Development of an Integrated Virtual Group Training System for COPD Patients

Jonathan B. J. Dikken[1], Bert-Jan F. van Beijnum[1], Dennis H. W. Hofs[1], Mike P. L. Botman[1], Miriam M. Vollenbroek-Hutten[1,2] and Hermie J. Hermens[1,2]

[1]*Institute for Biomedical Technology and Technical Medicine (MIRA), University of Twente, P.O. Box 217, 7500AE Enschede, The Netherlands*

[2]*Roessingh Research and Development, Roessinghsbleekweg 33b, 7522AH Enschede, The Netherlands*

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Abstract: COPD patients experience a downward spiral of fear for breathlessness, inactivity and social isolation which leads to a bad physical condition. Motivation to keep patients compliant to their training scheme is a key factor in home-based exercise training. This paper presents the Integrated Training System for COPD patients; a home based virtual group exercise system to facilitate improvement of the exercise capacity safely at home using a virtual group environment. The four components of the system are the *Home Trainer*, the *Virtual Exercise Environment*, the *Web Portal* and the *Controller*. These components are implemented in a prototype. An in-training evaluation was performed to evaluate the subsystems used during a training exercise. All subsystems are working correctly during the evaluation. In this paper the focus for the Integrated Training System is on COPD patients, but the system might be used for other groups such as Chronic Heart Failure patients or elderly people in general.

1 INTRODUCTION

Chronic Obstructive Pulmonary Disease, a common disease characterized by persistent airflow limitation, is one of the leading diseases in many countries which will grow to the 4th largest cause of death in 2030 (Global Initiative for Chronic Obstructive Lung Disease, 2013; Mathers & Loncar, 2006). In 2007 in the Netherlands 323.600 people, about 2% of the population, were diagnosed with COPD. These figures are comparable to the surrounding countries (Rijksinstituut voor Volksgezondheid en Milieu, 2010).

The downward spiral of breathlessness fear, inactivity and social isolation leads to a bad physical condition (Global Initiative for Chronic Obstructive Lung Disease, 2013). To overcome this downward spiral patients can be enrolled in a pulmonary rehabilitation program (PRP) which improve the exercise capacity (Croitoru et al., 2013; Nici et al., 2006; Shahin, Germain, Pastene, Viallet, & Annat, 2008). However, most benefits deteriorate after the rehabilitation program is finished (Egan et al., 2012; Gosselink, 2002; Karapolat et al., 2007; Nici et al., 2006; Spruit, Troosters, Trappenburg, Decramer, & Gosselink, 2004).

Maintenance strategies can retain the effects of a pulmonary rehabilitation program. Du Moulin et al. shows that home-based exercise training is effective as maintenance of the exercise capacity (Du Moulin, Taube, Wegscheider, Behnke, & Van Den Bussche, 2009). Also Beauchamp et al. showed a significant improvement of the exercise capacity with a community based maintenance exercise program (Beauchamp, Francella, Romano, Goldstein, & Brooks, 2013). Motivation to keep patients compliant to their training scheme is a key factor in home-based exercise training.

This paper presents a home-based virtual group exercise system to facilitate improvement and maintenance of the physical condition of COPD patients. In this paper we focus on the technical design of the system and the medical case it should cover. The system should cover all important aspects of home-based exercise training: means to do the training, motivational support and professional guidance. Therefore we call it the *integrated* training

B. J. Dikken J., F. van Beijnum B., H. W. Hofs D., P. L. Botman M., M. Vollenbroek-Hutten M. and J. Hermens H..
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system (ITS). The goal of the system is to facilitate improvement and maintenance of the physical condition of COPD patients safely at home using a (virtual) group environment. This will reduce disabilities in activities of daily living (Garcia-Aymerich et al., 2003; Tak, Kuiper, Chorus, & Hopman-Rock, 2013).

In *Backgrounds* relevant training aspects, motivation aspects, adherence aspects and existing exergames will be given. After the *Design Considerations* are explained, the *Architecture* of the ITS will be drawn. The *Implementation* will be tested in the *Evaluation*. With *Discussion and Conclusion* this paper will be finalized.

