), diabetes, and chronic obstructive pulmonary disease, require daily self-management and optimal adherence to treatment plans in order to reduce symptoms and improve health status. Exercise-based rehabilitation has been proven to be a core component of effective chronic disease management, resulting in reduced morbidity and mortality and improved cardiovascular and respiratory function as well as quality of life [1]. Group-based exercise programmes offered in the community, constitute a common treatment approach [2].

A shortcoming of the currently provided group-based exercise programmes is the lack of proper support to the trainer/instructor to allow optimal tailoring of the exercise programme. The trainer instructs exercises to a group of patients based on his/her expertise along with received visual or verbal feedback, and adapts the exercise session to the average patients' performance. However, the trainer has no access to objective quantitative information regarding the performance of individual participants in a class, thereby

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limiting the potential of fine-tuning the programme to maximise its effect on the individual patients' physical status. Consequently, adherence of patients to group-based exercise programmes might be limited due to the lack of tailoring to the patients' capabilities and needs. When a patient stops exercising on a regular basis, he/she is driven to the loss of gained cardiovascular benefits and the reduction of his/her functional capacity [3]. In this context, new computer-assisted services in exercise-based rehabilitation may attract patient interest and gain wide uptake.

In this paper, we demonstrate an approach to optimal exercise programme adaptation in patient groups by means of a computerised and sensor-enhanced system. In this regard the aim of this paper is to: a) demonstrate the structure and most important parameters of current exercise programmes according to current guidelines, along with associated challenges, and b) propose a design of a novel computer-assisted and sensor-enabled system, also highlighting directions for future research.

Exercise Programmes

Goals and Structure

Exercise programmes including aerobic exercises supplemented with resistance exercises, are recommended by international guidelines [4], to maximise health benefits for chronic patients. More specifically, these programmes are typically performed 3 times per week in a controlled environment (e.g., specialized rehabilitation centres, gyms, etc.), under the supervision of experts in exercise-based rehabilitation (trainers). The programme typically targets a specific patient group (e.g., patients with CVD), lasts at least 30 min, and consists of a series of exercises of different intensity and difficulty.

The effectiveness of exercise-based rehabilitation programmes largely depends on four exercise characteristics, namely Frequency, Intensity, Type, and Time (FITT) [5]. As such, a main goal of the programme is to guide patients to exercise within their target heart rate zones ("Intensity" characteristic in FITT), which play a key role in effective exercise performance [4]. Beneficial heart rate zones can be formulated based on the results of a cardiopulmonary exercise test (CPET), by which both resting heart rate and peak heart rate are identified. Perceived exertion and enjoyment should also be considered when structuring exercise programmes [6, 7].

Fig. 1 Patient group performing exercises instructed by a trainer in an exercise-based rehabilitation programme

An exercise session (Fig. 1) is divided into 3 separate phases: (a) the warm-up phase which targets a gradual heart rate increase, preparing the body for the execution of more intense exercises, (b) the main phase which corresponds to the main components of an exercise session, and (c) the cool-down phase which targets at a gradual transition from exercise to rest.

The different exercises of the programme ("Type" characteristic in FITT) are chosen by the trainer according to his expertise, the health status of the average participants and received visual or verbal cues. Overall, the trainer decides on the intensity of the exercise class based on the history of workouts ("Frequency" and "Time" characteristics in FITT) by the group and the condition and ability of the participants. Optimally, the trainer proposes a variety of exercises involving all body parts (legs, arms, trunk, etc.), with different levels of intensity and difficulty. For example, an exercise with low intensity (e.g., "walking on the spot") could be chosen during warm-up/cool-down, or after a series of exercises with high intensity (e.g., "jumping"). The trainer can also change the level of intensity or difficulty (e.g., exercises requiring balance or coordination of different body parts), if he/she notices discomfort, exhaustion, difficulties or dislike to be present in one or more participants.

Challenges

In current exercise-based rehabilitation in a group setting, a number of barriers preclude its effectiveness in optimally improving patient physical status and health condition. In brief some of these barriers are:

(a) *Lack of personalization*: Due to the fact that the programme is targeted at a patient group, there is an inherent problem of programme individualisation according to one's specific needs. In this respect, the trainer may instruct exercises which are not performed in the correct form by all participants due to fitness level, motor impairments, health problems, etc. Following the same rationale, an instructed exercise might be disliked or might be causing overexertion in some participants, depending on personal characteristics.

(b) *Lack of quantification*: The trainer mainly relies on his expertise and experience to adapt an exercise programme without support from important quantified feedback during an exercise class. In this respect, the trainer has no sign of whether a patient's optimal heart rate zone is reached, or whether he/she is adhering to the exercise form, and enjoys the training session.

(c) *Group statistics*: The trainer has no feedback on the overall group's performance (e.g., heart rate dynamics, motion accuracy, perceived exertion, etc.) and progress during an exercise session. This limits the possibility of taking the proper actions in terms of beneficial adaptations of an exercise class according to the FITT principles.