2 BACKGROUNDS

2.1 Training

Different opinions exist about the use of either power training or endurance training as the most suitable method to improve the physical capacity (Puhan, Schünemann, Scharplatz, & Bachmann, 2005). Studies have conflicting outcomes on which training intensity and method gain the best results, however all studies suggest an improvement of the physical capacity by physical training (Global Initiative for Chronic Obstructive Lung Disease, 2013; Gosselink, 2002; Korczak, Huber, Steinhauser, & Dietl, 2010; Puente-Maestu et al., 2000; Rijksinstituut voor Volksgezondheid en Milieu, 2010). The type of exercise should correspond as much as possible with the activities of daily living. Cycling, walking and walking stairs are the most suitable exercise forms.

To be effective, a training session should be intense enough. The optimal heart rate is between 60 and 80 percent of the maximal heart rate (Global Initiative for Chronic Obstructive Lung Disease, 2013; Janssen, 2001). With 60-80% of the maximal heart rate a patient will train in the aerobic zone. Staying in the aerobic zone for the whole training is not mandatory, but the total amount of time in the aerobic zone determines the efficiency of the training.

2.2 Adherence and Motivation

The above results regarding physical training for COPD patients have been used by the KNGF, the Dutch physical therapist association, to develop the therapeutic guideline for COPD patients (Gosselink et al., 2008).

The lack of therapy adherence of COPD patients is a known problem with physical exercises (Nici et al., 2006). Therapy adherence can be increased by enjoyment and social interaction (Ryan, Frederick, Lepes, Rubio, & Sheldon, 1997). Burke et al conducted a meta-analysis of 44 studies to qualify the effect of the setting of the training (Burke, Carron, Eys, Ntoumanis, & Estabrooks, 2006). Four categories where defined: home-based training without involvement of third parties, home based training with consultation (e.g. by phone), center-based training and center based training with additional attention for group dynamics. A superior result was found in groups with a high social cohesion among the participants in comparison to normal center-based training and home-based training with consultation. The latter two had a superior result in regard to individual training without involvement of third parties. One can conclude that both good group dynamics as professional consultation result in a better therapy outcome.

Social motivation theories can help in increasing therapy adherence. One social motivation theory is social support, which is associated with how networking helps people cope with stressful events and enhance psychological well-being and can be categorized in appraisal, companionship, emotional, instrumental and informational support (House, 1981; Sonderen, 1991). Another theory is the social comparison theory which includes competition, cooperation and normative comparison between members of a groups (Janssen, 2001). These theories will be used in the implementation of the Integrated Training System.

2.3 Existing Exergaming

Several professional and consumer exergames are used for improving the physical condition of patients. Professional products include the Cybex Trazer, LightSpace, and Sportwall. Consumer products include the Sony PlayStation (with Dance Dance Revolution), Nintendo Wii and Xavix (with J-Mat). The energy expenditure with these 6 systems are comparable with the energy expenditure of walking (Bailey & McInnis, 2011). The Cybex Trazer, LightSpace, Sony PlayStation with DDR and Xavix are based on moving to specific positions. These four systems require non-continuous dynamic movements. Such movements are unsuitable for COPD patients because injuries can occur. Measuring and controlling the intensity of the non-continuous dynamic movements is difficult. The

Sony PlayStation with DDR supports multiplayer sessions at distinct locations. The other systems don't support virtual groups where users play at distinct locations and can see each other. Social interaction is limited when players are at distinct locations.

With Sportwall a player should hit specific positions on a wall with the hand or a ball. This system requires non-continuous dynamic movements as well. Because it is a professional product it is unsuitable to put at patients' homes. This system lacks the possibility to train in virtual groups and thus the possibility for social interaction.

Wii Sports include five simulation games which can be controlled by arm movements: baseball, boxing, bowling, golf and tennis. A precise motor system is important to use the described systems. Also this system has the disadvantages of non-continuous dynamic movements.