Proposed System Design

We propose a novel system (Fig. 2), based on the experience gained from the PATHway system for exercise-based cardiac rehabilitation at home [8, 9], which can help to overcome current barriers in exercise-based rehabilitation. More specifically, we propose a system consisting of the following components:

(a) *Motion tracking*: Kinect cameras target at capturing motion during exercise, which has been proven to be effective in the context of rehabilitation [10]. In this way motion accuracy can be evaluated via appropriately applied algorithms [11], which is important from kinesiology viewpoint for the safety and health of the participants. A Kinect sensor points to the trainer to recognise the selected exercise (based on a pool of available exercises in the system). Following exercise recognition, motion accuracy is detected for all group participants with separate Kinect sensors. Then, an overall average motion accuracy score for the group can be calculated for each individual exercise and displayed to a projector screen. The trainer can use this information to evaluate whether or not it is needed to emphasize on exercise execution by providing key instruction points or adapting the speed of the execution, especially for those who experience difficulties.

(b) *Heart rate monitoring*: Heart rate is monitored through Bluetooth-enabled wristband heart rate monitors worn by the participants. The accuracy of such devices has been reported in previous work [12]. The target heart rate zones for each individual are identified during system initialization before an exercise session starts, and based on CPET. During exercise, the trainer is enabled to view in the projector screen whether participants have reached their target heart rate as an overall percentage. This allows the trainer for example to change the exercise intensity when the percentage is low (e.g., less than 50%).

(c) *Exercise type monitoring*: The trainer is enabled to view the duration of the type of exercises already performed (aerobic, resistance, exercises for different muscle groups), and can decide on the type of exercise which patients should focus on.

(d) *Exertion and enjoyment monitoring*: The addition of push buttons to the wristband heart rate monitor can allow patients to easily indicate levels of exertion and/or enjoyment. The participant feedback in terms of perceived exertion and enjoyment can subsequently be viewed in the projector screen and the trainer can adapt the exercise session accordingly.

The proposed system is easy to set up. Each Kinect sensor is connected (via USB) with a laptop computer to enable motion recognition and heart rate monitoring in each

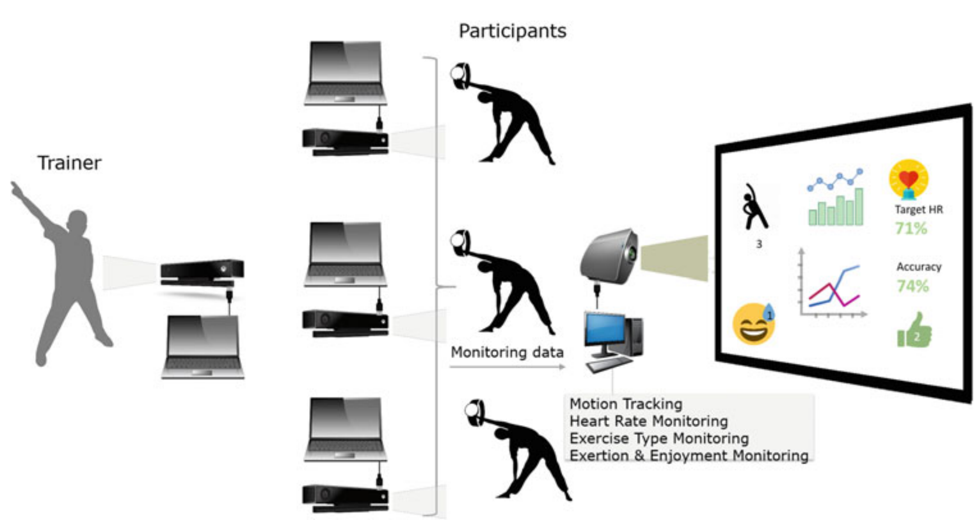

Fig. 2 System architecture utilizing Kinect sensors, wristband heart rate monitors, laptops, a projector screen and a central computer to process monitored data

participant. The Kinect should be placed in a distance 2 m - 3 m from the patient. The heart rate monitors connect via Bluetooth communication technology with the laptop computers. Motion and heart rate data from each patient are analyzed in terms of accuracy and intensity. Finally, all monitored data (heart rate, motion accuracy, self-reports of enjoyment and exertion) are transmitted via a LAN or Internet connection to a central computer which is responsible for data aggregation, processing, and display to a projector screen.

Discussion

Performance monitoring during exercise training with computer-assisted systems has been the focus of research presented e.g., in [13, 14], but only motion accuracy or steps were received as objective indicators of performance. In other systems, performance indicators included target heart rate, e.g., in [15], but only a single type of activity (i.e., cycling) was monitored. In [16], both accelerometry and heart rate were used to quantify personalised performance during exercise, but the focus was on outdoor activities and motion capturing was not applied. Therefore, to the authors' knowledge, the presented system which combines heart rate monitoring with motion accuracy tracking for group exercise-based rehabilitation is the first of its kind.

Future work could focus on the development of computer-assisted systems which are not only able to quantify the actual performance, but also able to predict the performance of the patients in an exercise session, in order to suggest adaptations to the exercise class and assist the trainer with decision making for programme optimisation. The usability of the proposed system for both patients and trainers needs to be investigated in future studies [17]. The feasibility and effectiveness of the described system could be explored in a clinical trial, in comparison with "traditional" group exercise-based rehabilitation.

Conclusions

We presented the design of a computer-assisted system for optimization of group exercise-based rehabilitation classes in a controlled environment (e.g., a gym) under supervision of a trainer. The system will empower trainers to provide more effective exercise programmes according to patient needs, based on quantified feedback on exercise performance and progress. As such, this work contributes to the development of the next-generation of computer-assisted systems targeting at better health management in the community.

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Conflict of Interest The authors declare that they have no conflict of interest.

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