A system more tailored to the need of elderly people is the Espresso Bike in combination with the NetAthlon riding software. This system was used in a randomized clinical trial in older adult cognition (Anderson-Hanley et al., 2012). It has a simple user interface and doesn't require very fast responses from the users. The training intensity is accurately controllable by changing the resistance of the bike. The intensity can be measured accurately. The system focus on cognition aspects and the improvement of the physical condition is a side issue.

For COPD patients a system is needed that is safe, has a low risk for injuries, can measure and control the intensity accurately and support social interaction.

None of these systems are built for – and suitable for accessible physical exercises at home for elderly people. None of the systems use a virtual group environment to support social interaction for the enhancement of therapy adherence.

3 DESIGN CONSIDERATIONS

Cycling on a home trainer was chosen, because a home trainer is well known for COPD patient from rehabilitation programs and can measure and set the training intensity. Using the home trainer at home increases the accessibility of the system. The ability to control the power by changing the resistance contributes to the safety of the system.

- A virtual environment will be used to be able to have a group setting at home. In the virtual environment patient can train and interact with each other.
- The oxygen saturation level should be above 90% during training sessions to prevent desaturations.

Requirements were elicitated from a literature review, observations of PRPs and interviews with physiotherapists and movement therapists using a scenario and the People-Activity-Context-Technology (PACT) framework (Huis in't Veld et al., 2010). A detailed description of the design process is given by Dikken et al. (Dikken, 2012; Dikken, van Beijnum, & Hermens, 2013).

4 ARCHITECTURE

The ITS (Integrated Training System) is divided into four components: the *home trainer* (HT), the *virtual exercise environment* (VEE), the *controller* (C) and the *web portal* (WP). The home trainer is an ergo bike with some additional sensors, the virtual exercise environment is a computer game in which a patient can cycle together with other patients and the controller ensure a safe and efficient training by collecting and analyzing data from the home trainer and giving feedback. The controller sends the physiological and exercise data to the web portal. On the web portal this data is shown. The overview of the architecture is shown in figure 1.

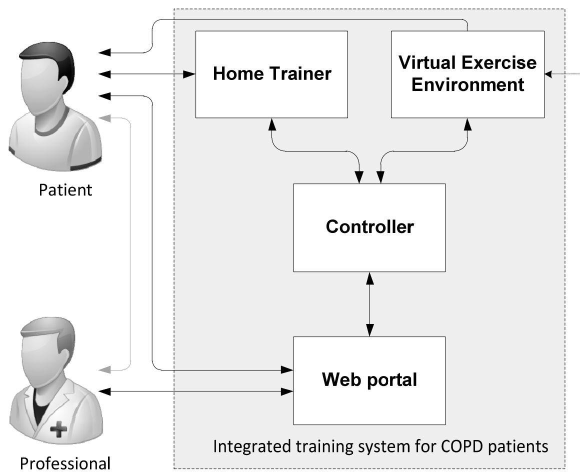

Figure 1: High level architecture of the Integrated Training System.

Users of the ITS are COPD patients and their supervisors, the physiotherapist. Patients use the whole system, while the physiotherapists only use the web portal component.

4.1 Home Trainer

With the home trainer patient can perform physical activities. On the home trainer the training intensity can be controlled and patient data is acquired. Patients will experience force feedback from the home trainer.

The home trainer component contains all sensors and actuators of the system. Quantities that need to be measured are power, cadence, heart rate and oxygen saturation level. This component consists of a home trainer, a heart rate belt and a pulse oximeter.

4.2 Virtual Exercise Environment

The virtual exercise environment (VEE), showed in figure 2, provides motivation during a physical training. The VEE is essentially a computer game in which multiple players can cycle in the same virtual environment. The avatar of a patient cycles with a speed that reflects the performance of the patient in the virtual environment, but the users are kept close to each other to up keep the group spirit during the whole training.

Several motivation theories are implemented, which is explained in the next section. Each session is a game in which the patient who cycles with the best performance will win the game (social comparison – competition). The performance is calculated by how close a patient cycles to his individual goal. Players are motivated when they cycle together in the virtual environment and can see each other (social support – companionship). When a patient fails to cycle with a similar performance of the other group members, he will slow down a get in the back. To prevent a player to drop out because he is too far behind, that player will get a boost to keep up with the other group members. The boost will stop when the player gets close to the other group members to prevent disturbance of the competition.

Figure 2: Virtual Exercise Environment.

During training all interaction with the user is provided by the VEE, except for the force feedback by the home trainer. The interaction of the VEE includes a user interface with an overview of the important measured values, such as power and heart rate and an overview with the current performance.

4.3 Web Portal

The web portal (WP) provides after-exercise motivation: patient can retrieve their progress, set and monitor personal and group goals and give feedback on training results of group mates. Also the portal is used to give the physiotherapist insight in the training progress and configure the system.

After a training session both the patient and the professional can see a summary of training on the web portal. This includes a good indication of the performance with a mark and important events such as overperformance, underperformance and possible desaturation events during the training. A screenshot is shown in figure 3. Patients can review each other's performance (figure 4; social comparison – competition and cooperation) and give feedback through messages to motivate each other (social support – companionship and emotional support). The professional will use the training summary to give advices.

A group of patients has the goal to reach each individual goal (social comparison – cooperation). The patients can compare themselves to a patient who is performing well (social comparison – normative comparison). Informational support (social support) is given by sharing patient stories with how they cope with the disease.

A detailed description of the web portal including design rationale and the design process is given by M. Botman (Botman, 2013).

4.4 Controller

The controller monitors and guides the safety and performance during a training session and facilitates data exchange between all components. For the safety and performance three control modules are used: the *performance loop*, the *safety loop* and the *positioning system*. The controller has several interface modules to connect to the other components. A design overview is shown in figure 5.

Important measured data, such as power, heart rate, oxygen saturation level and performance, is send to the web portal by the controller.

All modules, both interface modules as control

Figure 3: Web Portal - Training result page.

Figure 4: Web Portal - Patient profile page.

modules, use a data bus to exchange real-time data. With a data bus the controller is highly flexible. Modules are not aware of each other's existence and can be added, removed, updated and replaced easily. Different execution frequencies are possible, enabling usage of sensors with different sample.

4.4.1 Performance Loop

To facilitate improvement of the physical condition a training session needs to be effective. This is handled by the performance module. The performance is calculated to be able to give visual feedback on the performance and to adapt the resistance of the home trainer.

Based on the current power (P_c) and the target power (P_{target}), which is set in the web portal, the performance is calculated as shown in equation (1). The result is a dimensionless value between 0 and 1,

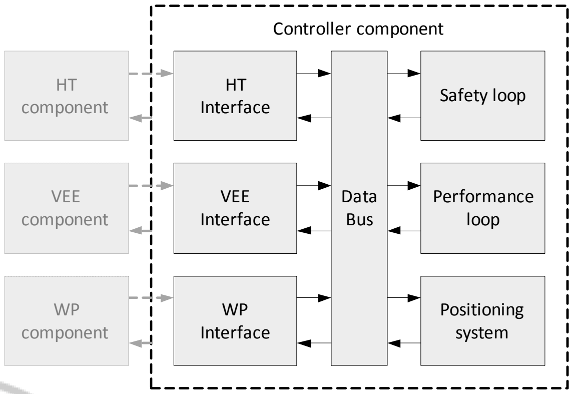

Figure 5: Modules of the Controller component. HT: Home Trainer, VEE: Virtual Exercise Environment, WP: Web Portal.

where 1 indicates the best possible performance and 0 the worst possible performance.

$$performance = \begin{cases} \dfrac{P_c}{P_{target}} & if \quad P_{target} > P_c \\ \dfrac{P_{target}}{P_c} & if \quad P_{target} \leq P_c \end{cases} \tag{1}$$

The speed for the VEE is calculated based on the performance and the configured maximal speed constant (v_{max}) as shown in equation (2).

$$v_{VEE} = v_{max} * performance \tag{2}$$

4.4.2 Safety Loop

The safety is handled by the safety module. The safety module has three different states based on the measured oxygen saturation level (SpO_2). The SpO_2 is compared with a desaturation threshold as shown in equation (3). The desaturation threshold is set in the web portal. The status is stored for the configured interval, for example 60 seconds. Based on the status values the saturation state is determined and the corresponding feedback is executed, as shown in table 1.

$$\text{Status} = \text{SpO}_2 > \text{Desaturation Threshold} \tag{3}$$

Table 1: Saturation state in safety module based on saturation status shown in equation (3).

Status values	State	Feedback
All true	Good	Continue normally
Some true	Warning	Patient is urged to slow down and intensity is decreased
All false	Bad	Training session is terminated

The target power is decreased in case of the warning state. As a result the performance loop will lower the training intensity by lowering the resistance of the home trainer.

4.4.3 Positioning System

Part of the motivational support is handled by the positioning module. As mentioned above patient are kept together in the virtual exercise environment. When a patient gets too far behind the player in front he will get a boost to prevent the patient from getting farther behind. For this equation (2) is extended with the speed correction factor (SCF). The new formula is shown in equation (4). The SCF is a value between 1 and 20. The farther a patient gets behind, the larger the SCF value.

$$v_{VEE} = v_{max} * performance * SCF \qquad (4)$$

5 IMPLEMENTATION

The four components described architecture is implemented in a prototype:

- HT: Bremshey BE5i home trainer with a polar T31 heart rate belt.
- VEE: WebAthletics cycling game running on an Asus ME301T Android tablet with a 22” LG 22EA53VQ monitor placed in front of the home trainer.
- C: Developed in Java and is running on the same tablet as the VEE.
- WP: Developed on top of the Liferay Portal, running on a dedicated server.

The Bremshey BE5i has a 32-step servo motor to control the resistance, the gear. To support patients with cycling at the right performance a controller module is built to set the gear based on the performance. When $P_c/P_{target} < 0.6$ for 5 seconds the gear is shifted up. When $P_c/P_{target} > 1.25$ for 5 seconds the gear is shifted down.

6 EVALUATION

The evaluation was performed with 4 healthy subjects, cycling in separated rooms in the same multiplayer session. Each subject was instructed to cycle as close as possible to the given target power. During the training session all relevant parameters were recorded (time, power, cadence, heart rate, speed in VEE, gear, distance, relative distance, target power, performance and SCF). The relative distance for each player is the distance between the player and player in front. Performance, relative distance and cadence are shown in figure 6. After the training session subjects were asked to fill in a short questionnaire.

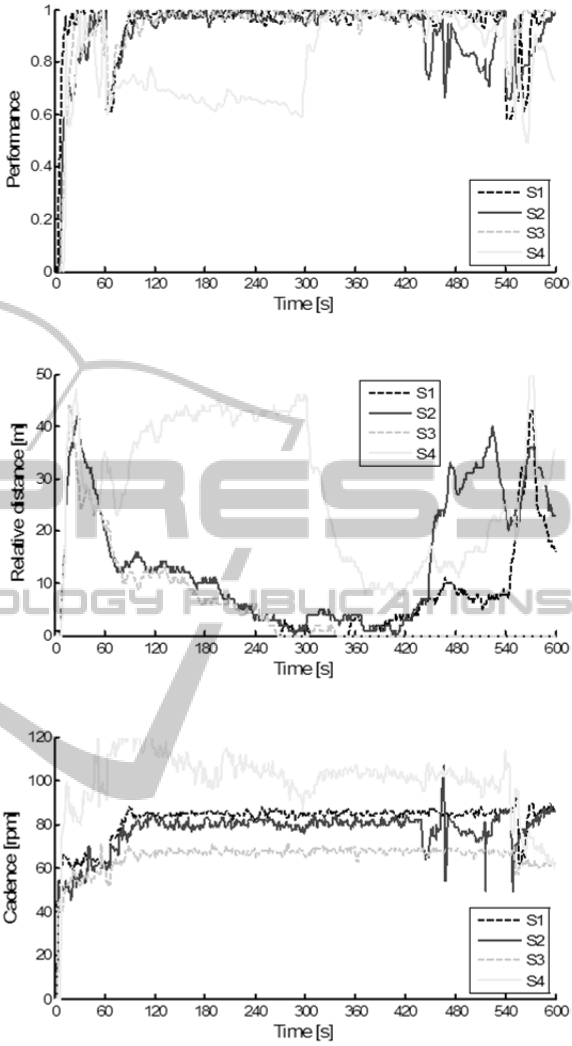

Figure 6: Performance, Relative Distance and Cadence of the four subjects during the exercise.

Results from the evaluation are shown in table 2. The distance between all players is small (min: 0.0 m, mean: 13.1 m, max: 51.0 m), while the performance for subject 4 was suboptimal. The performance was calculated from the recorded power and target power. This is compared with the recorded performance. The average deviation is less than 0.1%.

6.1 Control Modules

With a suboptimal performance of one of the subjects the distance control module managed to keep all subjects close to each other in the virtual

Table 2: Evaluation results.

Subject	S1	S2	S3	S4	All
Relative distance (m)					
Min	0	0	0	0	0
Mean	4,3	14,2	5,4	28,3	13,1
Max	43	42	44	51	51
Performance					
Mean	0,95	0,91	0,95	0,80	0,90
Performance deviation					
Mean	0,003	0,000	0,002	-0,001	0,001
Standard deviation	0,058	0,064	0,050	0,068	0,060

environment. The distance control module worked correctly during the training. Also the performance control module worked correctly. A small deviation exists between real-time calculated performance and the calculation afterwards. This might be caused by a small delay in the power value used in the real-time calculation.

6.2 Other Issues

The subjects reported some issues about the automatic gear control, feedback on the performance and feedback on the position of other users. The automatic gear control caused the suboptimal performance of one of the subjects. The subject was cycling with a low power and high cadence, but the gear didn't shift up. Manual gear control can be added to prevent this situation and give the users more control. Feedback about the performance is currently given by displaying the current power and the target power in the virtual exercise environment. Users have to compare these numbers themselves to get an indication about their performance, while the performance is an important parameter during the training session. Suggested is to use a graphical performance indicator.

Finally remarks were given about the position of other users in the virtual environment. A user can see other players in front of him with a limited range. Players who are too far in front or behind the user are not visible. A rear view or a third person view, a map of the environment with indicators of the other players, will overcome this problem.

7 DISCUSSION AND CONCLUSIONS

The goal of the Integrated Training System is to facilitate improvement and maintenance of the physical condition of COPD patients safely at home using a (virtual) group environment. The current prototype satisfies to the goal of the system, but leaves room for improvement. Further evaluation is recommended.

The algorithms used in controller modules need to be validated. For each algorithm several aspects of the algorithm can be varied. For example with the performance module the performance increases linear with an increasing power, when the power is lower than the target power. When the power is higher than the target power the performance decreases hyperbolic. This could be replaced by a linear function as well. Further evaluation will determine which alternative is the best indicator for the performance. The gear algorithm can be improved when the cadence is taken into account. With a high cadence the threshold to shift up can be decreased, while with a low cadence the threshold to shift down can be decreased.

In this paper the technical design of the Integrated Training System is described. Further research into the economic and legal aspects is needed. A sound business case should be created. Motivation theories are implemented in the system. The next step is to evaluate the system in a clinical trial with the objective to evaluate the system functionality with respect to the motivational strength and to investigate the effectiveness of the system with respect to improvements of adherence to the therapy.

The focus is on COPD patients in this study. However the Integrated Training System can be used for other groups with no or only limited adaptations to the system. It can be used for Chronic Heart Failure patients or even elderly people in common to facilitate improvement of the physical condition to improve the quality of life.

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